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AIR QUALITY FOR OCCUPANT HEALTH

Editors **Dr Alan Sherratt** & **Richard H Rooley** *FE*

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Contributors

Paul Appleby Paul Appleby is Divisional Director for the Building Health & Safety Division of Thorburn Colquhoun, specialising in diagnosis, prevention and alleviation of building-related illnesses and indoor environment problems. He is Chairman of the panel that has revised Section A1 of the CIBSE Guide - *Environmental Criteria for Design* to be published in the Autumn.

Dr Geoff Brundrett Immediate Past President of CIBSE and Chairman-elect of the Royal Society of Health Geoff Brundrett has specialised on environmental issues in buildings during his research career in the electricity industry and now practising as an Independent Consultant. He has written several books including *Legionella and Building Services* - Butterworth 1992 - the only Engineering reference on the subject.

Alan Carter Associate Director of ABS consulting, Alan Carter has over 35 years experience of designing building services systems. He is a member of the CIBSE Building Energy Code Task Group and is noted for his enthusiastic approach to improving building environments.

Dr Bill Cory Bill Cory has been in the ventilation and fan industry for 45 years and is well known in both Europe and the USA for his contribution to the development of standards for fan equipment and application. He has been Technical Director of The Company now known as Woods Air Movement since 1983 and is responsible for an engineering staff some 53 strong.

Oliver Griffiths With a background in marketing, Oliver Griffiths, Managing Director - Corporate Responsibility Consulting, manages the Atmosphere Improves Results (AIR) initiative which aims to improve air quality in pubs and bars in the UK and overseas. The AIR Initiative is supported by the licensed trade and the tobacco industry.

Dr Robert Maynard Senior Medical Officer and Head of the Air Pollution Unit at the UK Department of Health, Robert Maynard has taught and undertaken research in mechanisms of chest injury and pulmonary toxicology. He is Medical Secretary to the Committee on the Medical Effects of Air Pollutants and to the Expert Panel on Air Quality and editor of the World Health Organisation's Air Quality Guidelines for Europe. He is also Honorary Professor in the Institute of Public Health at the University of Birmingham

Peter MacDonald Air Handling Business Director with AAF-McQuay - major manufacturers of air filtration air conditioning and heating equipment, Peter MacDonald is a major contributor to the development of the building services industry through membership of industry committees both in the UK and overseas. He was Chairman of the Technical Committee of HEVAC's Air Conditioning Group for over 10 years

Richard Rooley FEng Richard Rooley has had wide experience of providing maintenance systems for services in buildings. He has been responsible for major Health, Public, Commercial and Housing projects. As Principal of Rooley Consultants he applies his engineering and maintenance experience to the solving of problems in the internal environment and designing user oriented buildings.

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Jim Ure An engineer with wide experience in contracting and consultancy, Jim Ure is Managing Director of ABS consulting where he applies leadership and management skills to take a broader view of business opportunities available.

Chapter 1

Buildings and Services Design for Health

Dr Geoffrey Brundrett

INTRODUCTION

Building services engineers have responsibility for creating an internal environment which is safe, comfortable and healthy. They are also expected to achieve these conditions at low environmental impact in terms of energy, to match the green credentials of the leading architects. Unfortunately the health implications of many design decisions are not realised until too late. Medical and epidemiological research continues to link contaminated air to discomfort and ill health. The diffuse nature of the construction industry means that it takes time for health issues to be translated into design and practice. Equally the owners of buildings can be unaware of the health implications of inadequate or inappropriate maintenance.

In cold countries the commercial buildings themselves are designed for low infiltration rates. This has an important impact on energy conservation, protects the buildings from ice spalling and destruction of wall panels, and minimises draughts for the occupants. It also means that the ventilation can be carefully

Dr Geoffrey Brundrett is an Environmental Consultant, Warrington.

designed and controlled through a mechanical system and therefore offers opportunities for heat recovery (ASHRAE 1997),

In hot countries commercial buildings are also designed for low infiltrating rates because they are air conditioned to provide the necessary cooling. The energy cost is directly related to the amount of air handled and therefore again the air *supply is carefully designed, usually with some air recirculation. The low infiltration rates enable the air conditioning to work successfully and for interstitial* condensation risks within the fabric to be minimised.

Britain has a temperate climate. It is mild and damp. At times of low energy cost in the past we built to keep out the rain and we considered generous unplanned infiltration necessary and healthy. We even talked of the building breathing naturally, We added to this the ability for occupants to open windows with or without the option of ventilation slots. Energy considerations led to big improvements to the thermal insulation of buildings and the ventilation loss is now the major unknown in design. In city centre buildings air conditioning is introduced for two reasons. The first is that it maximises the occupancy on the site through the design of deep plan buildings. The second is that the extra cost of the air conditioning plant brings a disproportionate increase in rent because clients value the summer cooling. Britain's experience of air conditioning is therefore relatively new.

Green pressures encouraged a move away from air conditioning solutions and created a new style of naturally ventilated buildings, even in city centres. This relies on planned holes and ventilation shafts being provided for the outdoor air to percolate through the building in accordance with the prevailing wind direction or the stack effect due to inside/outside temperature difference.

The new pressure on designers is to create low energy buildings. This means at least three things. The first is high levels of the thermal insulation within the building envelope. The second is planned and controlled ventilation. The third is a low infiltration building fabric to minimise the traditional large and variable unplanned ventilation which can be so troublesome (Perera 1994).

In autumn 1998 the Department of Environment, Transport and the Regions organised a series of discussion meetings with the construction industry. The purpose was to create better low energy buildings. The unanimous response from the industry was to move towards low infiltration design and to incorporate

pressure testing checks into future Building Regulations. When this happens the services engineer has the ability to create a much better internal environment and to make it healthier and more satisfying (Wadden 1983).

THE FOUR FACTORS WHICH INFLUENCE AIR QUALITY

1. The quality of the incoming outdoor air.

In rural buildings the air is usually clean except for seasonal occasions when the spring pollen count can be high and the mould spores concentration developing in autumn from rotting vegetation. In cities the situation is far more complex. The critical factor is the location of the air inlet with relation to the local pollution concentrations. (Irving 1999) In a city these pollution concentrations vary in quality, in time and in space continuously over the days and seasons. Engineers have now been taught about avoiding the close proximity of an evaporative cooling tower to the air inlet because of the risk of microbiological contamination from legionella. Less attention is paid to the location of ventilation exhausts or nearby chimneys of neighbouring buildings. Even less is known about the behaviour of the traffic exhaust fumes in city streets. Research is active in this field. (Harrison 1993)

City pollution is changing in both quality and concentration and Britain has now adopted a more scientific methodology for measuring such pollution. Black smoke has reduced consistently since the Clean Air Act of 1956. Sulphur dioxide concentrations have declined since coal heating gave way to sulphur free gas. Oxides of nitrogen have remained relatively constant. The very fine particulates from diesel exhaust have grown in concentration as diesel engines take over from petrol.

2. The air treatment.

There are three types of ventilation systems.

Natural ventilation in which the quantity of air is determined by the weather conditions at the time and the size and location of the open windows or ventilator slots in the building façade. Mechanical ventilation systems, where fans are provided to supply and or extract the air. Such systems are used widely on industrial plant for process contaminant control or in the printing industry for humidity control. They are also used in air conditioning systems. The fans used are sized sufficiently powerfully to permit air filters to be placed at the air inlet to protect the heat exchange equipment from excessive dirt. The air velocity and temperature are chosen to circulate the air in a planned way inside the building. The third way is mixed mode ventilation where the system is basically a natural ventilation one but with fans incorporated to be available whenever the weather conditions are insufficient to drive the ventilation.

Small rural buildings tend to be simply ventilated through open windows. In the case of houses additional fans are used in kitchen and bathroom for moisture control. Large city buildings tend to be air conditioned.

3. Unplanned air infiltration

The building envelope is never airtight. Casual unplanned air infiltration occurs in all buildings. In some countries the architect specifically designs the infiltration rate to be small. The concept is new to Britain and our building infiltration rates are usually very high and widely variable between each other. Such high rates of infiltration bring in external pollution and undermine the effects of the air filters on the incoming air. Experimental measurements suggest that in a conventional building there is little difference in internal/external air pollution regardless of whether or not the building is air conditioned. In reality the air conditioned building occasionally reached abnormally high internal pollution levels because the air inlet was sited downwind of a chimney. Such unplanned ventilation takes a significant amount of energy. In public discussions last autumn the Department of Environment, Transport and the Regions asked for comment from the construction industry on how to conserve more energy. The top priority was to 'build tight -ventilate right' with a performance specification on airtightness which could be checked by pressure testing the finished building. (Lamb 1994, Potter 1995)

4. The air distribution system.

In natural ventilation systems the air inlets are wall grilles and the extract system is usually a vertical air shaft. In mechanical ventilation systems the air is drawn through ductwork and distributed through the air diffusers to the room. The diffusers create a flow pattern which is designed to dilute any internally generated pollutants such as body odour. A mechanical ventilation system extracts the stale air.

Problems have been experienced with contaminated ductwork or air inlet grilles. Pigeon droppings, urban dirt, and city debris can pollute the incoming air. Danish surveys showed that the odour source in their office ductwork was equivalent

to three times the body odour from the occupants. (Fanger et al 1988) Dirt will stick on the fan impeller and can dramatically impair the fan output. Current British guidance asks for duct cleaning to be done annually. In Sweden the Building Regulations recommend ductwork cleaning and checking every few years. In the first few years of such testing the failure rate was approximately two thirds of systems examined.

Inside the room the air can move quickly and dilute the contaminant by mixing intimately with it. This is the traditional way. The alternative method is piston flow whereby the air is introduced at low level and low speed and rises to the ceiling as a piston displacement action.

HEALTH RISKS

There are four conventional types of risk

1. Nuisance and disturbance.

Personal stress can be induced by persistent minor irritations, particularly if the occupants feel that such disturbances are outside their control or are not being considered sufficiently seriously by management. Each irritation in itself may be small but over time it becomes a major distraction. Low humidity, below 40% RH, is associated with electrostatic shocks, particularly in open plan offices because the body voltage builds up with distance walked. Noise disturbances from both the services equipment and the office machinery can be troublesome. Some air pollution can cause headaches as well as eye irritation. (Brundrett 1990, Appleby 1996)

2. Physical discomfort.

Low humidity in winter and high internal dust burdens can create eye irritation, particularly for those who wear contact lenses. This is exaggerated in the presence of tobacco smoke. High internal humidities or high temperatures can cause excessive perspiration which saturates clothing with moisture which can then cause chilling when moving outdoors. Strong odours can reduce appetite.

3. Infection / allergic reaction

There are six main causes of such responses

(a) **Mould spores.** Damp conditions in buildings encourage the ever present mould spores around us to germinate and thrive into mouldy patches.As these patches grow the mould sheds large numbers of spores into the air.These are small and remain suspended for very long periods. When susceptible individuals inhale such spores the spores can settle in the lungs and create an infection. Heating and ventilation to maintain moderate humidities in the room prevent mould growth. Unfortunately, once mould develops, water is a waste product and the mould can thrive then in lower humidity atmospheres. Preventing growth in the first instance is necessary.

(b) **House dust mite.** House dust mites live in warm damp conditions. They prosper within the mattress of the bed and live from minute amounts of the fine mould which grow on the dead skin scales which rest there. The waste products of such mites can create a night time asthmatic response in some people, Heating and ventilation can lower the relative humidity in the house and minimise the problem.

(c) **Humidifier fever.** Many humidifiers work by recirculating water through the incoming air stream. In doing so the water washes dirt out of the airstream and it circulates with the water. Microorganisms prosper in the dirty water and, when recirculated, can be entrained within the airstream. The building occupants then inhale the contaminated air and become ill with high temperature and sickness. The attack rate is normally high. It is an occupational hazard in the packaging and printing industry where crude humidity control is used to keep the colour registration precise in printing and to enable the packaging material to remain flexible. (HSE, 1993)

(d) **Pontiac fever and Lochgoilhead fever.** These are two airborne generated flu like fevers caused by different species of legionella. Legionella multiplies in lukewarm water which contains nutrient. When this contaminated water is aerosolised by bubbles bursting as in a whirlpool spa, or by splashing in a water spray, it poses a hazard to those in the neighbourhood who may inhale it. HSE Guidelines are available to minimise the risk by requiring all employers to undertake a risk analysis and to rectify any faults found. The attack rate is near I 00% of the exposed population when it occurs. It is not normally life threatening. (Brundrett 1992)

(e) **Legionnaires' disease.** This is a pneumonia caused by the water home legionelia bacteria. The disease is life threatening and requires medical treatment, It occurs when susceptible persons inhale the legionella bacteria in contaminated water aerosols. The two main sources are from neglected evaporative cooling towers and to a lesser extent badly functioning hot tap water. The cause is either poor temperature control which leads to water standing lukewarm (25-40°C) before leaving the taps for some time or from the water sprays within cooling towers which have had inadequate biocidal treatment. The attack rate is very low. Susceptible persons include elderly males, smokers, those on suppressant drugs, and any with a preexisting medical condition.

HSE guidelines require a risk analysis. Cooling towers are a particularly sensitive area. AU cooling towers must now be registered with the local authority. They are frequently sited at the top of tall buildings and could be close to the air inlet for that building. In suitable conditions of high humidity the aerosol droplets remain moist for some time and the infective range for travel can be 500 metres. (HSE 1992, HSC 1991)

(f) **Respiratory sensitisers.** Certain substances cause sensitisation of the respiratory tract if inhaled or of the skin if contact occurs. Respiratory sensitisers can cause asthma, rhinitis, or extrinsic allergic alveolitis. Only a proportion of the exposed population become sensitised and those who do cannot anticipate the effect, Some industrial materials such as wood dust are more likely to be sensitisers and these are specially marked in the occupational standards guidance. (HSE 1994, HSE 1998)

4. Toxic materials.

Some of these are generated within the building itself Cigarette smoking has been the major indoor hazard in the past but modern management practices restrict smoking to special zones for smokers. Passive smoking is therefore no longer a large problem in places of work. Guidelines are cautious of recommending safe ventilation rates for smoking areas because there is uncertainty on what constitutes a safe smoke concentration. There does not appear to be a safe threshold for suspended dust-

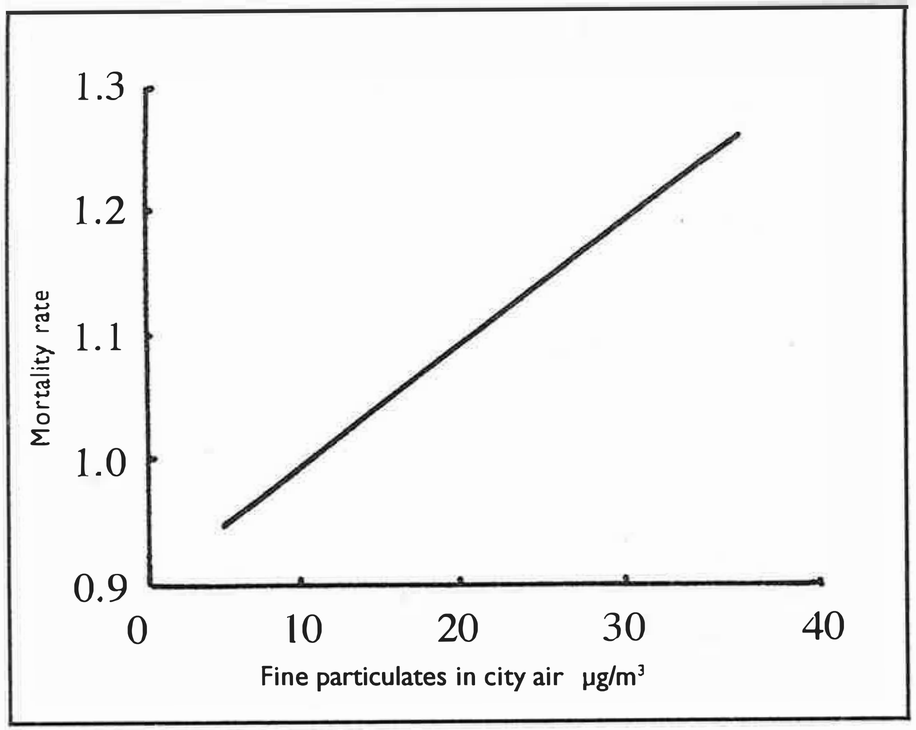

Figure 1.1 Relationship Between Mortality and City Dust Concentration
Dockery et al - six city study 1993

Combustion products, particularly the oxides of nitrogen, are released from gas cookers in the home. Modem gas burners work at much lower flame temperatures and create much less release of these oxides than older models. However there is evidence which strongly links the use of gas cooking to respiratory problems in the home, particularly for the young and the female. (Brauer et al 1996, Leynert et al 1996, Jarvis 1996) Planned ventilation is recommended for such applications. Carbon monoxide could be a problem with badly maintained gas fired heating equipment. The gas is odourless and has a much stronger affinity to haemoglobin in the bloodstream than oxygen. It therefore prevents a normal amount of oxygen being circulated around the body, Prolonged breathing of it is fatal. Free standing paraffin fires can release some carbon monoxide. Experiments with students working for around two hours in such fumes from these fires were shown to be mentally impaired at quite low concentrations of carbon

monoxide. (17-100ppm, average 61). Memory, new learning ability, attention, concentration and tracking skills all suffered from the short exposure. (Amitai et al 1998). Recently purchased office machinery does not emit noxious substances. Some older photocopying machinery released the unpleasant and damaging gas, ozone, into the room.

Industrial processes have their own health limits. (HSE 1998) Occupational exposure standards are provided for the bulk of harmful chemicals in wide use. This standard, defined over a finite period of usually a peak period of ten minutes or a working day average of eight hours, is the concentration at which no employee is likely to be injured if exposed to it for day after day. For some substances which are particularly dangerous there are maximum exposure limits over ten minutes or an eight hour day. These substances often do not have a threshold 'no effect' concentration. They are assigned to substances which have serious health implications, such as carcinogens.

There are two basic outdoor contaminants The first is radon gas, a radioactive gas which is released particularly from granite. It is odourless. The National Radiological Protection Board has plotted maps of Britain showing areas of potential gas release, which lie mainly in Scotland and the west country. Under floor ventilation together with tight air seals around the service penetrations to the house provide a solution.

The second is city centre pollution. This is a mixture of fine particles, acid gases such as oxides of nitrogen and sulphur dioxide together with ozone. Fumes and odours tend to create more of a local nuisance. The recent US six city study reveals surprisingly that the annual mean city dust concentration has a direct effect on respiratory health, Figure 1.1. (Dockery et al, 1993) Many urban cities break the international health guidelines and the latest medical judgement cannot find a safe threshold value for dust. This calls into question the conventional engineering assumption that outdoor air is fresh. With low infiltration buildings of the future a well designed mechanical ventilation system can provide an internal working and living environment which is healthier than the outdoor city air. (Kukadia et al 1996)

HEALTHY AIR

The definition of health should be a positive one of well being, not just absence of illness. Recent research shows that the enthalpy of air provides a good indication

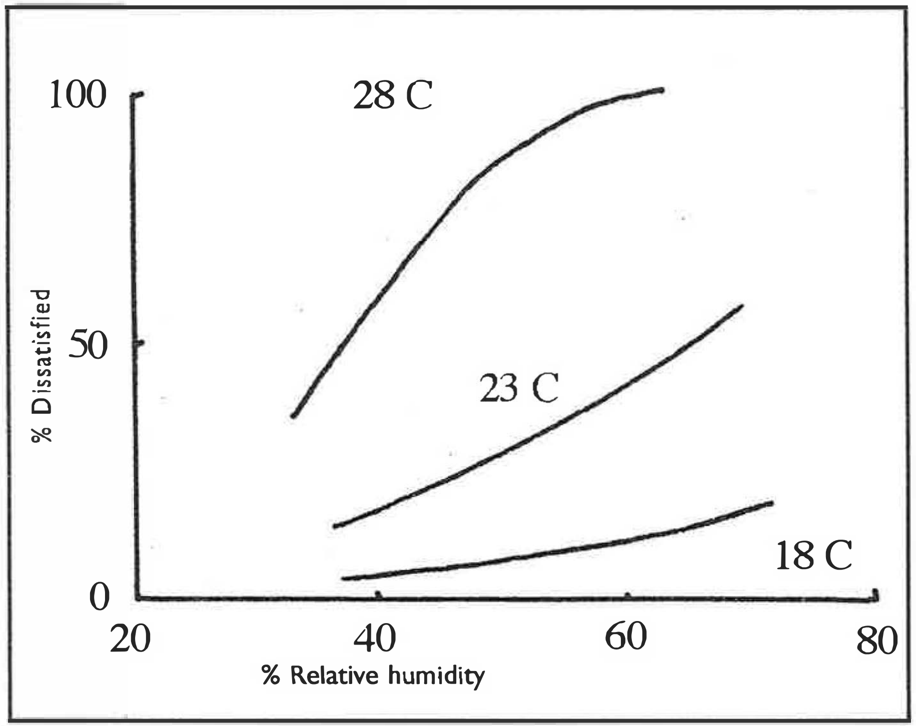

Figure 1.2 Perceived Air Quality as a Function of Temperature and humidity *Fang et al 1996*

of the freshness and pleasantness of that air. Clean air can smell stale and unattractive when warm and at high humidity. The results of this research are shown in Figure 1.2. Close temperature and humidity control will be the next positive air freshener once the air contamination aspects are solved. (Fang et al 1996)

ECONOMICS

Crude cost benefit studies show the importance of good air quality. Preliminary US figures suggest that increasing the air flow from 2-4 l/s per person to 9-4 l/s/p increased energy costs by £3.60p per person per year and required an additional equipment cost of £2.37p per person per year. In return this investment brought about a 10% reduction in respiratory illness which was equivalent to a saving of £24.37p per person and an improvement in productivity of 0.25% which was £56.25p per person, i.e. a benefit of £80.62p for a cost of £5.97

The benefit of high efficiency filtration was shown to be a 10% reduction in respiratory disease worth £24.37p per person per year and £43.75p per year from a 1% increase in productivity among the 20% workers who are allergic together with a £56.25p saving from decreasing the productivity loss from building related sickness from 1% to 0.75%.The cost of filtration was £14.37p per person per year with an associated annual energy cost of 62p per year each, i.e. a benefit of £124.37p per year per person at an annual cost of £14.99p per person. (Anon, ASHRAE 1998)

CONCLUSIONS

The role of ventilation becomes progressively more important as fabric insulation improves. The next major task in energy saving is to control the ventilation component, eventually leading to heat recovery opportunities. Unfortunately British buildings are notoriously leaky in terms of excessive infiltration despite exhortations to the contrary. The Government is seriously contemplating low infiltration buildings for Britain.This gives the engineers the opportunity to control, for the first time, the air quality inside buildings.

For houses, planned ventilation for moisture control has started.The next urgent step is to provide proper ventilation hoods for cookers, particularly gas cookers.

For factories, ventilation provides contaminant control through extraction at source and in dilution of the indoor air to safe levels. Good temperature control is needed to avoid the workforce from opening all doors and windows and defeating the planned extract air flow.

For city offices, outdoor air must be treated as contaminated and cleaning techniques established to remove the fine particulates from the incoming air. The retrofit market may struggle to adapt existing equipment to the pressure drops associated with simply replacing the existing filters with finer ones. There is a new market for low pressure drop electrostatic filters.

Finally, once the indoor air is clean, engineers may look again at the enhanced satisfaction which good temperature and humidity control can bring to the occupants.

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Chapter 2

Health Effects of Indoor Air Pollutants, Current Perceptions

Dr Robert L Maynard

INTRODUCTION

People in developed countries such as the United Kingdom (UK) spend more than 80% of their lives indoors; in less technologically developed countries the percentage of the day spent indoors is rather less than this. If we accept that the effects of exposure to air pollutants are in some way proportional to total exposure to those pollutants, it follows that the indoor environment may play a larger role than the outdoor environment. Of course, it may be that the response to a given pollutant is more dependent on the peak concentration encountered than on the total exposure – if this is the case then exposure outdoors may assume primary importance if peak concentrations outdoors are greater than those found indoors. This would be the case regarding sulphur dioxide.

Some pollutants of great importance outdoors, for example ozone, hardly present an indoor hazard as they are rapidly absorbed by materials indoors and there are no significant indoor sources. Other pollutants, including carbon monoxide

Dr Robert Maynard is Senior Medical Officer & Head of the Air Pollution Unit, UK Department of Health, London

The views in this Chapter are those of the author and should not be taken as those of the UK Department of Health and nitrogen dioxide, pose hazards both indoors and outdoors. Accidental deaths from carbon monoxide poisoning are almost entirely an indoor problem.

Despite the clear importance of exposures that take place indoors, nearly all we know about the effects of air pollutants on health has been learnt from studies that relate outdoor concentrations to effects on health. This is not completely true: studies of volunteers exposed in chambers and studies on experimental animals also tell us a good deal. In the past ten or so years, emphasis has been placed on time-series based epidemiological studies that relate, generally, daily average outdoor concentrations of air pollutants to daily counts of health-related events such as death and hospital admissions. These studies have built up an impressive body of evidence that shows that air pollutants have significant effects on health at concentrations that would, hitherto, have been regarded as harmless. It should be understood that the studies say nothing about exposure to pollutants or where that exposure occurs: the findings simply indicate, for example, that on a day when the 24 hour average concentrations of pollutant *p* rises by c $\mu g/m^3$, the number of deaths occurring on that day rises by *d*. At least as far as daily deaths are concerned there is some evidence to suggest that the elderly and especially those suffering from chronic heart and lung disease are most likely to be affected. Now it is likely that such people spend more than an average amount of time indoors: they are certainly not jogging in the park. Thus, we can deduce that the time-series studies are telling us something about the effects of indoor exposure to air pollutants.

The time-series database has been exposed to intense scientific scrutiny and is generally accepted as sound. A great deal of effort has been put into adjusting for confounding factors of which temperature is perhaps the most important. It is well known that deaths from cardiovascular diseases (heart attacks and strokes) rise rapidly after a sudden fall in temperature to be followed some days later by an increase in deaths from respiratory diseases. The exact mechanisms of effects are unknown and there is some debate about whether a small fall in indoor temperature or short duration exposures to lower outdoor temperatures plays the larger part.

Detailed statistical analysis of the time-series data by both parametric and non-parametric methods has produced a variety of results. The former approach leads to linear relationships with no clear evidence of a threshold concentration; the latter, which do not impose structure on the data, lead to relationships that are not monotonic and which do provide some evidence of a threshold. The

latter seem more toxicologically likely than the former: or at least, less counter-intuitive. Both methods, however, show effects at unexpectedly low concentrations of pollutants. Some of these studies are discussed particularly in relation to indoor air pollutants below.

Outdoor air pollution is amenable to enforced monitoring, standard setting and, thence, regulation; indoor air pollution is not. In the UK, a wide network of outdoor air pollutant monitors has been established, standards have been recommended by the Expert Panel on Air Quality Standards and objectives to be achieved by specific dates are set out in the Revised UK National Air Quality Strategy.[1] No such formal approach has been adopted with regard to indoor air pollution – neither in the UK nor in other countries. This is not to say that the UK has no policy regarding indoor air pollution. A policy exists and is based upon:

(a) research;

(b) provision of advice to the public, for example, by means of pamphlets;

(c) suitable amendment of building regulations and regulations applying to sources of indoor airpollutants, such as gas fires, as necessary.

It is clearly impossible to monitor indoor air pollutants except on a voluntary and research basis. Also, it is not possible to regulate peoples' activities indoors so as to proscribe all pollutant-producing activities. Advice has thus been seen as the way forward and campaigns, including one dealing with carbon monoxide, have been developed.

Has indoor air quality improved in parallel with outdoor air quality? In general, the answer should be yes. In the pre Clean Air Act (1956) period, outdoor air pollution often penetrated indoors. In London, performances at the English National Opera and the showing of films in cinemas had been abandoned due to smog penetrating from outdoors to indoors. Additionally, it is likely that during temperature inversions, when the chimneys of open coal fires drew poorly, indoor concentrations of sulphur dioxide were high. Today's houses are, on the other hand generally less well ventilated (the open grate was an excellent source of draughts) and some new pollutants have been introduced. Formaldehyde, given off by some cavity wall insulation and from artificially prepared boards, is a comparatively recent problem. Gas fires and gas boilers rely on good maintenance for their safety and may also cause problems. Gas-powered water heaters, geysers, of the type that used to be common in bathrooms, proved a lethal source of carbon monoxide unless well maintained: this was a very significant problem in some mainland European countries.

Indoor air pollution thus remains an important problem. A few important indoor air pollutants are discussed in more detail below. Much of the following account is based on the excellent reports on indoor air pollutants published by the MRC Institute for Environment and Health (Leicester).[2,3]

CARBON MONOXIDE

Carbon monoxide (CO) is perhaps the most dangerous of the indoor air pollutants. It is produced whenever carbon-containing fuel (ie, fuel of organic origin) burns in a restricted supply of air. Badly adjusted gas burners are an important indoor source of CO. Blocked flues are also a common cause of accumulation of CO in rooms. In the UK, about 50 people die each year as a result of accidental indoor exposure to CO. People often die in groups, eg, families all being affected. Deaths can occur in houses, flats, mobile homes and caravans. In the latter, bottled-gas heaters and, less common today, paraffin heaters, can be a hazard – unless they are well maintained.[3]

Carbon monoxide binds to haemoglobin in precisely the same way as oxygen but with more than 200 times the avidity of oxygen. Thus, CO competes exceptionally effectively with oxygen and in an atmosphere containing 20% oxygen and only 20/200, ie, 0.1% CO, haemoglobin will be 50% saturated with oxygen and 50% saturated with CO. Binding is not instantaneous and Figure 2.1 shows the uptake curves for carbon monoxide.[3]

The final percentage saturation of haemoglobin is shown on the right hand vertical axis. The outdoor air quality standard for CO in the UK is 10 ppm (averaged) over 8 hours: this ensures that the proportion of haemoglobin that is bound to CO (ie, the percentage carboxyhaemoglobin, COHb) stays at less than 2%. Such a % COHb has generally been regarded as harmless.

Carbon monoxide poisoning is difficult to diagnose: patients may present with symptoms that are difficult to distinguish from food poisoning or respiratory viral infections: headache, nausea and weakness are common complaints. This leads to cases of poisoning being missed and patients being returned to their

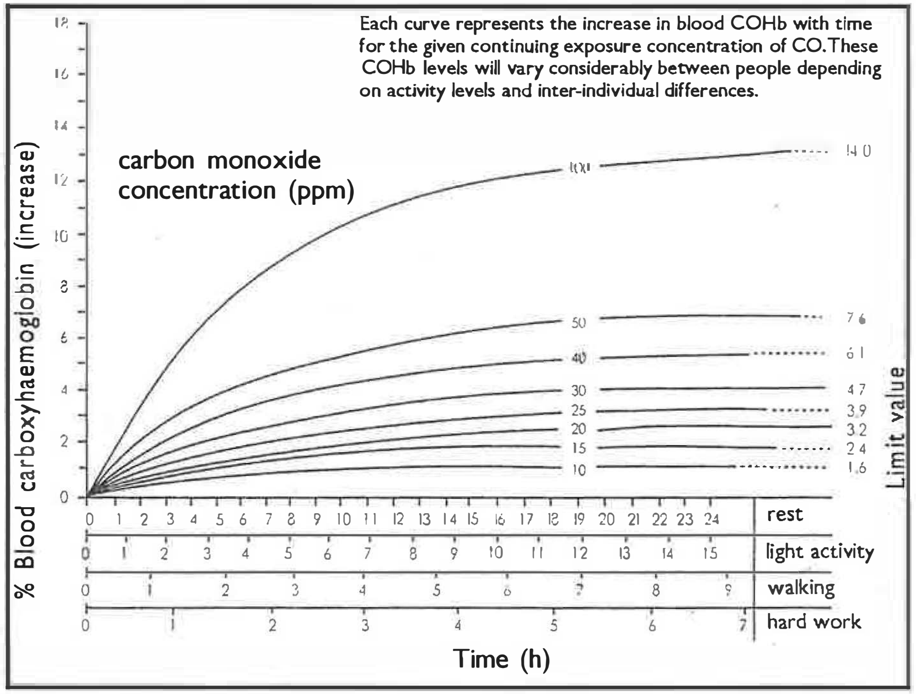

Figure 2.1 Uptake for carbon monoxide

homes where exposure often continues and where they may die. Tragic incidents are recorded each year. Poisoning that leads to unconsciousness may be followed by long-term neurological damage from which some patients never make a complete recovery. It has been suggested that long-term exposure to concentrations of CO that do not produce clear signs and symptoms of poisoning may be associated with the development of more subtle neurological damage: this has not been clearly proven, however.

During the past few years CO has figured in time-series epidemiological studies of the association between outdoor concentrations of pollutants and daily counts of health-related events. Outdoor concentrations of CO are generally low and have been regarded as unlikely to produce adverse effects on health. Studies of COHb concentrations even in those exposed for long periods to street-level pollution has failed to find evidence of dangerous levels of exposure. The time-series studies, however, have shown an association between outdoor CO concentrations (sometimes measured as 24 hour average concentrations and sometimes as peak 1 hour average concentrations) and daily counts of hospital admissions for treatment of heart failure. It is known that carbon monoxide binds to myoglobin, a muscle cell protein that, like haemoglobin, is involved in oxygen transport. This may be important in muscle cells close to the inner surface (endocardium) of the heart which may be relatively deprived of oxygen in patients suffering from coronary artery disease. Some support for this idea has been provided by studies that involved exposing patients who suffered from angina to concentrations of CO sufficient to bring the COHb level to 2% and then exercising them on a treadmill. Both the time to onset of anginal pain and to the appearance of specific changes in the electrocardiogram were reduced. These findings have raised concerns about the effects of exposure to carbon monoxide indoors. In 1998 the Chief Medical Officer wrote to all General Practitioners in England (similar letters were sent in Wales, Scotland and Northern Ireland) pointing out the dangers of CO exposure and providing advice on diagnosis and treatment.[4] A campaign to increase awareness of the danger posed by CO is currently being pursued by both the Department of Health and the Department of the Environment, Transport and the Regions.

NITROGEN DIOXIDE

Nitrogen dioxide (NO_2) is an important pollutant in both outdoor and indoor air. In the urban outdoor setting petrol and diesel powered vehicles are an important source and produce a mixture of nitric oxide (NO) and NO_2: the NO is oxidised to NO_2 rapidly if ozone is present, slowly if no ozone is present. Indoors, gas cookers and gas fires are important sources. Studies of indoor concentrations of NO_2 have shown that concentrations in houses using gas as the main cooking fuel are consistently higher than in those using electricity for cooking. Data from a study done in Avon are shown in Table 2.1.

The raised levels in homes using gas, though long-term average concentrations are still low, have led some workers to speculate that children growing up in homes that use gas for cooking and heating might be adversely affected: there is some, though rather inconsistent, evidence to support this hypothesis.

Though nitrogen dioxide is an important outdoor air pollutant, the effects of exposure to ambient concentration on health remain uncertain: indeed, uncertainty characterises our knowledge of the toxicology of this pollutant. Let us begin with what is known.

Table 2.1 NO_2 concentrations in μg/m³ related to main cooking fuel, in homes in the Avon area

Room	Season	MAIN COOKING FUEL: Natural gas		Electricity	
		Mean	n	Mean	n
Kitchens	Spring	29.0	56	12.9[a]	62
	Summer	25.4	61	15.4[a]	66
	Autumn	28.4	48	15.3[a]	65
	Winter	29.7	60	15.8[a]	67
Living rooms	Spring	20.1	54	12.6[a]	62
	Summer	20.8	61	15.9	66
	Autumn	16.0	50	14.2	65
	Winter	19.2	60	13.7	67
Bedrooms	Spring	14.8	56	10.8	63
	Summer	19.6	61	12.4[b]	65
	Autumn	16.4	51	14.2	66
	Winter	13.9	61	9.7[c]	66

[a] $p < 0.01$; [b] $p < 0.02$; [c] $p < 0.05$

Exposure to high concentrations (eg, > 5 ppm) produces delayed pulmonary oedema which may, in some cases, lead on to an inflammatory and ultimately fibrotic disease of the small airways of the lung. There is no evidence to suggest that ambient exposure produces such effects. Exposure to concentrations of greater than about 600 ppb leads to measurable reductions in standard indices of lung function eg, FEV_1, and this suggests that at these concentrations NO_2 acts to narrow the airways, ie, is a bronchoconstrictor agent. At concentrations of less than about 400 ppb, little bronchoconstrictor activity can be detected, though exposure of patients suffering from asthma to such concentrations can lead to an enhanced response to other bronchoconstrictor agents. Interestingly, pre-exposure to NO_2 can also increase the response of such patients to allergens to which they have been sensitised. Long-term exposure to low concentrations of NO_2 has, in some studies, been shown to be associated with a slight reduction in standard indices of lung function.[2]

In December 1991, an air pollution episode in London led to peak hourly average concentrations of NO_2 exceeding 450 ppb. A study of daily deaths, hospital admissions and general practitioner consultations showed an effect on health. The authors of the study were, however, careful to point out that concentrations of particles were raised at the same time and that the effects might have, at least in part, been attributed as well to particles as to NO_2.[5]

The mechanism of action of NO_2 is very poorly understood. That free radicals are generated as a result of reactive absorption of NO_2 in the lining fluid of the airways is clear. Further damage via free radical cascading is likely with lipid peroxidation playing an important part. It is known that nitrogen dioxide induces an inflammatory response in the airways though NO_2 is not as inflammatory a compound as ozone. Nitrogen dioxide also has effects on the defence mechanisms of the lung and has, at high concentrations, been shown to impair the capacity of alveolar macrophages to attack bacteria.

A large number of studies of the effects of indoor exposure to NO_2 have been undertaken. These are summarised in the MRC Institute for Environment and Health report quoted above. Space here does not permit a detailed consideration of the studies and just a few summarising points will be made.

(a) There is evidence to suggest that children living in homes that use gas as the primary cooking fuel are at greater risk of respiratory infections than children in homes using electricity. A much quoted meta-analysis by Hasselblad estimated that a long term increase in NO_2 concentration of 30 $\mu g/m^3$ (equivalent to the use of a gas cooker) was associated with a 20% increase in the risk of respiratory illness in children.[6]

(b) As is usually the case with studies of the effects of nitrogen dioxide, other studies, some of which were not available for inclusion in Hasselblad's meta-analysis found no effects.

(c) A number of studies have used gas cooking as a surrogate for exposure to NO_2. Studies that have involved monitoring of NO_2 have tended to show either less effects than those that use gas cooking as a surrogate or no effects at all.

(d) Though in 1996 the authors of the MRC Institute's report concluded that there was "little evidence to suggest that the use of gas cookers has any effects on the incidence of respiratory disease in women" a recent study done in East Anglia has produced different results. Women suffering from asthma who used gas cookers were shown to have depressed lung function when compared with subjects who used electricity.[7] The results of this study have been in part confirmed by a broader study conducted in Europe.[8] Once again both significant findings (ie, depressed lung function) or alternatively, no effects, were recorded depending on the study location. It is clearly difficult to produce a definitive view on the issue, but it is my impression that the evidence in favour of effects has strengthened during the past few years. It should be noted that if there is, indeed, an effect, it is still not known whether this is related to the transiently very high concentrations of NO_2 produced close to gas cookers during cooking (> 1000 ppb), or to the more modestly increased background concentrations found in houses that use gas for cooking. Further research on this issue is clearly needed.

(e) A number of studies of the putative effects of indoor exposure to NO_2 may have been confounded by exposure to environmental tobacco smoke (ETS). ETS is known to increase the likelihood of respiratory diseases in childhood: including respiratory infections, asthma and glue ear. The latter is, of course, not a respiratory disease *per se* but a result of middle ear infection.[2]

(f) Nitrogen dioxide is known to increase the bronchoconstrictor response of sensitised individuals to inhaled allergens. Thus, exposure to mites and moulds may add to the effects of NO_2 *per se*.[2]

Nitrogen dioxide is thus an important indoor air pollutant, though it should be accepted that its effects are only partially understood.

FORMALDEHYDE

Formaldehyde is the last of the pollutants dealt with in this brief review. Formaldehyde, unlike nitrogen dioxide and carbon monoxide, is almost entirely an indoor air problem. Indoor sources include cigarette smoke and up to 25% of the indoor concentrations of formaldehyde can be cigarette derived. The other key sources are fibre board and chip board, in which the glue that binds the fibres or wood chips releases formaldehyde. Urea-formaldehyde foam wall insulation is also an important source. Cleaning materials, disinfectants and water-based paints also make a contribution. Concentrations in UK houses have been studied by Crump and Gardiner.[2] In a survey of 10 houses, indoor concentrations averaged 0.034 and 0.057 mg/m^3 in winter and summer, respectively, whilst the equivalent outdoor concentrations were 0.029 and 0.020 mg/m^3. The highest average indoor concentration recorded was 0.12 mg/m^3. Further studies have shown, as expected, that concentrations of formaldehyde in homes with urea-formaldehyde foam wall insulation are higher than in those without. A greater difference between indoor and outdoor concentrations was recorded in a study of 174 homes in the Bristol area which showed an average indoor concentration of 0.025 mg/m^3; the outdoor average was 0.002 mg/m^3.[9] As might be imagined, concentrations of formaldehyde in mobile homes and caravans tend to be higher than in conventional homes. The greater use of fibre/chip board explains this effect. Similarly, houses with recently installed urea-formaldehyde foam wall insulation have raised concentrations of formaldehyde and these levels fall as the time from foam installation increases. Concentrations of up to 0.5 mg/m^3 have been reported in mobile homes. The authors of the IEH report point out that concentrations are, in general, lower than this and tend to be about 0.1 mg/m^3. The concentrations can be put into perspective by comparing them with air quality standards and guidelines. In 1987, the World Health Organisation (WHO) recommended 0.1 mg/m^3 (30-minute average concentration) as a guideline.[10] The Canadian Department of National Health recommends 0.12 mg/m^3 (5-minute average) as an action level and 0.06 mg/m^3 as a target.[11] It will be seen that concentrations in at least some homes and especially mobile homes, may be close to, or may exceed these guidelines.

HEALTH EFFECTS OF FORMALDEHYDE

Formaldehyde at high concentrations is a strong irritant of the skin, the eyes and the respiratory tract. Formaldehyde is accepted to be a probable human carcinogen (IARC classification: 2A). As far as indoor exposures are concerned, only the irritant effects are of significance. It is of interest that such effects may be reported at concentrations very similar to those found in some dwellings. For example, detection of odour, eye irritation and upper respiratory tract irritation all begin to appear at concentrations of between 0.01 and 0.12 mg/m^3. It will be appreciated, then, that effects may occur at below the level recommended in the WHO Air Quality Guidelines for Europe (0.1 mg/m^3).[9] It is debatable whether damage, in a physical sense, occurs at < 0.1 mg/m^3, but some individuals can certainly detect such concentrations.

Before discussing the irritant effects in more detail, it may be useful to deal briefly with the carcinogenic effects. Evidence of effects comes from occupational studies involving high level exposures. The cancers associated with such exposure are of the nasopharynx and the sinuses. Animal data also show carcinogenic effects and mutagenicity studies indicate that formaldehyde should be regarded as a genotoxic carcinogen. As such, no completely safe level of exposure can be recommended. Predicting the likelihood of cancer being induced by long-term exposure to low concentrations is difficult: a range of models could be used but the estimates produced are likely to be imprecise and not to be amenable to verification. In updating the WHO Air Quality Guidelines, it was agreed that exposure to the guideline concentration (0.1 mg/m^3) represented a level at which there is a negligible risk of upper respiratory tract cancer in humans.

Irritant effects have been recorded in mobile homes and in homes insulated with urea-formaldehyde foam insulation. The report on Indoor Air Quality in the Home published by the MRC Institute for Environment and Health provides a comprehensive review of publications in this area. An important study by Liu *et al* investigated 2490 occupants of mobile homes.[12] Symptoms associated with exposure to formaldehyde included: burning/tearing (crying) of eyes; stinging/burning of skin; sore throats; fatigue; and problems with sleeping. It was found that subjects suffering from chronic respiratory disorders such as chronic bronchitis and asthma were more susceptible to such effects than other individuals.

It is hardly surprising that people suffering from asthma are more affected by exposure to formaldehyde than are normal individuals. Asthma is a disease characterised by hyper-irritability of the airways and formaldehyde is certainly an irritant. A more important question is: does exposure to formaldehyde at indoor concentrations *cause* asthma? This question has been asked about outdoor air pollutants and the general consensus amongst experts is that air pollution does not *cause* asthma. An indoor air pollutant that does seem to increase the susceptibility of people, in this case children, to developing asthma is environmental tobacco smoke. The exact mechanism of effect is unknown – but then, in many cases so is the cause of an individual's asthma. Samet *et al* concluded that indoor exposure to formaldehyde was unlikely to cause asthma.[13,14] Kryzanowski *et al*, on the other hand, reported an increase in asthma and chronic bronchitis in people living in homes with formaldehyde concentrations in excess of 0.072 mg/m^3.[15] Several other authors have reported associations between formaldehyde and upper respiratory tract symptoms, but have failed to demonstrate associations with objective indicators of lung function such as FVC, FEV_1 and FEF_{25-75}.[1] This finding differs from that of the Kryzanowski study in which a decrement in morning peak flow rates in children – especially in children with asthma, was found with a formaldehyde concentration as low as 0.036 mg/m^3.

What conclusions can be drawn from these findings and from other data, not reviewed here, that have been collected in chamber studies of subjects, both normal and asthmatic, exposed to low concentrations of formaldehyde? It seems clear that sensitive subjects may experience eye irritation at concentrations as low as 0.01 mg/m^3. Concentrations of formaldehyde higher than this can occur in homes with new furnishings and especially in those with recently installed urea-formaldehyde foam insulation. The position regarding irritation of the upper respiratory tract is less clear – though it seems likely that concentrations of formaldehyde can increase sufficiently to induce such effects. That exposure to concentrations of formaldehyde found in the home causes chronic lung disease seems unlikely.

CONCLUSIONS

Carbon monoxide, nitrogen dioxide and formaldehyde are three substances that present problems as indoor air pollutants rather than as outdoor pollutants. Of course carbon monoxide and nitrogen dioxide have important outdoor sources; formaldehyde, on the other hand, is almost entirely an indoor problem. Predicting the effects on health of indoor exposure to air pollutants on the basis of the results of studies that look at associations between concentrations of pollutants outdoors and health is unsatisfactory. Concentrations and patterns of exposure differ significantly in the two environments and our understanding of the relationships between concentration, duration of exposure and effects on health is still inadequate. This means that further research on the effects of indoor air pollution on health is warranted. This has been recognised by the Department of Health and a research initiative focused on indoor air was launched in 1998. As our understanding of the effects of air pollutants on health develops it may be possible to regard indoor and outdoor air, rightly, as a continuum. Developing policies to control peoples' exposure to pollutants wherever they are is the goal.

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Chapter 3

UK Guidance on IAQ - the New CIBSE Guide

Paul Appleby

INTRODUCTION

The CIBSE is to publish new guidance on environmental criteria later this year. This includes new material on Indoor Air Quality which provides a strategy for minimising indoor air quality problems in buildings and improving the effectiveness of outdoor air supply in controlling indoor pollution. This Chapter explains the reasons for this approach and the basis for the guidance given.

APPROACH

The philosophy behind the new CIBSE Guide Section A1 *Environmental Criteria for Design* is to provide recommended default values for specific design criteria whilst providing the assumptions on which they are based and procedures and data to use for adapting them to "non-standard" situations.

The approach recommended for controlling indoor air quality follows the principals behind occupational hygiene and the COSHH Regulations, i.e. source identification and control. The same approach can be used at the design stage or when carrying out ongoing air quality checks or a COSHH Assessment.

Paul Appleby is Divisional Director, Building Health & Safety Division, Thorburn Colquhoun, London

The starting point is to identify what materials, equipment etc. emit pollutants into the air.

Where possible information should be obtained on the chemicals involved, their release rate, their toxicity, and occupational exposure limits and/or guideline values to exposure (e.g. WHO Air Quality Guidelines).

The following strategy should then be applied in order to minimise the risk of exposure and reduce the burden on ventilation:

1. eliminate the substance at source, or:
2. substitute either the source or the substance for one with a lower potential for health effects or odour, or:
3. reduce emission rates, or:
4. segregate occupants from the source, and, once all of these alternatives have been accounted for:
5. develop an appropriate ventilation strategy, and, if none of these measures can be guaranteed to control exposure below an acceptable level:
6. provide appropriate personal protection (mask, air-fed respirator etc.).

The latter option would normally only apply to industrial exposure and the requirements are set out in the Personal Protective Equipment at Work Regulations 1992.

The order given above is chronological, however some combination of factors 1 to 4 will normally be considered in order to reduce the dependence on ventilation to a minimum. Ventilation options available range from openable windows through mechanical dilution and displacement systems, local exhaust ventilation to enclosures. Again some combination of these may be applicable, with the aim of reducing the reliance on mechanical ventilation to a minimum.

SOURCE CONTROL

Although CIBSE provide default outdoor air supply rates based on those in the 1986 Guide the emphasis has been changed to identifying potential sources of indoor pollution and taking steps to eliminate or control them.

Potential pollutants are listed, including occupancy-dependant body-odours and environmental tobacco smoke, but also substances which originate from building materials, office furniture and equipment, cooking, moulds and from external sources such as motor vehicles, in-fill sites and industrial processes.

CIBSE recognises the concern internationally over the health effects of passive smoking and the difficulty in creating a comfortable environment for non-smokers where smoking is allowed. The trend in the UK is towards smoking controls in the workplace, and CIBSE strongly supports the introduction of these controls.

The Guide divides indoor pollutants broadly into two categories:

1. odour-free at concentrations which can have an identifiable health effect
2. malodorous - resulting in discomfort.

Many substances become irritants at concentrations above the odour threshold. Some result in narcosis or other short term health effects, whilst chronic illness may result from long term exposure.

The workplace atmosphere is a cocktail of, perhaps, thousands of substances, most of which will be at very low concentrations. Because of the uncertainties associated with exposure to these cocktails CIBSE recommend that all reasonable steps be taken to eliminate sources and control emissions, both in the design and specification of the building and its contents and during maintenance and cleaning processes.

SPECIFIC POLLUTANTS

The new Guide gives Guideline values for individual substances adapted from both the WHO Air Quality Guidelines, which have been recently revised, and the Air Quality Regulations 1997. These have been adopted by CIBSE for the non-industrial workplace, rather than Occupational Exposure Limits (OELs), which are not considered appropriate for non-industrial exposure. WHO Guidelines are based on different criteria to OELs, resulting in significantly lower values. The OEL for toluene, a commonly found solvent vapour in the non-industrial workplace, is 50 ppm for a time-weighted average (TWA) exposure of 8 hours, whereas the Guide recommends the 1998 WHO Guideline be adopted, which is 0.068 ppm for a 1 week exposure.

A table is provided in the Guide which quotes WHO Guideline concentrations for a range of airborne substances, including vapours, gases and particulates associated with both indoor and outdoor sources. These include some substances associated with vehicle exhausts for which Air Quality Objective Levels (AQOLs) have been set for England and Wales under the Air Quality Regulations 1997. Although these are intended for the use of Local Authorities, as a measure of compliance with their obligations under the Environment Act 1995 by the year 2005, CIBSE refers to them because they represent the quality of outdoor air from which it will be expected that building ventilation will draw, which, de-facto, should not be exceeded indoors.

It is interesting to note that all of the WHO Guideline and AQOL concentrations given are below the thresholds of odour for the substances listed, apart from that for Ozone, which can be detected at concentrations as low as 15 ppb, whilst the WHO Guideline is 60 ppb (8 hour TWA). Adoption of the WHO Guideline does not guarantee that discomfort from odour would not occur for short periods. For example Toluene can be detected at 5 ppm, whilst the WHO Guideline is 0.068 ppm, time weighted over a week. This means that brief excursions to concentrations above 5000 ppb would not push the 1 week TWA above 68 ppb provided they were compensated by a sufficient duration of concentrations below the TWA.

i.e. $\Sigma \{(C_1 - TWA) \times time\} = \Sigma \{(TWA - C_2) \times time\}$,

where C_1 and C_2 are concentrations above and below the TWA respectively.

The list includes known carcinogens, namely arsenic, benzene, man-made vitreous refractory ceramic fibres, nickel, radon and trichloroethylene, and provides estimated deaths from cancer for a given population size exposed to a given concentration averaged over a lifetime. For example for benzene, an ingredient of fuel for combustion engines, it has been estimated that 6 deaths from cancer could occur in a population of 1 million through lifetime exposure of 1 $\mu g/m^3$. The Local Authorities have been tasked to reduce the annual average ambient levels to 16 $\mu g/m^3$, although occupational exposure allows an 8 hour TWA exposure of 16,000 $\mu g/m^3$!

The Guide provides a procedure for determining the outdoor air supply rate for controlling the concentration of specific pollutants to below a desired level, where the emission rate of the pollutant is known, and taking account of the average concentration of the pollutant in the outdoor air. The procedure can also take account of the ventilation effectiveness, which can vary depending on how the air is supplied into a room, the amount of short-circuiting and the buoyancy of the supply air. For example, cool air introduced close to the floor with extract at high level may result in pollutants being carried upwards before they mix with room air, i.e. displacement ventilation. Hence up to 40% less air could be used to achieve the same concentration in the breathing zone compared with full mixing.

GENERAL ODOURS

CIBSE refer to Fanger's work at the University of Denmark which has clearly demonstrated that the building, with its contents and services, represents a significant odour source which can greatly exceed the odour emitted from the occupants. The procedure which Fanger has developed for calculating outdoor air supply rate from the known odour sources in the building has not been adopted. It was considered that the basis for the procedure had not been sufficiently developed. The units of the olf and decipol are introduced however, where the olf is defined as "the sensory load on the air from an average sedentary adult in thermal neutrality" and the decipol is "the perceived air quality in a space with a sensory pollution load of 1 olf, ventilated by 10 litres per second of clean (odourless) air".

From Fanger's work, CIBSE recommend that building services designers and architects specify materials which minimise the "olf-load" on the building and hence reduce the burden placed on the outdoor air from sources other than the occupants. This philosophy should cover the maintainability of the building and its services, since many of the odour sources discovered by Fanger and his workers had become so because of inadequate maintenance.

PRESCRIBED OUTDOOR AIR SUPPLY RATES

The outdoor air supply rates recommended by CIBSE are those which were included in the 1986 Guide Section B2 : *Ventilation &Air Conditioning (Requirements)*. CIBSE have decided to retain separate outdoor air supply rates for rooms in which there would be no smoking of tobacco products and rooms where various degrees of smoking are expected.

For non-smoking rooms an outdoor air supply rate of 8 litres/s per person is recommended, whilst where there is "some smoking" the recommended rate remains as 16 litres/s per person, where "some" is defined as 25% of the occupants who are smokers, although not all smoking at the same time. This corresponds to a typical open-plan situation.

It is worth noting that ASHRAE have recently decided to omit recommended outdoor air supply rates for smoking environments from their Standard 62 because of concerns about the health effects of passive smoking. CIBSE take the view that the building services designer, whilst discouraging a client from allowing for smokers and non-smokers to work in the same space, should have the design criteria available should the client demand it. CIBSE do warn however that outdoor air supply alone may not prevent non-smokers experiencing either discomfort or long-term health effects from environmental tobacco smoke.

DUST & FILTRATION

For the first time in a CIBSE Guide a strategy is given for the use of filtration to reduce indoor air quality problems in buildings. This is treated primarily in the context of removing particulates, although reference is made to filtration equipment for the removal of gases and vapours, no design criteria are provided. CIBSE promote good quality particulate air filtration to not only reduce the pollution entering the occupied space but also to minimise the soiling of the internal surfaces of the air handling system and hence reduce the need for expensive and disruptive duct cleaning.

Criteria are provided for the specification of particulate air filters, based on those set out in BS EN 779 : *Particulate Air Filters for General Ventilation*. This standard is currently under revision for publication at the end of 1999. The test method for efficiency is being brought into line with EUROVENT 4/9, using a test aerosol and particle counter to rate filters instead of atmospheric dust and opacity measurement. A synthetic dust is used to determine the Arrestance and dust holding capacity of coarse filters.

Coarse filters are classified from G1 to G4 at a specified design final pressure drop (default value 250 Pa) and face velocity. Fine filters are classified from F5 to F9 at a specified design final pressure drop (default 450 Pa) and face velocity. The efficiency test determines an Average Efficiency (E_m %) from a number of tests at particle sizes from 0.2 to 4.0 µm. Classifications are based on the results for 0.4 µm particles, which have been found to be closest to those for atmospheric dust.

Classifications are recommended according to application. For example CIBSE recommend F6 or F7 filters be used for general offices, although if executive offices are supplied from the same air handling plant then F7 filters should be installed. An F7 filter should have an Average Efficiency for removing 0.4 µm particles of between 80 and 90%.

In addition CIBSE recommend that the following be accounted for in the selection and design of filter installations:

- Fine filters should be protected by a bank of coarse filters upstream, depending on the expected dust concentration in the incoming air. This is particularly important for locations where construction or other dust generating activities are expected nearby, and will significantly increase the life of the costly fine filters.
- Efficiency ratings apply to the entire filter installation and cannot be achieved if close attention is not paid during installation and maintenance to the fit of the filter in its frame and the frame within the air handling unit.
- Access for withdrawal of filters is essential - it is easy to damage new filters during installation if inadequate space is provided.
- Filters can become odour sources, particularly if moisture is allowed to penetrate them, hence they should be well protected from driving rain, humidifier spray etc.

CONCLUSIONS

Revision of Volume A of the CIBSE Guide is long overdue. Indeed Section A1 has not change significantly since 1976, and not at all since 1986. With the attention that has been paid to "Sick Building Syndrome", or "Building Related Sickness" as it is now more accurately termed, there has been a vast amount of research into the workplace environment, and indoor air quality in particular.

Although adherence to CIBSE Guidance will not completely eradicate this syndrome, the new guidance should represent a significant step in the journey towards improving the indoor environment.

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Chapter 4

Particulates are Killers

Peter MacDonald

INTRODUCTION

Much publicity has been given to the potential health risks posed by buildings, particularly those with mechanical ventilation or air conditioning. There have been concerns over the possible effects of the VOCs given off by the furnishings and finishes, of fungal spores shed from dirty ducting, of legionella distributed by wet cooling towers, of insufficient ventilation air, etc., etc. The list of concerns is a long one. But what about the effects on the building occupants of the air brought in from outside, the so-called 'fresh air'?

Compared with when domestic coal fires and 'smoke stack' industries were prevalent, present-day pollution levels are low. Despite this though, researchers recently have begun to find startling evidence that outdoor air can be positively harmful to health and that the biggest threat is the fine particles which are semi-permanently suspended in it. These don't just make people feel off-colour. They can kill.

Peter MacDonald is Air Handling Business Director, AAF-McQuay, Cramlington.

THE HARVARD STUDY

The most comprehensive study into the effect of air pollution on mortality has been that conducted by Dockery *et al* of the Harvard School of Public Health, which was published in 1993.

The research team took a random sample from six cities of 8111 white adults aged 25 through to 74 years and, over a 14-16 year period, compared their mortality rate with the pollution levels in their cities. All the subjects in the study had undergone lung function testing and had completed a standardised questionnaire which included questions about age, sex, weight, education level, complete smoking history, occupational exposures and medical history. So this allowed control for individual smoking status, sex, age, and other risk factors.

Concentrations of particulate matter, sulphur dioxide, ozone, suspended sulphates and hydrogen ions (for aerosol acidity) were monitored at a central location in each of the six cities. As well as measuring the total suspended particulate matter they measured the concentration of inhalable particles (aerodynamic

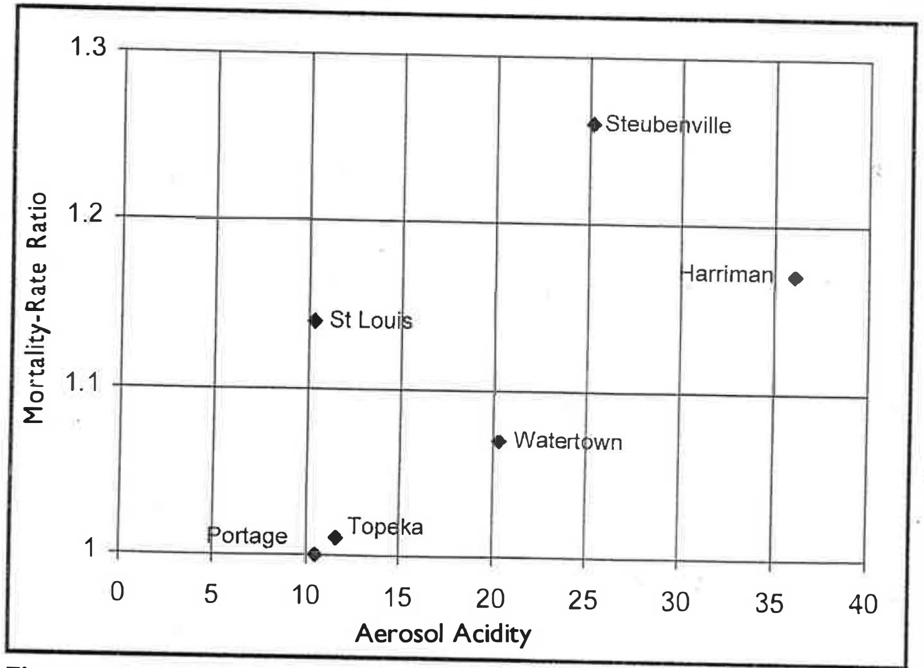

Figure 4.1 Relationship between Mortality-Rate Ratio and Annual Average Aerosol Acidity

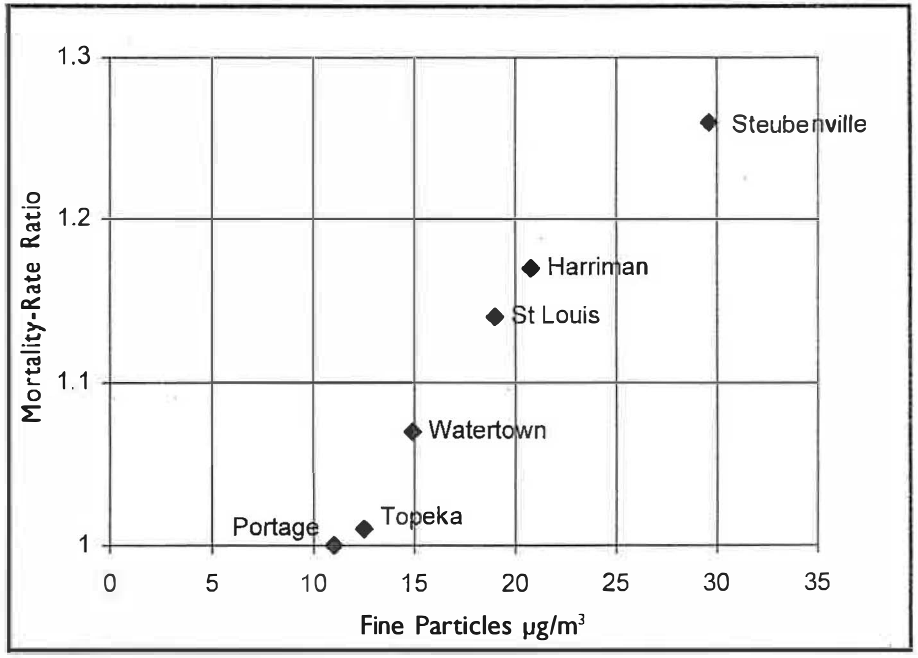

Figure 4.2 Relationship between Mortality-Rate Ratio and Annual Average Concentration of Fine ($PM_{2.5}$) Particles

diameter <10µm, commonly referred to as PM_{10} particles) and fine particles (aerodynamic diameter <2.5µm, referred to as $PM_{2.5}$ particles).

Mortality was most strongly associated with cigarette smoking and increased mortality was also associated with having less than a high-school education and with increased body-mass index. But after simultaneous adjustments for these risk factors, the differences in mortality among the six cities remained significant.

What was found was that city-specific mortality rates, adjusted for a variety of health risk factors, were associated with the annual average levels of air pollutants in the cities. Mortality was more strongly associated with the levels of inhalable, fine and sulphate particles than with the levels of total suspended particles, the sulphur dioxide levels, the nitrogen dioxide levels or the acidity of the aerosol. Figure 4.1 shows the scatter of the latter.

However, as Figure 4.2 indicates, there was found to be virtually a straight-line relationship between the levels of the fine $PM_{2.5}$ particles and the mortality rate.

The difference in mortality rate between the most and least polluted cities was an amazing 27%. But the most worrying aspect is that the increased risk of death occurred at concentrations well below those currently considered acceptable, as the annual average level of the inhalable, PM_{10} particulate was only 46.5µg/m³ in the most polluted city in the study.

OTHER STUDIES

This decade, following the revelations of the Dockery report, there has been a flurry of research activity into the harmful effects of air pollution. A recent UK study by Poloniecki *et al* has reported a statistically significant association between the daily incidence of myocardial infarction and daily concentrations of pollutants, especially particulate matter. The authors suggest that in the UK some 6,000 myocardial infarctions may each year be related to exposure to air pollutants.

This work on the immediate, short-term effects of pollution has been taken further. The Department of Health asked the Committee on the Medical Effects of Air Pollutants (COMEAP) to advise on the effects of air pollutants on health

Table 4.1 Effects of Each 10µg/m³ Increase in PM_{10} on Indicators of Ill-Health

	% change in health indicators
Increase in daily mortality	
Total deaths	1.0
Respiratory deaths	3.4
Cardiovascular deaths	1.4
Increase in hospital usage	
All respiratory admissions	0.8
Emergency department admissions	1.0
Exacerbation of asthma	
Asthmatic attacks	3.0
Bronchodilator use	2.9
Hospital admissions	1.9
Increase in respiratory symptoms reports	
Lower respiratory	3.0
Upper respiratory	0.7
Cough	1.2

in the UK, including an estimate of the numbers of people affected. Their report estimated that in the UK, 8,100 deaths of vulnerable people were brought forward by particulate air pollution. It was also associated with 10,500 hospital admissions, brought forward or additional, of vulnerable people suffering from respiratory problems.

For every 10µg/m³ increase in concentration of PM_{10} particles it has been estimated that there will be a 1% increase in the total death rate, a 3.4% increase in respiratory deaths and a 1.4% increase in cardiovascular deaths (see Table 4.1). Yes, particulates are killers.

WHY ARE PARTICULATES KILLERS?

It is not clear yet as to why fine particles are so dangerous, although a recent paper in the Lancet suggests that the immune system may be reacting to them as if they were invading organisms. This immune response causes inflammation of the tissues in a similar manner to the allergic reaction of a hay-fever sufferer, but with the ultra-fine particles the inflammation is deep in the lungs. The finer the particle size, the deeper it will penetrate. That is why many experts are calling for the monitoring and control of $PM_{2.5}$ particles (2.5µm diameter) instead of PM_{10} particles. It is even being suggested that ultrafine particles (< 0.05µm diameter) may play a role

WHERE DO THE PARTICLES COME FROM?

The primary sources of fine particles are old coal fired power stations, industry and especially road vehicles. By far the worse culprits are diesel engined vehicles – it is estimated that 90% of fine particles in the urban atmosphere are from this source.

Diesels use 20-25% less fuel than petrol engines, so have been trumpeted as being environmentally friendlier and have rapidly become popular. However, since combusting one litre of diesel oil produces about 15% more carbon dioxide than one litre of petrol, emissions of the 'greenhouse gas' carbon dioxide are only slightly less from diesel cars. Emissions from new diesel cars are estimated to be 3-4 times more carcinogenic than emissions from petrol cars. A modern diesel, even when it is correctly set up, emits 10–15 times more particles than a modern petrol engined car. Worse still, the particle sizes emitted by a diesel are considerable finer, more damaging to health.

Unless there are technological advances which will enable the cleaning up of diesel exhausts, or the Government takes steps to curb the growth in sales of diesel engined vehicles, the concentration of fine particles in the atmosphere, especially in our cities, will not decrease. It will probably increase.

IS THERE A SOLUTION?

Whilst the wearing of personal face masks, as favoured by some of our Japanese cousins, may provide a degree of apparent protection in the street, our buildings can be made relatively safe havens from the scourge of particulate pollution. How? By making sure that the 'fresh air' from outdoors is admitted in a controlled fashion, via an air filtration system.

This effectively means that a mechanical ventilation or air conditioning system is needed. A naturally ventilated city building can seriously damage its occupants' health is the message!

AIR FILTRATION TECHNIQUES

Contrary to what many might believe, air filters in ventilation systems do not work by straining or sieving the particulate matter out of the air. Instead they

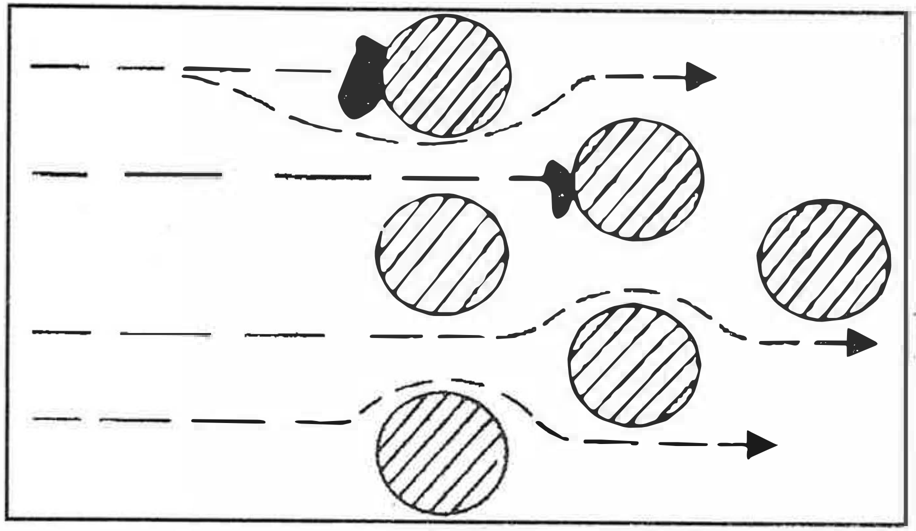

Figure 4.3 Inertial Impaction Principle

rely on three major collection mechanisms: inertial impaction, diffusion/interception and electrostatic precipitation. The last mechanism is not commonly employed, due to certain problems and drawbacks, not the least cost, so will not be covered in this Chapter.

INERTIAL IMPACTION

Particles in an airstream have mass and velocity, hence have a momentum associated with them. As the air and entrained particles pass through the filter medium the air takes the path of least resistance to flow and diverts round the fibres of the filter medium. The particles, because of their inertia, tend though to travel in a straight line and as a result, those particles located at or near the centre of the flow line impact on the fibre and are removed (see Figure 4.3)

Filters employing the inertial impaction mechanism are humble panel filters. These comprise a matt of fibres which is between 13 to 50mm thick, the thicker the better to provide as many obstacles (filter target fibres) as possible to produce sufficient deviations of the airstream. Typically the fibres are around 35µm in diameter and can be of graduated density so that the atmospheric contamination is collected throughout the depth of the matt, rather than just at the front.

The larger the particle and the faster the airstream the greater the particle's inertia, so the higher the likelihood of impaction taking place. However, if the velocity is too high, the particle can be blown off the fibre, so reducing the overall efficiency.

Filters relying on inertial impaction as a consequence start becoming ineffective at velocities through the filter medium above 3m/s. Below about 1.5m/s their efficiency drops off, due to the reduction in momentum. They are also only effective against the larger particle sizes, those above 5µm diameter, which, whilst accounting for just over half the total mass of typical atmospheric contamination, only account for a tiny percentage of the total number of particles present in the air.

This type of filter can typically remove 85% of 5µm particles from the airstream, but its efficiency drops to around only 15% for 1µm diameter particles. Put another way, 85% of the 1µm particles will pass through, will penetrate this type of filter.

DIFFUSION/ INTERCEPTION

Small, very light particles follow the airstream but are, under certain conditions, intercepted by molecular attraction forces between the particles and the filter fibres. This is called the interception principle.

Furthermore, all extremely small particles (<1µm) are subject to erratic motion, termed Brownian motion, which is caused by colliding air molecules, so that they move in a random fashion around the fluid flowlines. It is possible to trap these small randomly moving particles by placing densely packed obstacles in their path. As the particles diffuse through the obstacles, hence diffusion principle, they are trapped. See Figure 4.4 for a depiction of the diffusion/interception principle.

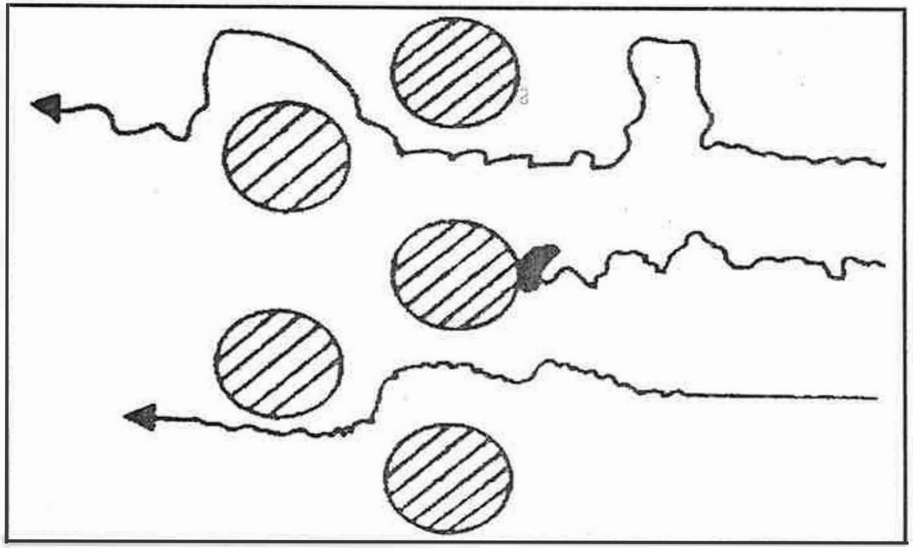

Figure 4.4 Interception/Diffusion Principle

All medium/high/ultra-high efficiency air filters, including bag, cartridge and HEPA (High Efficiency Particulate Air) filters employ the diffusion/interception principle. To help the process the air velocity through the filter is reduced to between 0.1m/s and 0.2m/s in the case of medium/high efficiency filters, either by fashioning the medium into the form of deep pockets (bag filters) or deep pleating it (cartridge filters). The velocity through the medium and the fibre diameter govern the filter efficiency - the lower the velocity and the finer the diameter the higher the efficiency, especially against the smaller particles. Typically the fibres used are

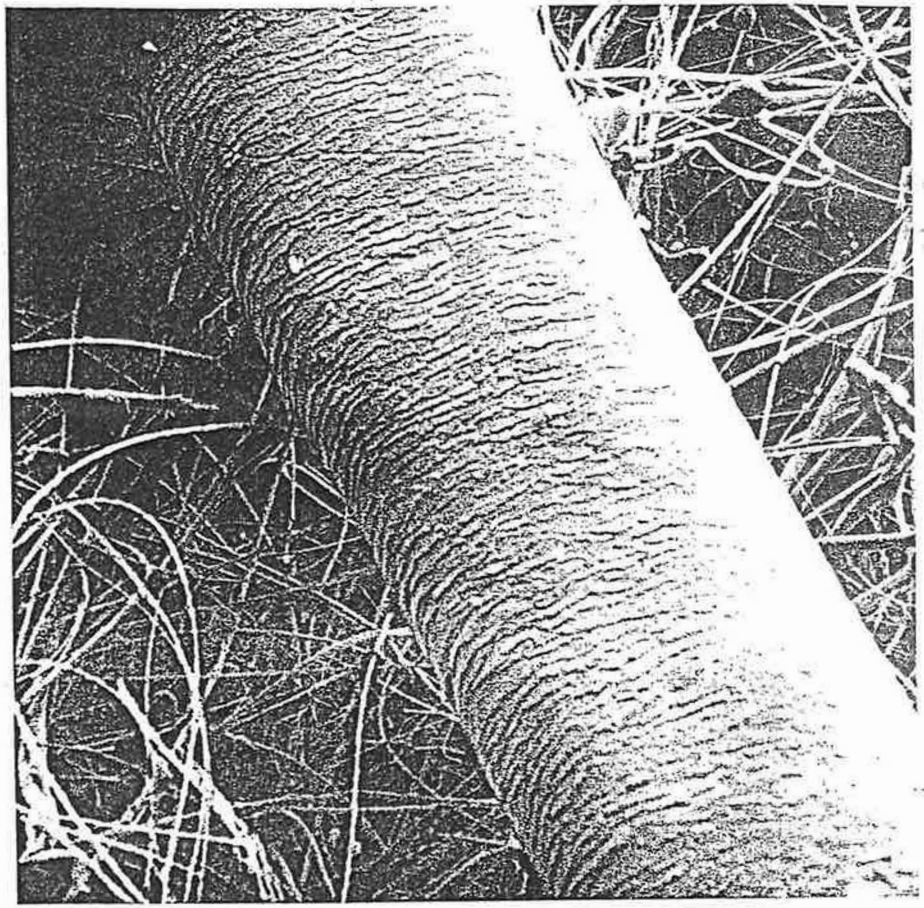

Figure 4.5 Human Hair Caught in Bag Filter Medium

less than 1µm diameter, as can be seen from Figure 4.5, a highly magnified electron microscope photograph of a human hair (35µm diameter) caught in a bag filter. Note that fibres, because of their relatively long length, are the exception as they are sieved out of the airstream by an air filter.

A high efficiency filter, class F8 to European filter standard EN 779, will remove 99.5% plus of 5µm particles from the airstream, and will only let 10% or so 0.5µm diameter particles penetrate. Figure 4.6 shows the comparative performance of three differing classes of filter against 0.5, 1 and 5µm particles.

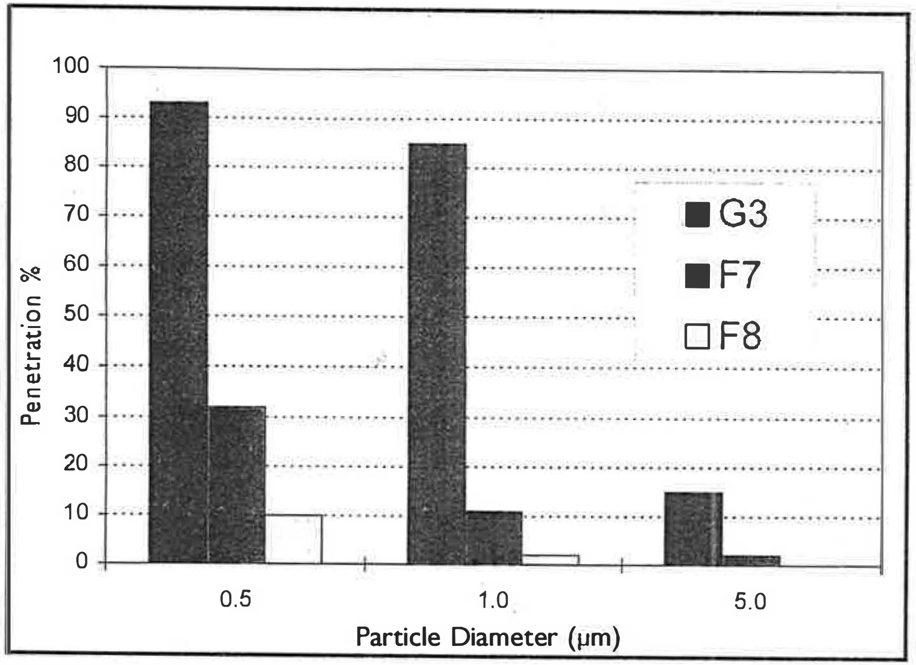

Figure 4.6 Penetration of a Filter as a Function of Particle Size and Filter Class

THE CORRECT FILTER TYPE

It is an unfortunate that with air filters it is almost axiomatic that as their efficiency increases, so does their cost and operating resistance. Possibly that is why so many installations have nothing better than panel filters, often poor ones at that, which as Figure 4.6 indicates, do virtually nothing to stop the dangerous, fine particles from entering the building. They are there to protect the items of plant such as heat exchangers from being affected by a build up of larger particles. They certainly are not there to protect the occupants.

At the other extreme, it would be completely unwarranted to install HEPA filters, which are capable of intercepting between 99.5 and 99.999995%, depending upon the filter grade, of even the most penetrating particles (these are approximately 0.2µm in size). Unwarranted unless there are special requirements, such as within a laboratory handling health-hazardous material. Using HEPA filters for general applications cannot be justified, due to their high cost and high pressure drop.

Most suitable are filter classes F7 or F8. Certainly an F7 filter is very effective against $PM_{2.5}$ particles, typically allowing only 5% or so to penetrate. But if the suspicion were substantiated that it is the ultra-fine particles that are the real health risk, then F8 filters would have to become the norm, as their performance when challenged by sub-micron particles is several orders better than that of the next grade lower filter.

CORRECT INSTALLATION

Air cannot be allowed to come through random holes in the building. The building must be slightly pressurised and airtight, the importance of which is beginning to be appreciated, so that air is only drawn in through the ventilation inlets, from where it is forced to pass through air filters.

Very obvious, but sometimes overlooked, is the siting of the inlets. These should be as high as possible, certainly away from street level and basement car parking, from where vehicle emissions can be directly drawn in.

Through-the-wall ventilation or air conditioning equipment rarely has other than a minimal panel filter, often so thin as to be of dubious efficiency, so is not recommended. All fresh air, even for decentralised systems, should be introduced into the building by air handling units, which can be fitted with effective filters of the required efficiency.

Finally, but not least, filters should be maintained and changed frequently. Seals need to be checked/replaced to prevent the by-pass of unfiltered air. After all, a filter is only as good as its seal. Also, there are now filters available which are treated with an antimicrobial. Filters can themselves become a potential hazard to IAQ if left too long between changes such that they can become a source of odours and growth of mould, mildew, fungi and bacteria. An antimicrobial can help combat this.

THE FUTURE

With the worldwide interest currently being shown in the harmful effects of particulate pollution we can expect to see research that more positively identifies and more precisely quantifies the problem. Meanwhile, the Government is trying to reduce the level of particulate pollution, but despite current efforts, has admitted that the UK will not reach its pollution target for particulates by 2005 as planned. Hence the need for effective filtration will definitely still be there.

Chapter 5

Atmosphere Improves Results The *AIR* Initiative

Oliver Griffiths

INTRODUCTION

CRC has been integrally involved in the development of the practical measures to improve the provision of cleaner air particularly for staff and non-smokers in pubs through an initiative called AIR (Atmosphere Improves Results). This aims to provide the licensed trade with the motivation and the tools to provide cleaner air for all, smokers and non smokers alike, rather than to allow the government to ban the smokers from them - who currently represent over half of their trade.

In the great British pub, or the traditional club, historically very few have taken air quality seriously. The average pub is stuffy, smoky and probably smelly. This is so true that many pub goers think that this is the way that pubs should be; any more accommodating and pleasant environment wouldn't be a 'real' pub.

Oliver Griffiths is Manager of the AIR Initiative, CRC, London

But times changing. The smoky pub is slowly becoming a thing of the past. This is partly driven by market forces, but it is being much accelerated by the government's concerns over the amount of tobacco smoke in the air and its effect on the welfare of staff and customers.

That traditional, familiar British pub (usually owned or at least rented or leased by the proprietor) is under tough competition. And it is likely that it is losing. The competition is mainly coming from the major managed house groups, often with their own brands such as All Bar One, Pitcher and Piano, Yates's Wine Lodge or Hogshead. These are run by managers, often well trained, and focused on the professional standards that can make these venues great commercial successes.

They also, in many cases, make a lot of their money from food (at least at lunchtimes) and as a result care rather more about their air quality. In our local Hogshead the air is fresh, the food is good, the staff are accommodating and the décor fresh. There is no contest between that and the authentic 'local' next door where the air is stale, the food tasteless, the staff tired and surly and the décor delightful nicotine brown.

And the fresh air plays an important role in this success because it helps people to taste their food better, keeps the staff awake and stops the cigarette smoke from staining every surface. But the interesting thing is that there are rather more smokers in the Hogshead than in the local!

THE SMOKING CONUNDRUM

Whilst some people may like a smoke no-one likes second hand tobacco smoke. It is irritating particularly in the way that it clings to your clothes and hair (of ten leading to domestic problems). Research in Ireland found that 48% of pub-goers who were smokers found the pubs unacceptably smoky. It didn't stop them from smoking of course - but they were keen for someone else to get rid of the smoke.

This feeling that smoke is putting customers off and the general modernisation of the pub is leading to changes. The need to serve food, to keep staff happy and keep the expensive décor in good order is forcing the companies to address the smokiness of their venues. To get rid of the smoke but not the smoking customers; customers that represent over half of their business.

There are some leading lights in this. J D Wetherspoon, a relative newcomer to the pub market has made a selling point of its cleaner air - and has even gone further with a ban on smoking at the bar. Other groups have made a feature of their ventilation with huge exposed ducts with signs on them saying 'supply' and 'extract' (whatever the real function of that piece of equipment). Others again have unobtrusively made changes which have greatly changed the air quality, and rigorously build in ventilation standards when they open or refurbish a venue. Unfortunately these are in a minority and even among this group of industry leaders their cleaner air policies don't always work.

Many of these venues with heavy investments in ventilation and air filtration are still smoky - often because staff have failed to switch on the equipment; sometimes because the equipment is poorly specified, installed or maintained. Many others don't have the basic understanding that equipment should be well maintained and that there should be some supply air to work with the 'extract' of which many are so fond.

For these modern companies, and the more traditional pub or club, there is money in putting this right.

THE 'ATMOSPHERE IMPROVES RESULTS' (*AIR*) PROJECT

As part of our AIR project we took a stab at defining the benefits of cleaner air, and assessing how pubs could most easily achieve it.

We based our improvements on the CIBSE guidelines of 8 litres per person per second (28.8 m^3 per person per hour) of supply air. This fits in well with the Health and Safety Executive requirement that the ventilation rate should not fall below 5-8 l/p/s for any workspace. And crucially we used extract to develop an airflow through the outlet - taking smoke away from staff, customers and food and over the smokers.

In our research it had become very clear that there aren't really smoky pubs, just smoky areas in pubs from which the smoke spreads out unless it is stopped at source. To tackle this issue we added some filtration for the smokiest parts of the pub (around the pool table the darts board and the bar), but this was essentially to work with the ventilation not to replace it.

Essentially the resulting solution was supply - filter - extract.

The results were remarkably consistent:

- For food led houses — 24-55% increases in food sale; 2-9% increases in drink sales
- For drink only houses — 10-21% increase in drink sales

These houses were across the country, town and rural, big and small serving prosperous and disadvantaged communities. Every pub made more money as a result of improving its air quality.

The reasons for improvement were also universal:

- Less smoke means more taste for food
- Less smoke build-up means customers stay longer
- Less smoke on clothes means more repeat visits (especially from men with forceful wives or girlfriends)

It almost goes without saying that not even the most cynical customers, licensees and bar staff - in any of the venues - asked to have the equipment taken away because they really preferred the smoky atmosphere before.

These results have been instrumental in the industry's successful negotiation of the Public Places Charter on smoking with the government. This commits the hospitality industry (including restaurants, hotels, holiday parks and other venues) to improving its provision for non-smokers and to cutting the air contamination.

The industry in return has retained the flexibility to resolve the issue as they think best (using a mix of ventilation, filtration and separation)- on an outlet by outlet basis. They also have the incentive to do so, as they know that they can make more money as a result.

The Charter sets out that all venues should:

- Accept management responsibility for the issue
- Have a written policy statement
- Communicate the policy through external signs

- Implement changes
- Support shared expertise and technical development

This will probably break down into five policy options with varying levels of ventilation required:

- Non smoking throughout
- Non smoking area
- Non smoking area with superior ventilation
- Superior ventilation, no restrictions
- Smoking throughout

As you will have noticed there is no measure of air filtration in these options this is because there is a high degree of cynicism in the Government about the equipment and how it is maintained and used. We believe that it has a very useful role to play and so have undertaken test work with BSRIA to establish an objective measurement of performance called PRR (Particle Removal Rate) for the equipment when the filter is clean and when it is heavily loaded with tobacco smoke particles. Fifteen manufacturers are participating in the test programme and we expect to have the initial results in September 1999.

This is likely to be added into the detailed code that is under development at the moment. The draft code is under trial by leading retailers across the country at the moment. The launch of the detail code is likely to be at Pub and Bar Show in mid September this year.

There are however some remaining challenges. Whilst the Public Places Charter may be signed up and nearing completion the hospitality face a challenge from the HSE in the form of an Approved Code of Practice on 'Passive Smoking at Work'. This is aimed at reducing staff exposure in all workplaces, especially offices, and would be far more draconian than the Charter if implemented against the hospitality trade.

There are also the more practical issues to overcome:

- The intelligent use of smoke and other sensors to reduce employee involvement in air quality management

- Energy efficiency, avoiding the apparent loss of expensively heated air
- The concerns about draughts from supply ventilation - especially in winter

These issues are key to the effective take-up of the hospitality industry of these cleaner air measures. There is a lot of money in this for the right simple solutions and we would be very keen to publicise any good initiatives in this area or in the wider area of smoke control in public places.

Chapter 6

Pubs and Clubs Managing Air Quality

Dr Bill Cory

INTRODUCTION

The ventilation industry has, for the past few years, been agonising over an acceptable standard for indoor air quality. Debate has been, at the very least, vigorous. This is not surprising for here one is dealing, not only with scientific fact, but with individual perceptions as they relate to odour, cigarette smoking etc. Certain researchers have endeavoured to quantify such human reactions and devised scales with new units. Mention of Ole Fanger with his 'olfs' and 'decipols' is calculated to raise the temperature of any knowledgeable collection of engineers. They are still recovering within the European Community from the rejection of a proposed standard covering the quantification of indoor air quality, and it is not proposed to enter that debate.

At the same time, the energy consumed by mechanical ventilation systems has been perceived by some as being significant to the greenhouse effect. If the government is therefore to meet its commitments under the Rio and Kyoto protocols, lower levels of ventilation are seen as necessary. In this way installed

Dr Bill Cory is Technical Director, Woods Air Movement, Colchester

kWh can be reduced and consequently the CO_2 generated by the burning of fossil fuels will be lessened.

A third strand also has to be contended with in the overall arguments. The medical profession has weighed in with the slogan that passive smoking kills. Whilst this remains unproven as far as the Courts (and indeed WHO and EPA reports) are concerned, one can appreciate that they would find the contention a powerful ally in the campaign to reduce cigarette smoking per se. It can however be asserted, with less fear of argument, that environmental tobacco smoke (ETS) is particularly annoying as it makes eyes smart, smells appallingly and hangs on hair and clothes for literally hours.

INDOOR AIR QUALITY

Over the last decade considerable research has been conducted both in Europe and the USA to determine what pollutants exist in the ambient atmosphere and within buildings. These studies have principally looked at the prevalence of volatile organic compounds, pesticides, carbon monoxide and particulates.

Whilst many will be aware of reports of increased numbers of persons suffering, for example, from asthma, it is extremely difficult to correlate these with an increase in particular pollutants. A number of scientists and engineers have concluded that most people are likely to have the greatest contact with potentially toxic pollutants not **outside** but **within** buildings.

If the gross amounts of one particular carcinogen, i.e. benzene, released into the **atmosphere** are considered, the greatest proportion comes from automobile fuel (82%). The next highest sources are industry (14%) and domestic usage (3%). Cigarette smoke only contributes around 0.1% of the total.

Within the confines of a **building**, however approximately 45% of the total exposure **may** come from smoking, 36% from inhaling petrol fumes and other common products and only 3% from industrial processes.

The corollary of these figures is to conclude that improved ventilation with an increase in fresh air levels and in association with improved filtration is a must. It could greatly improve the indoor air quality and hence reduce the risk of disease. Buildings could then claim to be more friendly to health. Similar conclusions can be reached for many other chemicals found at quite high concentrations inside

buildings - even the 'perc' used by dry cleaners or the deodorisers used by ever increasing numbers, have been reported to cause cancer at high concentrations. If the potential risks due to carbon monoxide are added (from incomplete combustion in kitchens and elsewhere) and radon (a natural radioactive gas seeping from foundations and brickwork), one wonders why the population should spend up to 90% of its life within buildings.

IMPENDING LEGISLATION

Since the last election there has been much discussion on the answer to all these particular problems and the future way forward.

At one end of the spectrum there are those who wish to ban smoking in all public buildings (perhaps with the eventual aim of making tobacco smoking a proscribed activity). Certainly this would be supported by the medical lobby who would foresee a reduction in the cancer, asthma and heart disease care bill.

The opposite view as propounded by the hospitality and tobacco industries might be encapsulated as smoking is still a legal activity from which the government derives considerable revenue. Pubs and clubs, where the percentage of smokers is greater than that in the population at large, would be especially hit and the activity could be driven underground, where control would be more difficult.

Luckily for us all, the debate appears to have been terminated by the publication of a white paper. This accepts that smoking in clubs and other licensed premises, should not be banned at this time but rather that the hospitality industry should be allowed to put its own house in order. This will be achieved by improved ventilation, segregating smokers from non-smokers and perhaps even by air filtration.

IMPROVING VENTILATION

The need for improved indoor air quality has persuaded many ventilation engineers that the way forward is to increase the amounts of outside **fresh** air circulated within buildings. But if that outside air is far from fresh then there is problem. It is more than a possibility that the windows and door of a Suffolk pub can be opened for a cooling breeze. Provided the customer is not too disturbed by the smell of silage or fertilisers, this is the most environmentally friendly way to ensure that he doesn't breathe in Joe's Old Holborn or whatever. It requires zero fan power and therefore has no effect on the CO_2 emissions from Eye Power station.

In a big city pub there is a different set of problems. The air outside is often worse than that inside. If its not the dust, its the petrol fumes. And if its not the petrol fumes then there's that other pollutant, noise.

There are, therefore, three techniques which can be used to achieve an acceptable indoor environment :

i) dispersion
ii) dilution
iii) filtration

These techniques result in the following strategies :

i) Smoking areas should be separated from non-smoking areas. Fresh air inlets should be adjacent to the non smoking areas whilst extract should be adjacent to smoking areas. A push - pull system is appropriate.

ii) Fresh air should be well above the minimum specified for preventing the build up of CO_2 and should be used to dilute the smoke produced from cigarettes.

iii) Filtration can be incorporated to reduce the amounts of fresh air necessary by allowing air to be recirculated back to the areas of occupancy. In inner city areas, 'fresh' air may also need to be filtered. This will also ensure that air which has been heated is not completely rejected to atmosphere, thus saving on heating bills.

iv) Whilst simple propeller fans can be used in the smaller pubs, ducted systems are necessary for the larger clubs, especially where dancing is a vital part of the entertainment. Cooling may be necessary bearing in mind the large amounts of body heat generated.

CALCULATION OF THE VENTILATION RATE

To sustain life, oxygen is necessary for the metabolism of food. Human beings breath in air (with its oxygen content) and exhale air (with a significant amount

of its oxygen converted to carbon dioxide). Trees on the other hand take in carbon dioxide and change it back into oxygen. Hence the animal and vegetable worlds are in balance and rely on each other. The carbon and hydrogen in foods are 'burnt' to produce carbon dioxide (CO_2) and water (H_2O) and these are rejected by the body either by exhaling or as waste. Foods can be principally classified as:

i) carbohydrates
ii) fats
iii) proteins

The ratio of carbon to hydrogen in each is different. The amount of carbon dioxide produced by a person as a fraction of the oxygen consumed can be measured, and this is defined as the respiratory quotient (RQ)

RQ varies according to diet :

0.71 for a diet of 100% fat
0.8 for a diet of 100% protein
1.0 for a diet of 100% carbo-hydrates

A value of 0.83 may be taken as a reasonable average for a normal dietary mix.

A simple equation gives the outdoor air flow rate needed to maintain CO_2 percentages at a constant level :

$$V_o = \frac{N}{60(C_s - C_o)}$$

where
V_o = outdoor airflow rate per person l/s
N = CO_2 generation rate per person l/min
C_s = CO_2 concentration in the space
C_o = CO_2 concentration in outside air

Indoor air should not contain contaminants at levels in excess of those known to be injurious to health or to cause discomfort to occupants. Reference to ANSI/ASHRAE Standard No. 62 - 1989 shows that the rate at which oxygen is consumed and at which carbon dioxide is generated depends on physical activity.

(see Figure 6.1) Figures for acceptable maximum concentrations of carbon dioxide differ considerably from country to country. However, a not unreasonable average would be about 0.1%. Equally the outdoor air concentration would be

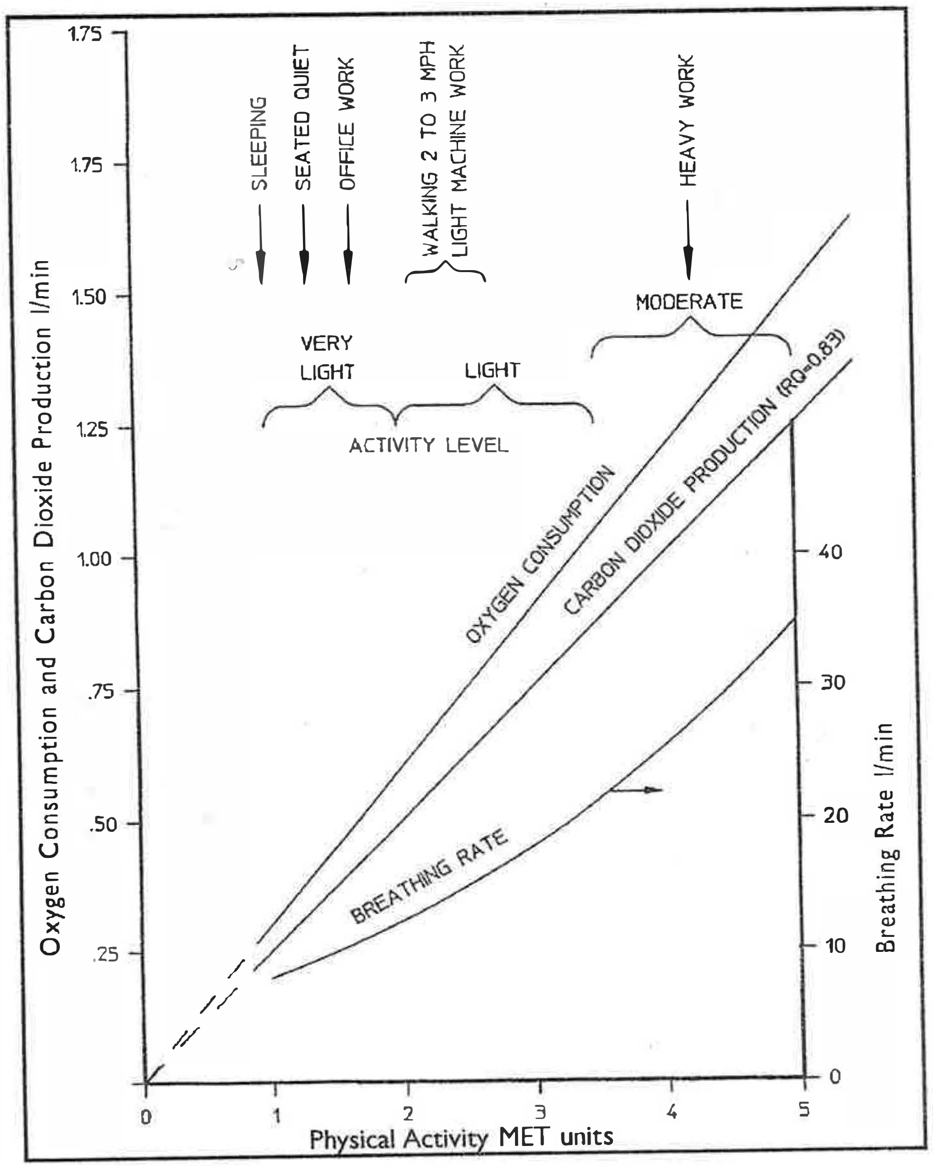

Figure 6.1 O_2 consumption & CO_2 generation (ANSI/ASHRAE Standard No. 62 - 1989)

about 0.03%. Assuming a very light activity level of 1.2 metabolic units i.e. 70W/m² then the fresh air makeup level may be calculated. The carbon dioxide generation rate is assessed as 0.3 litres/min for a respiratory quotient of 0.83.

$$V_o = \frac{0.3}{60(0.001 - 0.0003)}$$

= 7 litres/sec per person

This is only just a little less than the recommended 8 litres/sec/person which must be seen as inadequate for any appreciable physical activity.

In a discotheque, or ballroom, the metabolic rate can easily reach 4 units and the CO_2 production can be 1.0 litres/min.

$$V_o = \frac{1}{60(0.001 - 0.0003)}$$

= 23 litres/sec per person

When one considers that occupancy levels in such places can be exceedingly high - certainly in excess of the accepted 'norm' of 1 person / m^2 - then it will be appreciated that fresh air make-up can be considerable. With the often low ceiling heights and large floor areas, this is far in excess of anything possible from natural ventilation. Many pubs in the London area utilise basements for entertainment which makes the problem even worse.

It will be noted that these calculations make no allowance for the effects of smoking. Whilst a number of figures have been given, none of these have been universally accepted. A figure of 160 m^3 of air per cigarette has been suggested, but whether this is for combustion, dilution, dispersion or a combination of all these has not been exactly defined. Certainly it cannot possibly be for combustion alone, and this may be the only addition to the fresh air flowrate - at least if air filtration is practised.

To obtain some sort of figure, it can be assumed that 48% of all pub and club customers are likely to smoke and that the rate of smoking may reach 1 cigarette/hour.

These calculations should be compared with those given in the CIBSE Guide, Section B2.2 (1986) see Table 6.1

Table 6.1 Recommended outdoor air supply rate (CIBSE Guide 1986)

Condition	Recommended outdoor air supply rate (litres per second per person)
With no smoking	8
With some smoking	16
With heavy smoking	24
With very heavy smoking	32

The immediate reaction is that these recommendations are probably on the low side - certainly if physical activity (dancing) takes place a figure up to 53 litres/sec/person may be necessary. Such a figure is far higher than the licensed trade is currently contemplating.

AIR FILTRATION

One of the axioms in ventilation is that it is always best to deal with a problem as near to its source as possible. Thus it is essential that extract should be close to the smokers. The heaviest emissions of smoke are likely to be in the games areas such as darts or snooker.

An alternative approach is to pass the ventilation air through some sort of filter. This will result in a reduction in the amounts of fresh air necessary and also save on the heating bills. It must not however be assumed that ventilation can always be reduced to 8 litres/sec/person. That would only exchange one set of problems for another - ETS for an increase in CO_2 levels and possible problems from the heat generated by closely packed bodies. A conclusion is that one should still consider a minimum fresh air level of 16 litres/sec/person and that this should be increased where dancing takes place.

There are a number of different types of filter available, each with its own respective merits. The restaurant in my local uses an electrostatic precipitator - its brilliant. The combination of high ceilings and filter means that smokers and non-smokers are mixed without problem, and the air is perfectly clear, as cigarette smoke has the right resistivity for efficient collection. Precipitators consist of an

initial bank of positively charged ionising wires between co-planar grounded electrodes followed by a bank of grounded collection plates. Between each pair of collection plates is a positively charged repulsion plate. Using relatively low voltages and currents of positive polarity ozone formation is reduced to a minimum. Other types of filter which are suitable include absolute paper (HEPA) filters and those using other types of media.

CONCLUSIONS

Efficient ventilation is a definite plus in the promotion of licensed premises. It can provide an atmosphere which should satisfy the most fastidious. It even allows them to stay longer in the local than they would otherwise wish. None of us like ETS any more than the next CHO, but some friends may be smokers. Many people wish to continue to have the opportunity to socialise with them. Its more than possible that ventilation can be installed that will allow everyone to do this in perfect safety even **if** ETS is **proved** to be a danger.

In any case, ventilation is essential to provide oxygen for breathing and to remove the heat generated by the occupants. If the fans are of the variable speed type with appropriate controls, then the rate of ventilation can be adjusted to meet the demand, according to occupancy and activity. More and more systems are in fact being provided with sensors and the control of both heating and ventilating systems can then be integrated. This is especially the case with the larger ducted systems where in-duct cleaning can also be incorporated.

Ventilation at the rates described will achieve an acceptable level of air quality not only in respect of tobacco annoyance, but also in other particulates, odours, carbon dioxide levels, biological aerosols, formaldehydes, radon etc. The manufacturers will of course be more than happy to supply the increased numbers of fans now suggested, but if larger more efficient units are selected, energy consumption will not rise disproportionally and per air change may even be less. The air cleaner manufacturers should also be happy, as with their equipment installed, the quantities of fresh air can be reduced to non-smoker levels and heating costs correspondingly contained.

All such systems however, must be easily cleaned and maintained regularly if they are to continue to function satisfactorily. Controls need to be behind the bar and should be automated as much as possible. Staff must be trained and provided with permanent operating instructions. It has to be recognised that maintenance is unlikely to be carried out effectively by bar staff and the owners should be encouraged to take out a maintenance contract. A non-smoking area should be incorporated wherever possible. Ducted systems, whilst desirable for the larger installations, will be especially vulnerable to a lack of cleaning. Those who are connoisseurs of fine bitters, will know the value of keeping the pipes clean. Its no different for a ventilation fan and ducting or a filter (electrostatic or HEPA).

Chapter 7

Building Services Design and Operation for Air Quality and Occupant Satisfaction

Alan Carter and Jim Ure

INTRODUCTION

This paper will demonstrate that there is a growing concern that in our indoor environment, be it home, office or car, we are far more likely to be exposed to air pollution than we are in the "great outdoors". This paper provides an overview of some of the issues that designers and operators have to face when they attempt to improve indoor air quality (IAQ) and occupant satisfaction and introduces sites on the world wide web that provide information.

In spite of the recognition of the importance of indoor air quality there has not been much progress in agreeing an international standard. This is because of the complexity of the issues and the need to develop instrumentation to measure the quality of the air internally. Currently the International Standards Organisation (ISO) are accelerating their work on IAQ.

Alan Carter is Associate Director ABS consulting, London.
Jim Ure is Managing Director ABS consulting, London.

USING THE ENVIRONMENTAL MANAGEMENT APPROACH TO IAQ

The Environment Agency regard environmental management as a cyclical process (www.environment-agency.gov.uk). The same general approach can be used for specific aspects, such as indoor air quality, that contribute to the overall environment. Modifying the EA approach to consider indoor air quality we get the diagram shown in Figure 7.1

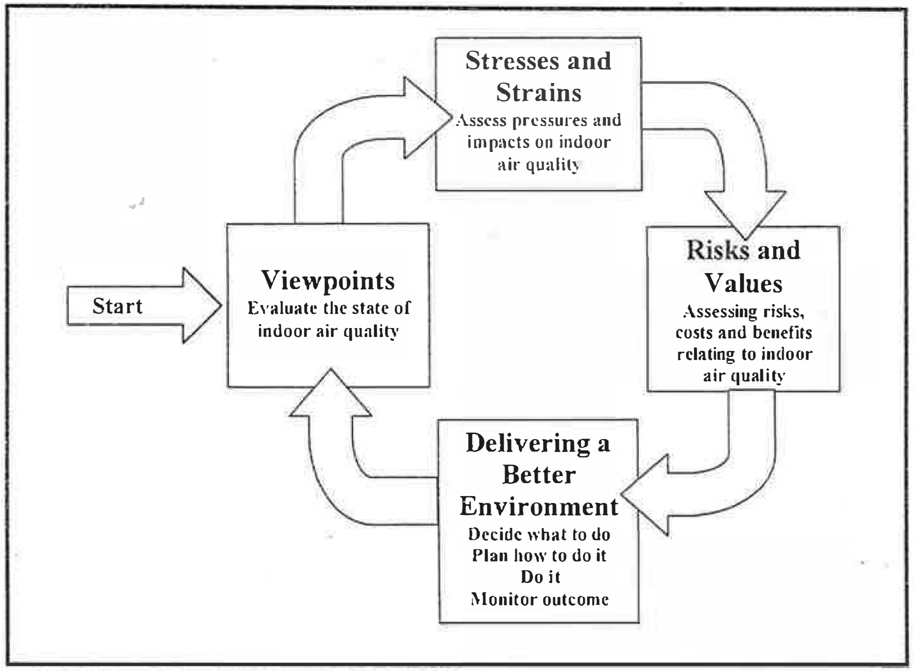

Figure 7.1 Environmental Management Approach

Developing the approach gives the following:-

VIEWPOINTS

Air is essential to human life and is a key part of the environment. We regard air as polluted when substances present in the air reach a level where they have harmful effects on life and the environment. Air quality is a measure of the "cleanliness" of air or the level of concentration of air pollutants.

ASHRAE President George Jackins stated

> *"Medical experts estimate each one of us takes in and expels 20,000 breaths a day. If we spend 90% of our time indoors, that means that each day we*

> *intake and exhale 18,000 breaths of conditioned indoor air. When you think about it in these terms it underscores the awesome responsibility our industry bears as the designers and suppliers of the indoor air environment."* (see HAC March 1999).

STRESSES AND STRAINS

There are many pressures on indoor air quality for example:-

General External Air Quality

Hutchings at the EA web site under the heading "Improving Air Quality" states the following:-

> *"Legislative measures are very effective in improving and maintaining air quality. EC directives and strategy aim to limit and reduce the concentrations of major air pollutants. They have an impact on the U.K. policy on air quality. EC and international agreements are also bringing about concerted actions across Europe to tackle trans boundary air pollution. In the U.K., there are laws to control emissions from industrial sources, reduce emissions from vehicles, and control emissions of smoke, dust and grit from industrial combustion processes and domestic premises. The most significant recent development is the National Air Quality Strategy, which sets out policies for the management of ambient air quality. In addition, the European Commission is considering the practicability of introducing some forms of energy tax across the Member States, which could be effective in achieving a reduction in air pollution."*

At the same web site Paul Williams in an article entitled Urban Air Quality indicates graphically that in the UK nitrogen dioxide levels are fairly stable and carbon monoxide and sulphur dioxide levels are on the decrease.

So we are fortunate that generally external air quality seems to be improving.

Local External Pollution

Local sources of pollution can have disasterous effects on internal air quality. Years ago the air conditioning system at the House of Lords nearly put their Lordships to sleep permanently when a lorry driver parked in front of the fresh air intake and left his engine running! Inspite of the general improvement in external air quality there are still many buildings whose proximity to heavy traffic requires that special steps are taken.

More recently, the occupants of a Mayfair office building, whose displacement ventilation system drew its air from a garden, were subject to all sorts of culinary smells when a neighbour decided to install a restaurant kitchen in an adjacent basement. The displacement ventilation system was found to be very effective at distributing the smells evenly throughout the building!

Public concern regarding the emissions from aircraft around airports surfaced during the late sixties. There is a web site which focusses on all the aircraft issues at:- www.soton.ac.uk/~engenvir/index/air_pollu.html

Other sources of local external pollution worth mentioning are dry cleaners, petrol stations, print shops, chimneys, cooling towers and breweries.

Internal pollution

Below are extracts from a web site devoted to indoor air found at:- www.enviroliteracy.org/indoor_air.html

> *"Concern about air quality has traditionally focused on outside air even though people generally spend more time indoors. Outdoor air pollutants tend to become dispersed and diluted rather quickly by wind, rain, and other natural processes. Indoor pollutants, however, are shielded from nature's cleaning agents."*

Attention has shifted recently to health problems associated with indoor air quality. As this article from Michigan State University's 'Institute for Environmental Toxicology' reports,

> *"indoor air can be many times (in some cases hundreds of times) more contaminated than the outside air."*

> *"Indoor air pollution comes from a variety of man-made and natural sources including combustion, cleaning agents, and a variety of other substances. Improper ventilation has led to a number of accidental carbon monoxide poisonings."*

> *"Natural pollutants, such as mold, mildew, pet dander, and bacteria can pose a threat to health. Recently, studies have suggested that the increase in incidence of childhood asthma is connected to indoor pollutants such as dust mites, and particularly, cockroach droppings."*

> ***"Natural contaminants pose the greatest risk when they are dispersed through heating, air conditioning, and ventilation systems. Probably one of the most well known cases of such contamination occurred during an American Legion convention in 1976. The legionnaires were exposed to an airborne bacteria that circulated from a hotel air conditioning system where they had been staying. Twenty-nine people died and over one-hundred-eighty became ill as a result of the condition, later known as legionellosis."***

> *"Concentrations of most of these indoor pollutants are generally too low to have an adverse effect on human health. Mitigation measures include improving ventilation and removing the source of the pollutant. Controversy arises, however, from the question of how much exposure is necessary to create a health risk. Paracelsus, a sixteenth century Swiss physician and philosopher once noted:* ***Everything is a poison, nothing is a poison, the dose alone makes the poison.*** *Substances like mercury and benzene are known to be toxic in small amounts, but there is less certainty about the threshold of exposure at which other substances, such as radon, are dangerous to human health."*

Exposure Indoors to Toxic Pollutants and other Threats

The following quotes are from a paper featured on the Scientific American web site found at www.sciam.com/1998/0298issue/0298.html

> *"Most environmental laws in the U.S. seek to control only the release of potentially dangerous wastes into the air and water, not the amount of contact people actually have with those pollutants. This focus on emissions rather than exposure essentially disregards the reality that toxic substances produce health problems only if they reach the body."*

> ***"Still, these studies produced results that were disturbing: most citizens were very likely to have the greatest contact with potentially toxic pollutants not outside but inside the places they usually consider to be essentially unpolluted, such as homes, offices and automobiles."***

> *"The chief sources appeared to be ordinary consumer products, such as air fresheners and cleaning compounds, and various building materials."*

> *"Many other volatile organic compounds that are quite toxic at high concentrations are also more prevalent indoors than out. For example, the chemical* tetrachloroethylene, *which has been shown to cause cancer in laboratory animals, is used to dry-clean clothes. Thus, the greatest exposure occurs when people live in a building with dry-cleaning facilities, wear recently dry-cleaned clothes or store such chemically laden garments in their closets.*

Moth-repellent cakes or crystals, toilet disinfectants, and deodorizers are the major source of exposure to paradichlorobenzene, *which also causes cancer in animals."*

"Another environmental concern that appears more severe indoors is the danger from fine particles in the air. The higher exposures arose, at least in part, because people do not simply float through the air; rather they tend to stir up "personal clouds" of particle-laden dust from their surroundings as they move about."

"Even more disturbing were the results from two studies of indoor air contaminants conducted during the late 1980s in Jacksonville, Fla., and Springfield, Mass. In those places, investigators found that indoor air contained at least five (but typically 10 or more) times higher concentrations of pesticides than outside air–and those residues included insecticides approved only for outdoor use."

From the above paper comes the clear message that you are more likely to be exposed to dangerous substances in your home, car or office than in the great outdoors!

Social Influences

There is a tendency for occupants to be more demanding of their internal environment. Since the publicity on subjects such as "sick building syndrome" an awareness has developed that just because a building is mechanically ventilated or air conditioned this does not necessarily mean that all is well.

Occupants themselves pollute the indoor environment with dried skin, body odour, deodourants, perfume and breath (germs). The anti smoking lobby has generally driven smokers out of the building and onto the streets (hopefully not in front of the building's air intake).

RISKS AND VALUES

The risks involved in not providing acceptable indoor air quality are becoming greater for the following reasons:-

- Occupants and their representatives are becoming more aware of the issues. Information is more readily available especially on the web.

- Medical science is getting better at establishing cause and effect.
- The potential size of claims is attracting the attention of the lawyers.
- The drive for energy cost reductions is tending to reduce the use of outside air for ventilation.

Occupants see a safe and clean environment as fundamental to good personal health and they are quick to blame failings in the environment for health problems.

As external pollution (with the possible exception of localised traffic pollution) is coming under control, it would appear that the greatest threat to indoor air quality comes from substances in the indoor environment itself or the plant that serves it.

DELIVERING A BETTER ENVIRONMENT BY IMPROVING INDOOR AIR QUALITY

It appears that increasing outside air ventilation rates reduces health risks. There is some evidence (see "Air Pollution Levels Inside Buildings In Urban Areas" a paper given at CIBSE/ASHRAE conference 1998) that a naturally ventilated building can experience higher outside air change rates than a mechanically ventilated building.

What Building Services Designers Can Do

Look for guidance from the new CIBSE Guide Section A1 which is due to be published in autumn 1999.

Position air intakes for buildings preferrably at high level and certainly away from extract air discharge points, chimneys, cooling towers and condensers, traffic, underground car park discharge points, exhausts from kitchens, dry cleaners etc. This will require close liaison with other members of the design team and the building services designer may be required to present a strong factual case for getting suitable locations.

With mechanical ventilation systems and air conditioning systems use generous quantities of outside air where possible, coupled with energy recovery devices such as cross flow plate heat exchangers. Make sure there are bypasses fitted to recovery devices so they can be switched off when energy transfer is not required.

When using air damper systems to provide varying quantities of outside and return air ensure that dampers having reasonable characteristics are used.

Use displacement ventilation systems in preference to air distribution systems that rely on mixing in the occupied space. Displacement systems have been shown to result in dust particle levels that are a quarter of those in circulation in the occupied space when mixing systems have been used.

WHAT FACILITY MANAGERS CAN DO

Firmer guidance for occupants on the use of potentially dangerous substances in the indoor environment is required. If it is essential to use such substances then steps should be taken to prevent the contaminents being spread around the building.

More information regarding pollution potential needs to be sought from manufacturers of products used inside buildings.

Cleaning activities that generate dust in the internal environment should be carried out when the building is unoccupied.

Filters should be cleaned or changed before they are fully loaded.

Plantrooms should be kept clean and dust free especially if they contain air handling units that operate at sub amspheric presure.

MEASURING SUCCESS

The most valuable information for operators and designers of buildings is feedback from the occupants. A building that wins an award for its environmental credentials, its aesthetic qualities, or the efficiency of its building services, is a failure if it is not liked by the occupants.

A technique for assessing what occupants think of their building has been developed by ABS Consulting in collaboration with University of Manchester Institute of Science and Technology (UMIST). It is called "Overall Liking Score" or OLS.

The process provides a consensus of occupants' liking of the building, the employer, colleagues, facilities management service, etc, based on how important particular

features and services are to them and whether or not they like what they get. It has been used to assess some 20 buildings in the UK and the results have supported the anecdotal evidence and the intuitive assessment of experienced facilities managers. The results therefore provide robust evidence of the successes and failures of the building and the facilities management service as perceived by the occupants. An example of typical questions is shown in Figure 7.2.

Overall do you like the office?... How important is it for your ideal?

	dislike						like	unimportant						important
1. noise level	-3	-2	-1	0	1	2	3	-3	-2	-1	0	1	2	3
2. daylight	-3	-2	-1	0	1	2	3	-3	-2	-1	0	1	2	3

comments:

Figure 7.1 Sample OLS Questions

Occupant feedback can be obtained anecdotally and intuitively or by the response to formal questionnaires. The former is the most common and cannot be entirely replaced by a formal process. However, a formal process will support intuition and provide a benchmark by which changes in services provision can be measured. OLS can be used on any building to obtain information on occupant concerns, to identify successful features or as a key performance indicator (KPI) for maintenance and facilities management services. The process has recently been extended to gain an indication of employee support for an employer's environmental initiates.

CONCLUSIONS

Improving indoor air quality is a complex issue and more research is needed to explore the significance of the different factors. The sooner international standards are set the better, but there is little value in having standards unless there is a method of measuring them. In the meantime designers need to focus on where they are getting their outside air from, how much of it they are using and how they can overcome any problems from internal pollutants.

Facility managers need to know what is going on in their buildings and how the occupants feel about their internal environment. They should regularly monitor air quality within buildings and ensure that mechanical ventilation systems are not circulating harmful quantities of contaminants.