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SICK BUILDING SYNDROME: A REVIEW

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SUMMARY

This paper reviews published information on 'sick building syndrome', the cause of reputedly high incidence of sickness amongst occupants of sealed, mechanically ventilated buildings. It discusses symptoms, common features of 'sick buildings' and possible causes. On the basis of reported cases, there appears to be no single cause but a series of contributing factors.

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INTRODUCTION

Concern about the reportedly high incidence of sickness amongst people who work in sealed buildings, especially offices, has attracted considerable attention. In the UK this is a comparatively recent problem, most reports having been published since 1980, but in other countries, especially in North America and Scandinavia, the problem was first reported some 30 years ago, both in the workplace and the home.

Various terms have been used to describe the phenomenon - 'building sickness', 'sick building syndrome', 'sick office syndrome', 'tight building syndrome', 'office eye syndrome' and others. None adequately describe the condition but the term 'sick building syndrome' has been accorded recognition by the World Health Organisation (WHO)[1] and is the most widely used.

'Sick building syndrome' continues to attract both speculation and controversy and, unfortunately, many of the plethora of papers on the subject are devoted more to speculation than to fact. Its nature, prevalence, causes and even its existence are open to debate. This paper reviews current published information on the subject.

DEFINITION

'Sick building syndrome' is, by its nature, ill defined. One definition used is "a building in which complaints of ill health are more common than might reasonably be expected"[3]. This has some drawbacks since it does not address the question of whether such complaints are, or are not, justified. However, the common feature of sick buildings is that their occupants suffer, or appear to suffer, a measurably higher incidence of illness than expected for no readily identifiable reason. Clinically diagnosed illnesses which can be readily attributed to a particular cause such as humidifier fever, Legionnaires disease or to exposure to a toxic agent in the environment are not usually regarded as 'sick building syndrome'.

Various authorities and authors have attempted to subdivide 'sick building syndrome' into different categories. Most notably, WHO[1], differentiates between 'temporarily sick buildings' where symptoms decrease and disappear in time and 'permanently sick buildings' where they persist, often despite the most extensive remedial measures. Some researchers and authors have postulated sub species of 'sick building syndrome' based on their particular area of interest[4],[5]. Such an approach may have advantages if the different symptoms suffered by the occupants of sick buildings can be shown to have many different causes.

REPORTED CASES

Reports of 'sick building syndrome' fall into two categories - investigation of cases in order to prescribe a remedy, and surveys of office and other buildings to assess the extent of the problem and its likely causes. Many in the latter category usefully include 'sick' and 'control' buildings to enable comparison. Appendix 1 lists the reports considered and possible causes.

One noteable shortcoming is that few investigations are completely multidisciplinary in approach so that papers often consider separately the medical aspects, measurement of airborne contaminants or an assessment of the physical environment and the ventilation or air conditioning system. Few simultaneously study all three aspects of the problem. This means that some investigations have drawn conclusions which do not appear to be fully supported by the reported facts, possibly because not all of the information found in the investigation is reported or possibly because the investigators have made assumptions. Whatever the reason, some conjecture appears to be subsequently reported as fact, especially in the press. Unfortunately, few investigations have conclusively proven a cause by the successful application of remedial measures in a controlled sequence.

In addition to case investigation and studies, a number of papers consider a particular, narrow aspect of 'sick building syndrome' or one postulated cause. Some provide a useful and detailed insight into that aspect whilst in others it appears that the particular author has used 'sick building syndrome' as an excuse, rather than a reason, for the work.

SYMPTOMS AND PREVALENCE

Most reports of outbreaks detail a common list of symptoms. These are summarised by WHO[1] as:

- eye nose and throat irritation
- sensation of dry mucous membranes and skin
- erythema (skin rash)
- mental fatigue
- headaches, high frequency of airway infections and cough
- hoarseness, wheezing, itching and unspecified hypersensitivity
- nausea, dizziness.

Some investigations have produced more extensive lists of symptoms including, for example, high blood pressure[6] and miscarriages[7]. However, these are mentioned as occurring amongst staff in sick buildings; they are not specifically attributed to 'sick building syndrome'.

The range of symptoms and their prevalence may depend, to some extent, on the questionnaire used. Investigation of symptoms is often carried out by a self administered questionnaire and the response may, in some cases, be influenced by the number and nature of the questions.

Studies in the UK [3,8,9,41,42] show a number of patterns:

(a) Symptoms are most common in air conditioned buildings but they also occur in buildings that are naturally ventilated.

(b) Clerical staff are more likely than managerial staff to suffer, and complaints are more frequent in the public than the private sector. Complaints are also more frequent in offices housing many staff.

(c) People with most symptoms have least perceived control over their environment.

(d) Symptoms are more frequent in the afternoon than the morning.

Some investigators have sought to show a link between 'sick building syndrome' and performance/ neurological tests. Sterling and Sterling[10] used 'tremor' tests and 'T crossing' tests but failed to show a difference between the test and control groups. Bergund[11] tested volunteers in 'sick' and study buildings for stress, memory, vigilance, reaction time and steadiness, again without finding adverse effects. Although various papers have discussed the effects of exposure to toxic substances on behaviour[12,14] and mental fatigue is one of the symptoms of sick building syndrome, those studies by Sterling and Sterling and by Berglund failed to show a measurable link between sick building syndrome and performance. One major survey does suggest a reduction in efficiency of 20% amongst occupants of sick buildings, but this is based on personal opinions of those showing symptoms rather than on performance measurements.

The prevalence and overall effect of 'sick building syndrome' are difficult to assess since most people occasionally suffer from some symptoms whilst at work, particularly headaches and chest complaints. Except where the incidence of illness is compared with a control, or it can be shown to change when remedial measures are instituted, the findings are of little value. Some papers suggest that up to 30% of new and remodelled buildings (with recirculating ventilation or air conditioning systems) have an excess of illness amongst staff and that up to 85% of staff in such buildings suffer from some symptoms[8,9,13]. There is little information on the severity of symptoms although since relatively few cases appear to cause extensive absence from work (except some reported cases from the USA etc) it is to be assumed that they are relatively mild. However, reports on its prevalence suggests that the total number of sufferers is great and despite the inconclusive results from performance tests, some reduction in personal performance and motivation cannot be ruled out.

COMMON FEATURES OF SICK BUILDINGS

The WHO[1] identifies a number of features common to sick buildings. Summarised, these are:

(a) They often have forced ventilation (WHO does not make specific reference to air conditioning although air conditioning will fall into this general category).

(b) They are often of light construction.

(c) Indoor surfaces are often covered in textiles (carpets, furnishing fabrics etc).

(d) They are energy efficient, kept relatively warm and have a homogeneous thermal environment.

(e) They are airtight, ie windows etc cannot be opened.

Subsequent comparative studies in the UK have tended to confirm these common features[38,9,41,42] although sick building syndrome does not occur in all buildings with these features Wilson and Hedge[9] in their survey of 46 buildings in the UK, considered the building environment and air conditioning system design in relation to the prevalence of symptoms and found significant differences even amongst buildings conforming to the WHO list of features. In general, cheaply constructed buildings with poorer air conditioning systems, especially public sector buildings constructed in the 1970s, showed more problems than well constructed buildings with more expensive air conditioning systems dating from the 1980s. The type of glazing also appeared to be significant - all of the least healthy buildings, but none of the healthier buildings, had tinted glazing.

POSSIBLE CAUSES

Many causes have been suggested for sick building syndrome, including:

(a) Airborne pollutants -

(i) chemical pollutants from the building occupants, fabric and furnishings, office machinery and from outside.

(ii) Airborne dusts and fibres.

(iii) Microbiological contaminants from carpets, furnishings, building occupants or from the ventilation or air conditioning system.

These may have a directly toxic, pathogenic or irritant effect on occupants or they may have an allergenic effect (ie once occupants are sensitised, subsequent very small challenges may cause illness).

(b) Odours

(c) Lack of negatively charged small air ions

(d) Inadequate ventilation/fresh air supply

(e) Low relative humidity

(f) Poor working environment/discomfort due to

(i) High temperatures.

(ii) Inadequate air movements/stuffiness.

(iii)Poor lighting.

(g) General dissatisfaction or psychosomatic causes.

Many of these are interrelated subjects and 'sick building syndrome' may well result from the simultaneous effect of a number of challenges. Except in a few cases where symptoms follow a specific change in the working environment, eg. the installation of a new carpet[15], isolation of the cause is notoriously difficult. Comparison studies between 'sick' and 'control' buildings will highlight those features which are common to 'sick buildings' and do not occur in others but identification of the cause may well become a procedure of 'trial and error' and since many supposed causes would involve major and very expensive remedies, such a course is rarely tried and the cause remains a matter of conjecture.

The possible causes, as identified from published papers, are discussed in the following paragraphs.

AIRBORNE POLLUTANTS

The potential range of pollutants in the office and similar environments is enormous. However, levels actually occurring have generally been found to be minute, sometimes requiring techniques more sensitive than normal occupational hygiene practice for their measurement[16]. Hicks[81] reports typical levels of air pollution measured in 'tight building' investigations (Table 1, Appendix 2).

Various sources of airborne pollution can be identified, the main ones being:

(a) **Building Occupants**

Pollutants released by occupants of the building include CO_2, water vapour and microbial organisms and matter.

Carbon dioxide levels due to respiration alone can rise to several thousand parts per million in well sealed buildings. Although there are no reports of levels above the occupational exposure limit (5000 ppm) levels of up to 1800 ppm have been reported[17] and since, in some cases, building ventilation systems are controlled by CO_2 monitoring with the monitors set to operate at levels of up to 2,500 ppm, it is possible that CO_2 levels will, in some circumstances, approach the exposure limit (this will be discussed later with other aspects of ventilation). Whilst it is unlikely that CO_2 at these levels is itself the cause of illness it may be an indicator for the presence of other airborne pollutants. The Ontario Ministry of Labour[81], for example, have adopted an indoor CO_2 standard of 600 ppm on this basis. However, such a standard will only be valid if there are no other sources of CO_2.

Smoking creates a much more considerable source of airborne contamination. Table 2 (Appendix 2) lists those gases to be found in cigarette smoke[18,20]. There are many reports analysing pollutants from tobacco smoke; a review by Brundrett[20] listed carbon monoxide, carbon dioxide, nicotine, furfal, aldehydes, ammonia, phenols, hydrogen cyanide, pyridines, oxides of nitrogen, acrolein and particulates, many of which have toxic or irritant properties.

Brundrett also lists physical symptoms caused to smokers and passive smokers (Appendix 2, Table 3) which bear similarities to some symptoms of 'sick building syndrome'.

There is debate over whether smoking does contribute to 'sick building syndrome' (or even whether it contributes to airborne pollutant levels). Some researchers have suggested that smoking does not affect either contaminant levels or 'sick building syndrome'; Sterling et al[21,22] in reviews of NIOSH and CDSC reports of 350 investigations found lower levels where smoking was allowed than where it was not allowed. However, Sterling does not, in his report, discuss the building ventilation rates. Since 1981, the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)[24] has advocated a much higher ventilation rate where smoking is permitted (7.5 l/s/person) than where it is not permitted (2.5l/s/person) and this may well account for these anomalies. Other research in the USA by the Environmental Protection Agency (EPA)[23] identified higher levels of contamination in residential buildings where smoking was permitted than where it was not permitted.

In general, it is difficult to show a link between smoking and 'sick building syndrome'. The evidence of field studies is inconclusive and many researchers believe there is no link. However, WHO[1,2] suggested that there should be more vigorous efforts to curtail smoking, especially in public places but admitted the need for more information on health effects. The fourth report of the Frogatt Committee[94] also considered the effects of smoking on non smokers, concluding that it presented some hazard and advocated the segregation of smokers from non-smokers at work etc.

(b) Building Fabric and Furnishings

Many sources of pollution have been attributed to releases (or 'off-gassing') from the fabric and furnishings of the building and in some cases a strong link has been shown with building illness. Pollutants include:

(i) Formaldehyde, especially from urea formaldehyde insulation and certain types of board. Formaldehyde is an irritant and may, therefore, cause some symptoms similar to those of 'sick building syndrome'. Its release from urea formaldehyde insulation into domestic premises has caused concern in some countries where measurement by various researchers have revealed substantial levels with peak values up to 2.8 mg/m^3, 1,25-28 and indoor air standards have been introduced, for example, in Germany (0.12 mg/m^3), Netherlands (0.12 mg/m^3) and Sweden (0.10 mg/m^3), although their precise status is unclear. Other building materials have also been shown to release formaldehyde; for example, particle board has been shown to cause levels of 1.0 ppm (1.25 mg/m^3) when newly installed, dropping with time and ventilation rate[25,29]. This has prompted speculation that formaldehyde is a cause of 'sick building syndrome'[15,27]. In one investigation, Dement[27] found complaints of upper respiratory and eye irritation in a temporary building with particle board panelling etc where formaldehyde levels of up to 0.23 ppm (0.29 mg/m^3) were measured. On 'fumigation' with ammonia and increased ventilation, formaldehyde levels dropped to below 0.1 ppm and complaints subsided.

Whilst some reports from the USA and other countries link formaldehyde with 'sick building syndrome', other surveys, for example, by NIOSH[15] have discounted it. Studies in the UK have also discounted it.

(ii) Organics and solvent vapours. These can be produced from various sources including adhesives used in furniture and for sticking carpets, floor tiles etc. One outbreak of illness in the USA[15] was attributed either to the carpet or the adhesive used but most investigations have failed to show the presence of organic vapours in sufficient quantity to cause illness. Several papers have attributed symptoms to a 'photochemical smog' caused by the action of ultraviolet light on organic contaminants but these are based on a single study of two buildings[10] and the theory does not appear to have been conclusively proven.

(iii) Dust and fibres. Some authors have attributed 'sick building syndrome' to dust and fibres from carpets, furnishings and insulating materials[34]. General papers also consider organic dusts from carpets suggesting that they can harbour organisms such as house mites that cause asthmatic attacks or that dampness can lead to microbial contamination which in turn causes illness amongst building occupants[30-34]. Most papers are speculative and some give more opinion than fact. However, a few cases of 'temporarily sick buildings' may have been caused by airborne dust[15,35].

(c) Office Machinery

Although photocopiers have been suggested as a cause of building sickness, and pollutants such as ozone can collect in very poorly ventilated photocopying rooms[36], only one investigation links a photocopier ('wet type') with symptoms[37]. Another investigation, involving a large number of buildings, discounts ozone from photocopiers. HSE investigations have shown pollution levels in photocopier rooms to be generally low so they appear unlikely to be a major cause of symptoms other, perhaps, than amongst some staff working in poorly ventilated photocopier rooms.

(d) Heaters

Direct fired heaters are able to release toxic gases - particularly carbon monoxide and oxides of nitrogen into occupied areas. Various studies of airborne pollution in homes[38,39] have suggested that nitrogen dioxide from combustion products may cause illness amongst children and some outbreaks of illness amongst building occupants investigated by HSE have been attributed to products of combustion from faulty heating equipment. However, there is no evidence to link heating or combustion equipment with published cases of 'sick building syndrome' and such buildings are unlikely to have unflued heaters.

(e) Ventilation and Air Conditioning Systems

Ventilation and air conditioning systems can transmit airborne disease including Legionnaires disease, humidifier fever, and various infections[40]. Some, particularly Legionnaires disease, originate outside the system. Others, of which humidifier fever is the prime example, are caused by organic and/or microbial growth in items of plant in the system. Most of these illnesses have readily identifiable causes and their symptoms of for example, Legionnaires disease, are different from those of 'sick building syndrome'.

However, there may be a link between some cases of 'sick building syndrome' and humidifier fever. Papers by Finnegan and others[3,41,42] report two cases of humidifier fever amongst the population of a 'sick building', and a higher incidence of respiratory symptoms amongst people in a humidified building than a non humidified building. They did not find a higher incidence of other symptoms. Wilson and Hedge[9] also report a higher incidence of symptoms amongst occupants of buildings with 'non sterile' forms of humidification than those with steam humidification.

Even where air conditioning systems do not contain humidifiers, items of plant can act as breeding sites for organic growth. This is true of items such as cooling coils where condensed water can collect, and these have been shown to release micro-organisms into the airstream[2]. No link has been shown between cases of 'sick building syndrome' and other items of air conditioning plant although Wilson and Hedge[9] report different symptom rates with different types of air conditioning system which are not explained by differences in temperature etc so a link cannot be entirely discounted.

Some authors have attempted to link 'sick building syndrome' with insulating materials associated with building services and heating and ventilating systems, particularly with asbestos[31], but this is purely speculation and none have justified their views.

It may be possible for ventilation or air conditioning systems to transport contaminants or pathogens from one area to another within a 'sick building'. Aerobiologists in the health service have shown that pathogens can be carried in hospital ventilation systems, thus spreading infection. Despite some speculation, this has not been shown to be a cause of 'sick building syndrome'. There is also little evidence to suggest that outside pollution drawn in through the ventilation system is a cause of sick building syndrome. One reported NIOSH[15] case involves complaints of 'noxious' odours possibly drawn in from a parking area but there is no record of symptoms.

EFFECT OF AIRBORNE CONTAMINANTS

If airborne contaminants are responsible for the symptoms of 'sick building syndrome' whether acting alone or synergistically as components of a complex cocktail, this may be due to several mechanisms, including:-

(i) Toxicity. All investigations where levels of contamination are reported indicate that these are low, and often very low indeed, in relation to the appropriate occupational exposure limits. However, whilst there is as yet no proven link between 'sick building syndrome' and the toxic effects of airborne pollutants, the toxicology on which exposure limits are based is not necessarily relevant to the low level, chronic exposure that might occur in sick buildings, so the toxic effect of airborne pollutants cannot be discounted.

(ii) Irritation. Several reports attribute 'sick building syndrome', or some of its symptoms, to the irritant effect of airborne contamination. Some of the contaminants are known to have irritant properties, formaldehyde for example. Frank[4] specifically attributes eye symptoms to drying of the eyes, possibly caused by the altered stability and composition of the eye film due to irritants such as formaldehyde, although he does not report levels of contaminant in air. Molhave[19] suggests that levels of volatile organic compound between 0.16 and 2.0 mg/ms are responsible for mucous irritation, and suggests that there should be future investigations to establish a dose-response relationship for organic compounds in sick buildings. However, since Frank, Molhave and other authors do not appear to have established these links experimentally, their hypotheses are as yet unproven.

(iii) Infection. Although micro-organisms can be released from air conditioning systems etc, and ventilation systems in hospitals have been shown to transmit pathogens, there is little reason to believe that 'sick building syndrome' is due to this mode of cross-infection. Outbreaks of other illness may occur amongst occupants, for example, influenza or even Legionnaires disease but these are not to be confused with 'sick building syndrome'. The continuing nature of symptoms of 'sick building syndrome' and the fact that they occur only when at work, suggest that they are not due to infection.

(iv) Allergy. The nature of the symptoms suggests that allergenic reaction to airborne pollutants, whether chemical or microbiological agents, is possible. The allergenic effect of many agents is well recorded and sensitised people can be affected by even minute quantities of some agents, which might explain why symptoms occur even when air sampling fails to reveal significant levels of contamination. Unfortunately, unless the allergenic agent can be traced and affected persons tested for their reaction to it, proof is particularly difficult and the differences between 'sick' air conditioned buildings and their naturally ventilated controls cannot readily be explained as an allergy unless the agent originates in the air conditioning system itself. A few investigators have indicated such a link in particular cases but it has not been universally established.

ODOURS

A few papers consider odours in relation to 'sick building syndrome'. Bergund et al[5] discuss sensory perception (including smell) and suggests that 'sick building syndrome' is caused by sensations to imperceptibly small stimuli of all sorts; some case investigations mention odours but there is little suggestion that they are, or might be, the cause of symptoms. Two papers[43,44] link odours with outbreaks of psychogenic illness but there is no reason to relate such outbreaks to 'sick building syndrome'.

CHARGED AIR IONS

Small air ions are molecules of air which have either a positive or negative charge. They occur naturally by various means, or may be created artificially using an air ioniser. Small numbers of charged air ions exist in outside air, typically one in 10^{16} molecules, but these become depleted indoors to perhaps one tenth of the outdoor level[45]. Several reasons are suggested for this depletion - loss of ions in metal ventilation ducts, water vapour, dust and smoke acting as condensation nuclei, the depleting effects of VDUs.

Air ions are claimed to have a number of effects on human physiology and health. For example, medical research papers from Isreal claim that during certain weather conditions, the increased positive ion concentration in air causes increased neuroticism (Serotin Irritation Syndrome) which can be overcome in some patients either by the use of tranquillisers or by the generation of negatively charged small air ions[46,47]. Other researchers suggest that negative air ions act as catalysts to remove trace gases, kill micro-organisms, affect the dispersal of aerosols containing micro-organisms, and claim that they relieve anxiety in rats and mice and reduce the death rates in rats and mice injected with influenza virus[48]. Negative ions have also been shown to affect the mammalian respiratory tract although the researchers doubted whether this would also apply to man[49,52]. Some papers have shown that positive ions increase air uptake in exercise[50] and there is some evidence, albeit conflicting, that air ions may be beneficial to asthmatics[51].

Considered selectively, some published information on this subject can be interpreted to show that negative ions have great benefits. Some suppliers of negative ion generators have shown great selectivity in their interpretation, claiming benefits for their products that include relief from bronchitis, hay fever, catarrh, asthma, rheumatism, headaches, colds, eczema, high blood pressure, palpitations, conjunctivitis, and laryngitis, plus resistance to influenza, increased ability to concentrate and reduced fatigue[53] and, of course, a reduction in the incidence of 'sick building syndrome'[54]. A number of such claims have prompted action by authorities, particularly the US Food and Drug Administration[53,55] who seized nine brands of generator for misleading claims between 1959 and 1967, and the UK Advertising Standards Authority.

The claim in the UK that negative ion generators have a beneficial effect on 'sick building syndrome' is largely based on work by Hawkins at Surrey University[45]. However, in subsequent work, Hawkins failed to repeat his earlier findings[49]. Investigation by other researchers showed either that negative ions had no effect in sick buildings[56] or that they had no measureable effect on human mood and performance[54]. One investigation report[57,58] gave higher negative ion concentrations in the 'sick' building than in the control.

There may be reasons, besides the obvious one, why tests on negative ion generators have failed to show benefit. Krueger and Reed[48] suggested errors in observation caused by pollutants (including O_2 and NO_2 from the generator) and failure to earth the subject. Even if they were correct, their suggestions do not auger well for the practical benefits of negative ion generators. Whilst the research shows that negative and positive ions may well have some effect on comfort and well being - either detrimental or beneficial - and it is difficult to prove beyond all doubt that negative ion generators have no benefit whatsoever, the balance of evidence suggests that they are of little practical benefit for dealing with 'sick building syndrome'.

INADEQUATE VENTILATION

Of all the features common to 'sick buildings', the system of ventilation is often regarded as most significant; sick building syndrome generally affects buildings which are sealed and have mechanical ventilation or air conditioning. This leads to a presumption that lack of fresh air is a major cause of 'sick building syndrome'.

Mechanical ventilation of buildings differs from natural ventilation in a number of ways, most significantly:

- Whilst mechanical ventilation and air conditioning can exercise more precise overall environmental control only rarely do they allow little personal choice or local control.

- the make-up air supply into mechanical ventilation systems can often be varied during operation in order to increase the proportion of air that is recirculated and reducing the quantity of fresh air drawn in from outside.

- mechanical ventilation and air conditioning systems have components that are susceptible to failure and to poor design or installation.

- recirculating ventilation and air conditioning systems can harbour organic growth and may distribute contaminants from one area throughout the building (this aspect has already been considered).

Fresh air is required for various reasons, the main ones being to supply air for respiration and to dilute CO_2, odours, cigarette smoke and other contaminants. Ventilation, although not necessarily fresh air may also be required to maintain personal comfort, ie, for the control of air temperature.

Several standards have been set for ventilation and fresh air supply rates to offices, usually based on the air required to dilute cigarette smoke or body odours. The Chartered Institution of Building Services Engineers[59] and BS5720[93] set a standard which ranges from 5 litres per second per person in general offices up to 25 litres per second (l/s) per person for personal offices or boardrooms where smoking is heavy. In the USA, the American Society of Heating, Refrigeration and Air Conditioning (ASHRAE)[24] standard is most widely accepted and has been periodically revised downwards. In the early 1900s it is reputed to have been 30 cfm (15 l/s) per person, which dropped to 10 cfm (5 l/s) in the 1930s as a result of work by Yaglou on body odour, then to 2.5 l/s per person in 1981 (7.5 l/s per person for offices where smoking was permitted). This last rate was based on achieving an indoor CO_2 level of 2500 ppm; it also requires that 80% of the occupants should be 'satisfied'. Fortunately this standard is now being changed; the latest ASHRAE standard will require 7.5 litres per second per person for all offices, whether or not smoking is permitted.

The impetus to seal buildings and increase the control over the environment is usually motivated either by necessity ('deep' buildings with open plan offices are difficult to ventilate naturally) or by a desire to save energy (and money). The practice of tight control over the indoor environment poses problems if the ventilation or air conditioning system is in any way imperfect. Tales of dissatisfaction amongst building occupants because of inadequacies in the ventilation etc system are legion. Youle[60] and Waller[73] detail a number of such problem buildings where an excessive number of complaints were received because of inadequacies in the ventilation or air conditioning systems due to poor design, installation and maintenance. Since the reports give no details of medical symptoms, these cases cannot be considered as sick building syndrome, but they do indicate a possible contributory factor.

The practice, fortunately rarer in the UK than USA, of using CO_2 monitors to control mechanical ventilation rates may also cause problems. Jansen and Hill[61] describe such a system set to operate at 2,500 ppm CO_2, ie the system would not draw in fresh air until the CO_2 level reached 2,500 ppm. However, since CO_2 levels did not rise above 1800 ppm the system did not draw in fresh air. The ASHRAE standard of 2.5 litres/second/person was based on an indoor CO_2 standard of 2,500 ppm.

The evidence suggests that inadequate fresh air is a contributory factor rather than a sole cause of 'sick building syndrome'. Many authors have advocated increased ventilation, either alone or in conjunction with other precautions; few have studied the direct effect of increased ventilation rate in sick buildings. However, several 'temporarily sick buildings' have been 'cured' by increased ventilation, amongst other measures[15]. Two papers dealing with buildings that appeared to be 'permanently sick' were able to show a reduction in symptoms with increased ventilation[37,10]. In one, the fresh air rate was increased from 6 to 20 cfm per person; the fresh air rates were not given in the other.

It would therefore appear that whilst some cases of 'sick building syndrome' are related to an inadequate fresh air supply, this is not universally true.

RELATIVE HUMIDITY

Various researchers have shown that low relative humidity can lead to an increase in the incidence of respiratory infection[62,63,64]. The CIBSE Guide[59] recommends that humidity should be maintained between 40 and 70%.

The reasons for increased incidence of infection is a subject for debate. Four possible reasons are given:

(i) Humidity may affect the survival of bacteria and viruses[63,65,66] so airborne micro-organisms are less likely to survive in relative humidities of the order of 50%. However, it is also true that very high humidities cause dampness which may encourage the growth of micro-organisms[64] and humidifiers can, themselves, release airborne micro-organisms.

(ii) Higher humidities encourage the agglomeration of airborne particles and these larger particles are believed to be less likely to cause infection than smaller particles[63].

(iii) Dry air may produce microfissures in the upper respiratory tract which act as landing sites for infection[67].

(iv) Increased mucous flow favours rejection of micro-organisms. There is, however, some debate about whether mucous flow increases at higher humidities, which researchers finding both for and against the theory[68,69].

It is debatable whether much of this work is relevant to 'sick building syndrome' since the balance of evidence suggests that the syndrome is not caused by infection.

Few investigations have included detailed consideration of humidity and comparative studies by Robertson et al[42] showed similar relative humidities in 'sick' and control buildings, suggesting that low relative humidity was not the cause. However, low humidity is known to cause some of the symptoms noted in sick buildings. Erythema (skin rash) may be caused by low humidity; Griffiths and Wilkinson[76] quote an incidence of itchy erythema of the face and neck amongst factory workers which was cured by raising the ambient humidity from 30-35% to 45-50%. McIntyre[70] was able to demonstrate some increase in eye irritation at very low humidities (20%), presumably due to drying effect. Thus, whilst low humidity is unlikely to be a major cause, it may sometimes be responsible for symptoms.

WORKING ENVIRONMENT, COMFORT AND SENSORY PERCEPTION

Various standards have been set for the optimum comfort of building occupants, the most widely accepted being that derived by Fanger and used as the basis for ISO 7730-1984[71]. As with most such standards, ISO 7730-1984 sets an optimum temperature (air, radiant, and radiant symmetry) range for people at different metabolic rates and wearing different clothing. Although the work is based on sensory perception it draws up complex equations to allow for the calculation of the 'operative temperature'. Recommended comfort requirements, from ISO 7730-1984, are:

(a) Operative temperature 20°C-24°C (22°C±2°C).

(b) Vertical air temperature difference 1.1 m and 0.1 metres (head and ankle height) less than 3°C.

(c) Floor surface temperature 19-26°C (29°C with floor heating systems).

(d) Mean air velocity less than 0.15 metres/sec.

(e) Radiant temperature assymetry (due to windows etc) less than 10°C.

(f) Radiant temperature assymetry from a warm ceiling less than 5°C.

The standard is based on the 'prediction mean vote' (PMV) and the 'predicted percentage of dissatisfied' (PPD) - and predicts conditions which are most satisfactory to most people for most of the time. 'Ideal' conditions can vary from population to population (surveys have shown optimum temperatures ranging 17°C for English gentlefolk in winter to 37°C for Bagdhad office workers in summer) and from person to person within a population. Whilst the preferred temperature may be influenced by expectation and possibly by extreme outdoor temperatures, these studies show that no single thermal environment is ideal for everyone; even if conditions are 'ideal', a percentage of occupants will be dissatisfied.

Dissatisfaction with the thermal environment is a greater problem in large air conditioned buildings than in smaller and naturally ventilated buildings. The standards set in ISO 7730-1984 are complex and not easy to achieve. Whereas in a building with opening windows and radiators the occupants are able to vary the thermal environment to some extent, if the air conditioning or heating system in a large, 'tight' building fails to control the thermal environment, there is often little that the occupants can do to improve conditions.

A sensation of 'stuffiness' may also play a part. Stuffiness generally indicates dissatisfaction with the environment. Bedford[72] attributes stuffiness to lack of stimulation, suggesting that a change of air velocity will stimulate the nerve tactile endings in the skin, which fits in part with the theory by Berglund et al[5] that imperceptibly small stimuli may be to blame. Two papers report investigations where it was possible to reduce complaints of stuffiness by the use of individual fans to increase the air velocity from 0.05 to 0.6 metres/second[74] and by reducing air temperature by 2^{0}C[75] (from 23^{0}C to 21^{0}C).

Clearly discomfort and dissatisfaction with the thermal environment will lead to complaints and many articles have equated 'sick building syndrome' with those complaints. A building cannot be classed as 'sick' just because its occupants are uncomfortable but some investigations have shown that symptoms are more often prevalent where occupants find their environment uncomfortable. However, others have failed to link symptoms with comfort and in some cases, 'sick building syndrome' has remained even when problems of discomfort have been dealt with[77]. Comparative studies of 'sick' and 'control' buildings often show similar thermal conditions in both air conditioned and naturally ventilated buildings.

LIGHTING

Poor lighting and glare are known to contribute towards strain and headache. Robertson & Burge considered glare in their investigations[58] and rejected it but Wilson and Hedge[9] found the greatest number of symptoms amongst occupants of poorly illuminated buildings, ie those with very uniform artificial lighting, dull decor and tinted glass windows that reduce the amount of daylight entering.

One aspect that has received attention is the effect of certain types of light on indoor chemical pollution. Several articles and papers[7,66,74,83,85] have considered this point, postulating that ultra violet rays in light from certain types of fitting cause photosynthesis of chemical pollution to create a photochemical smog that causes the symptoms of 'sick building syndrome'. This is based on work by Sterling and Sterling[7] in which they found that by increasing the ventilation rate in the building and by changing the lighting fittings to reduce the ultraviolet light they were able to reduce the incidence of symptoms. Despite being unable to measure photochemical smog in the building concerned, they assumed that this was the cause of the problem rather than either the lack of fresh air or the type of lighting.

VISUAL DISPLAY UNITS (VDUs)

There have been suggestions that VDUs can cause adverse effects to their users due to the emission of radiation. HSE[80] considered these effects and discounts any link between radiation from VDUs and cataracts, miscarriages or facial dermatitis (erythema), which is attributed to low relative humidity or environmental agents.

DISSATISFACTION AND PSYCHOLOGICAL CAUSES

A popular and often expressed view, especially in the air conditioning and allied industries and amongst those responsible for 'sick' buildings, is that the causes are wholly or in part of a psychological nature.

Some outbreaks of illness amongst workers have been attributed to psychological causes. Guidotti[97] describes an outbreak of illness in a telephone exchange when 81 members of staff were taken ill. Air sampling results were negative and the outbreak was eventually attributed to an employee with a "military history of involvement in psychological operations". Smith et al[62] describe three outbreaks of mass psychogenic illness in industrial plants with many symptoms similar to those of 'sick building syndrome'. These outbreaks were found to affect workers in a predominantly female workforce who were under some physical and psychological job stress, and were triggered by a physical stimulus of some sort, most commonly a strange odour (Guidotti also mentions a strange odour in his paper).

Clearly, there are some similarities between symptoms of 'sick building syndrome' and those of psychological origin. However, there is little evidence to link sick building syndrome with outbreaks of psychogenic illness of the type reported by Guidotti and Smith et al. Pickering and Finnegan[47] suggest that symptoms are only likely to be of psychological origin in a small number of cases. In further studies, Robertson et al found none of the symptoms of mass hysteria amongst workers examined and therefore conclude that the symptoms are physical rather than psychological.

Whilst mass hysteria is discounted, there is a suggestion by some investigators that dissatisfaction with the working environment, especially with lack of control, and with other working conditions may play some part in 'sick building syndrome'. Waller[48] in a case study of a large air conditioned insurance office attributes complaints to frustration at lack of environmental control, poor management, discomfort and dislike of open plan offices. However, the paper does not mention medical symptoms. WHO[1] also discusses complaints and a 'negative attitude' towards air conditioning, again without mention of symptoms. Wilson and Hatch[9] consider the link between symptoms and employees' working environment, their perceived ability to control the environment and their job satisfaction. They found more symptoms in buildings where occupants had little perceived control over the environment (temperature, ventilation, lighting, noise etc) and the highest rates were in public sector 'clerical factory' environments.

CONCLUSION

From the many cases reported there can be little doubt that the occupants of certain buildings suffer from a higher incidence of illness whilst at work than would normally be expected. Although symptoms are generally mild, and there is little evidence in most cases to suggest that they result in higher rates of absenteeism, they do appear to cause distress to a large number of people employed in those buildings.

Despite the great number of papers on 'sick building syndrome', no single cause has been identified. Well documented illnesses such as Legionnaires' disease and humidifier fever can be discounted in most cases. Whilst airborne contaminants may attribute for a few cases, especially of 'temporarily sick' buildings reported from the USA, few investigations have reported more than trace levels of airborne pollution and a link between pollutants and building sickness has yet to be proven in most cases. The table in Appendix 1 gives information on the results of many of the published investigations into 'sick building syndrome'; few common threads appear amongst their findings.

It therefore seems that this is a complex phenomenon with a number of potential causes, possibly exacerbated by the victim's reaction and attitude towards the workplace environment. In some cases, different stimuli may cause different symptoms, for example, organisms or toxins from humidifiers may be responsible for some chest symptoms.

Whilst the evidence is largely circumstantial, it is useful to summarise the factors that may contribute towards symptoms associated with building sickness. These are:

(a) Ventilation rates; in a number of cases symptoms have been reduced by increasing the fresh air input, although there is insufficient evidence to stipulate a minimum, safe rate.

(b) Temperature and air movement; there is some evidence to suggest that high, uniform temperatures and lack of air movement result in more symptoms.

(c) Humidity; low relative humidity may sometimes cause erythema and eye irritation.

(d) Lighting standards; symptoms have been shown to be more prevalent in buildings with certain types of lighting, especially where the lighting and decor are dull and uniform and there is little daylight.

(e) Airborne pollution; although pollutant levels have been found to be very low, pollution may have been responsible in some cases. The mechanism is unclear; presumably symptoms are due to irritation or sensitisation but this is not proven.

(f) Airborne organ ic matter from the air conditioning system; matter of organic origin from the air conditioning system, especially from humidifiers, may be responsible for some chest symptoms.

(g) Low morale and general dissatisfaction; although 'sick building syndrome' is unlikely to be a psychogenic illness, there is strong evidence to suggest that it is partially caused or exacerbated by general dissatisfaction with work and/or the workplace environment.

On the basis of current knowledge it seems unlikely that building related sickness will be completely eradicated since symptoms occur, albeit at a very much lower rate, in control as well as in sick buildings. However, if acceptable conditions can be maintained for indefinite periods in such well sealed environments as submarines[90] there is no reason why they should not also be maintained in sealed buildings. Even if future investigation fails to identify a cause the problem can be minimised in many cases by sufficient attention to the design, construction and maintenance of air conditioning and ventilation systems, to the general working environment and to the morale of staff who work in such buildings.

REFERENCES

1. WORLD HEALTH ORGANISATION REGIONAL OFFICE FOR EUROPE: Indoor air pollutants: exposure and health effects: Report on a WHO meeting, Norlingen, 8-11 June 1982. ISBN 92 890 12447.

2. WORLD HEALTH ORGANISATION REGIONAL OFFICE FOR EUROPE: Health aspects related to indoor air quality: Report on a WHO meeting Bilthoven 3-6 April 1979. ISBN 92 9020 160 6.

3. Finnegan, M.S., Pickering, C.A.C., Burge, P.S., The Sick Building Syndrome: prevalence studies. Brit Med J Vol 289, pp 1573-1575, Dec 1984.

4. Frank, C., Eye symptoms and signs in buildings with indoor climate problems ('Office eye syndrome'). Acta Opthalmologica 64, 306-311, 1986.

5. Berglund, B., Berglund, U., and Lindvale, T., et al. Characterisation of Indoor Air Quality and 'Sick Buildings' ASHRAE Transactions 1984, Vol 90, Part 1B, pp 1045-1055.

6. Whorton M.D., et al. Investigation and work up of Tight Building Syndrome. J. Occ Medicine, Vol 29, Feb 87.

7. Ferahrian, R.H., Indoor Air Pollution - Some Canadian Experiences. Indoor Air, Vol 1, Swedish Council for Building Research, 1984.

8. Building Related Illnesses. Crown Eagle Communications Ltd, Vernon House, Sicilian Ave, London WC1A 3QT. 1987.

9. Wilson, S., and Hedge, H., The Office Environment Survey: A study of Building Sickness. Building Use Studies Ltd, 14/16 Stephenson Way, Euston, London NW1 2HD, 1987.

10. Sterling, E., & Sterling, T. The Impact of Different Ventilation Levels and Fluorescent Lighting on Building Illness: An Experiment Study. Canadian Journal of Public Health Vol. 74 p 385-392 1983.

11. Bergund B. et al. Do sick buildings affect Human Performance? How should one assess them? Report from Dept Psychology, University of Stockholm 1983.

12. Colligan, M.J. The psychological effect of indoor air pollution. Bulletin of the New York Academy of Medicine 1014-1026. 1981.

13. Stellman, M.J., et al. Air Quality and Ergonomics in the Office: Survey Results and Metholologic Issues. Am Ind Hyg Assoc J, 46(5) 286-293 (1985).

14. Evans, G.W., and Jacobs, S. Air pollution and human behaviour. Journal of Social Issues, 37, 95-125, 1981.

15. University of Washington Conference: INDOOR AIR PROBLEMS - THE OFFICE ENVIRONMENT - A National Epidemic. Dec 7-9, 1982.

16. Proceedings of the American Industrial Hygiene Conference, Montreal, Quebec, Canada, May 31-June 5, 1987.

17. Janssen, J.E., & Hill, T.J. Ventilation for Control of Indoor Air Quality: A Case Study. Environment International, Vol. 8 pp 487-496 1982.

18. Hobbs, M.E., Osborne, J.S., and Adamek, S. Some compounds of gas phase of cigarette smoke. Anal. Chem. 28, 211-215, 1956.

19. Molhave, L. Indoor air quality in relation to sensory irritation to volatile organic compounds.

20. Brundrett, G.W., Ventilation Requirements in Rooms Occupied by Smokers: A Review. Electricity Council Research Centre, Capenhurst, Chester. 1975.

21. Sterling, T.D., & Sterling, E.M. Investigations on the Effect of Regulating Smoking on Levels of Indoor Pollution and on the Perception of Health and Comfort of Office Workers. European Journal of Resp Diseases, Vol 65, pp 17-32, 1984.

22. Sterling, T.D., et al. Environmental Tobacco Smoke and Indoor Air Quality in Modern Office Environments. J OCC Medicine Vol 29, p57-62, Jan 1987.

23. Wallace, L., & Bromberg, S. Plan and Preliminary Results of the US Environmental Protection Agency's Indoor Air Monitoring Program 1982. Indoor Air Vol. 1, Swedish Council for Building Research 1984.

24. ASHRAE: Ventilation for Acceptable Indoor Air Quality (ASHRAE Standard 62-1981) Atlanta (1981).

25. Meyer, B. Formaldehyde Release from Building Products. Indoor Air Vol 3. Swedish Council for Building Research 1984.

26. Wanner, H.U., & Kuhn, M. Indoor Air Pollution by Building Materials. Indoor Air Vol 3. Swedish Council for Building Research 1984.

27. Dement, J.M., et al. An Evaluation of Formaldehyde Sources, Exposure and Possible Remedial Actions in Two Office Environments. Indoor Air Vol 3, Swedish Council for Building Research 1984.

28. Matthews, T.G., et al. Formaldehyde Emissions from Consumer and Construction Products: Potential Impact on Indoor Formaldehyde Concentrations. Indoor Air Vol 3. Swedish Council for Building Research 1984.

29. Sundin, B. Formaldehyde emission from wood products; technical experiences and problem solutions from Sweden. 3rd Medical Legal Symposium on Formaldehyde Issues, Washington, D.C., Oct 22-23 1982.

30. Anderson, I., & Korsgaard, J. Asthma and the Indoor Environment: Assessment of the Health Implications of High Indoor Air Humidity. Indoor Air Vol 1, Swedish Council for Building Research 1984.

31. Bishop, V.L., Auster, D.E., Vogel, R.H. The Sick Building Syndrome. What it is and How to Prevent It. National Safety & Health News, December 1985.

32. Custer, D.E. Sources of Building Contamination. National Safety & Health News, December 1985.

33. Gravesen, S., et al. Demonstration of micro organisms and dust in schools and offices. An observational study of non-industrial buildings. Allergy Vol 41, p520-525. ISSN D105-4538. Sept 1986.

34. Reisenberg, D.E., & Arehard-Treichel, J. Sick Building Syndrome Plagues Workers, Dwellers. J. Am. Medical Assoc, Vol 255, p3063, 13 June 1986.

35. Brown Skeers, V.M. The Puzzling Case of the S.O.B (State Office Building). Occ Health Nursing, May 1984.

36. Rajhans, G.S., Indoor Air Quality and CO_2 Levels. Occupational Health in Ontario, Vol 4, No 4 (Pub Ontario Ministry of Labour Oct 1983).

37. Taylor, P.R., et al. Illness in an office building with limited fresh air access. J Environ Health, 47/1 (24-27) 1984.

38. Mant, D.C., and Muir Gray, J.A. Building Regulation and Health. Building Research Establishment, Garston, Watford WD2 7JR. 1986.

39. Melia, R.J.W., et al. The relationship between respiratory illness in primary school children and the use of gas for cooking. Int. J of Epidermiology. 8 pp 333-338 1979.

40. Blowens, R., Lidwell, O.M., & Williams, R.G.O., Infection in operating theatres in relation to air conditioning equipment. J.I.H.V.E., 30, 244-245, 1962.

41. Pickering, A.C., et al. Sick Building Syndrome. Indoor Air Vol 3, Swedish Council for Building Research 1984.

42. Robertson, A.S., et al. Comparison of health problems related to work and environmental measurements in two office buildings with different ventilation systems. Brit Med J. Vol 291, 10 Aug 1985.

43. Guidotti, T.L., et al. Epidemiological features that may distinguish between building associated illness outbreaks due to chemical exposure or psychogenic origin. J. Occ. Medicine. Vol 29, No 2. p148-150, Feb 1987.

44. Smith, M.J., Colligan, M.J., & Hurrell, J.J. Three Incidents of Industrial Mass Psychogenic Illness. J of OCC Medicine, Vol. 20, June 1978.

45. Hawkins, L.H. Air Ions and Office Health. Occupational Health, p116-124, March 1982.

46. Assael, M., Pfeifer, Y., Sulman, F.G. Influence of Artificial Air Ionisation on the Human Electroencephalogram. Int. J Biometior, Vol 18, no. 4, pp306-312, 1984.

47. Rim, Y. Psychological Test Performance of Different Personality Types on Sharov Days in Artificial Air Ionisation. Int. J. Biometior, Vol. 21, No. 4, pp 337-320, 1977.

48. Krueger, A.P., & Reed, E.J. Biological Impact of Small Air Ions. Science, pp 1209-1213, 24 September 1976.

49. Krueger, A.P., & Smith, R.F. Negative Air ion effects on the concentration and metabolism of 5-hydroxytriptamine in the mammalian respiratory tract. J. General Physiology, vol 44, 1960.

50. David, T.A., et al. The Sedating Effect of Polarised Air. Proc 2nd Inst Bioclimatological Congress, Royal Soc Medicine, London 4-10 Sept 1960. (Pub Pergamon Press 1962).

51. Albrechtsen, O., et al. Influence of Small Atmospheric Ions on the Airways in Patients with Brochial Asthama. Technical University of Denmark.

52. Hamburger, R.J. On the Influence of Artificial Ionisation of the Air on the Oxygen Uptake During Exercise. Proc. 2nd International Bioclimatological Congress. London 4-10 Sept 1960.

53. Ball, D.J. A Sceptic's View of Air Ionisation. Building Services & Environmental Engineer. September 1982.

54. A Hedge and M D Collis. Do negative ions affect human mood and performance? Ann Occup Hyg., Vol 31, No 3, pp 285-290. 1987.

55. US Food and Drug Administration, Negative ion generators, 5 Feb 1980.

56. Hawkins, L.H., and Morris, L. Air Ions and Sick Building Syndrome. Indoor Air, Vol 1, Swedish Council for Building Research 1984.

57. Finnegan, M.J., et al. Effect of negative ion generators in a sick building. Brit Med J. Vol 294 pp 1195-1196, 9.5.87.

58. Robertson, A., & Burge, S. Building Sickness - all in the mind? Occupational Health, March 1986.

59. CIBSE Guide. Chartered Institution of Building Services Engineers, Delta House, 22 Balham High Road, London SW12 9BS.

60. Youle, A. Occupational Hygiene Problems in Office Environments: The Influence of Building Services. Ann Occ Hyg Vol 30 No 3 pp 275-287 1986.

61. Janssen, J.E., & Hill, T.J. Ventilation for Control of Indoor Air Quality: A Case Study. Environment International, vol 8, pp 487-496 1982.

62. Gilperin, A. Humidification and upper respiratory infection incidence. Heating/Piping/Air Conditioning. March 1973.

63. Green, G.H. Field Studies of the effect of air humidity on respiratory diseases. Dept of Mechanical Engineering, University of Seskatchewan, Saskatoon, Canada.

64. Green, G.H. The Health Implications of the Level of Indoor Air Humidity. Indoor Air Vol 1, Swedish Council for Building Research 1984.

65. Sale, C.S. Humidification to reduce respiratory illnesses in nursery school children. Southern Medical Journal, vol 65, No. 7, 1972.

66. Dimmick, R.L., & Akers, A.B. An Introduction to Experimental Aerobiology, Wiley, New York 1969.

67. Tromp, S.W. Medical Biometeorology, Elsener Publishing Co, Amsterdam 1963.

68. Andersen, I., Lundqvist, G.R., and Proctor, D.F. Human Mucosal function under four controlled humidities. American Review of Respiratory Diseases, 101, 438-449 1972.

69. Ewart, G. On the mucous flow rate in the human nose. Acta Oto Layyng (Stockholm), 200 suppl. 21, 56, 1965.

70. McIntyre, D.A. Subjective Responses to Relative Humidity: A Second Experiment. The Electricity Council Research Centre, Capenhurst, Chester, February 1975.

71. International Standard ISO 7730-1984. Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.

72. Bedford's Basic Principles of Ventilation and Heating. H K Lewis & Co Ltd, London 1974.

73. Waller, R.A. Case Study of a Sick Building. Indoor Air Vol 1, Swedish Council for Building Research, 1984.

74. Int. Hout, L. Tight Building Syndrome: Is it hot air? Heating/Piping/Air Conditioning, 99-103, January 1984.

75. Matthews R. Pollution Begins at Home. New Scientist 5 12 85.

76. Griffiths, W.A.D., and Wilkinson, D.S. Essentials of Industrial Dermatology. Blackwell Scientific Publications Ltd. 1985.

77. Hanssen, S.O., and Rodahl, E. An Office Environment - Problems and Improvements. Indoor Air Vol. 3, Swedish Council for Indoor Research 1984.

78. Richards, A. Office Sickness Syndrome. Occupational Health & Safety, February 1986.

79. McLellan, R.K. The Health Hazards of Office Work. Toxic Substances J, Vol 5, No. 3, p 162-181. Oct 1983.

80. Visual Display Units. Health & Safety Executive. Pub HMSO 1983. ISBN 0 11 883685 4.

81. Hicks, J.B. Tight Building Syndrome: When Work Makes You Sick. Occupational Health & Safety. January 1984.

82. Rittfield, R., et al. Indoor air pollutants due to floor tiles. Indoor Air Vol. 1. Swedish Council for Building Research. 1984.

83. Hansen, T.B., and Andersen, B. Ozone and Other Air Pollutants from Photocopying Machines. An. Ind. Hyg. Assoc. J., 47(10), 659-665 (1986).

84. Hanssen, S.O., & Rodahl, E. An Office environment - problems and improvements. Indoor Air Vol 3, Swedish Council for Building Research, 1984.

85. Andersen, I., Lundqvist, G.R., Molhave, L. Indoor air pollution due to chipboard used as a construction material. Atmospheric environment Vol 9. pp 1121-1127. 1985.

86. Bell, S.J., & Khati, B. Indoor Air Quality in Office Buildings. Occupational Health in Ontario, Vol 4, No 3, July 1983.

87. Repace, J.M. Indoor Air Pollution. Environment International, Vol 8, pp 22-36. 1982.

88. Woods, J.E. Ventilation, Health & Energy Consumption: A Status Report. ASHRAE Journal, pp 23-27. July 1979.

89. McNall, P.E. Building Ventilation Measurements, Predictions and Standards. Symposium on Indoor Air Pollution, New York Academy of Medicine, 1981.

90. Schulte, J.H. Sealed Environments In Relation to Health and Disease. US Navy, Submarine Medicine Division. March 1964.

91. Walkinshaw, D.S. Indoor air quality research in Canada. Indoor Air Quality Seminar, Atlanta, Georgia. 1984.

92. Air Conditioning. Is it good for you? Heating and Ventilating Contractors' Association, 34 Palace Court, London W2 4JG.

93. BS 5720: 1979. Code of practice for mechanical ventilation and air conditioning in buildings.

94. Fourth Report of the Independent Scientific Committee on Smoking and Health, HMSO, 1988.

95. Wilson, S., O'Sullivan, P.E., Jones, P., and Hedge, A. Sick Building Syndrome and Environmental Conditions: Case Studies of nine buildings. Building Use Studies Ltd, 14/16 Stephenson Way, Euston, London NW1 2HD, December 1987.

APPENDIX 1

INVESTIGATION AND RESEARCH REPORTS ON BUILDING SICKNESS

REF	AUTHORS	COUNTRY YEAR	COMPARATIVE STUDY	NUMBER OF AFFECTED		CAUSES (a = strong link; b= postulated but unconfirmed; c = discounted or disproven									MEASURED EFFECT ON PERFORMANCE
				BUILDINGS	PEOPLE	AIR POLLUTION	HUMIDIFIERS	INADEQUATE VENTILATION FRESH AIR ETC	TEMPERATURE THERMAL COMFORT	POOR LIGHTING ETC	HUMIDITY	AIR IONS	PSYCHOLOGICAL CAUSE	GENERAL DISSATIS-FACTION	
3	Finnegan et al	UK 1984	Yes	9		b	a	b				b	c	b	-
6	Whorton et al	USA 1987	No	1	172	c		a							-
7	Ferahian	Canada 1984	No	1	1000	c		b							-
9	Wilson & Hedge	UK 1987	Yes	46	4373		a			a				a	-
10	Sterling & Sterling	Canada 1983	No			b				b	c		c		None
11	Berglund et al	Denmark 1983	Yes	2											None
13	Stellman et al	USA 1985													None
15	Washington University	USA 1982	No	10		a/b		b	b		b			b	-
35	Brown-Skeers	USA 1984	No	1		a									-
37	Taylor et al	USA 1984		1		b		a							-
41	Pickering et al	UK 1984	Yes	2	289		b				a			a	* -
42	Robertson et al	UK 1985	Yes	2		c	c	b	c	a	c	c	c		-
45	Hawkins	UK 1982	No	1					a			a			-
56	Hawkins & Morris	UK 1984	No									c		-	
57	Finnegan et al	UK 1987	No	1							c	c		-	
58	Robertson & Burge	UK 1986	Yes	2/1/89		c	a	c	b/c	b/c	c	c		-	
73	Waller	UK 1984				c		a						a	-
84	Hanssen & Rodahl	Norway 1984	No	1		c		c	c	c	c				-

APPENDIX 2

TABLE 1 (WALLER, 1984)

AIR CONTAMINANTS DETECTED IN TIGHT BUILDING INVESTIGATIONS

Substance	**Concentration**	
Total dust	20-40	ug/m^3
Respirable dust	10-25	ug/m^3
Coal Tar Pitch Volatiles	0.05-0.02	ug/m^3
Formaldehyde	5-40	ppb
Toluene	10-30	ppb
o,m,p-Xylene	10-20	ppb
Ethylbenzene	5-15	ppb
Hexane	10-25	ppb
1,1,1-Trichloroethane	50-150	ppb
1,1,2,2-Perchloroethylene	40-80	ppb
C,-C Alkanes	10-50	ppb
Ozone	5-10	ppb
NOx	200	ppb
Carbon Monoxide	2-5 ppm	
Carbon Dioxide	0.05-0.09%	

TABLE 2 (HOBBS, OSBORNE AND ADAMIK, 1956)

GASES FOUND IN CIGARETTE SMOKE

	Conc. ppm	Threshold limit values for 8h exposure pm	Ratio above threshold	Toxic action on lung
Carbon monoxide	42,000	50	840	Unknown
Carbon dioxide	92,000	5000	18.4	None
Methane, ethane etc	87,000	500	174	None
Acetylene, ethylene	31,000	5000	6.2	None
Formaldehyde	30	2	15	Irritant
Acetaldehyde	3,200	100	32	Irritant
Acrolein	150	0.1	1500	Irritant
Methanol	700	200	3.5	Irritant
Acetone	1,100	1000	1.1	Irritant
Methyl ethyl ketone	500	250	2	Irritant
Ammonia	300	25	12	Irritant
Nitrogen dioxide	250	5	50	Irritant
Methyl nitrite	200	-	-	Unknown
Hydrogen sulphide	40	10	4	Irritant
Hydrogen cyanide	1,600	10	160	Enzyme poison
Methyl chloride	1,200	100	12	Unknown

TABLE 3 (BRUNDRETT 1975)

PHYSICAL IRRITATION CAUSED BY SMOKERS

BOGEN		SPEER			CAMERON		"WHICH" CONSUMER MAGAZINE	
1929		1968			1972		February 1975	
U.S. Sample size not given		U.S. 250 non-allergic,			U.S. 1710 children		British: 1155 adults	
smokers		non-smokers			7-15 yrs old		non-smokers	
Ill-effects: % population		Ill-effects: % population			Ill-effects: % population		Irritation type: % population	
			Non-allergic	Allergic				
Shortness of breath	35%	Eye irritation	69%	73%	Eye irritation	47%	Stinging eyes	26%
Biting and irritation	30%	Nose symptoms	29%	67%	Cough	37%	Coughing	16%
Coughing	30%	Headache	32%	46%	Headache	12%	Difficult breathing	8%
Burning	15%	Cough	25%	46%	Nasal irritation	11%	Nasal irritation	6%
Nausea	10%	Wheezing	4%	22%	Throat, nausea	5-10%	Sore throat	6%
Palpatation of heart	5%	Sore throat	6%	23%			Nausea	5%
Hoarseness	5%	Nausea	6%	15%			Headache	3%
Salivation	5%	Hoarseness	4%	16%			Dizziness	1%
		Dizziness	6%	5%				