# Health issues in building services

CIBSE TM40: 2006

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## Note from the publisher

This publication is primarily intended to provide guidance to those responsible for the design, installation, commissioning, operation and maintenance of building services. It is not intended to be exhaustive or definitive and it will be necessary for users of the guidance given to exercise their own professional judgement when deciding whether to abide by or depart from it.

## Foreword

The increasing importance of health issues for building services engineers needs to be emphasised and therefore the decision was taken to include more information on health aspects of building services in CIBSE Guide A: *Environmental design*. A review of the current legislation was undertaken, along with a review of current guidelines and their relevance to building services engineers. The results of this study are now published on the CIBSE website (www.cibse.org) as CIBSE TM40: *Health issues in building services*, and extracts from this publication comprise chapter 8 in the 2006 edition of CIBSE Guide A. The full text of TM40 is also included on the CD-ROM that accompanies CIBSE Guide A. The objective is to inform and educate building service designers and managers of the health implications of the services for which they are responsible, and to give recommendations for limiting, or preferably avoiding, any adverse health effects.

I would like to take this opportunity to express my thanks to the members of the CIBSE Health Issues Task Group, whose members are listed below, for their contributions to this report.

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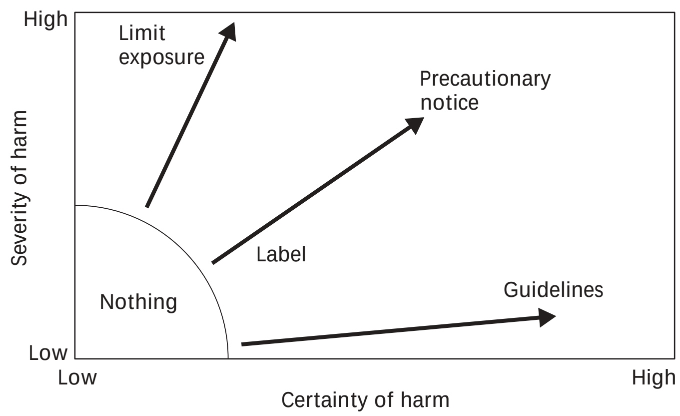
# 1 Introduction

The constitution of the World Health Organisation defines good health as '... a state of complete physical, mental and social well being, not merely the absence of disease and infirmity'. While the indoor environment should be managed in such a way as to promote health, not merely to avoid illness, in the first instance we need to ensure that the environment does not contribute to ill health and undesirable stress.

The boundaries between health, welfare and safety are vague. Neglect of health or poor welfare can reduce the safety. Discomfort introduces stress, which if maintained can affect health. HSE surveys show that stress related absenteeism has risen 107% from 1996 to 2001 and we must ensure that our building services are not contributing significantly to the problem. The health hazard is the ill effect upon the person. The risk of ill health is a function of the likelihood of the effect. Occupational health specialists express their type of concern as the relationship between the two (Figure 1.1).

*Figure 1.1 Risk analysis for occupational hazards.*
*The relationship between certainty and severity determine the action.*




Short term effects of magnitude are becoming more clearly related to a wide range of single causes and the Health and Safety Executive updates annually its list of permissible occupational exposure standards (OESs) for several hundred specific substances. However the effect of a prolonged exposure over months or even years to a low dose is less easy to establish and many health problems may involve one or more of four kinds of issue.

(1) The first is that the problem may be a combination of pollution factors, not one single factor. The environmental damage of cigarette smoke was challenged for many years because no-one could identify exactly which of the many harmful combustion products created the health problem. It is only relatively recently that the empirical epidemiological evidence of the harmful nature of the smoke has been universally accepted.

(2) The second is that our traditional target for environmental criteria inside buildings has been to satisfy 80% of the occupants while accepting that 20% will not be satisfied. Employers now want all the staff to be satisfied because dissatisfaction itself can lead to stress and excessive stress is one of our growing problems in employment. The new target for engineers is to cater more fully for these minority groups and to include health and minimise irritation in the design criteria.

(3) Some individuals are particularly susceptible. The very young, the elderly and any with an underlying disease can be affected more seriously by exposure to pollution. Even the microbiologically spread Legionnaire's disease has a low attack rate (~3%) for the population as a whole but one which favours males, those already ill, the elderly and smokers. Recently The National Radiation Protection Board introduced different exposure limits for electromagnetic fields for the public and for the working environment. The exposure limits for the public are 20% lower, see chapter 7.

(4) Some pollutants may have a threshold value below which healthy workers would be unaffected but some susceptible individuals may still experience health problems. Other pollutants (e.g. carcinogens) have a simple relationship between exposure and risk of ill health. For such materials the lowest possible practicable exposure is desired. Recent research suggests that there may now be non-carcinogenic pollutants which have no safe long term health threshold (e.g. PM10 particulates). There will be a continuous health improvement if exposure to such particulates can be reduced (see chapter 4).

Britain has two kinds of independent legislation affecting buildings. Regulations for the construction and services within new buildings from the Buildings Act 1984 are embodied in the Building and Buildings England and Wales Building Regulations 2000[(1)]. Regulations for the working conditions within buildings apply to employers and come from the Health and Safety at Work etc Act 1974[(2)].

## 1.1 Health and Safety Commission/Executive

The Health and Safety Commission (HSC) and Executive (HSE) are non-departmental government bodies with specific statutory functions in relation to the regulation of health and safety in Great Britain. The HSC is a tripartite body appointed by Government, made up of representatives of employers, employees, local authorities and others. The HSE is the operational arm of the HSC and they provide the HSC with the policy and technical advice to enable it to carry out its functions.

In addition the HSC is advised by a number of subject/industry specific advisory committees. The HSE enforces health and safety law in premises ranging from factories, farms, hospitals, schools, offshore installations, nuclear plants and mines. Local authorities Environmental Health Officers enforce in other premises such as the retail sector. The enforcement officers visit businesses regularly to check compliance and have two control procedures. When they discover minor failings they can issue an Improvement Notice which draws the fault to the attention of the employer and records an agreed action plan, including timescale, for remedial action. Whenever they find a serious fault they are obliged to close down the equipment immediately and issue a Prohibition Notice which requires the equipment to be put into good order before the equipment can be used again. Courts can prosecute for corporate manslaughter when there is a death and can impose fines up to £20 000 per offence for breaches of the Health, Safety and Welfare etc. Act (HSW Act), an Improvement Notice or Prohibition Notice or a court remedy order.

## 1.2 Health and safety law

Broadly speaking the architecture of health and safety law in Great Britain is set out as follows:

(*a*) Acts of Parliament are the primary legislative tool. The Health and Safety at Work etc. Act 1974[(2)] sets out the general duties of employers and enables the more specific health and safety regulations which clarify the more general duties in the Act.

(*b*) Regulations describe legal obligations, e.g. to assist in the control of legionnaire's disease all employers who use an evaporative cooling tower are obliged to register with their local authority. Regulations also have the full force of law.

(*c*) HSE/HSC Approved Codes of Practice (ACoPs) represent good management practice and have special legal status. If employers are prosecuted for a breach of health and safety law, and it is proved that they have not followed the relevant provisions of the code, a court will find them at fault unless they can show that they have complied with the law in some other way. Following the advice in an ACoP on the specific matters on which the Code gives advice is enough to comply with the law.

(*d*) HSE/HSC Guidance notes can be combined with an Approved Code or be provided without an ACoP and provide more detailed implementation information.

## 1.3 Health at work

There are legal duties on employers to prevent ill health that can be caused by work. The two main pieces of law are the Health and Safety at Work etc. Act 1974[2] (HSW Act) and the Management of Health and Safety at Work Regulations[3] 1999 (MHSW Regulations).

Under the HSW Act, employers have to ensure the health and safety of employees and others who may be affected by their work. The Act applies to all work activities and premises. Employers are required to provide suitable control equipment and train, instruct, inform and supervise employees so that their health at work is not affected. Employees have responsibilities under the HSW Act not to endanger themselves or others. The MHSW Regulations build on the HSW Act and include duties to assess risks and make arrangements for health and safety. HSC's Approved Code of Practice on the MHSW Regulations gives guidance on what is meant by these terms. This guide explains this in more detail, particularly in relation to health risks.

The Workplace (Health, Safety and Welfare) Regulations[4] set out in general terms how workplaces should be managed to ensure that they meet the health, safety and welfare needs of those in the workplace. In addition there are several laws that relate to specific risks to health at work, such as lead, asbestos, chemicals and noise, and some that relate to particular industries.

In deciding what the risks to health might be, central to most health and safety legislation is the requirement for an assessment of risks from work. Simplistically, risk assessment is a means of determining the risk associated with a particular hazard. In the workplace, this is most often broken down into five steps:

(*a*) hazard identification

(*b*) deciding who may be harmed and how

(*c*) assessing how likely it is that harm will arise and whether existing precautions are adequate

(*d*) making a record of findings

(*e*) reviewing and revising the assessment as necessary.

The assessment needs to be 'suitable and sufficient'. It should:

(*a*) reflect the nature of the work activity being assessed; the more hazardous a scenario, the more in-depth the assessment required

(*b*) draw on specialist advice as required;

(*c*) consider all those who may be affected by the work

(*d*) anticipate foreseeable risks

(*e*) be appropriate to the nature of the work and identify how long the assessment is likely to remain valid.

For information about health and safety, the Health and Safety Executive provides an information service*. Pamphlets may be downloaded free of charge from the HSE website (www.hse.gov.uk).

## References

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# 2 Thermal conditions for stress

## 2.1 Legislation

The Fuel and Electricity (Heating) (Control) Order 1974[1] and The Fuel and Electricity (Heating) (Control) (Amendment) Order 1980[2] prohibit the use of fuels to heat premises above 19°C. This Order does not apply where contributions from heat sources (other than from space heating) take the room to higher temperatures.

The Workplace (Health Safety and Welfare) Regulations 1992[3] require the workplace temperature to be reasonable without the need for special clothes, that the method of heating shall not be injurious nor offensive and that sufficient thermometers shall be provided to enable the workforce to determine the indoor temperature. The Workplace (Health, Safety and Welfare) Approved Code of Practice 1992[4] requires workplace temperatures to be normally at least 16 °C unless much of the task is severe physical work, in which case 13 °C is the minimum acceptable temperature. For temperatures below 13 °C the employer is required to provide personal protective equipment.

The Provision and Use of Work Equipment Regulations 1992[5] requires protection from hot surfaces, particularly when siting temporary heaters. Care home and hospitals are required to maintain all exposed heater surfaces at or below 43 °C[6]. Temperatures above and around 43 °C will begin to cause skin damage if the skin contact is of sufficient duration. Below this temperature discomfort, pain sensation and burns will be avoided.

Employers are required to provide hot and cold water for washing. Initially no water temperatures were specified. Sustained outbreaks of legionnaire's disease however have been attributed to lukewarm water aerosols from hot and cold water supplies, evaporative cooling towers or whirlpool spas. Guidance is now in place to ensure that water supplies for those in employment are below 20 °C, at the cold tap, within two minutes and above 50 °C, at the hot tap, within one minute. Any hot water calorifier should store the hot water at 60 °C or above. Risk analysis to control the risk of legionellosis is required for any other water outlet which is capable of generating an aerosol accessible to persons and which operates between 20 °C and 50 °C[7].

More specific guidelines are provided for institutions such as prisons, hospitals, schools, and care homes to limit the hot water temperature to around 44 °C so that the occupants of these institutions do not harm themselves or others. Such institutions require thermostatically controlled valves to ensure the storage and distribution temperature is hot enough to control legionella but becomes thermally safe at the tap outlets[8] The water temperature of bidets in hospital and health premises is limited to 38 °C to minimise the shock that may occur when the hot water reaches the skin. Unexpected thermal shock while using a bidet may unbalance the user and cause a fall. Free flowing hot water, as in showers or washbasins, is regulated to a maximum 41 °C[6].

## 2.2 Heat stress

The current heat stress index is based on the wet bulb globe thermometer (WBGT). This index allows for the combined effects of radiation, air temperature and humidity. Activity level is also taken into account. Many industries where an employee may be exposed to environments with the potential to cause heat stress permit exposure times based on this index, shortening permissible exposure times with increasing values of the index. However, it is recognised that in conditions where specialised personal protective equipment (PPE) is worn, e.g. NBC clothing, or asbestos stripping clothing, the allowable exposure time will be significantly reduced in even moderate environments. Working details for Britain are given in a British Standard, BS EN 27243[9].

Neither HSE nor NIOSH yet specify an upper limit for thermal stress. In extreme environments, the physiological effects of such work on the well-being of an individual should be monitored[10]. Medical supervision of personnel may be required for work in extreme environments up to 50 °C[11]

Working in a hot climate can lead to a number of disorders. Heat stroke is potentially the most serious and is life threatening. Heat stroke is an acute condition caused by the body temperature rising above 40.5 °C (cf. normally 37.6° C ). It is thought to be caused by a failure of the central drive for sweating, whereby the body effectively ‘runs out’ of sweat. This leads to a decrease in the ability of the body to cool by evaporation, which is the main pathway by which heat is lost from the body, resulting in an uncontrolled accelerated rise in body temperature. Symptoms may include mental confusion, mottled or cyanotic skin, loss of consciousness and/or convulsions. Without treatment, it is fatal. Heat stroke will have a lasting effect on a person’s ability to tolerate heat.

Heat syncope is a less severe heat illness than heat stroke and results from the pooling of blood in dilated vessels of the skin and/or in the lower extremities. Fainting may occur particularly if the person is standing up and immobile(12). It usually affects un-acclimatised individuals. Recovery of consciousness is rapid. Heat exhaustion can occur either through the loss of salt or excess loss of water after heavy perspiration for several hours. Oral temperature may be normal or low, but rectal temperature is usually elevated (37.5–38.5 °C). Heat cramps, skin eruptions and behavioural disorders are also commonly associated with heat exposure. Those who are regularly exposed to heat stress develop an increased tolerance to heat. This process is known as acclimatisation(12).

## 2.3 Cold stress

In cold environments, cold air will generally produce severe discomfort before any effects on health occur. If however, no remedial action is taken and cold exposure persists, then body temperature will decline. The rate and total amount of heat loss from the body will depend upon a variety of factors including air temperature, air velocity, activity level and the clothing of the individual. Therefore, there is no simple relationship between hypothermia and room temperature.

If the core temperature of an individual falls to approximately 35 °C (cf. normally 37.6 °C) then this is generally recognised as hypothermia. A person with hypothermia will often not realise they are in trouble, or act counter to common sense and further precipitate cooling and may also become aggressive making treatment difficult. The clinical presentations of progressive hypothermia are well described in literature(12) but fall outside the scope of this discussion.

Deaths from acute hypothermia remain rare, however cold stress can trigger a variety of well known biological mechanisms(13) that can lead to heart attack, stroke and respiratory infection. The body’s defence against cold is to shut down blood vessels in the skin to reduce heat loss from the core. This displaces around a litre of blood and overloads the central organs. In order to reduce this excess, salt and water are excreted. This in turn requires more salt and water to leave the bloodstream through the walls of the blood capillaries. This adjusts the blood volume to the reduced capacity of the circulation system, but leaves the blood more concentrated. Some of the smaller molecules of the blood plasma, including the anti-thrombotic vitamin C, are able to redistribute through the capillary walls, but the red and white blood cells, platelets, fibrinogen and cholesterol are too large and remain in increased concentration in the blood plasma. All promote viscosity and hyper-coagulability, which increases blood pressure. Cold stress thus stimulates a range of biological processes that result in the blood becoming thicker, significantly increasing the likelihood of cardio- or cerebro-vascular incidents. Low indoor temperatures in energy inefficient dwellings may well provide the causal mechanism for the unusually high rate of excess winter deaths in the UK(14).

The WHO(15) has identified possible health risks associated with cold temperatures. No risk is expected between 18 °C and 24 °C for the normal population although 20 °C is the minimum recommended temperature for the very old and the very young. A review of relevant literature concluded that conditions below 16 °C and above 65% relative humidity impose additional hazards particularly from respiratory diseases and allergic responses to moulds, fungi and yeasts. Temperatures below 12 °C may pose a health risk for preschool children and the elderly the sick and those handicapped. The elderly and very young may be at special risk when bedroom temperatures fall at night(15). Susceptibility to infection from airborne pathogens is believed to increase below 16 °C(16).

In outdoor conditions the heat loss from the body is very sensitive to wind speed and air temperature. The wind chill index combines these two factors to express the rate of cooling of skin assumed to be at 33 °C(17). It is less satisfactory at predicting total heat loss from the body because the cooling effect of the wind is modified by the thermal insulation of the clothing. Wind has less of an effect on well insulated persons when compared to nude people. The index is however a useful tool for predicting the heat loss from exposed skin such as hands, ear and the face of those working outside in cold weather.

Wind chill index:

$$\text{WCI} = (10\sqrt{v} + 10.45 - v)(33 - T_{air})\ \text{kg·cal/m}^2\text{·h}$$

where $v$ is the air velocity (m/s) and $T_{air}$ is the air temperatures (°C).

For example, an index of 200 is considered pleasant, 400 cool and 800 cold. A wind speed of 6 m/s (light breeze, Beaufort Scale 3) at 5 °C would have an index around 800. The old units are no longer quoted nor modernised because the index number has been in use for so long that it is readily recognised by those working in cold climates.

The rate of accidents has been shown to increase with declining air temperatures[(18)]. This has been shown to be through a reduction in manual dexterity. Aspects of dexterity that may be affected by cold exposure include strength, joint mobility, tactile sensitivity and speed of movement. Finger strength and manual dexterity for bare hands has been shown to progressively decline with room temperatures from 24 °C down to 6 °C[(19)]. However if adequate protection is worn, effects on manual dexterity can be minimised although there is a pay-off between the lessened effect of cold and the hobbling effect of many types of personal protective equipment against the cold.

Difficulties can also arise when handling materials at low temperatures with bare hands. Contact with a cold material may be accidental or through intentional sustained handling. Depending upon the material being handled, the duration of contact and the temperature of the material, pain, numbness and/or skin damage can result. During contact with a cold material, heat will flow away from the warmer skin to the colder material. As the skin temperature falls, pain sensations (at a skin temperature of approximately 15 °C) may be experienced and the hand may become numb at a skin temperature around 7 °C. Manual dexterity also suffers significantly. If the skin temperature falls further, freezing occurs (around a skin temperature of 0 °C) with the associated skin/tissue damage. The speed of decreasing skin temperature is dependant upon the thermal characteristics of the material, how tightly the material is held and how low the temperature of the material is. Heat will always flow from a warm body to a cold body as per the laws of thermodynamics. Different materials will conduct heat away from the skin at different speeds depending upon their thermal properties. For example, aluminium is a good conductor of heat and will conduct heat from skin quickly, whereas wood is a poor conductor of heat and heat will be lost more slowly from the skin[(20)].

Factors including the topography of the material, the pressure at which it is gripped, the temperature of the material and the duration of contact etc. should also be considered.

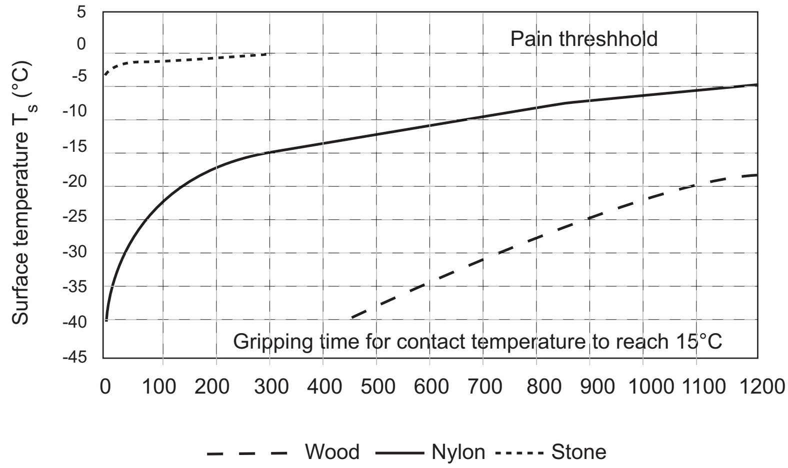
Thermal penetration is related to:

$$\text{Thermal penetration factor } (F_c) = \sqrt{(\rho\, k\, c)}$$

where $\rho$ is the density of the material (kg/m$^3$), $k$ is the thermal conductivity (W/m·K) and $c$ is the specific thermal capacity of the material (J/kg·K). As described above, the risk of thermal damage increases with higher values of the thermal penetration factor.

This means that the time taken to reach the critical temperatures in terms of freezing skin damage (0 °C), severe falls in dexterity (numbness at 7 °C), and some pain sensations (15 °C) will be extended for materials with a low thermal penetration coefficient. This has obvious implications when choosing materials in terms of risk of possible skin damage (e.g. frost nip or frost bite) and also in terms of the risk potential accident and decreased productivity rates as a consequence of manual dexterity deficits (see BS EN ISO 13732-3[(21)]). Below is an illustration from BS EN ISO 13732-3 of the time taken to reach the temperature associated with the onset of pain whilst gripping a wood, nylon and stone bar.

*Figure 2.2 Predicted time to reach pain on gripping a bar (draft BS EN ISO 13732-3).*

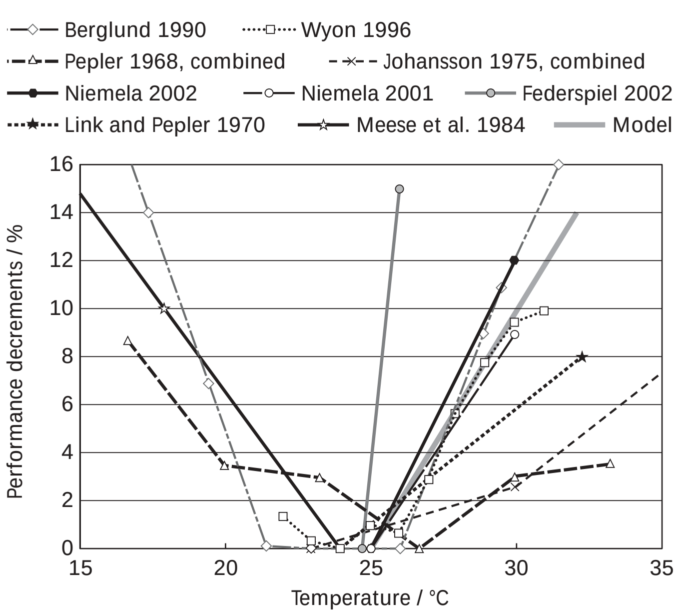



## 2.4 Effects of hot and cold stress

When individuals work under hot or cold conditions their performance can be affected. Performance in the cold deteriorates largely for physiological reasons, although pain and decreased motivation induced by thermal extremes play a part. As discussed in the previous section, at low temperatures manual dexterity may be affected (e.g. tactile finger sensitivity may be affected resulting in sensations of numbness. Thickening of synovial fluid (the fluid that lubricates joints) results in joints becoming stiff and the ability to perform skilled tasks is reduced. Strength, speed of movement (particularly flexion and extension of fingers) is also affected). Slower performance and an increase in mistakes are likely as a result. Cold sensation may also act as a distraction and result in a worker rushing to get out of the cold. This may also lead to an increase in the number of mistakes made.

In mild heat stress, where the body can maintain thermal equilibrium by sweating, numerous field studies show that there is a decrease in performance, although the level at which this occurs is widely disputed[22–23]. One review of the literature proposes the following model that is summarised in Figure 2.3. Tasks are broken down to illustrate the kinds of work studied. The effect of temperature on performance will vary with a number of factors including acclimatisation of the individual, the specific task and conditions and the skill of the subject etc.

*Figure 2.3 Illustrative relationship between room temperature and performance[24]*



Factors including increased sweating, which can make gripping of objects difficult, increased irritability and increased drowsiness/decreased arousal can all lead to an increase in the number of mistakes. Again, as with work in the cold, the fact that the environment may be perceived as unpleasant can result in people rushing to finish the job in order to get out of that environment[25] . The field evidence indicates that the performance of the more skilled individuals suffer less than that of the less skilled in carrying out well rehearsed procedures.

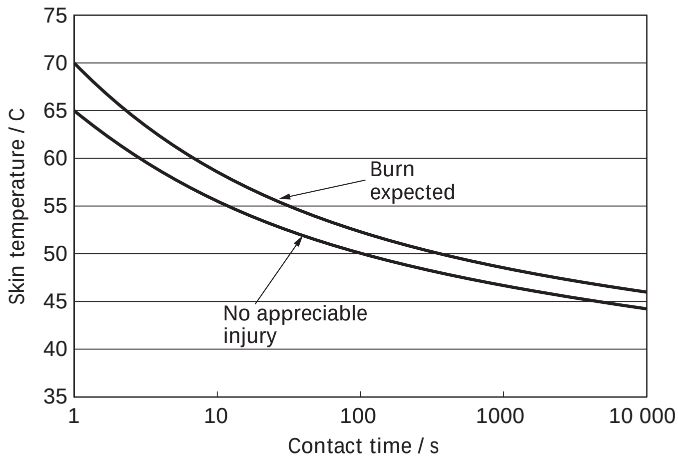
In time of a heat-wave some individuals become dehydrated, overheated, exhausted and experience heat stroke. Those who are susceptible include the old, babies and children, those with mental problems, those with chronic conditions such as breathing and heart problems, those with a high temperature from infection, those with mobility problems and those physically active such as manual workers and sportspeople. The Department of Health has introduced four levels of awareness for the health professionals. The alert is triggered by three continuous days of hot weather above a declared maximum external temperature. Each critical temperature is allocated to each region of England. For London the critical temperature is 32 °C in the day and 18 °C at night. For NE England the corresponding temperatures are 28 °C and 15 °C.

## 2.5 Scalding

The rate of skin damage from a scald is a function of temperature and exposure time, regardless of the area of skin affected. However some areas of skin are more sensitive than other. Injury is more likely on the ears, thighs and buttocks and less on the neck and mid portion of the back. Very young children are more sensitive. The time for a scald almost halves for every degree rise in temperature between 44 °C and 51 °C but is slower at higher temperatures because the temperature is no longer steady state. The severity of the scald depends upon the area of skin damaged and the depth of the skin damage. Full thickness scalds destroy the underlying dermis, which creates the new skin cells. This makes the healing process very slow. Partial thickness burns destroy the epidermis but leave the dermis unharmed. Reported scalds occur mainly to the very young (one to three years old) and the very old and usually occur in the bath. Please note that scalding can occur after prolonged exposures to temperatures that would not normally be considered scalding temperatures in everyday terms.

There is a wide difference of opinion on the perception of water temperature but Figure 2.4 shows the relationship between temperature, time and degree of scalding for an adult[26].

*Figure 2.4 The relationship between temperature and time to cause a scald[26]*




## 2.6 Burns

Burns from hot surfaces are less predictable because the rate of heat transfer from the hot surface to the skin depends, like when considering contact with cold surfaces, upon the thermal properties of the material, the degree of contact with the surface and tightness and area of grip, as well as the type of skin and duration of the contact. Smooth metals can cause burns at similar temperatures to that of water because of the high thermal conductivity and good surface contact. Insulating materials such as cork or foam polyurethane require much higher temperatures to create a burn[27,28].

There is a possible danger in care homes or hospitals of a person falling and lying against a hot surface for several hours and experiencing a slow but still damaging burn. Low temperature protective shields are fitted to hot water central heating radiators in such areas to ensure that no exposed surface exceeds 43 °C[6]. Special consideration should be given to handles because if a hot handle is firmly gripped the thermal shock may lead to the container either being dropped possibly increasing the risk of scalding (depending upon the contents of the container) or an increased area of burn if the container is dropped on the person. This may exceed the damage that may have originally occurred if the container had been held  longer whilst being put down safely.

## 2.7 Recommendations

(1) Minimum  working temperature as specified by HSE are 16 °C, or 13 °C for those in severe physical activities. Personal protective clothing is needed below 13 °C. For energy considerations regulations forbid heating equipment at rooms above 19 °C. There are no upper limits for those at very hot conditions but medical supervision may be needed for those working up to 50 °C.

(2) WHO has identified low temperatures which are associated with possible ill health problems. Room conditions around 18–24 °C were considered safe for the normal population but 20 °C was recommendation for the minimum for the old and the very young. Studies indicated that infection increases below 16 °C.

(3) The HSE specify hot and cold water supplies for washing at work. Specific guidelines for legionella apply to any water supply between 20–50 °C which may be aerosolised. Scalds can occur above 44 °C and the time necessary shortens with increasing water temperature. Institutional buildings use thermostatic control to enable the hot water to pasteurise the stored water at 60 °C to achieve the desired tap water temperature of 44 °C for baths and basins or 41 °C for running water such as showers.

(4) Burns are less predictable due to the thermal properties of the material, the tightness of the contact and the area of the grip. If the container holds hot material the potential danger is increased when the handle is too hot to hold and the contain spells. Details are given in the BS 4086[27] and BS EN 563[28]. The maximum temperature for surfaces in institutional buildings, including heating radiators, is 43 °C.

(5) Wind chill can exaggerate the cooling effect of cold air in external conditions.

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# 3 Humidity

## 3.1 Introduction

Humidity has a significant effect on thermal comfort only at high temperatures when high humidity impedes the ease of evaporative cooling through sweating. However, the combination of high temperature and high humidity does introduce a feeling of sultriness or oppression which occurs at 70% RH at 21 °C and 60% RH at 23 °C[1]. Humidity has many other important roles although less well defined than is that for temperature. In normal circumstances, humidity in the range 40–70 % RH is acceptable but with the optimum being around 65% RH at comfort temperature. There is a wide range of differences between individuals[2]. Moving suddenly into high humidity zones can provide transient warmth from the adsorption of moisture into the clothing. Equally, moving from a humid zone to a dry one can provide a chilling effect for the reverse process of desorption of water from the clothing fabric. The thermal insulation of clothing and bedding is strongly influenced by the moisture content of the materials used. Damp materials associated with high humidities lose much of their thermal insulation[3]. Moisture control is particularly important in dwellings and is expected to become even more important as the new Building Regulations require low infiltration constructions and the universal application of double glazing removes the window condensation so prevalent in single glazed housing. The average moisture release in a five person household is estimated to be around 7 kg per day, with a further 5 kg if clothes drying is undertaken within the house[4]. High room humidity may occur through a combination of evaporation from moisture sources and poor ventilation, and/or high outdoor humidity. Bathrooms and kitchens are particularly prone.

## 3.2 Skin/hair effects

Skin dryness is clearly related to both temperature and humidity. The skin of each individual has a critical humidity at which the skin neither gains nor loses moisture. This critical value is unaffected by exposure time, season or skin temperature in the absence of sweating but varies widely between individuals. Humidities above the critical value result in a higher skin moisture and could lead to discomfort from damp and 'sticky' clothing. The first indicator of dry conditions is dry lips[2]. In very dry conditions below the critical value the dead surface skin cells lose their cohesion and the skin becomes rough. This condition can occur after a few hours exposure to very dry conditions and can disappear quickly on return to more humid conditions. If the dryness is intense then the skin can become chapped and cracked, but this is usually only in subzero conditions. If the basal layer of growing cells is torn then such skin fissures will be slow to heal.

## 3.3 Problems with high humidity

Allergies and respiratory illnesses have long been associated with mould growth and moisture, particularly for asthma and rhinitis[5–8]. Asthma is a disease produced by an allergic reaction to an inhaled or ingested substance. This allergic reaction causes the lungs to constrict and fill with fluid resulting in reduced lung capacity and breathing difficulties. Rhinitis is an inflammation of the nose which causes similar effects. Both are particularly distressing if they occur at night and interrupt sleep. Asthma has a proven causal link[9] with an allergic response to house dust mite proteins concentrated in their waste products. Both asthma and rhinitis are now closely associated with an allergic response to the house dust mites and their waste products. The incidence of symptoms reaches its peak in teenagers and thereafter declines with age[10].

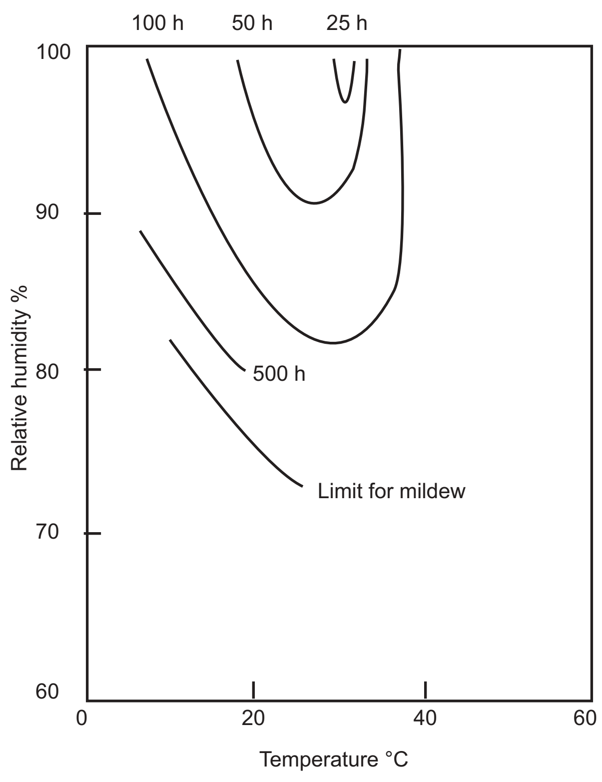
This mite prospers in warm damp conditions providing there is a supply of food. Pioneering Dutch work starting in the 1960s identified mites as the major source of allergens in house dust which caused this response and the studies have developed throughout the world[11–14]. There is a dose response relationship between the proteins in the mite faeces and the allergic response [15].

The most common type of the house dust mite is the UK is *Dermatophagoides pteronyssinus (DP)*. Such mites are barely visible to the naked eye (around 300 μm long) and can only be distinguished from dust when they move on their eight limbs. Although known to thrive on semen, in the main their nutrient is human skin scales. Such scales are hygroscopic and often colonised by an *Aspergillus* mould which causes the scales to swell and soften thus aiding digestion[16]. House dust mites obtain water in four ways: ingestion with food, production of metabolic water from oxidation of carbohydrates and fats, passive absorption and active absorption from saturated air via salt glands situated behind the first pair of legs which leads to the mouth via a narrow groove. The critical relative humidity for this salt is around 73% RH[17]. Below this value the solution crystallises and dehydration occurs. Above this RH the salt deliquesces into a more flowing liquid and runs into the mouth of the mite supplying water. Humidities above 85% inhibit multiplication. This is attributed to toxins from the proliferation of moulds at this humidity[18]. High humidities do not need to be continuously sustained. Mites survived for ten weeks at 35% RH at 16 °C when exposed to air at 76% RH for 1.5 hours per day. Egg production did not begin until the exposure time to moist air was increased to three hours per day. Population growth occurred at six hours per day exposure to moist air[19]. Life expectation in ideal conditions is three months[20]. Mites are sensitive to temperature and at their optimum relative humidity of 80% their multiplication rate is zero at 10 °C, slow at 15 °C, peaks at 28 °C and then falls rapidly at higher temperatures with only modest multiplication at 37 °C[21]. The eggs hatch after 6–12 days but can remain viable after seven months at 10 °C, 60% RH[6].

Mites can be controlled if their immediate microclimate can be maintained below 73% RH. However the insulating properties of carpets can mean that there can be a temperature gradient within the carpet with a corresponding increase in RH. at the lower temperature. Measurements suggest that this is of the order of 10% RH[17], i.e. this means maintaining the room condition below 63% RH at all times to prevent mite multiplication. The mite faeces are typically 10–20 μm is size but do break up into finer particles[22]. Cleaning operations can increase the dust suspended by one or more orders of magnitude[23,24].

Buildings in which there are prolonged high air humidities are likely to experience problems such as airborne fungi and house dust mites, particularly if room humidities exceed 70% RH for periods. Fungi generally grow on damp organic material but they do not necessarily require either high air humidity or high air temperature for growth if the substrate conditions are suitable. The growth rate is dependant upon the nutrient, the temperature and the humidity, e.g. Figure 3.1 Each mould has its special growth characteristics. Once mould has started to grow it is difficult to stop by lowering the humidity because one of the metabolic products of growth is water, which enables the mould to continue to grow in drier conditions.

*Figure 3.1 Time for mildew germination on book covers — Pennicillium chryogenum*[25]




For the purposes of designing air conditioning systems, a maximum room relative humidity of 60% within the recommended range of summer design dry resultant temperatures would provide acceptable comfort conditions for human occupancy and minimise the risk of mould growth and house dust mites. Condensation should be avoided within buildings on surfaces that could support microbial growth or be stained or otherwise damaged by moisture. This may be achieved by ensuring that, where possible, all surfaces are above the dew-point of the adjacent air.

## 3.4 Problems with low humidity

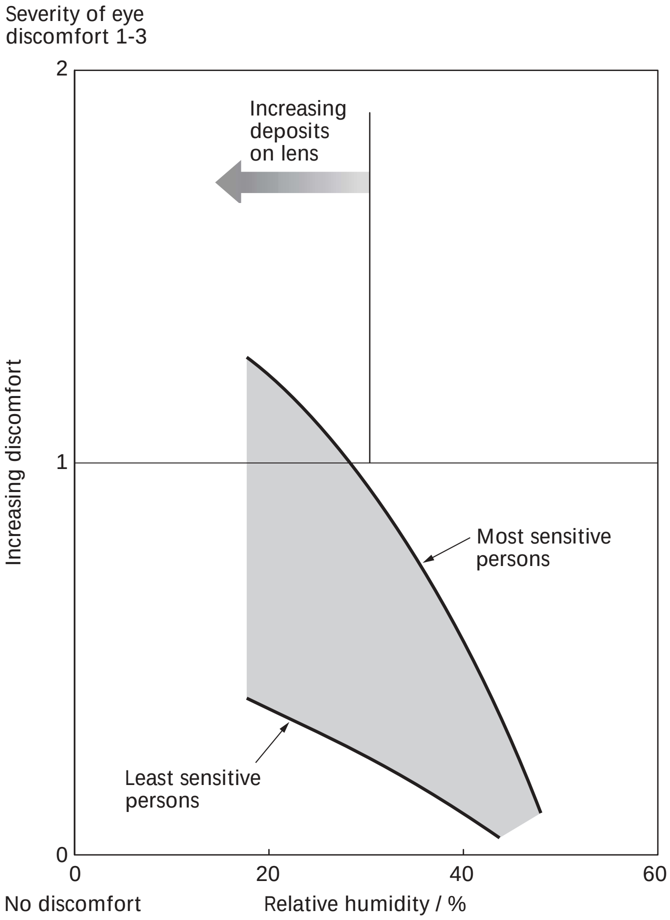
Complaints of dryness are frequently found in office workers but not clearly linked to the actual humidity. It is likely that there is a second effect where low humidities interact with some other pollutant and increase its effect. Lowering the humidity increases peoples perception to smells and makes the smell more objectionable. It also increases the irritation of cigarette smoke. It also increases the smoke production from cigarettes and permits fine particles to stay suspended in the atmosphere and prolong the nuisance[26]. More recent research shows that the concept of freshness is linked to reduced humidities[27].

Moisture can also have an effect upon the gaseous emissions from some chipboard.

Formaldehyde gas can be released from the binder of imperfectly cured chipboard and even small quantities of this gas can be unpleasant. Laboratory experiments showed that the equilibrium concentration of formaldehyde in a room was directly proportional to both the ambient water vapour pressure and to the room temperature[28].

There is some evidence from recent investigations into problem buildings that there is a correlation between low room humidity and symptoms associated with dryness and irritation of the mucosa. It has been suggested that low room moisture content increases evaporation from the mucosa and can produce micro-fissures in the upper respiratory tract which may act as sites for infection. The reduction in mucous flow inhibits the dilution and rejection of dust, micro-organisms and irritant chemicals such as formaldehyde. This is a particular problem for wearers of contact lenses[29].

*Figure 3.2 The influence of relative humidity on eye discomfort with contact lens*[30]

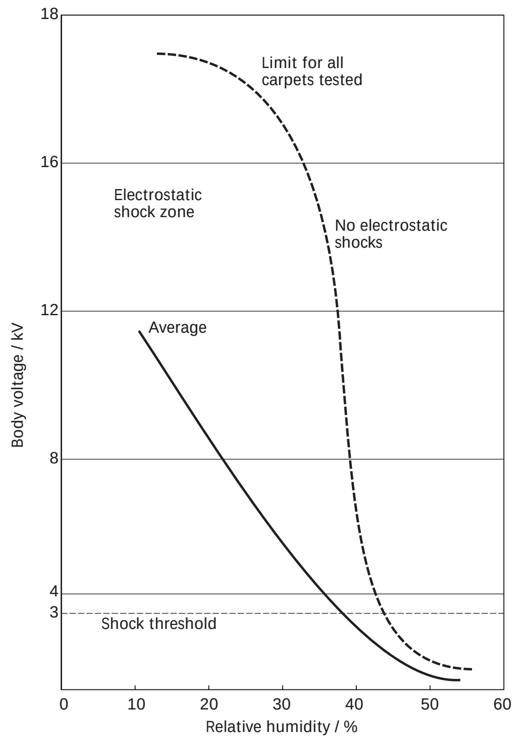



If possible, at the design temperatures normally appropriate to sedentary occupancy, the room humidity should be above 40% RH. Lower humidity is often acceptable for short periods. Humidity of 30% RH or below may be acceptable but precautions should be taken to limit the generation of dust and airborne irritants, such as tobacco smoke, and to prevent static discharge from occupants. Note that for heated-only buildings in the UK, the humidity can remain below 40% RH during periods of sustained cold weather.

Shocks due to static electricity are unlikely with humidities above 40% RH or at lower humidities if special precautions are taken in the specification of materials to prevent the build-up of static electricity. Static electricity can lead to shocks when occupants are not adequately earthed via their shoes and the floor covering. The incidence of electrostatic shocks depends on the electrical resistance of the floor covering and the speed and distance walked. The resistance is a function of the material itself and its moisture content. The carpet becomes more insulating in dryer conditions. Dryer conditions, faster walking, and longer walked distances increase the voltage rise and risk of electrostatic shocks.

At low room humidity, some types of carpet can become highly charged and electrostatic shocks may be experienced. Typical body voltages are shown in Figure 3.3 as a function of room percentage saturation. Extreme values, as reported, and the shock voltage threshold are also shown. Women are more sensitive to shocks than men. In general, shocks are unlikely above 40% saturation. Carpeted buildings with underfloor heating have particularly dry carpets and require humidity to be above 55% saturation to avoid electrostatic shocks.

*Figure 3.3 Relationship between relative humidity and electrostatic shocks*[30]




Electrostatic discharges can be dangerous in the presence of hazardous gases or explosive substances. In such conditions an atmosphere above 65% RH is considered safe. Electrostatic problems from machinery in manufacturing are reported at RH below 40%. Humidification can be used to eliminate this effect to protect the process and the person.

## 3.5 Recommendations

(1) No regulations have been located on moisture but CIBSE recommends 40–70% RH for normal conditions in buildings. The target value for design is 60% RH.

(2) Low relative humidities below 40% RH increase the frequency and severity of electric shocks in buildings. Perception of dryness occurs. The first symptom is dry lips. Low humidity can irritate some kinds of contact lens and can be noticed as dry hair, a rough surface of skin and dry throats. Low humidity usually enhances the smells present.

(3) High relative humidities over 60% RH can introduce sultriness, particularly at high temperatures, can encourage mould and mites and decrease the sensation of freshness in the air. Mites and mould are associated with allergies and respiratory illnesses. Prevention of mould is

essential because once mould is established the normal metabolic process of thriving generates more moisture. This means that once established the mould can continue to grow even though the room conditions are no longer supported growth.

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# 4 Air quality and ventilation

## 4.1 Legislation

### 4.1.1 Residential

The most recent building regulations covering Scotland (2004) state that, ‘Every building must be designed and constructed in such a way that the air quality inside the building is not a threat to the health of the occupants or the capability of the building to resist moisture, decay or infestation.’ However, there are no specific air quality standards in Britain for residential buildings. The prescriptive provisions for residential ventilation require:

— controllable ventilation slots of a given size (8000 and 4000 mm$^2$) for background (trickle) ventilation

— planned ventilation in the bathroom/toilet (15 L/s or 3 air changes per hour) and kitchen (30–60 L/s), usually by mechanical extract fans, to extract moisture, and

— openable panels, usually windows, in each room for occasional, high flow needs such as on a warm summer day to prevent overheating(1).

The recent regulations do, however, include stack(2), positive pressure and mechanical heat recovery ventilation systems as deemd to satisfy regimes for both ventilation requirements and condensation control.

### 4.1.2 Workplace

Workplace ventilation addresses the particular question of contaminants released at work, either within the building or around it. The Workplace (Health, Safety and Welfare) Regulations 1992(3) set out in general terms the requirements for ventilation of workplaces. They need to be adequately ventilated and the introduced air should drawn from an area outside the workplace that is not contaminated, e.g. by flues or chimneys. Ventilation should remove and dilute warm and/or humid air and there should be sufficient air movement to provide a sense of freshness without it being draughty. If there are processes carried out in the workplace which create heat, dust, fumes or vapours, additional ventilation may be required. Adequate ventilation may be provided by windows or other openings but additional mechanical ventilation may also be required. The Construction Products Directory(4) and the HSC require that products and surface finishes do not contribute to indoor air pollution(4,5).

When mechanical ventilation is provided an annual duct clean is recommended(6). If mechanical ventilation, e.g. local exhaust ventilation, is provided to control exposure to substances hazardous to health, e.g. chemicals, the Control of Substances Hazardous to Health Regulations 2002(7) (COSHH) require that it is maintained in proper working order and that it is subject to regular examination and testing. Certain hazardous substances are subject to occupational exposure limits (OELs) or maximum exposure limits (MELs)(8). For substances with an OEL, exposure needs to be reduced so as to comply with the OES; for those with an MEL, exposure must be reduced so far as is reasonably practicable, and in any case below the MEL; ventilation may be one means of reducing this exposure (see COSHH ACoP/guidance(9). HSE issue annually lists of OELs(8). These lists have legal status under COSHH Regulations 1999. The occupational exposure limits listed in EH40 are not exclusive; absence from the list does not imply that a substance has no ill effects on health nor that it is safe to use without control. Where a particular substance does not have an OEL the employer, in carrying out a risk assessment, should also determine an adequate level of control for the substance and, in effect, set an ‘in-house’ OEL.

Evidence that the relevant OEL has been exceeded can be used in enforcement, including prosecutions, under this legislation the basic requirement of which is to prevent the exposure of employees to substances hazardous to health. Where it is not reasonably practicable to prevent exposure to such substances then the employer must adequately control exposure.

As a general rule, the fresh air supply rate should not fall below between five and eight litres per second per occupant (8 L/s fresh air is equivalent to an elevation of 600 ppm of carbon dioxide which, when added to the normal outdoor carbon dioxide of 400 ppm, makes the internal carbon dioxide concentration

1000 ppm, 5 L/s would be equivalent to 1350 ppm internally) but this will depend on various other factors including floor area per occupant, processes carried out, equipment used and whether the work is strenuous[10] although the higher ventilation rate of 8 L/s per person is recommended[6] (i.e. ~1000 ppm $CO_2$ indoors).

More general guidance on workplace ventilation can be found in the following HSE publications:

— *General ventilation of the workplace* (HSG 202)[11]
— *How to deal with sick building syndrome* (HSG132)[12]

There is more specific HSE guidance for specialist industries such as catering (HSE Catering Sheet CAIS10[13]); working with wood (HSC L114[15], HSE WIS 23–26[16–19], HSE WIS 33[20]); chemical and microbiological work (HSE HSG 167[21]); welding (HSE HSG 204[22]) and in dusty conditions (HSE HSG 72[23], HSEHSG 103[24], HSE HSG 203[25]).

Part L of the Building Regulations requires designers to make significant changes to their current designs. Key features include standards of air tightness to minimise air infiltration and minimum energy efficiency standards for air conditioning and mechanical ventilation equipment. This means that in future the bulk of the ventilating air will come through planned routes and with an efficient supply system[26].

### 4.1.3 Schools

Schools have prescribed ventilation which specifies 3 L/s per person for background ventilation and 8 L/s per person when required[27].

## 4.2 Human sensitivity to inhalation of pollutants; bases of criteria

A substance that enters the nasal cavity may be sensed by two largely separate detection systems:

— the olfactory sense: responsible for odour detection.
— the limbic system: the general chemical sense which sensitive to irritants.

The general chemical sense is located all over the mucous membranes, in the eyes as well as the nose. The two senses may interact. For example, it is possible for an odour to be disguised by irritation and vice versa[28] or a single substance may evoke both odour and irritant sensations. Humans are known to adapt to odours with time, whereas irritation may increase with time[29,30].

There are two kinds of adaptation to odour. Over periods of about 30 minutes people become less sensitive to any odours present. Over much longer periods (i.e. weeks or months) people come to accept an odour as normal and harmless and therefore become less aware of it. Conversely, over a period of minutes or hours, the discomfort from exposure to irritants will normally increase. Over a longer period, adaptation is possible but this may be largely behavioural (e.g. by ceasing to wear contact lenses). The more likely outcome is to become sensitised so that the same concentration of an irritant has a greater effect. Sensitisation is also possible when a substance exerts its effect through the immune system (e.g. allergic reactions).

In the specific case of exposure to environmental tobacco smoke, one study[31] has found that irritation intensity increases by a factor of two during the first hour of exposure, after which steady state occurs. The same study found that perceived odour intensity declined by a factor of 50% and levelled out after only a few minutes. Many everyday occurrences result in the release of odours, some of which may be perceived as pleasant and some unpleasant. Some evolve from the release of potentially harmful substances but the airborne contaminants likely to be encountered in non industrial buildings do not usually result in irreversible health effects. However, the exceptions include *legionella* bacteria, radon gas and lead and benzene from motor vehicle exhaust emissions.

Building occupants may be exposed to a mixture of hundreds, or thousands, of airborne contaminants. The air within a modern office may contain chemicals and micro-organisms, which have originated from numerous sources, both inside and outside the building. Concentrations of individual contaminants are frequently in the order of one thousandth of published occupational exposure limits, or less, but may still be above odour detection thresholds[32].

For comfort, indoor air quality may be said to be acceptable if [33,34]:

— not more than 50% of the occupants can detect any odour, and
— not more than 20% experience discomfort, and
— not more than 10% suffer from mucosal irritation, and
— not more than 5% experience annoyance, for less than 2% of the time.

These comfort-based criteria do not account for potential effects on health of the contaminants found in buildings. Some of these, e.g. radon and its progeny, are odourless and do not affect comfort but may have serious effects on the health of any individuals exposed to them.
The following measures, in sequential order, should be adopted to eliminate or reduce exposure of occupants to airborne contaminants in buildings:

(1) eliminate contaminant(s) at source
(2) substitute with sources that produce non-toxic or less malodorous contaminants
(3) reduce emission rate of substance(s)
(4) segregate occupants from potential sources of toxic or malodorous substances
(5) improve ventilation, e.g. by local exhaust (if source of contamination is local), displacement or dilution
(6) provide personal protection.

These measures are not mutually exclusive, and some combination will usually be necessary. Adequate ventilation will always be required.

Published limits for indoor air pollutant requirements fall into two categories:

(*a*) those that have been derived from studies of health effects
(*b*) those based on the sensory effects.

### 4.2.1 Exposure limits based on effects on health

Occupational exposure limits (OELs) for the UK are published annually by the Health and Safety Executive in *Occupational exposure limits* (EH40)[8]. These limits are levels used to demonstrate compliance with the Health and Safety at Work etc. Act 1974[35] and the COSHH Regulations 1994[36]. This legislation applies not just to industrial workplaces but equally to all workplaces including offices. In practice, in most circumstances the levels of exposure and the modes of exposure do not present a significant risk to the occupants of non-industrial workspaces such as offices.

The occupational exposure limits listed in EH40 are not exclusive; absence from the list does not imply that a substance has no ill effects on health nor that it is safe to use without control. Where a particular substance does not have an OEL the employer, in carrying out a risk assessment, should also determine an adequate level of control for the substance and, in effect, set an 'in-house' OEL. Evidence that the relevant OEL has been exceeded can be used in enforcement, including prosecutions, under this legislation the basic requirement of which is to prevent the exposure of employees to substances hazardous to health. Where it is not reasonably practicable to prevent exposure to such substances then the employer must adequately control exposure. It is not appropriate to use OELs to calculate the required outside air supply. The provision of sufficient outside air is important but it is only one of a combination of measures required to provide adequate control of exposure. Such measures are outside the scope of this Guide and will often require specialist advice.

### 4.2.2 Exposure limits based on effects on senses

In practice, exposure of workers in non industrial environments to the same concentrations of malodorous substances that occur in industry would not be acceptable. This is primarily because expectations are generally much higher amongst occupants of non industrial buildings. Odour detection and hence comfort are not primary considerations in setting occupational exposure limits. Sensory comfort guidelines[36] are available for only a small number of single substances, see Table 4.2. These are based on the odour detection threshold for given averaging times. These values can be used to calculate dilution rates when it is known that a specific substance may be responsible for odour annoyance. However, the ideal is for the substance to be eliminated at source. For substances which do not appear in Table 4.1, an exposure limit for non-industrial applications can be estimated by multiplying the relevant occupational exposure limit from HSE EH40[8] by a factor of 0.1.

## 4.3 Outdoor air

In all the Regulations the assumption is that the outdoor air is clean and wholesome. However outdoor air is now becoming an urban pollution  problem and can no longer be automatically considered as a clean air source suitable for diluting indoor pollutants. The quality of outdoor air must be accounted for in the design of ventilation and air conditioning systems. An analysis of the most important pollutants should be carried out if there is any cause for concern about the quality of the air that can enter the building via windows or ventilation air intakes. The local environmental health department should be consulted to determine whether monitoring has already been carried out at a location with a similar environment close to the site under consideration. Data on atmospheric pollution in the UK are published annually[38]. Guidance on the design and positioning of ventilation air intakes is given in CIBSE TM21: *Minimising pollution at air intakes*[39].

The guideline values given in Table 4.2 apply to both indoor and outdoor pollutants. If a local survey indicates that these concentrations are likely to be exceeded in the incoming ventilation air on a regular basis then consideration should be given to specific filtration of the offending pollutants. If external pollutant concentrations rise above the standards during a typical day, then it may be possible to reduce ventilation rates during peak times provided that such periods are sufficiently short that higher ventilation rates at other times will provide adequate compensation. This will require continuous sensing of a key indicator of outdoor air quality, such as carbon monoxide. The external air may need treatment before being used in the building. It is prudent to ensure that the air quality of the incoming air to a building meets at least the approved DEFRA outdoor Air Quality Standards. Those areas above the recommended maximum pollution are identified as an Air Quality Management Area. One of the pollutants often in excess is fine dust particulates from diesel traffic. Careful selection and proper installation of air filters can reduce the incoming pollution. Local Authorities managing such areas require an Environmental Impact Assessment for new building work in these areas. See DEFRA website for a pollution map (*http://www.defra.gov.uk/environment/airquality/index.htm*).

## 4.4 Outdoor air quality

### 4.4.1 Pollutants

A great deal of work has been done in recent years to identify and quantify the human health impacts of outdoor air pollutants. The most important pollutants in ambient air are generally considered to be airborne particles (e.g. $PM_{10}$, $PM_{2.5}$*), ozone, nitrogen dioxide, carbon monoxide and sulphur dioxide. The UK Expert Panel on Air Quality Standards (EPAQS) has issued reports on all these substances as well as on lead and the carcinogens benzene, butadiene and polycyclic aromatic hydrocarbons[40–48]. The recommendations in these reports have largely driven the development of Air Quality Objective Levels within the UK's domestic *Air Quality Strategy* for ambient air[49], promulgated in England by the Department for Environment, Food and Rural Affairs (DEFRA) and enforced through the Air Quality (England) Regulations 2000.

Because of the duties on local authorities to manage and control ambient air pollution, a considerable amount of measurement and modelling is conducted, especially in urban areas, which can be used to help determine whether particular buildings are in high pollution areas and therefore might warrant extra consideration regarding the quality of incoming air. Conventional filters can remove particulates providing the quality of filtration matches the particulates to be removed. More sophisticated carbon adsorption filters are available for gaseous contaminants are and often used in smelly areas , for example in airport terminals to minimise the smell of paraffin from unburnt fuel for the planes.

* $PM_{10}$ is particulate matter with an aerodynamic diameter of 10 μm or less. $PM_{2.5}$ is particulate matter with an aerodynamic diameter of 2.5 μm or less.

## 4.4.2 Filtration strategy

If the main form of outdoor pollution is particulates, the pollution concentration of the incoming air can be reduced by passing the air through fabric or electrostatic filters. Reducing the concentration of gases and vapours requires additional equipment, usually in the form of absorption filters, see CIBSE Guide B(50).

The grade of filtration required depends on the following factors:

- external pollution levels
- exposure limits for the protection of occupants or processes within the building
- degree of protection required for the internal surfaces of the building, air handling plant and air distribution system.

BS EN 779(51) gives a method of rating and specifying filters based on average arrestance and average efficiency. These terms are defined as follows:

- average arrestance ($A_m$): the ratio of synthetic dust arrested by the filter to the weight of dust fed to the filter (%)
- average efficiency ($E_m$): the weighted average of the efficiencies for different specified dust loading levels (%).

BS EN 779(51) requires that the average efficiency be determined by injecting an artificial dust of known size distribution into the air upstream of the filter and measuring the upstream and downstream concentrations at specified particle sizes using a particle counter. The classification is based on particles of 0.4 μm diameter. Efficiencies should apply to the whole filter installation and not only to the filter media. EUROVENT publication 4/10(52) provides a method for in-situ testing of filter installations using a similar procedure to the proposed standard, which may be used to check the efficiency of the filter installation both during commissioning and as part of an on-going monitoring regime.

Table 4.1 gives the recommended classification for different applications. If high dust loadings are expected, it is wise to install coarse (i.e. G1 to G3) pre-filters upstream of the main filters. This will increase the replacement interval for the downstream higher efficiency (and therefore more costly) filters.

*Table 4.1 Classification of filters as defined in BS EN 779(51)*

| Classification | Average arrestance, $A_m$ (%) | Average efficiency, $E_m$ (%) |
|---|---|---|
| G 1 | $A_m < 65$ | — |
| G 2 | $65 \leqslant A_m < 80$ | — |
| G 3 | $80 \leqslant A_m < 90$ | — |
| G 4 | $A_m \geqslant 90$ | — |
| F 5 | — | $40 \leqslant E_m < 60$ |
| F 6 | — | $60 \leqslant E_m < 80$ |
| F 7 | — | $80 \leqslant E_m < 90$ |
| F 8 | — | $90 \leqslant E_m < 95$ |
| F 9 | — | $E_m \geqslant 95$ |

Air filters are designed to collect and retain particulate matter. This includes micro-organisms and mould spores. The presence of moisture in the vicinity of such filters can enable the micro-organisms to grow through the filter medium and contaminate the downstream air supply. Such material can also introduce unpleasant odours into the air intake. The design of filters must ensure that they are changed in accordance with the manufacturers' instructions and are located in a dry part of the ductwork(53–56). Recommended practice is to use two filters in series. The pre-filter will stop the coarse particulates. The filter grade will be F5 or better. The second filter stops the bulk of the finer dust. This filter will be grade F7 or finer (EUROVENT REC 06).

## 4.5 Indoor air quality

The World Health Organisation has also published guidelines for air quality[57], targeted at ambient air pollutants but intended to cover indoor air considerations where relevant. National governments and other bodies often take these WHO values as a starting point when establishing their own health based air quality standards.

The values given in Table 4.2 are based on exposure to single airborne chemicals through inhalation alone. They do not take account of additive, synergistic or antagonistic effects or exposure through routes other than inhalation. The basis for derivation is different for each chemical, hence they cannot be compared with each other within an overall hierarchy of exposure effects. For each chemical the WHO guidelines provide information on typical sources, occurrence in air, typical concentrations reported, routes of exposure, metabolic processes, proven and suspected health effects and an evaluation of human health risks.

*Table 4.2 Guideline values for individual substances*

| Substance | Averaging time | Guideline value concentration in air | | Source/notes |
|---|---|---|---|---|
| | | By mass | By volume | |
| Arsenic | Lifetime | — | — | Estimated 1500 deaths from cancer in population of 1 million through lifetime exposure of 1 $\mu g \cdot m^{-3}$ (WHO AQG: 1998; see note 1) |
| Benzene | 1 year (running) | 5 ppb | 16.0 $\mu g \cdot m^{-3}$ | AQOL; see note 2 |
| | Lifetime | — | — | Estimated 6 deaths from cancer in population of 1 million through lifetime exposure of 1 $\mu g \cdot m^{-3}$ (WHO AQG: 1998; see note 1) |
| 1,3-butadiene | 1 year (running) | 1 ppb | 2.26 $\mu g \cdot m^{-3}$ | AQOL; see note 2 |
| Cadmium | Annual | — | 5 $ng \cdot m^{-3}$ | WHO AQG: 1998; see note 1 |
| Carbon monoxide | 15 min<br>30 min<br>1 hour<br>8 hour (running) | 86 ppm<br>52 ppm<br>26 ppm<br>10 ppm | 100 $mg \cdot m^{-3}$<br>60 $mg \cdot m^{-3}$<br>30 $mg \cdot m^{-3}$<br>11.6 $mg \cdot m^{-3}$ | WHO AQG: 1998; see note 1<br>WHOAQG: 1998; see note 1<br>WHO AQG: 1998; see note 1<br>WHO AQG: 1998; see note 1 |
| Chromium | Lifetime | — | — | Estimated 40,000 deaths from cancer in population of 1 million through lifetime exposure of 1 $\mu g \cdot m^{-3}$ (WHO AQG: 1998; see note 1) |
| 1,2-dichloroethane | 24 hours | 168 ppb | 700 $\mu g \cdot m^{-3}$ | WHO AQG: 1998; see note 1 |
| Dichloromethane (methyl chloride) | 24 hours | 0.84 ppm | 3 $mg \cdot m^{-3}$ | WHO AQG: 1998; see note 1 |
| Formaldehyde | 30 min | 80 ppb | 100 $\mu g \cdot m^{-3}$ | WHO AQG: 1998; see note 1 |
| Hydrogen sulphide | 30 min | 5 ppb | 7 $\mu g \cdot m^{-3}$ | WHO AQG: 1998; see note 1 |
| Lead | 1 year | — | 0.5 $\mu g \cdot m^{-3}$ | Based on daily averages. AQOL; see note 2 |
| MMVF–RC (man-made vitreous fibres;refractory ceramic fibres) | Lifetime | — | — | Estimated 40,000 deaths from cancer in population of 1 million through lifetime exposure of 1 $\mu g \cdot m^{-3}$ (WHO AQG: 1998; see note 1) |
| Manganese | 1 year | — | 0.15 $\mu g \cdot m^{-3}$ | WHO AQG: 1998; see note 1 |
| Mercury | 1 year | — | 1 $\mu g \cdot m^{-3}$ | WHO AQG: 1998; see note 1 |
| Nickel | Lifetime | — | — | Estimated 380 deaths from cancer in population of 1 million through lifetime exposure of 1 $\mu g \cdot m^{-3}$ (WHO AQG: 1998; see note 1) |

*Table continues*

*Table 4.2 Guideline values for individual substances — continued*

| Substance | Averaging time | Guideline value concentration in air | | Source/notes |
|---|---|---|---|---|
| | | By mass | By volume | |
| Nitrogen dioxide | 1 hour (mean)<br>1 year | 150 ppb<br>21 ppb | 300 $\mu g \cdot m^{-3}$<br>42 $\mu g \cdot m^{-3}$ | AQOL; see note 2<br>Based on hourly averages. AQOL; see note 2 |
| Ozone | 8 hour | 60 ppb | 120 $\mu g \cdot m^{-3}$ | WHO AQG: 1998; see note 1 |
| $PM_{10}$ (particulate matter < 10 µm diam.) | 24 hour | — | 50 $\mu g \cdot m^{-3}$ | 99th. percentile (running). AQOL; see note 2 |
| Radon | Lifetime | — | — | Estimated 36 deaths from cancer in population of 1 million through lifetime exposure of 1 $Bq \cdot m^{-3}$ (WHO AQG: 1998; see note 1) |
| Styrene | 1 week | 60 ppb | 260 $\mu g \cdot m^{-3}$ | WHO AQG: 1998; see note 1 |
| Sulphur dioxide | 15 min<br>24 hour<br>1 year | 100 ppb<br>46 ppb<br>19 ppb | 270 $\mu g \cdot m^{-3}$<br>125 $\mu g \cdot m^{-3}$<br>50 $\mu g \cdot m^{-3}$ | 99.9th. percentile. AQOL; see note 2<br>WHO AQG: 1998; see note 1<br>WHO AQG: 1998; see note 1 |
| Tetrachloroethylene | 24 hour | — | 250 $\mu g \cdot m^{-3}$ | WHO AQG: 1998; see note 1 |
| Toluene | 1 week | 68 ppb | 260 $\mu g \cdot m^{-3}$ | WHO AQG: 1998; see note 1 |
| Trichloroethylene | Lifetime | — | — | Estimated 4 deaths from cancer in population of 10 million through lifetime exposure of 1 $\mu g \cdot m^{-3}$ (WHO AQG: 1998; see note 1) |

*Notes:*

(1) From WHO *Air Quality Guidelines for Europe* (1998), based on summary document of final consultation meeting held at WHO European Centre for Environment and Health, Bilthoven, Netherlands, 28–31 October 1996. These should be used along with the rationale given in the relevant chapters of the WHO publication[57].

(2) Air quality objective levels (AQOLS) are taken from the Air Quality Regulations 1997[58]. These levels are to be achieved outdoors throughout the UK by 2005. Local authorities have been tasked under Part IV of the Environment Act 1995[59] to review air quality within their areas to achieve these levels. The interpretation to the schedule in the Regulations defines how averaging should be achieved.

In 1996 the European Commission issued a Framework Directive on Air Quality (Framework Directive 96/62/EC), followed by a series of daughter directives on sulphur dioxide, nitrogen dioxide, particulate matter, lead and ozone – pollutants governed by existing ambient air quality objectives – and benzene, carbon monoxide, polycyclic aromatic hydrocarbons, cadmium, arsenic, nickel and mercury. The first Daughter Directive (1999/30/EC) relating to limit values for $NO_x$, $SO_2$, Pb and $PM_{10}$ in ambient air came into force in July 1999. The second Daughter Directive (2000/69/EC) relating to limit values for benzene and carbon monoxide came into force on the 13th of December 2000. The Commission's proposal for the third Daughter Directive on ozone appeared on 9th June 1999 as COM (1999) 125-2 final, and will eventually replace the current ozone Directive (92/72/EC). The fourth Daughter Directive, in preparation, will cover the remaining pollutants.

In 1998, the Department of Health's Committee on the Medical Effects of Air Pollutants (COMEAP) published an influential report, *The Quantification of the Effects of Air Pollution on Health in the United Kingdom*[60], which has led to various calculations and other assessments of the heath impacts of pollutants in ambient air, notably of $PM_{10}$, see Table 4.3 (below) There is no known safe threshold value for $PM_{10}$ and so the maximum permitted standard progressively reduces in future years. The Air Quality Standard for 2004 is an annual mean of 50 $\mu g/m^3$ with 35 permitted exceedances per year.

*Table 4.3 Increase in ill health attributed to each 10 μg/m³ increase in daily mean outdoor $PM_{10}$*

| Condition | Increase |
|---|---|
| Exacerbation of asthmatic attacks | 3% |
| Increased broncho-dilator use | 3% |
| Hospital admissions | 1.9% |
| Increase in lower respiratory problems | 3% |
| Increase in coughing | 1% |

In spite of all the regulatory and other activity surrounding pollution of outdoor air, there is very limited actual or considered regulation and control of indoor air quality and its determinants. Building Regulations ensure adequate ventilation on the basis that the outdoor air is clean, but there are currently no standards covering the quality of indoor air with respect to specific toxic pollutants derived from sources within buildings. This situation may change, however, and serious consideration is now being given to the development of guidelines and/or detailed guidance covering indoor pollutants(61). The only relevant standards that do exist for specific application to indoor air are those that relate to occupational exposure to known hazardous substances(8), but these are meant to apply to a 'healthy' worker population (i.e. excluding the old, the sick and other potentially more vulnerable individuals in the general population) and to a typical working day rather than 24-hour exposure. Attempts are sometimes made to 'convert' occupational standards to domestic/public health standards by dividing the concentration figure by 3 (i.e. 24/8) to allow for the different exposure periods and applying a 'safety' factor (of say 2 or 10) to account for individual vulnerability. Government guidelines propose that the air quality standards for the general population should be one fortieth of both the short term exposure limit (STEL) and the time weighted average (TWA) but one hundredth of the maximum exposure limit for substances scheduled under COSHH 8-hour Regulations(63). CIBSE traditionally recommend a criterion of one tenth of the relevant occupational limit from EH 40(8). However, this practice of using an arbitrary proportion of the OEL is very much discouraged because, for example, some HSE standards may include or be based on historical considerations of established practice and achievability. The WHO guidelines mentioned above are often used as 'default' guidelines for indoor air pollutants in the absence of specific national indoor standards. Some countries have developed their own specific guideline values for important air pollutants, see Table 4.4(62) (below)

*Table 4.4 A selection of national indoor air quality guideline values*[62]

| | WHO Air Quality Guidelines | Canada | Finland | | | Germany | | Norway |
|---|---|---|---|---|---|---|---|---|
| | | | S1 | S2 | S3 | GVI | GVII | |
| Ammonia | | | 30 μg/m$^3$ | 30 μg/m$^3$ | 40 μg/m$^3$ | | | |
| Carbon monoxide | 90 ppm (15 mins)<br>50 ppm (30 mins)<br>25 ppm (1 h)<br>10 ppm (8 h) | 28 μg/m$^3$ (1 h)<br>13 μg/m$^3$ (8 h) | 2 μg/m$^3$ | 3 μg/m$^3$ | 8 μg/m$^3$ | 1.5 μg/m$^3$ (8 h)<br>6 μg/m$^3$ (30 mins) | 15 μg/m$^3$ (8 h)<br>60 μg/m$^3$ (30 mins) | 25 μg/m$^3$ (1 h)<br>10 μg/m$^3$ (8 h) |
| Formaldehyde | 100 μg/m$^3$ (30 mins) | 120 μg/m$^3$ (5 mins) | 30 μg/m$^3$ | 50 μg/m$^3$ | 100 μg/m$^3$ | | | 100 μg/m$^3$ (30 mins) |
| Nitrogen dioxide | 100 ppb (1 h)<br>20 ppb (annual) | 480 μg/m$^3$ (1 h)<br>100 μg/m$^3$ (‘long term’) | | | | 6 μg/m$^3$ (1 week)<br>35 μg/m$^3$ (30 mins) | 60 μg/m$^3$ (1 week)<br>350 μg/m$^3$ (30 mins) | 50 ppb (1 h) |
| Ozone | 120 μg/m$^3$ (8 h) | 240 μg/m$^3$ (1 h) | 20 μg/m$^3$ | 50 μg/m$^3$ | 80 μg/m$^3$ | | | |
| Particles | [Unit risk] | $PM_{2.5}$<br>40 μg/m$^3$ (‘long term’)<br>100 μg/m$^3$ (1 h) | $PM_{10}$<br>20 μg/m$^3$ | $PM_{10}$<br>40 μg/m$^3$ | $PM_{10}$<br>50 μg/m$^3$ | | | $PM_{2.5}$<br>20 μg/m$^3$ (24 h) |
| Sulphur dioxide | 500 μg/m$^3$ (10 mins)<br>125 μg/m$^3$ (24 h)<br>50 μg/m$^3$ (annual) | 50 μg/m$^3$ (‘long term)<br>100 μg/m$^3$ (5 mins) | | | | | | |
| TVOC | | | 200 μg/m$^3$ | 300 μg/m$^3$ | 600 μg/m$^3$ | 1–3 mg/m$^3$* | | |

*Indicator value

## 4.6 Indoor/outdoor (I/O) pollution links

In the absence of a relevant indoor source, the concentration of a pollutant inside a building is directly related to the concentration outside. The ratio between indoor and outdoor levels will depend on the amount and nature of ventilation (and/or the ‘leakiness’ of the building) and on the reactivity and other physiochemical characteristics of the substance in question. Thus, for example, without an indoor source, ozone values tend to be low inside buildings because it is a very reactive gas; indoor/outside (I/O) ratio will therefore be very low at around 0.3. Carbon dioxide, on the other hand, is an unreactive gas and remains unchanged on entering the building and then adds to the carbon dioxide generated by the breathing of the occupants within the building. Nitrous oxide concentration remains unchanged. Nitrogen dioxide I/O is 0.7[65]

Generally speaking, I/O values are around 0.5 for most pollutants. However, very potent indoor sources of pollutants can be present within a building (see below), and it is not unusual in dwellings for concentrations of volatile organic substances (found, for example, in solvents, glues and paints), to be around 10 times higher inside than outside[66]. As well as the rate of supply of air to a building, air treatment (e.g. filtering) can obviously have an impact on indoor/outdoor concentration ratios, and also there can be important and efficient ‘sinks’ for air pollutants within a building. The ratio of supply rate to the building volume determines the time taken for the indoor pollution to build up. High ventilation rates supplied to small volume buildings, for example with low ceilings, can reach the maximum indoor pollution concentration much faster than low ventilation rates to spacious buildings.

## 4.7 Indoor sources

A building can contain many sources of exposure to air pollutants, both chemical and biological, some of which are very potent. Important sources of pollutants inside buildings include:

- building materials (including sealants, adhesives, paint)
- cleaning materials, solvents and other consumer products
- furnishings and fabrics
- furniture
- equipment such as photocopiers, printers, and document binders
- gas cookers, heaters and other un-flued fuel-burning appliances
- glues
- house dust mites
- moulds and bacteria
- pesticide products
- pets
- tobacco smoking
- radon seeping in from the ground.

Important pollutants released from these sources are:

- asbestos and man-made mineral fibres particularly in old buildings; specialist knowledge needed for safe removal although safe while undisturbed
- bacteria and mould spores particularly in neglected or damp buildings
- carbon monoxide from neglected unflued appliances such as paraffin heaters
- chlorinated organic compounds and organophosphates from solvents, aerosol products, foaming urethane and degreasing
- dust mite and pet allergen from moist damp houses and pets
- formaldehyde from insulation, packaging, and compressed wood products
- nitrogen dioxide (and other oxides of nitrogen) from cooking and other unflued combustion devices
- particles ($PM_{10}$ and smaller) from photocopiers, combustion products such as cooking, cigarette smoking and burning candles and from disturbed dust from the floor and other surfaces
- polycyclic aromatic hydrocarbons (PAHs) from fires, vehicle exhaust and coal tar.
- volatile organic compounds (VOCs) from people, building materials and furnishings
- ozone from photocopiers, laser printers, and electric motors
- radon; a radioactive gas released from the ground under the building and considered as a separate specialist topic for a small number of zones in Britain.

In addition there are the effluents produced by occupants themselves, notably carbon dioxide ($CO_2$) but also VOCs and various other compounds produced by, or present on, human beings.

The actual pollutants and pollutant sources present in a building will largely be determined by the type of building and its usage. For example, there is likely to be a greater diversity (and certainly a different range) of pollutants and pollutant sources in a home than in an office.

Many of these substances become irritants if concentrations are sufficiently high. Little is known about the possible additive or synergistic effects that may occur when a number of substances combine at low concentrations. This is particularly so in the case of ozone and VOCs.

A Building Research Establishment[66] study into VOCs in 876 dwellings in England had eight pertinent conclusions:

(1) Indoor TVOC concentrations vary significantly with season. Off-gassing appears to be affected by a combination of activities, temperature and ventilation.

(2) Benzene and toluene were positively correlated with smoking (as they are both constituents of tobacco smoke this is somewhat unsurprising).

(3) A built-in garage significantly increased TVOCs with a range of compounds found in paints, petrol and solvents migrating directly into the dwelling.

(4) Benzene and m/p-xylene were found in higher concentration in metropolitan areas Again as they are constituents of petrol fumes this is not surprising. M/p-xylene was also correlated with dwellings containing air freshners.

(5) Undecane was significantly increased by frequency of indoor painting.

(6) The main sources of VOCs were stored materials and/or car/fuel, frequency of decoration and type and age of fittings and furnishings, combustion of methane, and environmental tobacco smoke.

(7) There appeared to be no overall factor representing ventilation rates

(8) Most homes had VOC levels well below existing guidelines apart from benzene which was found in over 50% of dwellings to be above the National Air Quality Guidelines (NAQS) target for 2010.

## 4.8 Health effects of common indoor pollutants

A number of useful reviews of the health impacts of common indoor air pollutants have been published[68–71]. In non-industrial buildings, as with pollutant sources, the range of compounds present in the indoor air is likely to be greatest in homes, and many assessment of health effects of indoor air focus on the domestic environment. The most significant compounds in indoor air with respect to overall health impacts are probably carbon monoxide, house dust mite and pet allergens, moulds, formaldehyde, nitrogen dioxide (and other oxides of nitrogen), and possibly particles. While the significance of particulate matter in ambient air is undisputed, there is an unresolved question about the relative toxicities of vehicle derived and other airborne particles, such as may be generated by cooking and heating appliances inside buildings. Carbon dioxide at low concentrations is typically used as a marker for indoor air quality and for ventilation requirements, reflecting the pollutant loading from exhalation by the occupants. The maximum concentration at 5000 ppm in working conditions[8] and at extremely high concentrations, when it can be an asphyxiant. The role of VOCs in causing ill health is somewhat disputed, although the measurement of total VOCs has in the past been used as a general marker for indoor air quality, and VOCs have been implicated both in 'sick building syndrome' and so-called multiple chemical sensitivity.

A wide range of health effects can ensue from exposure to pollutants in indoor air. Leaving aside the issue of sick building syndrome (the precise causes of which are still largely undefined), the predominant consequences of exposure to air pollutants are to the lungs, as many are irritants[62]. Other impacts are to the immune system[72], either directly (as allergens) or indirectly (as 'adjuvants'; substances, often irritants, which enhance the immune response). Thus, for example, nitrogen dioxide exposure in children is associated with increased and /or prolonged coughs and colds, and house dust mite and pet allergen exposure is associated with asthma symptoms. Some pollutants — at sufficient concentrations — have more serious acute effects (e.g. death by carbon monoxide poisoning) or chronic consequences (e.g. leukaemia risk from long term inhalation of benzene). Exposure to particles in ambient air has been linked with both respiratory and cardiovascular disorders but it is not certain, for reasons previously explained, that this is true for particles generated indoors.

The prevention of discomfort from tobacco smoke may be achieved by the prohibition of smoking in rest rooms and rest areas or by providing separate rooms for smokers and non-smokers[10]. There is no known safe limit for continued exposure to tobacco smoke and ex-smokers can be particularly sensitive to throat and lung irritation from such smoke.

# 4.9 Microbiological contaminants

## 4.9.1 Allergens

Allergy is a form of immunity in which the natural defence mechanisms of the body have misfired, and instead of protecting, actually causes disease. The word allergy itself means an 'altered capacity to react'. The term has been expanded by Davies[73]:

> Allergy is the inappropriate and harmful response of the immune system to normally harmless substances.

The immune system is effectively the department of defence of the complex chemical plant that comprises the human body. It guards the body from foreign invaders that enter through the skin or respiratory system by mobilising cells designed to attack and kill any such intruder. It is the over- reaction of the immune system to relatively harmless subsatnces, by producing too many of these cells, that causes allergic reactions.

Allergy has four distinctive features:

— Allergy only develops after the substance causing it has been encountered several times

— Only a proportion of those exposed to the substance develop the disease

— It involves specific proteins (antibodies) present in the body

— Powerful chemicals (histamine) are released from mast cells

The area is complex but in general a range of substances can be classified under three headings:

— *Predisposers and adjuvants*: substances that can either prime the immune system or enhance the allergic reaction (eg paracetamol, high fat/salt diet,lack of infection, anti-biotics heavy metals etc.)

— *Sensitisers*: invariably proteins generated by house dust mites pets, plants, flowers, nuts etc.

— *Irritants*: substances that irritate the linings of the lung but do not stimulate market 'T-cell' activity. (chemicals, toxins, particulates, heavy metals, perfume, hairspray etc).

Increasingly, attention is moving away from 'chemical' pollutants to the role of the microbiological contaminants of indoor air found in increasing concentrations in indoor air. This applies both to the home, where dampness can cause severe infestation, and to commercial buildings with mechanical ventilation, which can harbour moulds and bacteria. . Moulds in particular are a current cause for concern, with respect both to their ability to cause lung irritation and the production of toxic, known as mycotoxins (e.g. *Alternaria*, *Cladosporium* and *Aspergillus* spp., and also from another common genus of indoor fungi, *Penicillium*[72]). Stachybotrys has been identified by some as a particularly important organism for its adverse impacts on human health and well-being. Moulds in general have (probably inadvisably) been labelled 'the new asbestos' with regard to potential future liabilities and litigation. However, although the association between damp and mouldy homes and respiratory effects, including asthma, is well known, there is little evidence for any particular mould species being responsible[69]; an exception to this is the adverse effects of *Alternaria* sp. exposure in asthmatics. The question of the health impacts of moulds is currently attracting considerable debate and research effort. It is certainly true that mould growth in ventilation plant is a problem and might well be associated with reported health effects in building occupants[74]. The role of mycotoxins and endotoxins in plant, animal and human health has recently been reviewed[75], but numerous knowledge gaps are apparent.

## 4.9.2 Airborne infection

### 4.9.2.1 Introduction

Micro-organisms occur in very large numbers in close association to humans, primarily on our skin and in out intestines; probably in a greater number than we have cells in our body. The vast majority of them do us no harm; indeed they protect us from other micro-organisms that may do us harm, mainly by crowding them out. The micro-organisms that live in harmless association with humans are known as 'commensals'. Much as we might attempt to clean the environment we live in, there are always many micro-organisms that surround us, on surfaces and in the air. These are similarly innocuous.

The main types of micro-organism are bacteria, viruses and fungi. Bacteria are small, simple, single-celled life-forms, each about 1 μm in size. Bacteria need water and nutrients to replicate. Viruses are even smaller than bacteria. They can only replicate by invading cells of other living organisms and 'programming' them to produce more viruses. Fungi have both large forms such as mushrooms and moulds, and microscopic forms such as yeasts and fungal spores. Fungal spores are reproductive cells released into the air by mushrooms and moulds, and are about 3–4 μm in diameter.

Occasionally we encounter micro-organisms that can invade parts of our body and cause harm. This is an infection. In the normal course of an infection, the body's immune response will eliminate the invaders. Infections doing us serious harm are very rare and usually occur in people whose immunity is not yet developed (the very young) or is declining (those with serious pre-existing illness or the very old). Micro-organisms that can establish an infection (known as 'pathogens') need special attributes to resist our immunity, even temporarily. Intact skin is very good at resisting infection; broken skin less so. Mucous membrane, such as in the mouth and nose, is more susceptible than intact skin to infection, it is the entry point for some viruses such as those causing colds or influenza, but can resist most bacteria and fungi.

We encounter many microbial pathogens without an infection resulting. They have to reach a susceptible site; a virus causing influenza landing on skin would not cause an infection, landing on the mucous membrane in the nose, it might cause infection. Once on a susceptible site, invading micro-organisms have to overcome a variety of host resistance mechanisms; the higher the number of potential invaders, the more likely they are to defeat host resistance.

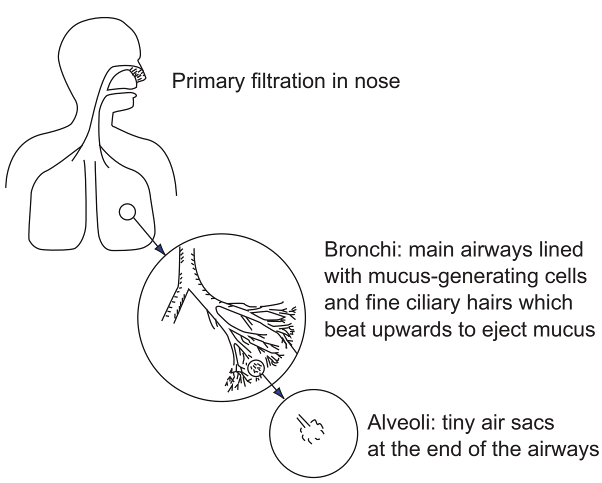
### 4.9.2.2 The respiratory tract and particle retention

Air enters the respiratory tract through the mouth or nose, see Figure 4.1 (below). It then passes down through the windpipe (trachea) which divides into two and goes into the lungs where it branches into numerous narrow vessels termed 'bronchi', then into more, narrower vessels called 'bronchioles' and finally into small sacs called 'alveoli' where the main function of the lungs, gas exchange with the blood, takes place. (The total area of the alveoli in both lungs in an adult is around 70 $m^2$). Air velocity and turbulence is higher in the upper parts of the respiratory tract, up to around 150 $cm \cdot s^{-1}$ in the trachea, and becomes progressively slower and less turbulent as it passes through the smaller vessels further inside the lungs, around 60 $cm \cdot s^{-1}$ in the bronchi, 10 $cm \cdot s^{-1}$ in the bronchioles and less than 1 $cm \cdot s^{-1}$ in the alveoli .

The larger the particle, the higher in the respiratory tract it will impact: particles over about 50 μm will impact in the nose or the back of the throat; particles down to 10 μm will impact in the trachea and bronchus; particles down to around 5 μm will impact in the bronchioles. Below this size, particles will settle out in the alveoli.

The respiratory tract has a self-cleansing mechanism whereby a layer of mucus continuously passes upwards inside the vessels from the bronchioles to the top of the trachea where, as sputum, it is either swallowed or coughed out. This removes impacted particles fairly effectively. Particles that impact below the level of the bronchioles, i.e. the particles of 5 μm and less that settle out in the alveoli, are beyond this clearance mechanism. In the alveoli there are cells of the immune system which can engulf and digest or remove most micro-organisms and other particles that have penetrated to this level.

*Figure 4.1 Finer particles penetrate further into the lung*



### 4.9.2.3 The production and nature of particles carrying micro-organisms

Particles carrying micro-organisms can arise in many ways, for example:

— Fungal fruiting bodies, such as mushrooms and moulds, produce very large numbers of fungal spores, released directly into the air.

— Dead cells are constantly being shed from the upper layer of the skin. A proportion of these will carry the bacteria that grow on, or may be contaminating, the skin.

— Water droplets can carry micro-organisms that were growing in, or contaminating, the water that gave rise to the droplets.

— Coughing and sneezing can produce droplets of mucus from the respiratory tract, contaminated with any micro-organisms that may be present.

— Mechanical action can break up solid or liquid structures or remobilise previously settled particles. Examples of the former are the demolition of buildings and surgical power-tools such as bone saws and dentists' drills; examples of the latter are waterless cleaning methods such as brooms or vacuum cleaners with unfiltered exhausts.

Micro-organisms can survive for highly variable periods in airborne suspension, depending on: innate survival ability (fungal spores can survive for weeks to months, some bacteria or viruses will die in minutes, others will survive for days or weeks, bacterial spores can survive for decades); adverse environmental conditions (sunlight or ultraviolet light will often shorten survival); suspending material (protein, as in the dried mucus from a cough or sneeze, will prolong survival); humidity (slow drying of particles tends to favour survival of micro-organisms within them) and many other more minor factors. Temperature differences within normal comfort zones are unlikely to have a significant effect.

The actual size of a particle carrying micro-organisms usually bears little relationship to the size of the micro-organism itself. For example, a bacterium from the skin will itself be around 1 μm, but will often be carried on a dead skin cell of around 5–15 μm; a common cold virus of around 0.03 μm will usually be within a particle of 1–15 μm derived from a sneeze or cough. Only with those airborne micro-organisms that are released directly into the air, such as fungal spores, or are aerosolised as individual cells in a water droplet which evaporates, such as some forms of legionella, will the particle size be that of the micro-organism itself.

Particles settle at rates proportional to their size. In static air, particles of 20 μm will fall at about a metre per minute, whereas particles of 1 μm will fall at about less than a centimetre per minute. At such low settling velocities, air currents and thermals can keep these small particles airborne for long periods.

The size of particles can change soon after production. Aqueous particles, such as water droplets or droplets from coughs and sneezes, will start to evaporate and become smaller and lighter as they fall. Those particles that dry completely before they reach the ground are termed 'droplet nuclei' and can travel considerable distances before eventually settling-out. Larger particles will fall rapidly and settle-out close to the point of their original generation. If carrying infectious micro-organisms, both have the potential to transmit that infection. The larger the particle, the more micro-organisms it is likely to contain and the greater the chance that it will have sufficient to initiate an infection. The smaller the particle, the less likely it will have sufficient micro-organisms in it to initiate an infection, but it will be airborne and available for inhalation for longer. Also, the more small particles are inhaled, the greater the chance of there being sufficient micro-organisms to initiate an infection. However, as these droplet nuclei disperse from the point of production, their dilution will decrease the chances of high number being inhaled. So distance from the point of production of infectious particles is inversely proportional to the probability of successful infection transmission.

### 4.9.2.4 Infectious diseases transmitted via the air

The most likely source of infectious disease is another person suffering from that infection. In disease spread by the airborne route, such as tuberculosis, chickenpox, measles, influenza, the common cold, diphtheria and severe acute respiratory syndrome (SARS), the respiratory tract will be the main point of replication for the responsible micro-organism and coughing or sneezing will expel droplets carrying the infectious micro-organism. Some of these droplets can then be inhaled by a nearby individual, impinge on the mucous membranes of their respiratory tract and, if there are sufficient numbers, initiate an infection.

Terming an infectious disease as having ‘airborne’ transmission is usually an over-simplification; it does not mean that transmission is solely airborne and, in practice, will usually involve a mixture of routes. Taking the common cold as an example, the causative virus is present in profusely-produced mucus from the upper respiratory tract. It can also be spread by large droplets contaminating nearly surfaces; hands contaminated during sneezes or nose-blowing; by dried, virus-containing mucus, previously deposited on a tissue or handkerchief, turning to airborne dust as it is stored in pocket or handbag, or the same dust contaminating hands as they reach into the pocket or handbag. The numbers of micro-organisms transferred is critical to initiating an infection; transmission by contact usually involves less dilution of original micro-organisms than a purely airborne route. Certainly with a purely airborne route, proximity is important in transferring an infectious dose.

This mixture of routes is true for all the ‘airborne’ diseases except tuberculosis and legionnaires' disease. In the normal transmission modes of both these diseases, the causal bacteria must be inhaled deep into the lungs to the alveoli where they can escape the mechanical removal (see above) that would occur if they impacted higher up the respiratory tract. The bacteria that cause these diseases are able to resist the host immunity in the alveoli and initiate the process of infection. In order to penetrate down to the alveolar level, the bacteria-carrying particles must be at or near the size of the isolated bacteria (around 1–5 μm).

For *Legionella pneumophila* (the bacterium that causes legionnaires'' disease) this can occur when airborne small droplets of water containing the bacteria dry down to ‘droplet nuclei’ (see above) before they fall to the ground[76,77]. This is why outbreaks of legionnaires'' disease are associated with situations where water forms droplets in air, such as cooling towers, fountains, showers and whirlpool spas, rather than with standing water, which is just as likely to contain the causative bacterium but does not form aerosols. legionnaires' disease is linked with ventilation systems only insofar as infectious aerosols can be generated by equipment that is associated with them; the infection is rarely distributed by a system's ductwork because designers are advised to site air inlets at some distance from cooling towers. Cases tend to be exposed either outside, downwind from the cooling tower, or if the infectious aerosol has entered though open windows.

For transmission of tuberculosis, the causative bacterium (*Mycobacterium tuberculosis*) multiplies in the lungs of an infected person and contaminates the mucus that rises from the lungs. One of the symptoms of tuberculosis is coughing, which produces a range of droplet sizes of this mucus (‘sputum’), some of which will dry before they fall to the ground and form droplet nuclei. Only a small proportion of these will contain infectious bacteria; the smaller the particle, the less likely it is to contain infectious bacteria. If sufficient of these are inhaled to overcome host defences, an infection can be initiated. (It is ironic that the larger sputum particles will contain more infectious bacteria but will be too large to penetrate to the alveoli in the lungs and so will not be able to transmit the infection). Tuberculosis is typically a disease that flourishes in the deprivation characterised by overcrowded accommodation. In these conditions, a susceptible individual has to be in prolonged, close proximity to a person with tuberculosis to inhale sufficient infectious particles to initiate the infection.

#### 4.9.2.5 Ventilation systems and infection transmission

The transmission of airborne infection between people is most effective in large droplets that will cover only short distances before falling to the ground. Smaller particles that can form true aerosols rapidly become too dilute to transmit infection effectively as the distance from their source increases. Thus the potential of building ventilation systems, outside some special healthcare situations, to transmit infection is minimal. Air will move between rooms and areas in a building, either by natural or mechanical ventilation, or a mixture of both. The further it moves, by whatever means, the more dilute any infectious aerosols become. Even with ventilation systems that recirculate a proportion of air, as in most large non-hospital systems, the redistribution of air and the fresh air make-up produces very substantial dilution.

Bacteria and fungi need both liquid water and nutrients to replicate (see *Introduction*). Whilst there are usually sufficient nutrients in the traces of organic deposits in much ventilation ductwork, liquid water should be absent. In this situation, if bacteria and fungi are found, they will be non-replicating contaminants that will die-off with time. There will be some liquid water present in the air handling unit, mainly around active chiller batteries and their condensate drip trays. These are unlikely to give rise to significant aerosols but, for their efficacy as much as hygiene, should be cleaned of biofilm regularly. There is no point in sampling filters in ventilation systems for bacteria and fungi as signs of contamination. If bacteria and fungi are isolated from these filters, it is because the filters have successfully filtered bacteria and fungi out of the air; it is a sign they are fulfilling their function. Viruses need other living systems in which to replicate; they will not replicate in ventilation systems.

## 4.10 Ventilation effectiveness

Ventilation within a building occurs partly by unplanned infiltration which is driven by a combination of indoor/outdoor temperatures differences and wind speed, partly by the planned ventilation systems provided, such as natural ventilation chimneys or mechanical fans and partly by opportunist means such as opening a window. In the past the bulk of ventilation in British buildings has been unplanned infiltration through cracks in the building construction, reinforced by the planned ventilation. New Regulatory requirements set out to reduce infiltration progressively over time[79]. This means that the planned ventilation is becoming the actual ventilation and now requires more serious design thinking. The ventilation criteria are usually based on the pollution concentration at the mouth of a sitting and a standing person. For many years the mechanical ventilation and air conditioning systems were based on well mixed air flow within the room with the incoming air delivered through ceiling mounted diffusers. In recent years designs for displacement ventilation are based on piston flow within the room with the incoming air being introduced at floor level. The pollution concentration in displacement ventilation is therefore much more sensitive to the location of the source of the pollutant. Such systems will be relatively unaffected by the release of pollutants at height but much more by low level sources.

Guidance on the ventilation effectiveness for the ventilation arrangements shown in Figure 4.2 is given in Table 4.5, see below. In each case, the space is considered as divided into two zones:

— the zone into which air is supplied/exhausted

— the remainder of the space, i.e. the ‘breathing zone’.

In mixing ventilation (cases (a) and (b) in Figure 4.2), the outside air supply rates given in Table 4.5 assume that the supply zone is usually above the breathing zone. The best conditions are achieved when mixing is sufficiently effective that the two zones merge to form a single zone. In displacement ventilation (Figure 4.2(c), the supply zone is usually at low level and occupied with people, and the exhaust zone is at a higher level. The best conditions are achieved when there is minimal mixing between the two zones. The values given in Table 4.5 consider the effects of air distribution and supply temperature but not the location of the pollutants, which are assumed to be evenly distributed throughout the ventilated space. For other types of displacement system, the ventilation effectiveness ($E_v$) may be assumed to be 1.

*Figure 4.2 Supply/extract arrangements for ventilation; (a) mixing, supply and exhaust at high level, (b) mixing, supply at high level, exhaust at low level, (c) displacement*

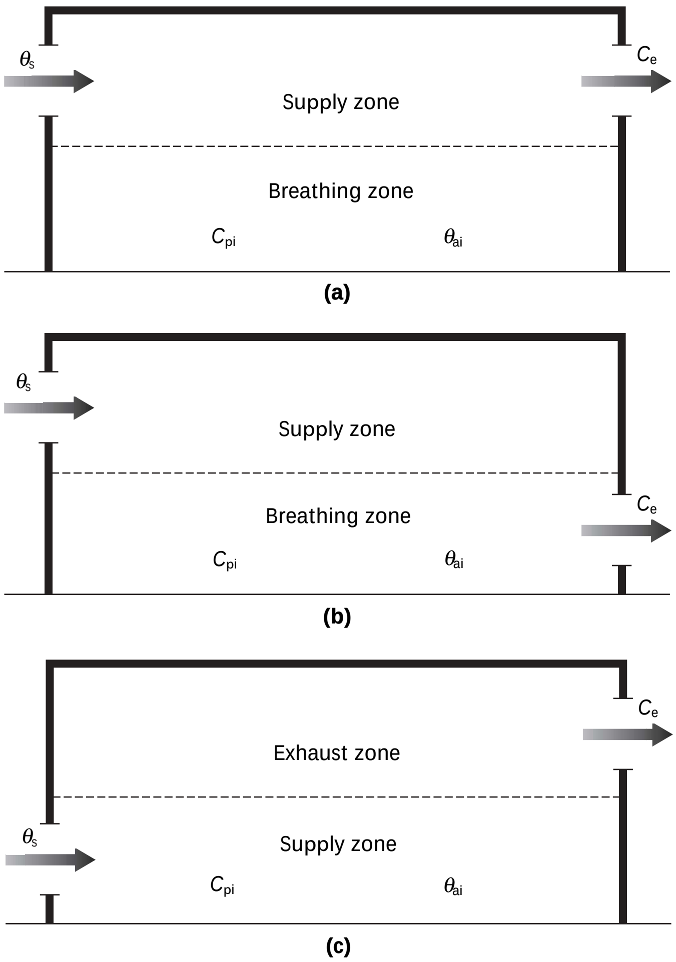



*Table 4.5 Ventilation effectiveness for ventilation arrangements shown in Figure 4.2*

| Ventilation arrangement | Temperature difference between supply air and room air, $(\theta_s - \theta_{ai})$ / K | Ventilation effectiveness, $E_v$ |
|---|---|---|
| Mixing; high-level supply and exhaust (Figure 4.2(a)) | < 0 | 0.9–1.0 |
| | 0–2 | 0.9 |
| | 2–5 | 0.8 |
| | > 5 | 0.4–0.7 |
| Mixing; high-level supply, low-level exhaust (Figure 4.2(b)) | < –5 | 0.9 |
| | (–5)–0 | 0.9–1.0 |
| | > 0 | 1.0 |
| Displacement (Figure 4.2(c)) | < 0 | 1.2–1.4 |
| | 0–2 | 0.7–0.9 |
| | > 2 | 0.2 – 0.7 |

## 4.11 Feedback from occupants

Two kinds of study have explored the links between health and ventilation. One important American Government study empirically explored the reported health of over 2000 office workers in 80 buildings and analysed the results in terms of basic measurements and observations of the building services. The study showed that the risk of reported respiratory symptoms tripled if debris lay in the air intake, and if there was poor drainage from the air handling unit condensate pans. The risk of respiratory symptoms more than doubled if the fresh air inlet was within 8 m (25 ft) of either an exhaust air outlet, a toilet exhaust ventilator outlet or a rubbish store. Dirty or badly fitting air filters doubled the risk(80). The air inlet must be placed well away from recognised polluted sources such as toilet vents, chimneys, vehicle exhaust pipes or carry over from evaporative cooling towers. The ductwork must be clean(6,10,39,78).

*Table 4.6 Increase in reported respiratory symptoms by office occupants*

| Cause | Increase |
|---|---|
| Debris lies in the air intake | 310% |
| Poor drainage from condensate pans | 300% |
| Ductwork not cleaned | 280% |
| Air inlet within 8 m of an exhaust ventilator | 240% |
| Air inlet within 8 m of a standing water | 230% |
| Air inlet within 8 m of a toilet exhaust ventilator | 220% |
| Moisture in the ductwork | 220% |
| Filters not secure | 220% |
| Air inlet within 8 m of a rubbish container | 200% |
| Air inlet within 8 m of vehicular traffic | 190% |
| Filters not clean | 190% |

Source: Sieber et al 1996(80)

The second study, commissioned by the Swedish Public Health Laboratories, used a multidisciplinary team to explore the literature linking ventilation rates to the satisfaction and health of the occupants. Many of the 105 peer reviewed studies lacked background information about the buildings or were inconclusive. There was consensus amongst the remaining 14 papers. This showed that higher ventilation rates than previously proposed were welcomed by the occupants but only if the ventilation system was designed correctly and properly maintained. Ventilation rates below 25 L/s per person increased the risk of sick building syndrome, increased short term sick leave and decreased perceptions of productivity. The literature also indicated that occupants of buildings with air conditioning systems may have an increased risk of sick building symptoms compared to naturally or mechanically ventilated ones and that negligent design, inadequate maintenance and malfunctioning air conditioning systems contributes to increased prevalence of sick building symptoms(74).

In some cases occupants experience symptoms, which may not be obviously related to a particular cause, but which become less severe or disappear when they leave a particular environment. These symptoms, such as nausea, mucosal dryness or irritation, runny nose, eye problems, headaches, skin problems, heavy head and flu like symptoms, may be quite severe and lead to reduced productivity or absenteeism. If a significant proportion of occupants experience these symptoms then, by definition , the occupants are suffering from ‘sick building syndrome’.

It is likely that the cause of sick building syndrome is multi factorial. Researchers have identified a statistically significant correlation between symptom prevalence and many different and unrelated factors. It would appear that if environmental conditions are within the comfort limits set out in CIBSE Guide A: *Environmental design*(64) then the risk of occupant dissatisfaction and sick building syndrome is reduced, though not eliminated.

# 4.12 Determination of required outdoor air supply rate

## 4.12.1 General

Ventilation requirements for a wide range of building types are summarised in CIBSE Guide A, chapter 1[64]. Detailed information on specific applications is given in chapter 2 of CIBSE Guide B[81]. For some industrial applications outdoor air may be required both to dilute specific pollutants and to make up the air exhausted through local extract ventilation systems, see chapter 3 of CIBSE Guide B[81]. Specialist advice should be sought in dealing with toxic and/or high emission pollutants.

In the following sections three methods are described for determining the outdoor air supply rate required for particular applications.

The first method is prescriptive, providing either an outdoor air supply rate per person or an air change rate, depending on the application. These values are based primarily on chamber studies, in which all sources of odour other than body odour and/or cigarette smoke were excluded. Therefore these prescribed rates may underestimate the outdoor air supply requirements if odour sources other than body odour or smoking dominate. Examples of such situations are spaces having large areas of new floor covering, upholstery, curtains etc. or spaces in which the standards of cleaning and maintenance are less than excellent.

Method 2 should be used in situations where there are known pollutants being released into the space at a known rate and local extract ventilation (LEV) is not practicable. To apply method 2, it is necessary to know the appropriate concentration limits for the pollutants. Local extract should be used wherever source location permits and for all applications where risks to the health of the occupants are not acceptable. The ventilation strategy should be based on a risk assessment under the Control of Substances Hazardous to Health Regulations 1994[7]. Design guidance is given in chapter 3 of CIBSE Guide B[81].

A further method has been suggested[82] which is intended for use where the pollution sources are known but (*a*) the emission rates of specific malodourous pollutants cannot be predicted, (*b*) their limiting concentrations are not known, or (*c*) odours are likely to result from complex mixtures of contaminants. Further research will be required to establish benchmark criteria. Ventilation rates calculated by this method will usually be higher than the prescribed rates determined using method 1. Details of this method are given in a report on ventilation requirements produced by the Commission for the European Community[83].

## 4.12.2 Method 1: Prescribed outdoor air supply rates

For applications in which the main odorous pollutants arise due to human activities, e.g. body odour and environmental tobacco smoke, it is possible to supply a quantity of outdoor air based on the number of occupants in a given space. If smoking is prohibited, as is increasingly the case, then the recommended outdoor air supply rates given in CIBSE Guide A[64] Table 1.5 apply.

Spaces in which smoking is permitted should be regarded as ‘smoking rooms’ and an outdoor air supply rate of 45 L/s per person is suggested for such rooms. However, it should be noted that this recommendation aims only to reduce discomfort and does not ensure health protection.

## 4.12.3 Method 2: Specific pollutant control

### 4.12.3.1 Steady-state conditions

For pollutants emitted at a constant rate, the ventilation rate required to prevent the mean equilibrium concentration rising above a prescribed level may be calculated from the following equation:

$$Q = \frac{P\,(10^6 - C_{\mathrm{pi}})}{E_{\mathrm{v}}\,(C_{\mathrm{pi}} - C_{\mathrm{po}})} \qquad (4.1)$$

where $Q$ is the outdoor air supply rate ($\mathrm{L \cdot s^{-1}}$), $P$ is the pollutant emission rate ($\mathrm{L \cdot s^{-1}}$), $C_{\mathrm{po}}$ is the concentration of pollutant in the outdoor air (ppm), $E_{\mathrm{v}}$ is the ventilation effectiveness and $C_{\mathrm{pi}}$ is the limit of concentration of pollutant in the indoor air (ppm). Values for $E_{\mathrm{v}}$ are given in Table 4.5

If the pollutant threshold is quoted in mg·m$^{-3}$, the concentration in parts per million may be obtained from:

$$C_p = (C_p' \times 24.05526) / M_p \tag{4.2}$$

where $C_p$ is the concentration of pollutant (ppm), $C_p'$ is the concentration of pollutant (mg·m$^{-3}$), $M_p$ is the molar mass of the pollutant (kg·mole$^{-1}$). The numerical factor is the molar volume of an ideal gas (m$^3$·mole$^{-1}$) at 20 °C and pressure of 1 atmosphere. Molecular masses for pollutants are given in HSE EH40[8] or from manufacturers' data.

If $C_{pi}$ is small (i.e. $C_{pi} \ll 10^6$), equation 4.1 becomes:

$$Q = \frac{P \times 10^6}{E_v\,(C_{pi} - C_o)} \tag{4.3}$$

If the incoming air is not contaminated by the pollutant in question, this equation simplifies to:

$$Q = (P \times 10^6) / E_v\, C_{pi} \tag{4.4}$$

Where there is more than one known pollutant, the calculation should be performed for each pollutant separately. The outdoor air supply rate for ventilation is then highest of these calculated rates.

Equations 4.2, 4.3 and 4.4 assume that the pollutants become thoroughly mixed with the indoor air so that a substantially uniform concentration exists throughout the space. If the ventilation results in a non uniform concentration so that higher than average concentrations occur in the inhaled air, the outdoor air supply rate would need to be increased above the value calculated by these equations.

*Example 4.1*

Toluene is being released at a rate of 20 mL·h$^{-1}$; determine the rate of ventilation required to meet the WHO Air Quality Guides for Europe[57], assuming a ventilation effectiveness ($E_v$) of 1.

The release rate of the pollutant, $P = 20$ mL·h$^{-1}$ $= 5.56 \times 10^{-6}$ L·s$^{-1}$.

From Table 4.2 the WHO AQG threshold for toluene is 68 ppb (i.e. 0.068 ppm).

Assuming there is no toluene in the outdoor air, $C_o = 0$.

Therefore, using equation 4.2:

$$Q = (5.56 \times 10^{-6} \times 10^6) / (1 \times 0.068) = 81.7 \text{ L·s}^{-1}$$

#### 4.12.3.2 Non-steady-state conditions

The ventilation rate given by equation 4.4 is independent of the room or building volume. However the volume of the space affects the time taken for the equilibrium condition to be reached. This becomes important when the emission of a pollutant occurs for a limited duration only. In such cases the ventilation rate derived from equation 4.4 will exceed that required to maintain the concentration below the specified limit.

The ratio by which the steady-state ventilation rate may be reduced in these circumstances is given by:

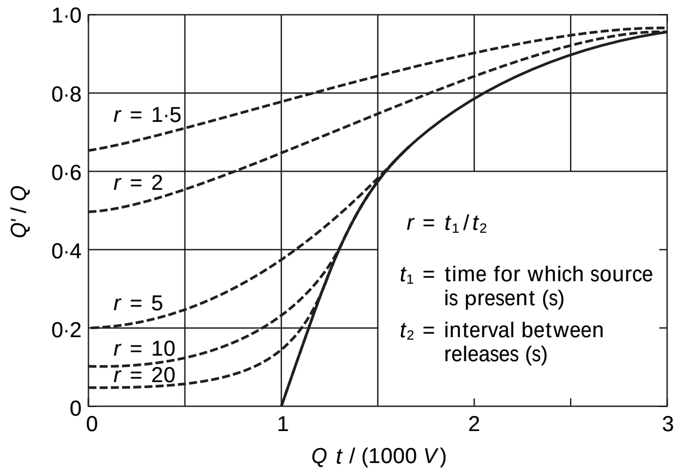
$$Q' / Q = f\,(Q\, t_p / 1000\, V) \tag{4.5}$$

where $Q'$ is the reduced ventilation rate (L·s$^{-1}$), $Q$ is the steady-state ventilation rate (L·s$^{-1}$), $t_p$ is the duration of release of the pollutant (s) and $V$ is the volume of the space (m$^3$).

The form of the function $f\,(Q\, t_p / 1000\, V)$ is given by the solid curve in Figure 4.4. Although theoretically no ventilation is required when $(Q\, t_p / 1000\, V) < 1.0$, some ventilation should be provided because subsequent releases of pollutant are likely to occur.

Recurrent emissions can be taken into account by considering a regular intermittent emission where the releases occur for periods of $t_1$ seconds at intervals of $t_2$ seconds. The ventilation rate ratio then becomes a function of $(Q\, t_1 / V)$ and the ratio of $t_1$ to $t_2$. The broken lines in Figure 4.3 may be used to determine $(Q' / Q)$ where these parameters are known.

*Figure 4.3 Reduction in fresh air rate for intermittent pollutant source*




*Example 4.2*

If the toluene in Example 4.1 were released into a ventilated space of 160 m$^3$ volume over a 40 minute period each day, determine the continuous outdoor air supply rate required to maintain the concentration of toluene at or below the WHO AQG value.

Initial data: $Q = 81.7$ L·s$^{-1}$, $t_p = 2400$ s, $V = 160$ m$^3$.

Therefore:

$$(Q\, t_p / 1000\, V) = (81.7 \times 2400) / (1000 \times 160) = 1.23$$

From Figure 4.3:

$$(Q' / Q) = 0.35$$

Therefore:

$$Q' = 0.35 \times 81.7 = 28.6 \text{ L·s}^{-1}$$

*Example 4.3*

If the toluene in Example 1.1 were periodically released for periods of 40 minutes with an interval of 20 minutes between releases, determine the appropriate outdoor air supply rate.

Initial data: $Q = 81.7$ L·s$^{-1}$, $t_p = 2400$ s, $V = 160$ m$^3$.

As for Example 4.2:

$$(Q\, t_p / 1000\, V) = 1.23$$

Ratio of source duration to return interval is given by:

$$r = t_1 / t_2 = 2400 / 1200 = 2$$

From Figure 4.3, for $r = 2$:

$$(Q' / Q) = 0.75$$

Therefore:

$$Q' = 0.75 \times 81.7 = 61.3 \text{ L}\cdot\text{s}^{-1}$$

## 4.13 Protection against deliberate harmful attacks

Deliberate airborne contamination has been used to injure the inhabitants of office buildings. Lethal quantities of such airborne releases can easily be carried by an individual. It is impossible to provide complete protection but sites can be made less attractive to prospective threats[84].

There are three levels of risk:

(1) *Hazardous substance introduced into the main air supply*: the most serious threat is direct release of a dangerous airborne material into the air inlet duct work of the building. Publicly accessible, low level air inlets are the biggest risk and any steps to restrict public access, introduce a secure zone around the air inlet or to elevate the air inlet well above ground level will help. Simple coarse protective screens placed in the neighbourhood of the air inlet would also be beneficial in hampering the throwing of material into the ducting. Plant rooms and access hatches into the ductwork can be securely locked so that access to the main air supply is more difficult. Reassessment of the grade and installation of the air inlet filters would define the size of the particles which would enter the building. An engineering assessment of the opportunities of introducing a finer filter or a multiple filter, coarse to fine, could be undertaken bearing in mind the pressure drop/flow characteristics of the filter bank (see 4.9.2).

(2) *Hazardous substance released into a room within the building*: this becomes more important in those buildings where the air is recirculated because any airborne contaminant released in one room could be carried to all other parts of the building. The best solution would be to limit the damage caused by the release harmful gas or particles by isolating the ventilation of the most likely rooms from the rest of the building (entrance lobby and mail room). An engineering reassessment of incorporating a suitable air filter into the recirculation air loop could reduce the risk from particulates.

(3) *Hazardous substance released in the vicinity of the building*: this is more likely to be linked to a large area scale attack rather than a personal scale attack. Low infiltration construction and well fitting windows, doors and air grille dampers enable the building to be isolated whenever such abuse is identified. An organised action plan could be helpful in such emergencies. In caring for those injured and in providing information to relatives and the media[85,86].

The integrity of the fire escape system must not be compromised by introducing any of these precautions.

## 4.14 Conclusions

(1) Health criteria are very personal and with very different sensitivities between individuals, even with healthy individuals. A statistical approach is necessary. The arbitrary definition for health for those in a building is for the condition at which 5% of the occupants experience annoyance for less than 2% of the time, with less than 10% of the occupants with mucosal irritation, with less than 20% in discomfort and with less than 50% of the occupants cannot detect odour.

(2) Absence of odour is not a sufficient criterion for health. Many gaseous pollutants are odourless, such as carbon dioxide, carbon monoxide and radon. Measurement is needed whenever high concentrations of those gases are suspected.

(3) Fine airborne particulates (smaller than 10 μm diameter) irritate the lungs and there is no threshold value. Health benefits continue with ever lower particulate concentrations.

(4) The traditional view of engineers was that the pollutants were released inside the building and the fresh air ventilation from outside was introduced to dilute the inside pollutants. Today urban pollutants are often above the recommended safe values. Engineers are urged to consider the cleanest location for the air intake for the building. This means away from exhaust ducts, chimneys and evaporative cooling towers. It means high up and away from the traffic pollution. Two zone filtration is recommended for the air inlet. The coarse filter (F5 or finer) pre-filtering the coarse dust. The second filter (F7 or finer) stops the bulk of the finer dust.

(5) The minimum fresh air ventilation is currently 8 L/s per person. The proposed Building Regulations recognise that tighter buildings will reduce adventitious ventilation and to compensate for that the minimum fresh air will be increased to 10 L/s per person. Empirical evidence from office surveys show that there is a health benefit up to fresh air rates up to 20 L/s per person, providing that the ventilation is properly designed and maintained.

## 4.15 Recommendations

(1) The legislation for residential buildings specify a controllable ventilation slit , normally in the window frame, for background ventilation, planned ventilation for bathroom and kitchen, normally by ventilation fans, and openable window for occasional high ventilation rates in summer. However the proposed Buildings Regulations are recommending 12 L/s per person.

(2) The HSE requires an adequate ventilation for work places and suggests 5 or 8 L/s per person unless specific contaminants are expected. In then case the employer will introduce measured occupational exposure limits to control the pollution; either occupational exposure standards (OESS) with no risk and maximum exposure limits (MELS) for those with some risk. Work of a variable pattern can have short term limits (STELS) with respect to a 15 minute period.

(3) Empirical evidence from office surveys found that there is a health benefit for increased ventilation up to 20 L/s per person, providing that the ventilation system is designed properly and maintained.

(4) There is concern about the outdoor air quality in urban areas. DEFRA has introduced Outdoor Air Standards and those areas which cannot achieve them have to declare an Air Quality Management Area. Special clean is needed for such areas. Local Authorities have to consider the Environment Impact Assessment for new buildings. Two stage filtration is recommended for all urban areas, using a F5 or better prefilter followed by a F7 or finer filter.

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# Appendix 4.A1: Definitions

**Aerosol**: a suspension of fine material in air

**Carbon dioxide**: a gas from combustion products from burning or oxidation of carbon containing material. A component of exhaled breath. Often used as an indicator for ventilation in occupied buildings.

**Hazard**: the type of effect, e.g. Legionnaire's disease.

**Legionella**: a water borne bacterium capable of causing fever (Pontiac or Lochgoilhead)or pneumonia (legionnaires'' disease) in susceptible humans when inhaled as an aerosol.

**MEL (Maximum exposure limit)**: such limits are set for substances which have no known safe level or in which achieving such a value is not reasonably practicable. Often used for the most serious health effects such as cancer

**Oxides of nitrogen**: nitrogen is relatively inert but at high temperatures it can react and form a number of irritating and harmful oxides ($NO_x$)

**OEL (Occupational exposure limit)**: the HSE reviews permitted occupational exposure limits (OELS) and publishes them annually[(8)]. These lists have legal status under the COSHH Regulations 1999

**Ozone**: is a very active, pungent form of oxygen which is an irritant at low concentrations and toxic at high concentrations. It has a short life.

**PAH (Polycyclic aromatic hydrocarbons)**: a product of combustion and an occupational hazard in aluminium smelting and coke manufacturing; causes cancer.

**Pathogenic**: harmful to humans.

**$PM_{10}$**: particulate matter suspended in air and below 10μm in size. Particle sizes above this do not penetrate far into the lung and do not remain in the body unless soluble. Usually specified as $\mu g/m^3$.

**$PM_{2.5}$**: particulate matter suspended in air and below 2.5μm in size. Believed to be more damaging to health because the finer particles penetrate more deeply into the lungs.

**Public population**: the general population are considered much susceptible for ill health than the working population. This includes the pregnant, the very young, the elderly and those with medication. E.g. The National Radiological Protection Board specifies maximum electromagnetic fields for the public for 20% of the values permitted for working people.

**Risk**: the likelihood of the harm and the severity of the effect.

**SARS (Severe acute respiratory syndrome)**: a viral infection from animals and very infectious.

**STEL (Short term exposure limit)**: permissible peaks over a 15 minute period are used to protect against short term exposure which may occur, rapidly such as eye or throat irritation

**TWA (Time weighted average)**: the average concentration over a given period of time. Long term exposure is based on an 8 hour daily exposure. Short term is based on 15 minute exposure (see STEL)

**Unflued**: a combustion device without a chimney, for example a gas cooker , a free standing paraffin or free standing room gas heater.

**VOCs**: volatile organic compounds)

**Working population**: the HSE Guidance applies to healthy working adults and where their employers have the opportunity to apply engineering and administrative measures in their working environment. Employers also provide personal protections when necessary.

# 5 The visual environment

## 5.1 Legislation

The three general lighting requirements are:

(1) That every workplace shall have suitable and sufficient lighting (i.e. at an appropriate and even illuminance, free from shadow, direct and reflected glare, clean, well maintained and flicker free and without stroboscopic effects).

(2) The lighting shall, as far as is practicable , be natural light.

(3) Emergency lighting shall be provided when workers would be exposed to danger in the event of failure in the electric lighting. This should be designed to illuminate the escape route, all hazards or hazardous tasks and the fire fighting equipment. It also can mean providing sufficient lighting to enable processes to be closed down safely at times of power failure.

Illuminance for safety while the normal lighting system is operating is usually satisfactory if the illuminance required for performance and/or pleasantness is maintained. Suitable values, for a wide range of applications, are given in the Society of Light and Lighting's (SLL) *Code for lighting*(1). However, in many instances there are legally enforced minimum standards and the Workplace (Health, Safety and Welfare) Regulations 1992(2) and the Provision and Use of Work Equipment Regulations(3) require that provision be made for 'suitable and sufficient lighting', with a preference for daylight, when available.

The Health and Safety Executive Guide *Lighting at Work*(4), indicates minimum lighting standards for safety in the workplace. These standards should not be confused with those given in the SLL *Code for lighting*(1), which are the lighting levels required in order to perform tasks quickly and accurately.

Although the main purpose of legislation is to ensure safety, there are situations where health and welfare are the primary considerations. For locations where food is prepared (other than in agriculture), the Food Hygiene (General) Regulations(5) require 'suitable and sufficient means of lighting' in order that proper cleanliness can be maintained and the local authority (which is responsible for enforcement of these regulations) should be consulted regarding the specific standards which apply.

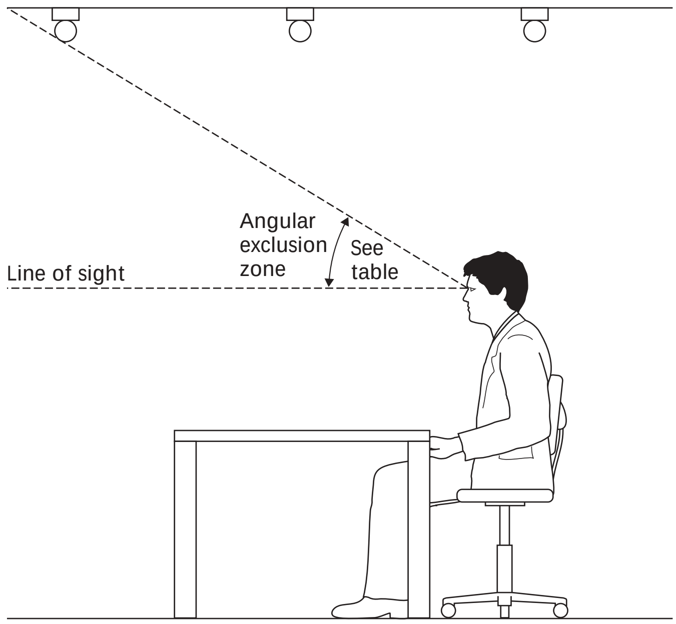
The Health and Safety (Display Screen Equipment) Regulations 1992(6,7) provide protection for users of display screens and keyboards, and require that 'satisfactory lighting conditions' be provided, allowing for background conditions, glare, reflections and the visual requirements of users.

In the cases of schools and hospitals, minimum lighting standards are specified by the Department for Education and Employment and the Department of Health, respectively. Guidance is also provided in CIBSE/SLL Lighting Guides LG5(8) and LG7(9).

The above summary of mandatory requirements is not comprehensive and identifies only a more the most important legislation concerning the provision of lighting for safety. There may be other, more demanding requirements, specific to particular applications and it is essential that the relevant authorities (e.g. local authority, HM Factories Inspectorate etc.) be consulted at an early stage in the design process.

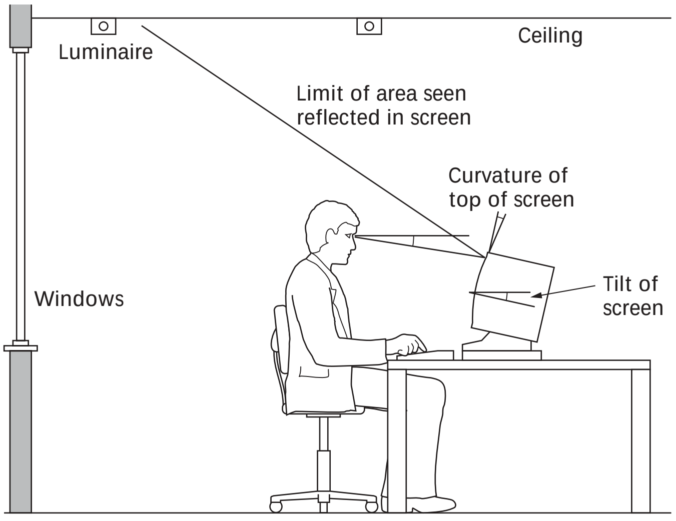
The HSE specify illuminances for a range of working conditions in terms of minimum and average values, with average values ranging from 20 lux for circulation space, 50 lux for the movement of people in hazardous zones, 100 lux for work requiring limited detail such as kitchens, 200 lux for office work and 500 lux for work requiring perception of detail such as drawing offices and electronics. They also specify the maximum ratio of illuminance between the work areas and those areas adjacent. Guidance also specifies the angular exclusion zone for different types of lamp to avoid discomfort and disability glare(4). Stroboscopic effects produced by discharge lamps operating on an AC supply can be reduced by wiring adjacent luminaries to different phases of the three phase supply of by the use of high frequency control gear. Such hazards are considered in SLL Lighting Guide LG1: *Industrial lighting*(10). Emergency lighting design is outlined in BS 5266 1988(11) and SLL Lighting Guide LG12: *Emergency lighting design guide*(12).

*Figure 5.1 Avoidance of direct glare from lamps*




| | |
|---|---|
| Angle of exclusion for fluorescent lamps | 10° |
| Angle of exclusion for coated discharge or frosted incandescent lamps | 20° |
| Angle of exclusion for discharge and clear incandescent lamps | 30° |

*Figure 5.2 Avoidance of reflected glare from a luminaire when using a visual display terminal (VDT)*




## 5.2 Introduction

Exposure to light can have both positive and negative impacts on human health, impacts that can become evident soon after exposure or only after many years. The effects of light on health can be conveniently arranged in four classes: Light treated as radiation; light operating through the visual system, light operating through the circadian system; and light acting as a purifier.

## 5.3 Light as radiation

Equipment which generates harmful radiation must be shielded from people and the maintenance staff trained in safe working on the equipment. The most likely exposure to intense UV radiation would be in the vicinity of welding or in the neighbourhood of high powered industrial discharge lamps and more recently high powered tungsten halogen lamps. Tissue damage is rapid at high doses (welders eye for UV, more slowly developing skin burns for infra red) but prolonged exposure at lower intensity can lead to skin cancer for UV exposure and cataracts for infra-red (glass blower's eye).

### 5.3.1 Tissue damage

Light can have an effect on human health simply as radiation, regardless of whether or not it stimulates the visual system or the circadian system. When considering the possibility of tissue damage caused by exposure to light the definition of light is stretched to include ultraviolet and infrared radiation as well as visible radiation, because many light sources produce all three types of radiation.

In sufficient doses, exposure to light can cause damage to both the eye and skin, through both thermal and photochemical mechanisms. For the eye, exposure to ultraviolet radiation can produce photokeratitis of the cornea. The symptoms of photokeratitis are clouding of the cornea, reddening of the eye, tearing, photophobia, twitching of the eyelids and a feeling of grit in the eye. Typically, all these symptoms clear up within about forty-eight hours(13). Photokeratitis occurs because of a photochemical reaction to ultraviolet radiation at the cornea, but not all the ultraviolet radiation incident on the eye is absorbed at the cornea. Significant amounts of longer wavelength ultraviolet radiation reach and are absorbed in the lens. The effect of exposing the lens to ultraviolet radiation is to produce a cataract, an opacity in the lens that absorbs and scatters light, thereby severely degrading the retinal image. This cataract formation can occur on two time scales, acute, i.e., with a few hours of exposure, and chronic, i.e., after many years of exposure.

As for the effects of ultraviolet radiation on the skin, within a few hours of exposure, the skin reddens. This reddening is called erythema. Erythema reaches a maximum about eight to twelve hours after exposure and fades away after a few days. High dose exposures may result in oedema, pain, blistering and, after a few days, peeling of the skin, i.e., sunburn. Repeated exposure to ultraviolet radiation produces a protective response in the skin. Specifically, pigment migration to the surface of the skin occurs and a new darker pigment is formed. Coincident with this, the outer layer of the skin thickens producing what used to be a socially acceptable tan. The effect of these changes is to decrease the sensitivity of the skin to ultraviolet radiation in the wavelength range below 290 nm(14). It is just as well this screening process occurs because frequent and prolonged exposure of the skin to ultraviolet radiation is associated with skin aging and increases the risk of developing certain types of skin cancer(15). Skin cancer comes in three forms, basal cell, squamous cell and malignant melanoma. The prevalences of both basal cell and squamous cell cancer show larger positive correlations with exposure to ultraviolet radiation from the sun than does malignant melanoma(16). Basal and squamous cell cancers can often be cured if treated promptly but the cure rate for malignant melanoma is lower.

Electromagnetic radiation in the wavelength range 400–1400 nm, i.e., the visible and near infrared, can damage the retina of the eye by burning. This effect goes under the name of chorio-retinal injury. Such injuries have a long history, mostly derived from looking directly at the sun for a prolonged period. The main symptom of chorio-retinal injury is the presence of a 'blind spot' or scotoma in the area where the absorption occurred. The scotoma can usually be seen under ophthalmic examination within five minutes of exposure and certainly within 24 hours. Recovery from chorio-retinal injury is limited or non-existent. The probability of chorio-retinal injury by exposure to visible and near infrared radiation depends on the retinal radiant exposure, the retinal area, larger areas of radiation are more likely to cause tissue damage than small areas, and the duration of exposure. The duration of exposure is important because the usual response to seeing a very bright light, which is what a high retinal irradiance in the wavelength range 400–760 nm will look like, is to blink and look away, i.e., an aversion response. This response has a reaction time of 150 to 300 ms. For exposure times below 150 ms, no aversive response is possible. Fortunately, very high retinal irradiances are required to produce a damaging radiant exposure in such short times. The most dangerous situation is if a light source were to produce a lot of radiation in the near infra-red and very little in the visible. In this situation, there would be no high brightness cue to trigger the protective aversion response.

Chorio-retinal damage is thermal damage to the retina, but there is also the possibility of rapid photochemical damage of the retina occurring following exposure to visible wavelengths. This is called photoretinitis(17). Radiation in the wavelength range from 400 to 500 nm is most likely to cause photoretinitis which explains its original name of blue-light hazard. Photoretinitis is rare in practice because the normal aversion to very bright lights causes people to shield their eyes or to look away before damage can occur. However, if exposure is sufficient to cause photoretinitis, the damage will not usually become apparent until about twelve hours later. Some recovery from the damage is possible.

Radiation between 1400 nm and 1900 nm is absorbed in the cornea and aqueous humour of the eye. Above 1900 nm, the cornea is the sole absorber. Infra-red radiation that is absorbed either in the ocular media or in the cornea needs to be considered because it raises the temperature where it is absorbed and may, by conduction, raise the temperature of adjacent areas. Fortunately, extremely high corneal irradiances, of the order of 100 W/cm$^2$, are necessary for changes in the lens to occur within the time taken for the common aversive reaction to occur. Further, only 10 W/cm$^2$ absorbed in the cornea will produce a powerful sensation of pain which should trigger the aversive response. It is generally considered that the aversive reaction provides protection for the eye against thermal effects of infrared radiation up to levels in excess of those that cause a flashburn of the skin.

Prolonged exposure to infrared radiation can also have adverse effects on health. Lydahl and Philipson[18,19] have shown an increased incidence of cataract amongst workers who have been exposed to molten glass or metal for many years. Unfortunately little is known about how this effect occurs. From a practical point of view, the important point to note is that whenever exposure to a light source produces a marked sensation of warmth on the skin, the possibility of long-term infrared radiation damage to the eye should be considered.

As for the skin, the effect of visible and infrared radiation is simply to raise the temperature. If the temperature elevation is sufficient then burns will be produced. It is important to realise that the focusing process of the eye makes it much more sensitive than the skin to such injury for visible radiation and near infra-red radiation. However, the skin and eye are equally at risk from longer wavelength infra-red radiation because the ocular media are virtually opaque for these wavelengths and the mechanism for acute damage is thermal. The efficiency with which a given irradiance raises the temperature of the skin depends on the exposed area, the reflectance of the skin and the duration of exposure. The threshold irradiance for thermal injury of the skin is greater than 1 W/cm$^2$. Such irradiances are very unlikely to be produced by sunlight or conventional lighting of interiors so such sources are unlikely to produce any degree of thermal injury to the skin by radiation.

### 5.3.2 Threshold limit values

Given the potential for tissue damage by ultraviolet, visible and infrared radiation, it should not be too surprising that there are recommended threshold limit values for exposure to such radiation. The threshold limit values are levels of exposure and conditions under which it is believed, based on the best available scientific evidence, that nearly all healthy workers may be repeatedly exposed, day after day, without adverse health effects[20]. The American Conference of Governmental Industrial Hygienists (ACGIH) publishes threshold limit values for exposure to ultraviolet radiation, to avoid photokertitis; for exposure to visible radiation, to avoid photoretinitis; and for visible and infra-red radiation to avoid cataract after prolonged exposure and chorio-retinal injury from low-luminance infra-red illumination sources. The recommendations of the ACGIH have been adopted by the Illuminating Engineering Society of North America (IESNA) and used to produce a recommended practice[21,22]. They have also been adopted, with slight modifications by the International Committee on Non-Ionising Radiation Protection (ICNIRP)[23]. Following any of these recommendations will limit the likelihood of tissue damage by ultraviolet, visible and infrared radiation. Full details of the threshold limit values can be obtained from the publications of the organisations mentioned[21,24–27].

### 5.3.3 Hazardous light sources

The Illuminating Engineering Society of North America Recommended Practice 27[21] not only adopts the ACGIH criteria for limiting tissue damage, it also gives details of how to make the necessary measurements and sets out a system for classifying light sources according to the level of potential risk they represent. This system has four classes; Exempt, and Risk Groups 1, 2 and 3. Exempt light sources are those that do not pose an ultraviolet hazard for eight hours of exposure, nor a near ultraviolet hazard, nor an infrared cornea / lens hazard within 1000 seconds; nor a retinal thermal hazard within 10 seconds, nor a blue-light hazard within 10000 seconds. For light sources where sound assumptions about typical use can be made, the radiometric measurements necessary to evaluate the light source against these criteria are made at a location where the light source is producing 500 lx, or at 20 cm from the light source if the distance at which 500 lx is achieved is less than 20 cm. For light sources where sound assumptions about use cannot be made, the necessary radiometric measurements are made at a distance of 20 cm. Any light source that is assigned to Risk Groups 1, 2 or 3 must exceed one or more of the criteria used for the Exempt Group. The philosophical basis for Risk Group 1 (low risk) is that light sources in this group exceed the limits set for the Exempt Group, but do not pose a hazard due to normal behavioural limitations on exposure. The philosophical basis for Risk Group 2 (moderate risk) is that light sources in this group exceed the limits set for the Exempt Group and Risk Group 1, but do not pose a hazard due to the aversive response to very bright light or to thermal discomfort. Any light source in Risk Group 3 (high risk) is believed to pose a hazard, even for momentary exposures. The criteria defining Risk Groups 1, 2 and 3 are the same as those for the Exempt Group but the permitted exposure times are reduced. Light sources falling into any of the Risk Groups should carry a warning label, indicating the nature of the hazard and suggested precautions that should be taken.

Wood et al(28) report measurements of incandescent and fluorescent lamps commonly used for the lighting of residences, following the IESNA 1996 procedure. They found that the incandescent and fluorescent lamps fell into the Exempt category and therefore are not a hazard for tissue damage in normal conditions of use. This comprehensive evaluation is consistent with the conclusions of other, more limited, studies of incandescent and fluorescent lamps for ultraviolet radiation(17,29–31) examined a wider range of light sources using the IESNA 1996 system. Again, both linear and compact fluorescent lamps fall into the Exempt Group for all criteria. Other light sources such as large wattage tungsten halogen lamps, and high wattage high pressure sodium, metal halide and mercury discharge lamps, all fall into Risk Group 1 or 3 on one or more hazard criteria.

It is important to appreciate that these observations about the potential for tissue damage posed by various light sources are generalisations. For electric light sources, the observations apply to lamps used for general lighting. They should not be taken to apply to all lamps of a given type. For example, while fluorescent lamps used for general lighting fall into the Exempt Group, there are fluorescent lamps used for sunbeds and for germicidal purposes that are designed to emit considerable ultra-violet radiation and that are not Exempt. Similarly, some mercury lamps are designed not as light sources, but rather as sources of ultraviolet radiation for industrial curing purposes. For the sun, the hazard posed depends on the path length through the atmosphere and the skin pigmentation of the individual. There is little hazard when the sun is low in the sky and the darker the skin pigmentation the less the risk at all sun elevations. The safest principle to follow when evaluating the potential for tissue damage from any specific light source is to assume the source is hazardous unless information suggesting otherwise is available.

### 5.3.4 Practical considerations

The key word when considering the hazards posed by different light sources is 'potential'. Whether the potential for tissue damage turns into actual damage depends on how the light source is used. The IESNA classification of a light source assumes a bare lamp viewed directly for an defined time. Light sources are normally used in luminaires, and are rarely viewed directly for an extended period of time. Placing the light source in a luminaire may dramatically change the spectrum of the radiation received by the viewer. For example, the ultra-violet radiation emitted by tungsten halogen lamps can be much reduced by using a glass cover. Dichroic reflectors can be used to transmit infrared radiation while reflecting visible radiation. Different plastics and glasses have very different ultra-violet transmittances(29,31).

Another factor that will change the spectrum of the radiation received by the viewer is what proportion of the radiation incident comes directly from the light source. The larger is the proportion of radiation received after reflection, the more likely it is that the spectral content will be changed, because there is no guarantee that the reflecting surface reflects ultra-violet, visible and infra-red radiation equally. What this variability implies is that where there is doubt about the risk of tissue damage by radiation from light sources, field measurements of the actual spectral radiance or irradiance are essential. If such measurements show that the hazard is actual rather potential, then action should be taken to reduce the hazard. Ideally, this would take the form of reducing the output from the light source to below that needed to create a hazard or reducing the exposure time. Where this is not always possible, a degree of protection is required. This can take the form of screening the source with suitable materials. i.e., those opaque to the damaging radiation and/or personal protection in the form of eye filters, helmets and clothing.

### 5.3.5 Special groups

All the methods for evaluating light sources for tissue damage are based on action spectra linked to the average adult human response to ultraviolet, visible and infrared radiation. Unfortunately, there are some groups who deviate markedly from that average sensitivity in the direction of making them much more sensitive to radiation in these wavelength ranges.

One such group consists of very premature babies, particularly those weighing less than 1000 g at birth. These infants have eyes that are still developing and exposure to light is believed to be involved in the retinopathy of prematurity, a visual disorder that can permanently damage the retina of such babies. Proposals to limit the light exposure of babies in neonatal intensive care units have been made[(33)].

Another population with a problem with exposure to light, but at the opposite end of life, are postoperative cataract patients who have had their lens removed, i.e., patients who are aphakic. Such patients are much more likely to suffer photochemical retinal damage due to short wavelength visible and ultra-violet radiation exposure than are people with their biological lens intact, unless they are fitted with an ultraviolet-absorbing, intraocular lens[(34,35)]. The ACGIH has recognised the hazard for aphakics by introducing a hazard weighting function specifically for this condition .

Three other groups who need to take special care about exposure to ultra-violet radiation are those who have medical conditions that enhance photosensitivity, e.g., lupus erythematosus[(36)]; those who are taking pharmaceuticals that increase photosensitivity; and those who are exposed to certain chemical agents in the environment, such as the whiteners used in some household products[(37)]. Unlike newborns and aphakics, where the hazard is confined to the retina, the effect of increased photosensitization primarily increases the hazard to the skin. How much the risk posed by exposure to ultraviolet radiation is increased will depend on the medical condition, or the specific pharmaceutical or chemical and the dose taken or level of exposure.

### 5.3.6 Phototherapy

Tissue damage is an undeniably negative effect of exposure to light but there are some positive effects. For example, exposure to ultraviolet radiation is important for the production of Vitamin D in the skin. Vitamin D deficiency leads to bone softening diseases such as rickets in children and osteomalacia in adults. Most of the vitamin D requirements of children and adults are met by exposure to sunlight. Groups who cannot achieve sufficient exposure, such as the infirm, or those who live in areas where sunlight is limited for several months, must depend on dietary sources and vitamin supplements to meet their vitamin D requirement[(38)].

There are also a number of medical conditions where exposure to light as radiation has been shown to be helpful[(39)]. Hyperbilirubinemia, commonly known as jaundice of the newborn, is one. The phototherapy for this condition involves exposing the naked baby to short-wavelength visible radiation, with the eyes shielded. Ultra-violet radiation is also used in the treatment of skin diseases such as psoriasis and eczema. Patients are given multiple whole-body exposures to sub-erythemogenic doses of UVB radiation. One other use of UV radiation is in the suppression of the immune system[(40)]. Such suppression may be helpful in cases of autoimmune diseases such as multiple sclerosis where hyperactivity of the immune system is a problem . Of course, it may also be dangerous for people who have already immuno-suppressed. Therapeutic exposure to UV should only be undertaken after consulting a qualified physician.

## 5.4 Light operating through the visual system

Light is necessary for the visual system to operate but if used in the wrong way it can be injurious to health. The most common effect of lighting operating through the visual system on health is colloquially known as eyestrain. Eyestrain is the result of prolonged experience of lighting conditions that cause discomfort. The symptoms of eyestrain are irritation of the eyes, evident as inflammation of the eyes and lids; breakdown of vision, evident as blurring or double vision; and referred effects, usually in the form of headaches, indigestion, and giddiness.

There are two mechanisms by which eyestrain can be caused, one physiological and one perceptual. The physiological is muscular strain occurring in the ocularmotor system, i.e., in the muscle systems that control the fixation, accommodation, convergence and pupil size of the eyes. The perceptual is the stress that is felt when the visual system has difficulty in achieving its primary aim, to make sense of the world around us. Conditions that require the ocularmotor system to hold a fixed position for a long time or to make frequent changes of the same type are likely to produce eyestrain through muscular exhaustion. Conditions that make it difficult to see what needs to be seen or which distract attention from what needs to be seen are likely to produce eyestrain through stress. Lighting conditions which have been shown to lead to eyestrain are inadequate illuminance for the task[41], excessive luminance ratios between different elements of a task[42] and lamp flicker, even when it is not visible[43].

Everyone is likely to experience eyestrain in poor lighting conditions but there are some groups who are particularly sensitive to lighting conditions. One such group are those who suffer from photoepilepsy. Given fluctuating light of the right frequency, covering a large area and at a high percentage modulation, these individuals can be driven into a seizure. The frequency to which people with photoepilepsy are most sensitive is about 15 Hz, although about 50 percent still show signs of a photoconvulsive response at 50 Hz[44].

A larger but related group are migraineurs. The exact cause of a migraine is not known but what is known is that migraineurs are more sensitive to light than people who do not experience migraine, even when they are headache-free[45]. This means migraineurs are much more likely to experience glare from luminaires and to complain about high light levels. In addition, migraineurs are likely to be hypersensitive to visual instability, no matter whether it is produced by fluctuations in light output from a light source, or by large area, regular patterns of very different reflectances[46,47]. One way to ensure that light output fluctuations do not cause trouble is either to use light sources that are inherently low in modulation, such as the incandescent lamp, or, if high modulation discharge light sources are to be used, to operate them from high frequency control gear. Wilkins et al[43] carried out a field study in an office of the effect of replacing magnetic control gear operating from a 50 Hz electricity supply with electronic control gear operating at 32 kHz, on the frequency of headaches and eyestrain. The results obtained showed that changing from magnetic to electronic control gear for fluorescent lamps does little for the mass of people but does reduce the frequency of headaches and eyestrain for people who frequently have such symptoms.

Another group who can be expected to be sensitive to fluctuations in light output are the autistic. The symptoms of autism are repetitive activities, stereotyped movements, resistance to changes in the environment and the daily routine and unusual responses to sensory experiences. The level of arousal in the autistic is chronically high and repetitive behaviours are believed to be a way of regulate it[48]. This implies that an increase in environmental stimulation will generate an increase in repetitive behaviour and regular fluctuations in light output can be regarded as a form of environmental stimulation. Observations of autistic children have demonstrated that repetitive behaviour does occur more frequently under fluorescent lighting than under incandescent lighting[49,50]. This suggests that autistics too would benefit benefit from the use of electronic control gear for fluorescent lamps. Care should also be taken to avoid lighting control systems that change light levels suddenly.

## 5.5 Light operating through the circadian system

The circadian system is fundamental to the functioning of many processes in life and a regular cycle of exposure to light and darkness is fundamental to the entrainment of the circadian system. The sleep/wake cycle is one of the most obvious and important of the circadian rhythms. There are a number of common sleep disorders. Those susceptible to treatment with light are concerned with the timing and duration of sleep. Those associated with timing are delayed and advanced sleep phase disorders. Delayed phase sleep phase disorder is characterised by late sleep onset and late awakening, and is predominantly experienced by young people. Advanced phase sleep disorder is characterised by early sleep onset and early morning awakening and is predominantly experienced by the elderly. Exposure to light has been shown to be an effective treatment for these sleep disorders. Czeisler et al[51] have demonstrated that exposure to 10 000 lx at appropriate times results in significant phase advances for people with delayed sleep phase disorder and significant phase delay for those with advanced sleep phase disorder. Campbell et al[52], in a study of elderly patients with advanced sleep phase disorder, showed not only a phase delay following exposure to 4000 lx in the evening but also an improvement in sleep quality.

As for sleep duration disorders, the classic problems are sleep onset insomnia with normal awakening and normal sleep onset with sleep maintenance insomnia. Both these disorders are common in the elderly[53]. Campbell and Dawson[54] and Lack and Schumacher[55] have shown that exposure to bright light in the evening produces longer and better quality sleep for people who were experiencing sleep maintenance insomnia.

Depression is one of the most common psychiatric conditions in patients visiting a doctor, with a lifetime prevalence of about 17 percent[56]. Seasonally affective disorder (SAD) is a subtype of major depression that is identified by a regular relationship between the onset of depression and the time of year; full remission of depression at another time of year; the pattern of onset and remission of depression at specific times of the year repeated over the last two years; no non-seasonal depression over the last two years; and episodes of seasonal depression substantially outnumbering non-seasonal depression over the individual's lifetime[57]. Two forms of SAD have been identified, winter and summer SAD, the former being much more common than the latter. Winter SAD can be recognised by the increase in feelings of depression and a reduced interest in all or most activities, typical of depression, together with such atypical symptoms as increased sleep, increased irritability and increased appetite with carbohydrate cravings and consequent weight gain. These symptoms disappear in Summer. Summer SAD is also associated with an increase in feelings of depression and lack of interest in activities but in this case there is a decrease in sleep, poor appetite and weight loss[58].

The cause of winter SAD is unknown but what is clear is that exposure to bright light is often an effective treatment[59–61]. What is meant by 'bright light' is usually exposure to a light box that produces an illuminance at the eye of between 2500 lx and 10 000 lx for durations ranging from 2 hours for 2500 lx to 30 minutes for 10 000 lx. A response to 'bright light' can usually be expected with two to four days and a measurable improvement is often seen within one week, but symptoms will reappear if light treatment is discontinued. The symptoms that are atypical of depression in general are the ones that are most responsive to light treatment, i.e., hypersomnia, increased appetite and carbohydrate cravings. As with most medical treatments, there are side effects of prolonged exposure to the high illuminances of a light box. Typically they are mild disturbances of vision and headaches that subside with time . However, care should be taken with patients who have a tendency towards mania, and whose skin is photosensitive or who already have retinal damage and who have a medical condition that makes retinal damage likely[62–64]. General guidance on the use of light in the treatment of SAD is available from a number of sources[65–67].

Alzheimer's disease is a degenerative disease of the brain and is the most common cause of dementia. Lighting can influence the abilities and behaviour of people with Alzheimer's disease, operating through both the visual system and the circadian system. Alzheimer's patients show reduced visual capabilities relative to healthy people of the same age[68]. This pattern of change is consistent with the reports of cell loss at both retinal and cortical level in Alzheimer's disease[69–71]. It has been argued that such reduced visual capabilities may exacerbate the effects of other cognitive losses in Alzheimer's patients, tending to increase confusion and social isolation[72,73]. This suggests that enhancing the luminance contrast of the stimulus would improve the functioning of Alzheimer's patients. Gilmore et al[74] have shown that increasing the luminance contrast does increase the speed of letter recognition by Alzheimer's patients. As for the circadian system, people with Alzheimer's disease and other forms of dementia often demonstrate fragmented rest/activity patterns throughout the day and night[75,76]. This makes such patients difficult to care for and is one of the main reasons for having them institutionalised[77]. The human circadian system is entrained by exposure to alternate periods of light and dark. This suggests that exposing Alzheimer's patients to bright light during the day and little light at night, thereby increasing the signal strength for entrainment, would help to make their rest activity patterns more stable. Van Someren et al[78] examined the effect of exposure to bright light during the day using institutionalised patients with various forms of dementia and found that this was indeed so.

## 5.6 Light as a purifier

Ultraviolet radiation has the ability to destroy many types of viruses, bacteria, molds and yeasts, some of which have the potential to damage human health. The mechanism of destruction is the absorption of UV radiation by the DNA molecule of the target organism. This absorption produces mutation or cell death, both of which stop the organism from multiplying. The light source used to provide the ultra-violet radiation is an electric discharge passed though a low pressure mercury vapour, the vapour being enclosed in either a special glass or a quartz tube that transmits ultra-violet radiation. Ninety-five percent of the energy emitted by these germicidal lamps is at a wavelength of 253.7 nm. The effectiveness of this radiation in destroying microorganisms depends on many parameters, including the susceptibility of the specific organism which is related to the thickness of the cell wall, the spectrum of the radiation received and the radiant exposure.

Ultra-violet radiation has been used to purify air and liquids. Interest in air purification by ultraviolet radiation has grown in recent years with the emergence of drug-resistant strains of airborne disease, such as tuberculosis[79,80]. Germicidal lamps are usually placed in one of two locations. Where air conditioning is used, the lamps can be placed in the ductwork. For this location, exposure times are short because of the high air velocity in the duct, so a high irradiance is required. Alternatively, the germicidal lamps can be placed inside the occupied space. This poses a problem because exposure to ultraviolet radiation can lead to photokeratitis and skin damage. There are two solutions to this problem. Where the ceiling height allows (>2.9 m) the lamps can be installed in luminaires that confine the ultra-violet radiation to the air volume above the occupants' heads, the surfaces directly irradiated having a reflectance at 253.7 nm of less than 0.05. Of course, this method relies on sufficient air circulation to move all the air in the occupied space through the irradiated volume frequently. If the ceiling height does not allow overhead purification, then the some form of local air circulation that brings the air of the occupied space through an enclosed fitting containing the germicidal lamp is possible.

## 5.7 Recommendations

(1) Legislation specify that in work places there will be suitable and sufficient lighting, predominately by natural light and supported by an emergency light system. The HSE specifies minimum illuminances and permissible glare limits. The SLL *Code for lighting*[1] provides more detail.

(2) Lamps provide a range of radiation. Those working close to powerful lamps may be exposed to ultraviolet wavelength radiation and the cornea can be burned. Some lamps can provide significant infra red which can harm the retina. The ACGIH (USA) give threshold limits and the IES (USA) classify lamps so that the risk can be understood.

(3) There is a small minority of individuals who are hypersensitivity to visual instability and experience a migraine or headache to high levels of light, from glare and from flicker from lamps. These migraineurs benefit from working under high frequency lamps and have the opportunity of adjusting the illuminance.

(4) Ultraviolet irradiation destroys viruses, bacteria, moulds and yeasts in air or water. It can be used to disinfect air conditioning systems either from lamps inside the ductwork or by directing the lamps to the upper part of the room. When used inside the room, care must be used to ensure that there are no UV (e.g. shiny metals) do not deflect the radiation to the occupied part of the room.

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# 6 Water quality

## 6.1 Legislation

There are guidelines for the quality of potable water supplied by the water utilities, for the distribution and storage of that water in terms of materials used and temperature for both hot and cold water[1–4]. There are also guidelines for industrial water use, such as evaporative cooling towers, vehicle washes, dental drills and portable humidifiers to prevent the incidence of Legionnaire's disease[5]. There are also guidelines for whirlpool spas[6].

## 6.2 Drinking water

The water utilities have a duty to provide wholesome water. They are permitted to deliver the water to the premises at no more than 25 °C but the employer is required to supply the water at no more than 20 °C to the employees[5]. In practice most cold water is supplied around 10 °C, slightly higher in summer and slightly cooler in winter. The utilities ask customers receiving water above 20 °C to notify them so that the reason can be investigated. In cities with underground trains there is a slow build up of ground temperature over the years and in some areas water supplies may exceed 20 °C during sustained periods of unusually high summer temperatures.

The water is not sterile. There will be traces of potentially harmful organisms and the engineers task is to ensure that they do not multiply. This is achieved by avoiding unused dead legs in the pipe-work, maintaining a regular flow of water through the system, for example by supplying toilets at the end of cold piping runs. keeping the temperature below 20 °C , ensuring a storage time of not longer than a day on the premises, and in those buildings with a storage cistern by maintaining the cistern covered and in a clean state[5]. The design should also avoid any opportunity for back-syphonage i.e. dirty water being drawn back into the clean water system[3]. The materials of construction should be neither nutrient for micro-organisms nor leach out any toxic material to the water[7].

Many existing buildings have internal lead piping for water distribution. Lead in the blood stream has an adverse effect on intelligence even down to 10 μg/dL. Soft water can dissolve lead salts and contaminate the drinking supply with harmful lead. There is concern that 20% of our delivered water supply fails to reach the 1993 WHO standard of 50 μg/L. The WHO has now changed its maximum to 10 μg/L. Bottle fed infants are at highest risk with high lead content water but replacement or lining of lead drinking water pipes is recommended for all[8].

## 6.3 Industrial water

Legionnaire's disease is associated with lukewarm water, particularly if rich in nutrient as in an evaporative cooling tower. Special guidance is provided for industrial water between 20 °C and 45 °C which may be disseminated as an aerosol to which persons may be exposed[5,9]. If this water is maintained at these lukewarm temperatures then biocidal treatment is needed and monitoring provided to ensure the success of the biocide regime. Weekly dip-slides should be used for a crude estimation of aerobic bacteria. For this application the incubation temperature is unusually 30 °C. Quarterly laboratory assessments of the presence of legionella are advised. There is no known threshold of safety for the legionella concentration in the water. Legionnaire's disease is a disease of susceptibility with an attack rate around 3%. The purpose of the laboratory test is to check the successful application of the biocide. The action levels are shown in Table 6.1.

*Table 6.1 Action levels following microbial monitoring for cooling towers*

| Aerobic count (CFU/ml at 30 °C (minimum 48 h incubation)) | *Legionella* bacteria (CFU/litre) | Action required |
|---|---|---|
| 10 000 or less | 100 or less | System under control |
| More than 10 000 and up to 100 000 | More than 100 and up to 1000 | *Review programme operation*: a review of the control measures and risk assessment should be carried out to identify any remedial actions and the count should be confirmed by immediate resampling. |
| More than 100 000 | More than 1000 | *Implement corrective action*: the system should immediately be re-sampled. It should then be 'shot dosed' with an appropriate biocide, as a precaution. The risk assessment and control measures should be reviewed to identify remedial actions. |

## 6.4 Swimming/whirlpool facilities

Whirlpool spas operate between 32 °C and 40 °C. Air is bubbled through the water to agitate it. The bursting bubbles create an enriched aerosol of whatever microorganism are in the water. This aerosol occupies half a metre above the water surface, directly in the breathing zone of the occupants of the spa. It is therefore particularly important to control the multiplication of bacteria within such spas.

The water is recirculated, filtered and chemically treated to control the multiplication of microorganisms. The two health criteria are the concentration of free chlorine in the water (3–5 ppm) and the pH (7.2–7.8 but preferably 7.4–7.6). Careful management of the cleanliness, operation and maintenance of the spa is necessary. Monthly checks of aerobic colony counts at 37 °C are required (max. 100 CFU/ml; target <10 CFU/ml), together with tests for *Escherichia coli* and *Pseudomonas aeruginosa* (absent in 100 ml sample)[(6)].

## 6.5 Recommendation

There are a set of water regulations for the supply for water. The water utility has to provide wholesome water. This will have traces of potentially harmful organisms. The water system shall be designed to ensure that system is clean, made in suitable materials and safe. The employer is required to ensure that the working conditions control the risk of legionellosis. Building services are recommended that they comply with HSE ACOP L8 for legionellosis[(5)], complemented by CIBSE TM13[(9)] showing more details.

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3 BS 6700 *Specification for the design, installation, testing and maintenance of services supplying water for domestic use within buildings and their cartilages* (London: British Standards Institution) (1997)

4 *Water supply (Water Quality) Regulations 1989* (London: The Stationary Office) (1989)

5 *Legionnaire's disease: The control of legionella bacteria in water systems* HSE Approved Code of Practice L8 (Sudbury: HSC) (2000)

6 *Hygiene for spa pools. Guidelines for their safe operation*. (London: Public Health Laboratory Service) (1994)

7 *Water fittings and materials directory* WRC (six monthly) (Oakdale: Water Research Centre) (2003)

8 Boxall J, Llewellyn J *Lead* Chapter 14, 49-50 in Raw GJ, Aizlewood CE, Hamilton RM (eds) Building Regulation; health and safety. BRE Report 417 (Watford: Building Research Establishment) (2001)

9 *Minimising the risk of Legionnaire's disease* CIBSE TM13 (London: Chartered Institution of Building Services Engineers) (2002)

# 7 Electrical and electromagnetic effects

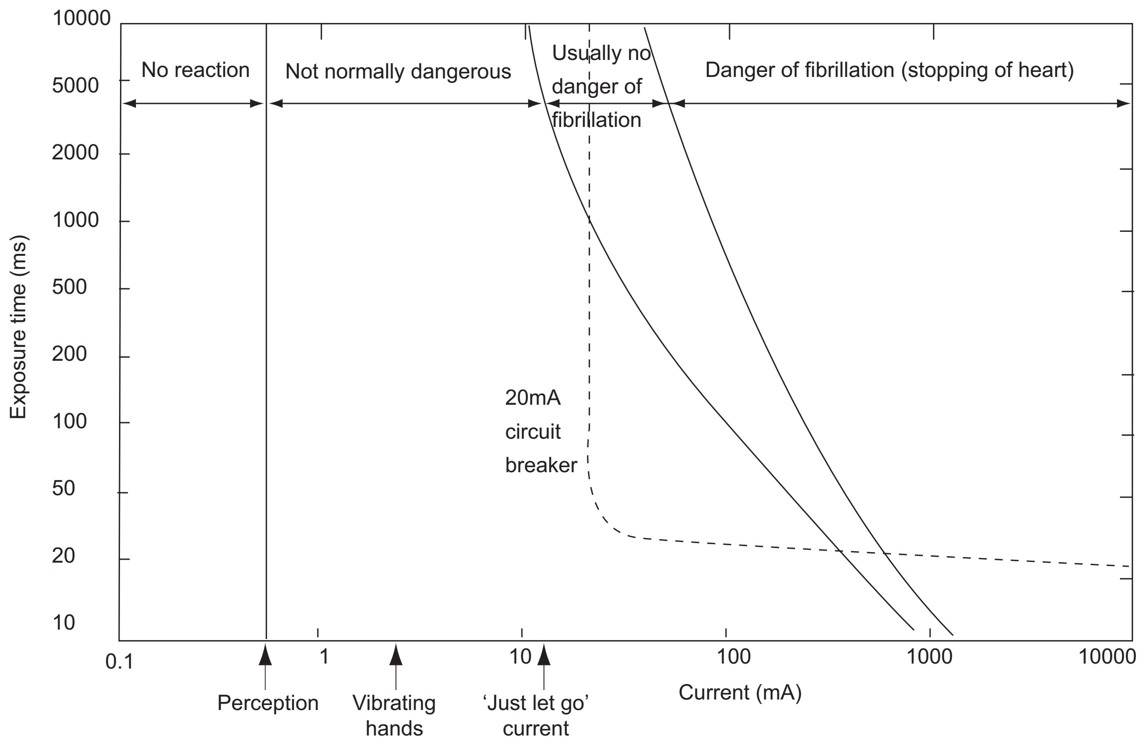
## 7.1 Legal guidance

The Electricity at Work Regulations 1989 require precautions to be taken against the risk of death or injury from electricity during work activities. The Regulations apply to all types of equipment and to the very lowest voltage because even very low voltages are capable of igniting flammable gases and initiating an explosion. HSE offer a number of supporting guides[1–5].

## 7.2 Electric shock

The flow of electricity through a person can cause muscular contraction, respiratory failure fibrillation of the heart, cardiac arrest or injury from internal burns. The mains frequency of 50 Hz is particularly hazardous to humans and even a few milliamps of current can be fatal (Figure 7.1). The effect can be worse if the electrical conductor is clasped because the electric shock can cause the hand muscles to go into spasm and continue clutching the conductor despite the shock. Electricity is at its most dangerous in wet conditions and when the current flows across the heart from one arm to the opposite leg. Simple precautions can minimise the risk. Sequential fusing, where the fuse rating matches the application, enables any electrical failure to be limited to the individual failed equipment and the larger rated fuses upstream are designed to protect the system from larger scale faults. Residual current detectors can detect an earth fault and isolate the supply before a fatal shock is received. Such devices depend upon the electricity to the equipment being identical to the current returning. When working properly this is zero. When there is a fault to earth the device senses the current differential and trips the circuit. Such devices are recommended for portable cutting tools where there is the higher risk of damage to the electrical cable. Low voltage equipment also reduces the risk of electrocution.

*Figure 7.1 Risk characteristics for electric shock; current and duration[6]*



## 7.3 Electric burns

Electric burns are different from burns caused by fire. They are caused by the heating effect of electric current through body tissue, usually at the point of contact. Such burns are very slow to heal.

## 7.4 Electrical fires

Electricity can cause fires in a number of ways. The most usual is through overheating of poor connections or the overheating of electric cables because the cable is carrying too much current for the size and type of cable in that environment (e.g. in a hot zone or passing through material of high thermal insulation). Leakage currents due to poor or inadequate electrical insulation can also initiate a fire.

## 7.5 Arcing

Arcing can occur between two uninsulated conductors. The arc generates ultraviolet radiation which causes skin damage similar to sun burn and which can also damage the conjunctiva of the eyes (welder's eye). Molten metal particles can penetrate and lodge in the skin.

## 7.6 Explosions

Electrical equipment can itself explode if subjected to excessive current. Electrical equipment can also ignite vapours, gases and dusts through sparks or high temperature operation.

## 7.7 Electromagnetic fields

Both electric and magnetic fields arise from the generation, transmission and use of electricity. Electric fields are related to the voltage and measured in terms of V/m. At mains frequency the electric fields do not penetrate the body but do charge up its surface. In the highest fields hair may move and small electric shocks may be observed. Most people will not experience shocks below 25 kV/m. Electric fields can be reduced by metal shielding. Magnetic fields are associated with the current and are measured in units of Tesla. Alternating magnetic fields cause electric currents to circulate within the body. In very high magnetic fields this current can cause flashes of light in the eye. Magnetic fields pass through most materials. Both fields reduce rapidly with distance. Exposure guidelines propose an investigation whenever the electric field at 50 Hz reaches 12 kV/m or the magnetic field 1.6 mT(7). Such fields are only found in specialist medical or industrial equipment.

However, since the 1960s there has been concern expressed regarding the possible effects on health of extremely low frequency electromagnetic fields (i.e. below 300 Hz). Some reports have suggested that exposure to these fields, such as might be experienced by those living near high voltage overhead power lines, increases the risk of cancer, particularly leukaemia, especially amongst children. Other studies have raised the possibility that 'electrical' occupations, such as those that entail prolonged proximity to visual display terminals, result in an increased risk of illness.

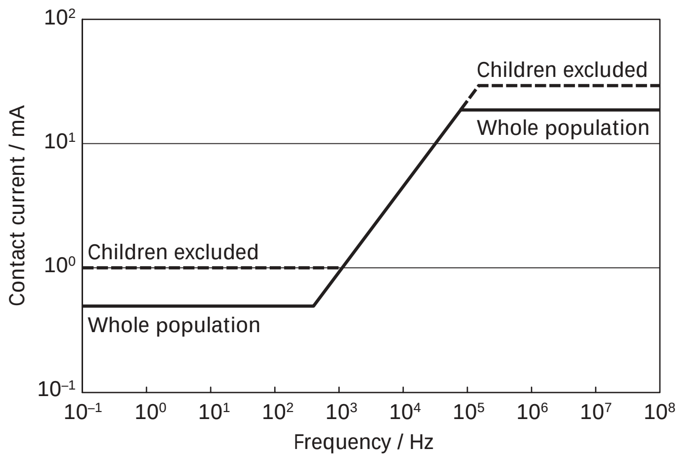
A review of these studies reveals that all suffer from methodological or other shortcomings but it is not clear whether these are sufficient to explain the results. Experiments with animals have produced conflicting and confusing results, and their relevance to the effect on humans is difficult to assess. No plausible mechanism for carcinogenesis due to exposure to electrical or magnetic fields has yet been deduced. It has been established that such fields affect the function of cardiac pacemakers but this is unlikely to be a hazard at the field strengths normally encountered and most modern pacemakers are designed to cope with high field strengths.

Therefore, current evidence does not permit firm conclusions to be drawn on the relationship between electromagnetic fields and physiological or psychological effects on humans. Until the situation is clarified by further research and provided that no significant cost penalties result, it is suggested that potential fields be minimised. Often this can be achieved by ensuring that line and return cables are in close proximity, as is usual practice for mains wiring.

The NPRB(8) adopted the recommendations by the International Committee of Non-Ionising Radiation Board (ICNIRB) for limiting exposures for electromagnetic (EMFS) effects from 0–300 GHz. Generally occupational exposures concern healthy adults under controlled conditions. These conditions include the opportunity to apply engineering and administrative measures and where necessary and practical to provide personal protection. For members of the public such controls do not generally exist and individuals of varying ages and response to exposures to emfs. The public include very young infants, the elderly, and those on medication. Their health status can be less robust. For these reasons the exposure restrictions for the public are 20% of those criteria for the working population.

There is also the risk of shock when a person makes contact with a metallic object, such as a fence or a car, in a time varying electric or magnetic field. Avoidance of the shock can be achieved by ensuring administrative or engineering controls to prevent people touching the metallic structure. If avoidance cannot be achieved then the magnitude of any contact current should be measured and investigated if the current exceeds the permissible values.

*Figure 7.2 Investigation levels for contact currents, 0–100 MHz*[7]




## 7.8 Air ionisation

It has been suggested that the ion balance of the air is an important factor in human comfort in that negative ions tend to produce sensations of freshness and well-being and positive ions cause headache, nausea and general malaise. Present evidence on the effects of air ions and, in particular, the effectiveness of air ionisers is inconclusive and hence no design criteria can be established.

## 7.9 Static electricity

See section 3.4, page 13.

## References

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# 8 The acoustic environment

Noise affects people in different ways depending on its level and may cause annoyance, interference to speech intelligibility or hearing damage. The acoustic environment must be designed, as far as possible, to avoid such detrimental effects.

## 8.1 Sound level in a room

The sound energy emitted by a source can be quantified by its sound power level. This is a property of the source and is not normally affected by the characteristics of the room in which it is located. The effects of a noise source on a listener are assessed in terms of sound pressure level. The sound power level of a source may be used to calculate the resulting sound pressure level in a room, which depends on the volume of the room and the amount of absorbing material it contains. These acoustic characteristics of a room contribute to its reverberation time, i.e. the time taken for a sound to decay by 60 dB. The propagation of sound in rooms is considered in CIBSE Guide B[(1)].

For a constant sound power input, the sound pressure level within a room will vary from place to place. The highest level is experienced near the noise source(s). It then decreases roughly with the square of the distance from the source until it reaches an approximately constant level. This constant level depends on the reverberation time of the room. At low frequencies the presence of standing waves (room modes) may cause additional level fluctuations. However, in a large room, such as an office in which the length is much greater than the height, the conditions are more complex and there is a gradual fall in level with distance from the source.

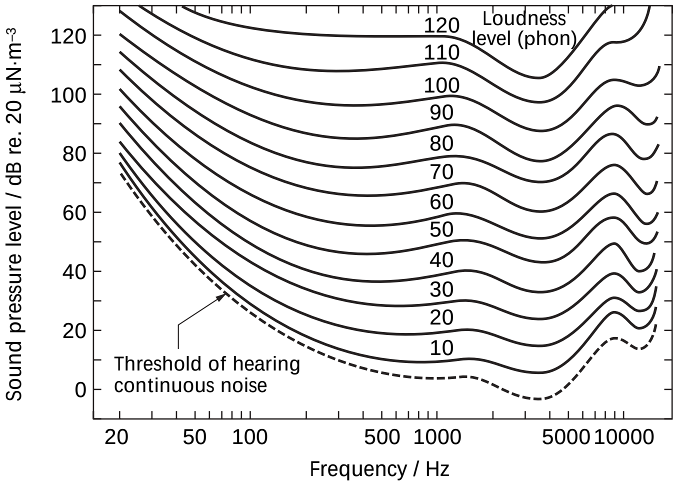
The calculation of noise levels within a space due to individual noise sources has been investigated by Beranek[(2)]. Noise from heating, ventilating and air conditioning plant is considered in CIBSE Guide B[(1)].

## 8.2 Human hearing response

The human hearing system responds to frequencies in the approximate range of 20 Hz to 20 000 Hz, but frequencies below 20 Hz (infrasound) are also audible at high levels. The precise range differs from person to person and hearing acuity at high frequencies tends to diminish with age due to deterioration in the receptor cells in the ear.

The response of the hearing system is non-linear and it is less sensitive to low and high frequencies than to mid-range frequencies. The sensitivity of the ear is represented by the curves of equal loudness shown in Figure 8.1. These curves have been derived by subjective experiments and show that the sensitivity of the ear varies with both sound pressure level and frequency.

*Figure 8.1 Equal loudness level contours*



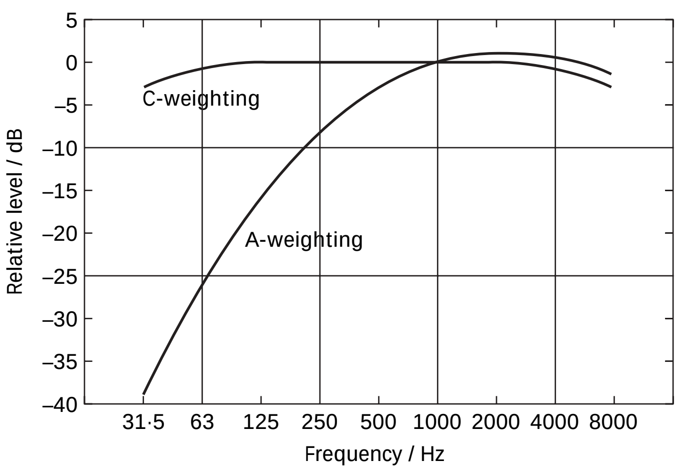
The unit of loudness level is the phon. For example, the curve representing a loudness of 60 phon illustrates that a 1000 Hz note at a sound pressure level of 60 dB is perceived as being of equal loudness to a 100 Hz note at 66 dB. However, this method of assessing loudness is too complicated for everyday use.

When sound levels are measured, the variation in the sensitivity of the ear can be approximated by incorporating frequency-weighting networks in the measuring instrument. The most widely used of these is the A-weighting network. Other networks are known as B- and C-weightings. The B-weighting has fallen into disuse so the main measurement curves are the A- and C-weighting curves in Figure 8.2. The C-weighting gives more prominence to lower frequencies than does the A-weighting, having an approximately level response above 31.5 Hz. In contrast, the A-weighting rises gradually to 1000 Hz, thus discriminating against lower frequencies. The reason for these differences arises from the different equal loudness responses of the human ear over a range of sound pressure levels, see Figure 8.1.

A-weighting was proposed in the 1930s for low sound pressure levels and C-weighting for high sound pressure levels.This distinction has since been lost with the result that the A-weighting is now employed at sound levels for which it was not originally intended. Problems may arise if there is an excess of low frequency noise, as sometimes occurs in HVAC installations, since this will not register its full subjective impact when measured using the A-weighting.

At the time that the weighting networks were devised, the complexities of the human hearing system were not fully understood. Methods of loudness evaluation were developed in the 1970s which take account of frequency and sound level in far more detail than do the simple A- and C-weighting networks.

*Figure 8.2 A- and C-weighting curves*




## 8.3 Noise assessment

The dBA measure is often used as an indicator of human subjective reactions to noise across the full range of audible frequencies. This index is simple to measure using a sound level meter incorporating an A-weighting network. In addition, the measured noise spectrum can be compared with reference curves such as the NR or NC curves which aid identification of any tonal frequency components[3].

Noise rating (NR) curves (Figure 8.2) have been commonly used in Europe for specifying noise levels from mechanical services in order to control the character of the noise. However, it should be noted that NR is not recognised by the International Standards Organisation or similar standardisation bodies. Noise criteria (NC) curves (Figure 8.3) are similar to NR but less stringent at high frequencies and more stringent at low frequencies. The curves are very close at middle frequencies, between 125 Hz and 2 kHz, and as long as there are no spectrum irregularities at low and high frequencies, they may be regarded as reasonably interchangeable. More recent developments in North America have lead to the introduction of Room criterion (RC) curves and the current ASHRAE recommendation is for the RC Mark 2[4].

*Figure 8.3 Noise rating (NR) curves*

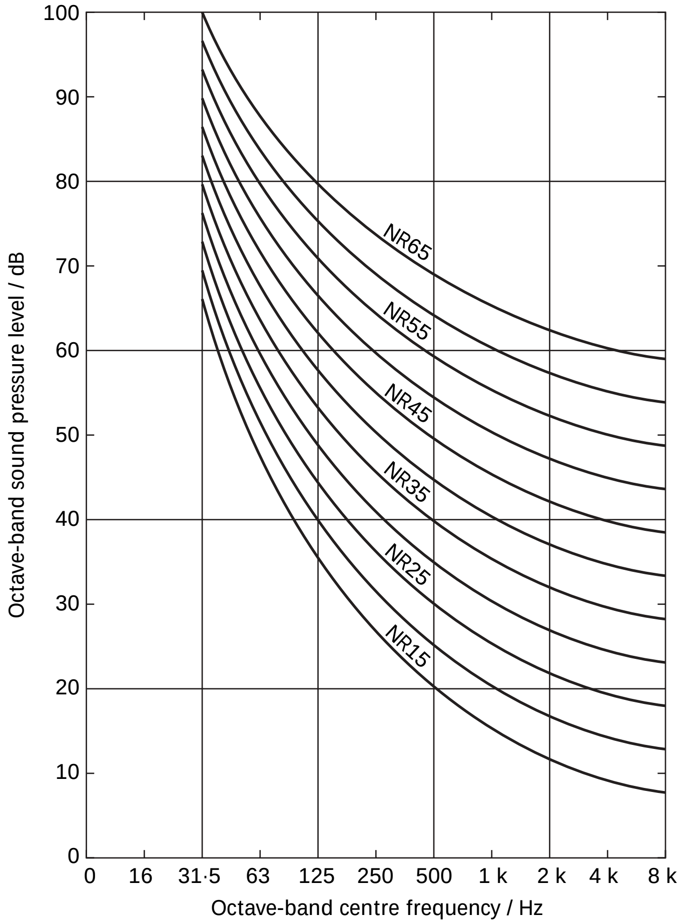
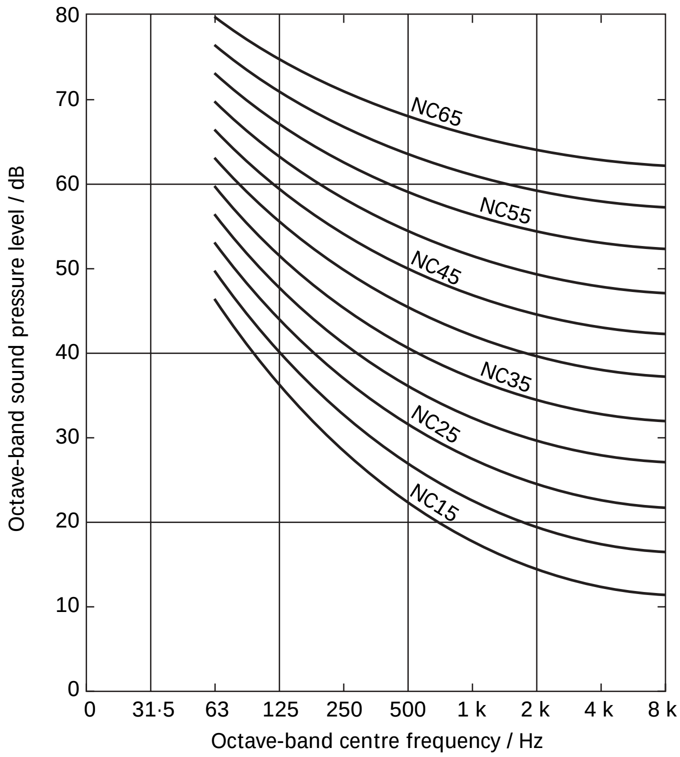



*Figure 8.4 Noise criterion (NC) curves*

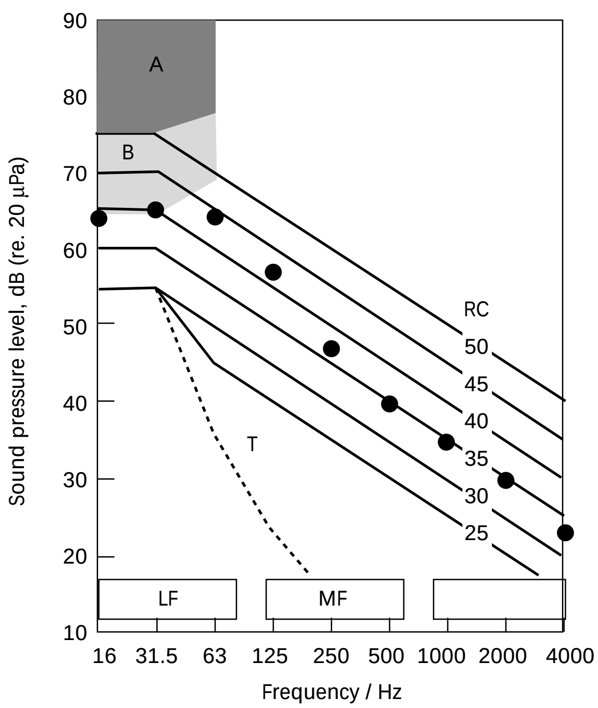


The relationship between NR and dBA is not constant, because it depends upon the spectral characteristics of the noise. However, for ordinary intrusive noise found in buildings, dBA is usually between 4 and 8 dB greater than the corresponding NR. If in doubt, both should be determined for the specific noise spectrum under consideration. Design limits for NR and NC for common situations are given in Table 8.1. Noise from many sources, such as road traffic and aircraft, varies with time and the human response to the noise depends on its amplitude and temporal characteristics. Single number indices, such as $L_{A10,T}$, $L_{A90,T}$ and $L_{Aeq,T}$ may be used to describe these types of noise.

$L_{A10,T}$ is the A-weighted sound pressure level exceeded for 10% of the measurement period, *T*, which must be stated. Similarly, $L_{A90,T}$ denotes the level exceeded for 90% of the measurement period. It is often used to measure background noise levels. $L_{Aeq,T}$ is the A-weighted sound pressure level of a continuous steady sound having the same energy as the variable noise over the same time period. It is found to correlate well with subjective response to noises having different characteristics, and is used with BS 8233[5]. Noise from plant may be audible outside the building and control measures may be necessary to avoid complaints. Noise limits may also be set by the local authority. Noise emanating from industrial premises in mixed industrial and residential areas is usually assessed according to BS 4142[6].

The past 20 years has seen significant developments in North American usage of noise criteria, but these have not yet made an impact in Europe. NR was never adopted in the US and ASHRAE no longer recommends NC as a general design criterion. For some time the preferred assessment method has been room criterion (RC) curves, Figure 8.5, first proposed by Blazier[7] in the early 1980s and subsequently developed to give a noise quality assessment[8] of the room noise.

*Figure 8.5 The RC Mark 2 curves showing low frequency (LF), medium frequency (MF) and high frequency (HF) regions.*




The curves level off at 16 Hz in order to control low frequency fluctuations which may be caused by poor running conditions of a fan.

Levels in shaded region A are likely to generate easily perceptible noise-induced vibrations, rattling of fittings etc.

Levels in shaded region B may produce perceptible vibration.

The solid dots show a typical spectrum for which a quality assessment is made in ASHRAE Handbook: *Applications* [4].

RC curves are based on actual measurements in air conditioned buildings in which the occupants are judged to have good acoustical environments. The result is a set of parallel lines falling from low to high frequencies at –5 dB/octave, but levelling off below 31.5 Hz. Noise spectra following these slopes are acoustically ‘neutral’. The use of the curves is explained in ASHRAE Handbook: *Applications*[4], where it is shown how to determine the noise quality of the room spectrum and the frequency regions where improvement is required RC curves provide a more detailed description of the noise than is available from NR. In addition, room criteria are more prescriptive at low frequencies than NR. At 31.5 Hz, permitted NR35 levels are 19 dB higher than RC35 levels. A noise which follows the NR curve will be unpleasantly 'rumbly' compared with the neutral sound of a noise that follows the RC curve. Therefore NR continues to be adequate only where low frequency noise levels are well below the NR limit. The potential drawback of NR curves is that they permit unacceptable noises that would have been rejected if RC had been applied.

## 8.4 Noise due to building services and other sources

In specifying noise design goals for a building, a balance must be sought between noise from the building services and noise from the activities taking place within the building. The acceptability of noise from building services does not depend only upon its absolute level and frequency content, but also on its relationship with noise from other sources. It is important that the designer considers the likely activity-related and extraneous noise level and frequency content at an early stage of design. However, while noise from the building services is controlled by the building services engineer, activity noise is a function of the office or other equipment in the space and is therefore under the control of the office management. Noise from outside the building, e.g. traffic noise, is controlled mainly by the fabric of the building, which is the responsibility of the architect. The building services engineer must work to an agreed specification for the noise level from the building services and may be able to influence the level set down in the specification.

Reasonable design limits to minimise annoyance from broadband continuous noise from building services installations are given in Table 8.1 (below). If the noise contains recognisable tones or is intermittent or impulsive it will be more annoying and the appropriate criterion value from Table 8.1 should be corrected using the factors given in Table 8.2 (below). Alternatively, a more detailed assessment will be given by the RC Mark 2 method.

Noise from the building services becomes more noticeable when other noise is at its minimum level, as is usually the case outside the occupied period. Noise levels for building services are often specified for the unoccupied space and compliance with contractual noise levels determined in the unoccupied space at night, when external noise is low. The building services designer cannot rely on external or activity noise in order to permit noise levels from services higher than those given in Table 8.1. Indeed, it may be necessary to control noise from these other sources to achieve an acceptable acoustical environment.

In the absence of noise from other sources, noise from building services may become noticeable. If so, the aim should be to reduce the services noise rather than to attempt to mask it by noise from other sources. However, provided that it is within the limits required by the specification, a steady level of services noise can sometimes help to improve acoustical privacy in open plan offices.

In modern offices, a prominent source of noise at workstations is the cooling fans in office equipment, such as personal computers. The characteristic of this noise is different from that of services noise, tending to have a tonal spectrum with peaks at about 250 Hz and associated harmonics, depending on the design of the fan. Clearly, this source of noise is not under the control of the building services engineer.

*Table 8.1 Suggested maximum permissible background noise levels generated by building services installations*[5]

| Situation | Noise rating (NC or NR) |
|---|---|
| *Studios and auditoria*: | |
| — sound broadcasting (drama) | 15 |
| — sound broadcasting (general), television (general), sound recording | 20 |
| — television (audience studio) | 25 |
| — concert hall, theatre | 20–25 |
| — lecture theatre, cinema | 25–30 |
| *Hospitals*: | |
| — audiometric room | 20–25 |
| — operating theatre, single bed ward | 30–35 |
| — multi–bed ward, waiting room | 35 |
| — corridor, laboratory | 35–40 |
| — wash room, toilet, kitchen | 35–40 |
| — staff room, recreation room | 30–40 |
| *Hotels*: | |
| — individual room, suite | 20–30 |
| — ballroom, banquet room | 30–35 |
| — corridor, lobby | 35–40 |
| — kitchen, laundry | 40–45 |
| *Restaurants, shops and stores*: | |
| — restaurant, department store (upper floors) | 35–40 |
| — night club, public house, cafeteria, canteen, department store (main floors) | 40–45 |
| *Offices*: | |
| — boardroom, large conference room | 25–30 |
| — small conference room, executive office, reception room | 30–35 |
| — open plan office | 35 |
| — drawing office, computer suite | 35–45 |
| *Public buildings*: | |
| — law court | 25–30 |
| — assembly hall | 25–35 |
| — library, bank, museum | 30–35 |
| — washroom, toilet | 35–45 |
| — swimming pool, sports arena | 40–50 |
| — garage, car park | 55 |
| *Ecclesiastical and academic buildings*: | |
| — church | 25–30 |
| — classroom, lecture theatre | 25–35 |
| — laboratory, workshop | 35–40 |
| — corridor, gymnasium | 35–45 |
| *Industrial*: | |
| — warehouse, garage | 45–50 |
| — light engineering workshop | 45–55 |
| — heavy engineering workshop | 50–65 |
| *Dwellings (urban)*: | |
| — bedroom | 25 |
| — living room | 30 |

*Note*: dBA ≈ NR + 6

*Table 8.2 Corrections to noise rating for certain types of noise*

| Type of noise | NR correction |
|---|---|
| Pure tone easily perceptible | +5 |
| Impulsive and/or intermittent noise | +3 |

## 8.5 Speech intelligibility

Speech intelligibility is dependent upon the ambient noise and the distance between listener and speaker. Table 8.3 gives an indication of the distance at which normal speech will be intelligible for various ambient noise levels[5]. Ambient noise may also interfere with the intelligibility of telephone conversations. However, conversation can be carried out in reasonable comfort if the ambient level is below 60 dBA, which should be the case in well-designed offices where the maximum levels are not likely to exceed 45 dBA.

*Table 8.3 Maximum noise levels and speech communication*[5]

| Distance between talker and listener (m) | Noise level, $L_{Aeq}$ (dB) | |
| --- | --- | --- |
| | Normal voice | Raised voice |
| 1 | 57 | 62 |
| 2 | 51 | 56 |
| 4 | 45 | 50 |
| 8 | 39 | 44 |

## 8.6 Hearing damage

Exposure to high noise levels, such as may occur in a plant room, can cause temporary or permanent hearing damage. Where workers are exposed to high levels of noise, the noise levels must be assessed by a qualified person. The the Noise at Work Regulations 2005[9]regulations identify two levels of 'daily personal noise exposure' (measured in a manner similar to $L_{Aeq,T}$) at which actions become necessary. These levels are 80 dBA for the lower level and 85 dBA for the higher level, corresponding to advisory and compulsory requirements. In addition, for impulse noise, there is a lower peak level limit of 112 Pa and a higher peak level limit of 140 Pa. These peak action levels control exposure to impulse noise. Suppliers of machinery must provide data for machines likely to cause exposure above the action levels.

## 8.7 Vibration

### 8.7.1 General

In the context of building services installations, vibrations arise from reciprocating machines or from unbalanced forces in rotating machines. The vibration is often most noticeable during machine start-up (i.e. low-frequency operation) , during which some machines pass through a critical (resonant) speed before reaching their normal operating condition. Vibration associated with start-up may not be important if the machine operates for long periods, since that condition occurs only infrequently. However, machines which switch on and off under thermostatic control, for example, may require special precautions.

Vibrations transmitted from machines through their bases to the building structure may be heard, and sometimes felt, at considerable distances from the plant and, in extreme cases, even in neighbouring buildings. Therefore, adequate isolation is important in those cases where vibration is expected. Vibration isolators must be chosen to withstand the static load of the machine as well as isolate it from the structure. Efficient vibration isolation is the preferred way of controlling structure-borne noise, which occurs when vibration transmitted to building surfaces is re-radiated as noise. Structure-borne noise is enhanced when the excitation frequency corresponds with a structural resonance frequency, causing unexpected noise problems.

### 8.7.2 Response of the human body to vibration

Vibrating motion of the human body can produce both physical and biological effects. The physical effect is the excitation of parts of the body and under extreme conditions physical damage may result, for example to the spine, which is a hazard to tractor drivers and similar occupations. Building vibration, which is at a much lower level, may affect the occupants by reducing both quality of life and working efficiency. Complaints about vibration in residential situations are likely to arise from occupants when the vibration levels are only slightly greater than the threshold of perception.

The levels of complaint resulting from vibration, and acceptable limits for building vibration, depend upon the characteristics of the vibration and the building environment, as well as individual response. These factors are incorporated in guidance given in BS 6472[10],which gives magnitudes of vibrations below which the probability of complaints is low.

### 8.7.3 Effects on structures

Vibration can damage building structures. The degree of damage depends largely on the magnitude and frequency of vibration. In general, the level of vibration likely to cause cosmetic damage, such as plaster cracking, is significantly greater than that which would be easily perceptible to the occupants. Therefore, the occupants themselves provide early warning of vibration levels likely to cause damage to the fabric.

Although vibrations from plant in buildings are often noticeable, there is little documented evidence to show that they produced even cosmetic damage[10–12].

## 8.8 Recommendations

(1) Hearing protection is advised whenever the ambient equivalent noise exceeds 80dBA. to avoid risk of hearing damage.

(2) The acceptable noise from building services to avoid irritation depends upon the type of room. Values are listed in Table 8.1

(3) Lower noise levels than (2) are needed to avoid irritation when speech intelligibility is essential. The required maximum noise depends upon the distance between the speaker and the listener. The values are given in Table 8.3.

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6 BS 4142: 1997: *Method for rating industrial noise affecting mixed residential and industrial areas* (London: British Standards Institution) (1997)

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10 BS 6472: 1992: *Guide to evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)* (London: British Standards Institution) (1992)

11 *Damage to structures from ground-borne vibration* BRE Digest 353 (Garston: Building Research Establishment) (1990)

12 BS 7385: *Evaluation and measurements for vibration in buildings: Part 1: 1990: Guide for measurement of vibration and evaluation of their effects on buildings* (London: British Standards Institution) (1990)

# 9 Further reading

## 9.1 Chapter 1: Introduction

For information about health and safety the Health & Safety Executive has provided a series of help lines. The address is HSE Information Services, Caerphilly Business park, Caerphilly, CF83 3GG. The email address is hseinformationservices@natbrit.com . Free pamphlets can be downloaded from their website (*www.hse.gov.uk*).

*Electricity at Work Regulations 1989* (London: The Stationary Office (2001) (1989)

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