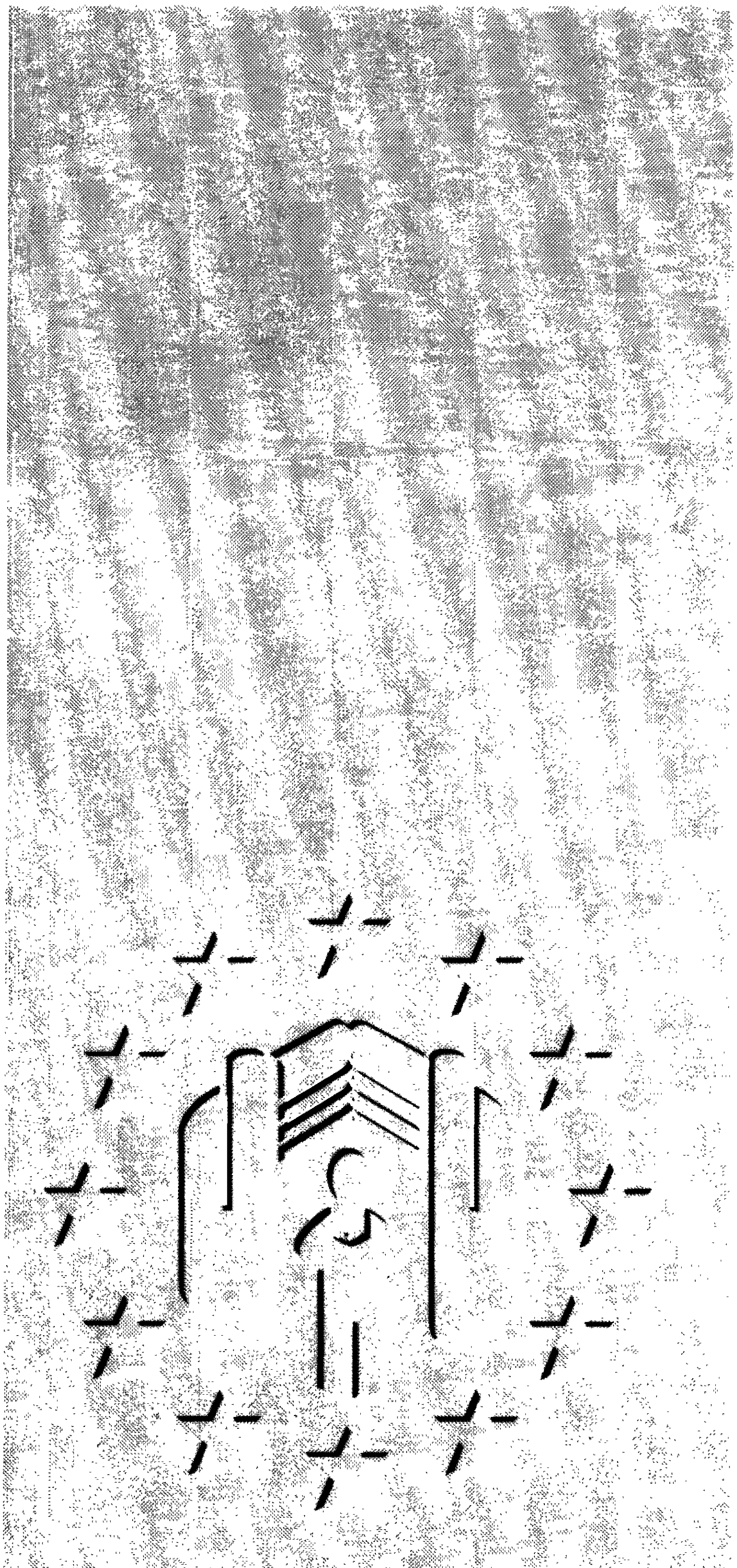
COMMISSION
OF THE EUROPEAN COMMUNITIES



A review of indoor air quality and its impact on the health and well-being of office workers

Health and safety

Report
EUR 14029 EN

A review of indoor air quality and its impact on the health and well-being of office workers

Health and safety series

Contract No 900540

Commission of the European Communities

health and safety

A review of indoor air quality and its impact on the health and well-being of office workers

Dr P. Leinster, E. Mitchell
Thomson Laboratories Ltd
Milton Keynes
United Kingdom

for the

Commission of the European Communities
L-2920 Luxembourg

Directorate-General
Employment, Industrial Relations and Social Affairs

1992

EUR 14029 EN

Published by the
COMMISSION OF THE EUROPEAN COMMUNITIES
Directorate-General
Telecommunications, Information Industries and Innovation
L-2920 Luxembourg

LEGAL NOTICE

Neither the Commission of the European Communities nor any person acting on behalf of the Commission is responsible for the use which might be made of the following information

Cataloguing data can be found at the end of this publication

Luxembourg: Office for Official Publications of the European Communities, 1992

ISBN 92-826-4279-8

Printed in Belgium

ABSTRACT

A review of the literature concerning problems related to indoor air quality and other factors which affect the indoor environment in offices has been undertaken. Within some buildings the causative agent is readily apparent. However, in others complaints of ill health are more common than might reasonably be expected and yet there is no readily discernible reason. This latter condition is commonly known as Sick Building Syndrome. Symptoms are experienced in a particular building but quickly disappear after people leave the building at night or over the weekend.

There are a number of features which are commonly found in buildings in which complaints related to the environment arise and these include: forced ventilation, indoor surfaces covered with textiles, buildings of light construction, energy efficient structures with a homogeneous thermal environment and windows that cannot be opened. Problems associated with the indoor environment are widely spread and involve chemical and physical parameters, for example chemical pollutants and the thermal environment and factors like management styles. Such problems can have a significant effect on productivity and can also cause material damage. One estimate of the cost due to losses in productivity in the USA is measured in billions of dollars.

Within the countries of the European Community many millions of people work within offices. If action can be taken to improve and safeguard the quality of the indoor environment in general and indoor air quality in particular many will benefit and substantial cost savings will be made.

There are few standards and guidelines against which conditions in offices can be assessed. It is considered by many that exposure limits set for industrial situations are inappropriate for office environments. Currently there is no overall agreement in the way building investigations should be undertaken. For example there is no agreed set of questions which should be included in occupant surveys and many different sampling and analytical techniques are used to measure indoor pollutants. Indeed, when assessing concentrations of volatile organic compounds (VOCs) procedures are used which will yield different answers and yet all will be quoted as levels of VOCs found.

It is evident that much of the study of indoor air quality and other factors affecting the indoor environment is in formative stages and that few definitive answers can be given to many of the problems encountered. However, on the basis of current knowledge it should be possible to take a pragmatic approach and alleviate a large number of the problems which are encountered within buildings. The information from the scientific literature needs to be interpreted and then communicated to those involved in the design, construction and refurbishment of buildings so that factors known to cause problems are not repeated. In addition, those involved in running buildings need to be informed of the ways in which they can maintain acceptable

working conditions.

Although it should be possible to improve conditions within existing buildings and not incorporate known problems into new and refurbished buildings many issues to do with indoor air quality still need to be resolved. Consensus guidelines against which conditions can be assessed need to be developed. Agreement on overall study design and parameters which should be considered for inclusion in an assessment is also required. This would also require agreement on standardised and validated sampling and analytical techniques.

A significant amount of work has been carried out evaluating the emissions of chemicals from materials used within buildings. This has also identified the need for the development and application of standardised evaluation procedures. Materials can be selected for use within buildings on the basis of such data. The cleaning and maintenance regimes used within buildings can also have a significant impact on the indoor environment.

It is evident from the survey of the literature that has been undertaken that there are many areas in which further information is required and these are summarised at the end of the review.

CONTENTS

FOREWORD

The Directorate-General for Employment, Industrial Relations and Social Affairs of the Commission of the European Communities awarded Thomson Laboratories Ltd, United Kingdom, a contract to produce a literature review on the Problems of Indoor Air Quality for the Health and Well-Being of Workers in Offices and Recommended Measures for Their Control, Including Legislative Requirements. This review, in addition to air quality, has included some consideration of other factors affecting the indoor environment such as thermal aspects and lighting. The majority of the literature reviewed has been restricted to that which specifically pertains to the office environment.

INTRODUCTION

As a result of the oil crisis in the 1970s more attention was given to the introduction of energy-saving measures in buildings. This resulted for example in a reduction in the amount of outdoor air being supplied into rooms. Over a similar period the type of furnishings within office buildings also changed. Now more floors are carpeted and soft furnishings are used more extensively. The use of such items results in the emission of a variety of chemicals into the indoor environment.

Many town-dwellers spend less than an hour a day in the outside environment. The rest of the time they are at home, at work or in some form of transport. With people spending 80 to 90 per cent of their time indoors the quality of air within buildings is of importance because of the numbers of people affected and the duration of such exposure.

Problems associated with the indoor environment are common and can be caused by factors such as temperature, air movement, stuffiness, odour and specific chemicals. Within some buildings there is an easily identifiable causative agent such as Humidifier Fever, Legionnaires' Disease, mould or exposure to a substance like ozone from a photocopier or carbon monoxide from an underground carpark. Such problems, even though they can be defined readily, can be extremely costly to remedy. In other buildings complaints of ill health are more common than might reasonably be expected and yet there is no readily discernible cause. In some cases significant levels of symptoms exist even after extensive remedial actions have been carried out.

A number of terms have been used to describe this phenomenon which was first reported around thirty years ago in North America and Scandinavia both in the workplace and in the home including; "building sickness", "sick building syndrome", "sick office syndrome", "tight building syndrome", "the indoor climate syndrome" and "building related illness". The term in most common use, which has also been accorded recognition by the World Health Organisation (WHO), is "Sick Building Syndrome" (SBS) (World Health Organisation, 1983).

Besides physical factors, stress, social and organisational conditions can increase the risk of an increased level of complaints within a building. For example facial erythema, a common complaint amongst office workers, is reported to be provoked by nervous, hormonal, psychological, chemical and physical stimuli (Stenberg, 1987).

With SBS it is typical for symptoms to appear after a short stay in the building and then gradually to increase during the day. In general the symptoms quickly disappear after people leave the building, eg during the night or over the weekend. In many cases an increase in the incidence of symptoms has been recorded due to moving into new premises or newly renovated premises.

Often the problems seem to appear in new buildings which are extensively tightened and where energy consumption is low which is typical for almost all new buildings. However, problems associated with old buildings are also known.

Individual parameters of the indoor physical, chemical and biological environment are normally well within occupational exposure limits for industrial situations or are in "acceptable" ranges. It is also possible that more than one factor results in the same symptom, for example heat radiation and formaldehyde can cause dryness of the eyes. It has been hypothesised that several factors, each with a value not likely to cause any symptoms, cause the symptoms when they occur together. According to Burge (1990) any serious cause or causes for the syndrome should be measurably different in sick and healthy buildings.

In general, where a pollutant originates outside and there is no indoor source, the outdoor concentration will exceed the indoor concentration. However, if there is an internal source, for example with volatile organic chemicals, levels indoors are, in the majority of cases that have been reported, significantly higher than those found outside in the vicinity.

The purpose of this study is to review the recent literature relating to indoor air quality. Reference will also be made to other factors which affect the quality of the indoor environment such as lighting. Problems encountered within buildings range from those in which the source can be easily identified and cheaply remedied to those in which there is no apparent cause and any suggested remedial action appears to be prohibitively expensive. This will be dealt with as though it were a continuum and therefore a clear distinction will not necessarily be made between these extremes, in this review.

Building-related symptoms are experienced in nearly all buildings, at least by some of the occupants, and so there is no clear, qualitative difference between a building which is sick and one which is not.

A report by the WHO (1983) differentiates between "temporarily sick buildings" where symptoms decrease and disappear with time and "permanently sick buildings" where they persist, often despite the most extensive remedial measures. A list of reports describing investigations of SBS together with possible causes is given in Appendix 1 of a review by Sykes (1988).

According to Sykes (1988) few investigations are truly multidisciplinary and most concentrate on particular aspects of a situation rather than address the total potential cause of the problem. Studies address the medical aspects, the measurement of physical parameters such as airborne contaminants or assess the building services. Some investigations appear to draw conclusions which are not fully justified by the reported facts, possibly because not all of the information found in the investigation is reported or because assumptions have been made. Subsequently, some conjecture can be reported as fact, especially in the press. Unfortunately, few investigations have conclusively proven a cause by the successful application of remedial measures.

From the research point of view, many problems to do with indoor air quality are challenging because they cross many disciplinary boundaries (including architecture, building science, occupational health and human behaviour) and cover many types of variables relating to buildings, including their layout and technology, the organisations which occupy them, the management styles and the people themselves. The research results make it easier to talk of likely levels of risk: air-conditioned buildings are more likely to cause problems than naturally-ventilated buildings; public-sector organisations are more prone to SBS than private-sector organisations, than it is to talk with certainty about causes. The causes of sick-building syndrome are not known with certainty, so there is a considerable research challenge in uncovering them; furthermore, experience suggests that the causes are multiple and may be different in each building.

From the business point of view, the relationship between work performance and the quality of the work environment is now high on the agenda of many organisations for two reasons, productivity and staff turnover.

Sick building syndrome is a tangible result of constraints being progressively imposed on buildings' occupants, first through the site (which affects microclimate); then through shell design (which affects variables like depth of space, floor-to-ceiling heights, and overall comfort conditions); through the services design (such as the air handling plant); then through the internal layout and housekeeping of the working areas; and, finally, to the individuals at their workstations (where people may have little or no control over their immediate ambient conditions). Each of these "levels" affects the levels beneath it. Basic decisions about site, building shell, services and working areas set constraints which are often impossible to change or reverse. If these constraints cannot be overcome, then their effects will be carried through the building's operation both as a physical system and as a system for accommodating organisations and people.

Similarly, interventions lower down in the hierarchy of levels can never completely resolve difficulties which arise from decisions made at a higher level of the building hierarchy. Furthermore, the building is a system rather than a collection of isolated components; therefore, the effects of changes to one component are modified by the state of the other components.

SYMPTOMS ASSOCIATED WITH PROBLEM BUILDINGS

SBS is a term which describes general non specific chronic symptoms such as headaches, stuffy nose and dry throat suffered by people during the time they are in a particular building, but which disappear again when they go home in the evening. The presence of the symptoms is therefore building-related. In a building where building sickness is prevalent not everyone will experience symptoms.

Problems such as Humidifier Fever and Legionnaires' Disease have to be dissociated from SBS. In 1970 the attention of the medical profession was drawn to the development of an allergic respiratory disorder (allergic alveolitis) among the employees working in air-conditioned offices by Bansazak *et al* (1970). It is similar to humidifier fever which has been described both in homes and in industrial situations where cold water spray humidification systems have become heavily contaminated with microorganisms.

Legionnaires' disease and its more benign homologue, Pontiac fever, are caused by the inhalation of *legionella* organisms from sources such as vapour drift from contaminated cooling towers or mists generated by contaminated showers. These illnesses usually present with easily recognised clinical manifestations.

Apart from these allergic and infectious disorders, doctors are confronted every day with a number of complaints affecting mucous membranes of eyes, nose and throat, headache and lethargy. These symptoms appear to be benign and related to the building in which the individuals work or live and constitute the SBS (Molina *et al*, 1989).

According to Molina *et al* (1989) the symptomatology of SBS is varied, but five symptom complexes are regularly encountered. These symptoms may occur singly or in combination with each other:

- **Nasal manifestations**
  the symptoms most frequently experienced are nasal irritation with rhinorrhoea and nasal obstruction, usually described as "nasal stuffiness";

- **Ocular manifestations**
  dryness and irritation of the mucous membrane of the eye;

- **Oropharyngeal manifestations**
  dryness and irritation of the throat;

- **Cutaneous manifestations**
  dryness and irritation of the skin, occasionally associated with a rash on exposed skin surfaces;

- **General manifestations**
  headaches and generalised lethargy and tiredness leading to poor concentration.

These symptoms have a characteristic periodicity increasing in severity over the working shift and resolving rapidly on leaving the building in the evening. Most manifestations, therefore, with the exception of some cutaneous symptoms, improve over weekends and all symptoms usually disappear on holiday.

Some constitutional diseases, *eg* eczema, sinusitis, may be exacerbated in certain buildings.

The diagnosis of sick building syndrome is suggested by the presence of the preceding symptom complexes. However, there are other causes of building related illness such as asthma, hypersensitivity pneumonitis or extrinsic allergic alveolitis, humidifier fever and allergic rhinitis.

The range of symptoms and their prevalence may depend to some extent on the questionnaire used. Investigations of symptoms is often carried out by means of self administered questionnaires and the response in some instances may be influenced by the number and nature of the questions and the frequency with which they are asked.

There is little information on the severity of symptoms although, since relatively few cases appear to cause extensive absence from work, 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 (Sykes, 1988).

The medical-legal aspect should also not be forgotten. In some countries (*eg* France) allergic manifestations in employees working in air-conditioned buildings, where the air conditioning systems are not properly and regularly maintained, are considered among occupational diseases (Molina *et al*, 1989).

A Health Impact Matrix has been proposed by Berry (1989c) as a framework for categorising different indoor quality scenarios. The two by two matrix defines the concepts of "large" and "limited" "populations exposed" and "health impacts". The primary purpose of the matrix framework is to provide a perspective for the varying levels of human exposure and severity of health consequences for the most obvious indoor air problems. Death, cancer, and serious illness such as heart disease and blood disorders are obviously large health impacts. Judgement must be used in separating severe health effects from limited health impact.

PSYCHOLOGICAL ASPECTS

Dissatisfaction with the working environment appears to be exacerbated by the fact that many office buildings are designed in such a way that the occupants have little ability to control their environment. Both Waller (1984) and a WHO working group (1983) discuss such matters but neither mentions them in association with symptoms. Wilson and Hedge (1987) 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.

Some investigators (Sterling and Sterling, 1983) have sought to demonstrate a relationship between SBS and performance tests but have failed to find any measurable link. Psychosociological surveys evaluating how the occupants viewed their working conditions in air-conditioned environments have also been undertaken (Breugnon *et al*, 1986). Others (Morris and Hawkins, 1987; Hedge *et al*, 1987b) have investigated the possible links between SBS and stress. Their results, though not clear-cut, would suggest that SBS may well be responsible for the stress rather than the reverse.

Psychological factors may play a role by increasing the stress of people thereby making them more susceptible to environmental factors (WHO, 1986). Skov and Valbjorn (1987) in a multifactorial analysis of the data from the Danish Town Hall Study showed that in addition to the building factor, other factors like sex, job and psychosocial influences are associated with the prevalence of mucosal irritation and general symptoms. There is also evidence that indoor air quality investigations can induce near panic in building occupants (Hedge *et al*, 1987b). Careful attention is therefore required in the design and implementation of indoor air quality investigations.

The psychophysical load at the working location (*eg* visual display unit) can cause eye irritation, tiredness and headache, and can be an additional factor in complaints on indoor climate and indoor air quality (Wanner in Molina *et al*, 1989).

PERCEPTIONS AND SENSORY EFFECTS

Fanger (1987; 1988) has introduced two new units, the "olf" and the "decipol", to quantify air pollution sources and levels of pollution as perceived by human beings. One olf is the emission rate of air pollutants (bioeffluents) from a standard sedentary person in thermal comfort. The source strength of any other pollution source can be quantified in olfs, *ie* the number of standard persons required to make the air felt equally annoying. One decipol is the air pollution caused by one standard person (1 olf), ventilated by 10 litres per second of unpolluted air. The decipol value can be assessed by a panel of judges. This method has been used successfully by Fanger *et al* (1988) to quantify pollution sources in spaces and ventilation systems in 15 office buildings. Comprehensive "hidden olfs" were identified in the buildings. The hidden olfs from materials and systems are claimed to be the major reason for the sick building syndrome. However, at the present time no studies have been conducted comparing olf levels with sickness levels within buildings. It has been demonstrated that in certain situations the olf value of a space can be estimated by simple addition of the individual sources (Lauridsen *et al*, 1988).

As a result of a study looking at adaptation to indoor air pollution it was concluded that ventilation for comfort may be reduced considerably if a few minutes of discomfort are acceptable or if the concentration of pollutants increases after the occupants have entered the room (Gunnarsen and Fanger, 1988). Perceived odour intensity was found to diminish during prolonged exposure, whereas irritation of the eyes and throat reached an asymptotic level (Hudnell *et al*, 1990). Both odour and irritation appeared to influence the assessment of air quality.

In a study using climatic chambers signs of changes in tear fluid quality were found in individuals exposed to a variety of materials used within buildings (Johnsen *et al*, 1990). Agreement was also found between a trained panel's evaluation of perceived air quality and the participants' opinion of general comfort. In a study in which 21 healthy subjects and 14 subjects suffering from SBS were exposed to 25 milligrammes per cubic metre of a mixture of 25 volatile organic chemicals, changes in subjective ratings (worse odour, worse indoor air quality, increased irritation of mucous membranes) were significantly associated with exposure and most pronounced with the SBS group (Kjaergaard *et al*, 1990). Increased numbers of polymorphonuclear leukocytes and slight performance changes were also found. A ventilation rate of 7 litres per second per person was required to satisfy 80% of the test subjects used to report the odour intensities and acceptability of bioeffluents (Iwashita *et al*, 1990). It was found that 20% of the participants reported dissatisfaction at 1.5 on the Yaglou odour intensity scale. (Yaglou *et al*, 1936).

Determining the frequency, severity and location of occupant complaints has been found to be a useful tool in the investigation of problems within buildings (Robertson, 1988b).

Work related problems were commonly found in buildings not selected on the basis of having obvious problems and were associated with absenteeism and with perceived rather than measured levels of indoor environmental variables (Broder, *et al*, 1990).

According to Berglund and Lindvall (1990) healthy buildings should be constructed on the basis of positive criteria that surpass the mere avoidance of negative effects on occupants and buildings and priority should be given to the sensitive part of the occupant population.

In the WHO (1987) Air Quality Guidelines for Europe it states that many substances in the indoor environment may cause sensory effects at concentrations far below those at which toxic effects occur. As an example odour annoyance may not be regarded as an adverse health effect by all but it is commonly viewed as adversely affecting the quality of life. For formaldehyde in the non-industrial indoor environment the airborne concentration should not exceed 0.1 milligrammes per cubic metre in order to avoid odour and sensory irritation in the general population (WHO, 1989a). In the case of especially sensitive groups the formaldehyde concentration should not exceed 0.01 milligrammes per cubic metre. Further, in another WHO document (1989b) it is recommended that in non-industrial indoor environments, unwanted odorous compounds should not be present in concentrations exceeding the 50th percentile effect dose (ED_{50}) detection threshold. Similarly, sensory irritants should not be present in excess of their ED_{10} detection threshold. In addition, it recommends that increased emphasis should be given to research in humans on the sensory effects of organic compounds at low concentrations. As criteria for acceptability and annoyance WHO (1987) uses the nuisance threshold level, being defined as the concentration at which not more than a small proportion of the population (less than 5%) experiences annoyance for a small part of the time (less than 2%). Since annoyance will be influenced by a number of psychological and socioeconomic factors, a nuisance threshold level, the WHO guidelines state, cannot be defined on the basis of concentration alone.

Fanger *et al* (1977) found that a slightly, but not significantly, lower temperature was preferred under red light conditions than blue. No noise effect was found. According to Hygye (1987) noise is thought to increase, and mild heat stress to decrease, arousal.

COMMON FEATURES OF BUILDINGS WITH PROBLEMS

Although it is not possible to give a definitive answer as to the cause of all problems within buildings common features have been identified. The following is a summary of the WHO (1983) list:

- they often have forced ventilation;
- they are often of light construction;
- indoor surfaces are often covered in textiles (carpets, furnishing fabrics *etc*);
- they are energy efficient, kept relatively warm and have a homogeneous thermal environment;
- windows cannot be opened.

Subsequent studies in the UK have tended to confirm these common features (Sykes, 1988) although SBS does not occur in all buildings with these features. Wilson and Hedge (1987) found significant differences even between buildings conforming to the WHO list of features. According to Berry (1989b), of all complaints related to large buildings that have been studied in the United States, about 50% have ventilation problems; about 15% are related to inside contamination from various products containing chemicals, especially gas-phase organic substances; 10% are due to outside contamination entering the environment; about 15% are due to detected biological contamination; and 10% of the complaints cannot be directly associated with a cause. He considers that the majority of these undetermined causes may be related to biocontaminants. In 43% of the 30 office buildings with a higher than average number of complaints surveyed in Canada by the Public Works Department, the problems were attributed to improper building systems design, operation and maintenance (Nathanson, 1990). The remainder of the problems were attributed to the generation of pollutants.

When building sickness rates were compared (Wilson and Hedge, 1987) two factors working independently of each other explained a high proportion of the variation:

- air conditioned buildings had consistently higher rates of sickness than buildings with either natural or mechanical systems of ventilation;
- buildings occupied by public sector organisations across all ventilation categories had consistently higher rates of sickness than those occupied by private sector organisations. However the buildings surveyed were generally older than the private sector buildings and were not in prime rental locations which in the speculative market is usually indicative of lower quality buildings and cheaper building systems.

Many authors have shown a statistically significant increase in symptoms among the workers in air conditioned offices over those in naturally ventilated ones (Finnegan and Pickering, 1987; Harrison *et al*, 1987; Hedge *et al*, 1987a). Hedge *et al* (1987a) state that there is a clear relationship between prevalence of symptoms and engineering characteristics of office ventilation systems. Naturally and mechanically ventilated buildings are much healthier than air conditioned ones and all air systems are better than those that use air and water. Within the air conditioned group, the type of humidifier is important. Symptoms of dry eyes, throat, stuffy nose and lethargy were more prevalent in air conditioned offices with evaporative or spray humidification than steam or no humidification. There is epidemiological evidence that more workers have symptoms in buildings with humidifiers and chillers than in those without such equipment and that very dry air (relative humidity less than 30%), which is very common in heated premises in very cold climates, increases many sick building symptoms (WHO, 1990).

Although building sickness is more prevalent in air conditioned buildings it is not exclusive to them: there is also considerable variation within buildings with the same broad category of system (Wilson and Hedge, 1987). All air systems were found among some of the unhealthiest and healthiest buildings suggesting that broad categories of system alone provide only a partial picture: standards of maintenance and design may be important. Older buildings - those built in the 1970s had higher rates of complaint than 1980s buildings in which variable air volume (VAV) systems predominated. This suggests that either modern systems are improving in standard or that over time systems are allowed to degrade and their performance to deteriorate.

Factors which appear to add to the risk of building sickness divide into two broad groups:

- those that create a poor environment measured in terms of prevailing and well established user needs (physiological, practical and psychological); and

- those that reduce an individual's tolerance threshold of poor conditions.

It has been suggested that many air conditioned buildings are oppressive because they block out a sense of the outside, for example tinted windows and sealed windows. The type of glazing also appeared to be significant - all of the least healthy buildings but none of the healthier buildings had tinted glazing.

The Danish Indoor Climate Group Town Hall Study looked at more than thirty different parameters to try and explain the difference in symptom prevalence between the town halls studied. They found that the possibility of potential pollutants was the factor with the highest correlation coefficient to mucosal irritation (Nielsen, 1987). The possibility of potential pollutants was determined on the basis of the amount of fleecy surfaces, the number of shelves and the cleaning programme used. Skov and Valbjorn (1987) using the same results, proposed that sex, personal characteristics, job related and psychosocial factors of work had a significant influence on the presence of work related symptoms. If these factors are taken into account, then the total weight and potentially allergenic portion of floor dust, the area of fleecy material and length of open shelves per cubic metre of air, the number of work places and the air temperature could be used to describe the difference in the prevalence of symptoms (Valbjorn and Skov, 1987).

A summary of patterns from various studies is given in Sykes (1988):

- symptoms are most common in air conditioned buildings but they also occur in buildings that are naturally ventilated;

- clerical staff are more likely than managerial staff to suffer and complaints are more frequent in the public than in the private sector. Complaints are also more likely in offices housing many staff. Women reported symptoms more frequently than men. However sex and grade are closely tied factors. Factors explaining sexual differences are therefore confounded with those explaining differences between grades of staff;

- people with most symptoms have least perceived control over their environment;

- symptoms are more frequent in the afternoon than they are in the morning.

Whilst the evidence is largely circumstantial, Sykes (1988) has produced a summary of factors that may contribute towards symptoms associated with building sickness. These are:

- 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;

  temperature and air movement; there is some evidence to suggest that high, uniform temperatures and lack of air movement result in more symptoms;

- humidity; low relative humidity may sometimes cause erythema and eye irritation;

- 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;

- airborne pollutants; 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;

- airborne organic 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;

- low morale and general dissatisfaction; although SBS 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. 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 (Sykes, 1988).

Burge (1990) states that there is a consistent finding that buildings with microbiological contamination, either from dampness or from chillers and humidifiers, have increased numbers of symptomatic workers. However, in most cases the airborne bacteria and fungi are not directly related to symptoms of SBS whereas soluble antigens in the air may be.

SCALE OF THE PROBLEM

The prevalence and overall effect of SBS 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 where it can be shown to change when remedial measures are instituted, the findings are of little value. Finnegan and Pickering (1987) were surprised at the high prevalence of symptoms in buildings without known problems and suggest that there is a considerable amount of discontent with the office environment at least in air conditioned offices in the United Kingdom. They also found that the pattern of symptoms in naturally ventilated buildings follows that in air conditioned offices. They suggest this indicates that whatever is the cause of the symptoms in the air conditioned offices is also present in the naturally ventilated offices only to a lesser degree. Some papers suggest that up to 30% of new and refurbished 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 (Taylor, 1987; Wilson and Hedge, 1987; Stellman *et al*, 1985; WHO, 1983; WHO; 1986).

In a national survey of office buildings carried out in 1986-7 (Wilson and Hedge, 1987), the five least-healthy of the buildings studied had building sickness symptoms scores ranging from 4.25 to 5.08 symptoms per person, whereas the five lowest scores were between 1.25 and 1.63 symptoms per person. The data obtained in this survey (Wilson and Hedge, 1987), involving 4373 questionnaire respondents in 46 buildings, suggests that as many as 20 per cent of British office buildings may be classified as sick on the criterion of displaying more than 4 symptoms per person. It was found that no less than 80% of the sample experienced symptoms of ill health which they associated with being in their place of work. Not only did many people feel unwell in their place of work but they perceived the ambient environment of their workplace to be poor. Participants were particularly critical of the air quality in their offices: 34% described the air in their offices as slightly or very stale and 45% as slightly or very dry.

One survey of office workers conducted by Honeywell (1985) found that 19% of respondents (115 of 600) often or sometimes had difficulty doing their work because of office air quality, 11% reported that a "tired/sleepy feeling" was a "very serious" or "somewhat serious" problem because of office air quality. Similarly, 9% of all respondents cited a "congested nose", 8% cited "eye irritation," and 8% cited "difficulty breathing" as being "very serious" or "somewhat serious" problems.

In a major study of Danish Town Halls and other buildings, approximate prevalence rates of work related symptoms were fatigue 28%, headaches 20%, eye irritation 13%, and nasal irritation 18% (Skov and Valbjorn, 1987).

COSTS

Productivity and Occupant Related Costs

It is not known if building sickness affects long term health but it is evident that people believe it affects their productivity. Building sickness does not necessarily result in people taking days off work which are recorded as certificated sick leave, but it may result in their leaving the office early or feeling incapacitated. The true costs of building sickness therefore are hidden. Pickering states that the consequences of sick building syndrome are a dissatisfied workforce with reduced working efficiency and increased sickness absence rates (Molina *et al*, 1989). Finnegan and Pickering (1987) considered that it may seem reasonable to suggest that a symptomatic office worker will be less efficient than a symptom free, or less symptomatic, worker.

Productivity losses due to indoor air pollution may take several forms. For example, workers may be less effective because they feel fatigued, or suffer from headaches, eye irritation, or other effects. Workers may therefore accomplish less per hour worked or may spend more time away from their work location, for example, taking breaks or walks outdoors to avoid poor air quality where they work. These effects will result in lower output per hour at work. In addition, workers may be off sick more often.

In the survey by Wilson and Hedge (1987) an analysis was made of the relationship between staff judgements of their productivity and the level of symptoms; from these data it was concluded that any building with more than 2 symptoms per person is likely to be creating productivity losses amongst its staff. Therefore, not only can a significant proportion of buildings be labelled as sick, but many of those that cannot definitively be so labelled are still causing problems. In this study 24% of the respondents thought that their work environment decreased their productivity by 24% or more, 59% thought it had little or no effect, and 16% thought it increased their productivity.

Robertson (1988a) made a comparative evaluation of the possible realistic cost reduction in the heating and ventilation of a large building on the one hand and of a 1% increase in absenteeism among the employees on the other. Under the hypotheses assumed for the calculation, the cost of the absenteeism is approximately 8 times greater than the money gained through energy savings. Moreover, the absenteeism attributed to SBS is probably much greater than 1% as it did not take into account the reduced working efficiency.

According to Axelrad (1989) the available evidence suggests that the costs imposed by indoor air pollution are very high. Three major types of economic costs are addressed: material and equipment damages, direct medical costs and lost productivity. A qualitative estimate of the economic costs from medical visits, sick days lost and productivity losses of white collar workers due to indoor air pollution was of the order of half a billion dollars per year in the USA (Axelrad 1989) whilst the estimated national annual cost of productivity losses in the USA associated with major illnesses caused by indoor air pollution ranged from $4.7 billion to $5.4 billion for new cases annually. He also suggested that productivity losses may be of the order of tens of billions of dollars per year. The cost estimates presented are said to be subject to great uncertainty and to be incomplete.

Costs incurred to improve indoor air quality may pay for themselves in increased productivity. According to Axelrad (1989) it is clear, that from a profit and loss standpoint, productivity, not energy consumption, is the dominant consideration for office environments.

Increasing ventilation capacity from 5 to 20 cubic feet per minute per occupant is estimated to increase total construction costs less than $0.50 per square foot under typical circumstances (Eto and Meyer, 1988). Given the dominance of labour costs, even a modest increase in productivity could justify substantial capital expenditures to improve indoor air quality.

As WHO has pointed out in the publication on Indoor Air Quality Research (WHO, 1986), the effort to save energy will continue in the coming years. Unless those responsible for designing and operating buildings realise that energy economy is not the sole criterion in evaluating costs there will be increasing problems in buildings. They point out that "energy-efficient but sick buildings often cost society far more than it gains by energy savings" and "people's confidence in the effectiveness of health and building authorities may be seriously harmed if sick buildings become a common phenomenon. For many people sensory warnings have a great emotional impact that may cause exaggerated responses even in buildings with only minor environmental problems and may cause unjustified claims of serious and persistent health effects. The added cost to society of the increased sensory irritation, the increased discomfort and the fear of more serious persistent health effects among the occupants is likely to exceed any of the gains that can be made on the margins of energy savings."

Flatheim (1990a) states that a 5 to 10% reduction in productivity has been shown to occur with only small departures from an optimal thermal climate. He assumes that productivity can be readily increased by up to 3% by improving the air quality and considers that even a productivity improvement of 1% would more than cover the increased costs of upgrading the indoor air quality. These increased costs include energy and capital costs. Flatheim (1990b) considers that a marginal increase in costs for upgrading the air quality must be looked upon from the viewpoint that demands for energy conservation have for a long time taken place at the expense of air quality. Total costs are dominated by wage related costs and investments and energy costs are negligible in comparison (Flatheim 1990b).

Poor indoor air lowers productivity and increases absenteeism costs

(Nathanson 1990). Over a 50-year span, building capital costs 2 to 4%, building operating costs 6 to 8%, and salaries cost 88-92% of the total building expenditure.

A study in the Netherlands indicated that absenteeism was related to several building, workplace and job related characteristics and that these may constitute a significant economic loss (Preller *et al*, 1990). Productivity was again found to be related to a range of personal and building factors in a paper by Raw *et al* (1990). They suggested that productivity would be improved by reducing building-related symptoms, avoiding large open plan offices, and improving the standard of (and personal control over) the indoor environment. Building-related symptoms were reported to negatively affect productivity when they averaged more than 2 per person.

In a study reported by Zyla-Wisensale and Stolwijk (1990) worker output was related to proximity to supply and return vents and fluorescent lights.

Material and Equipment Costs

According to Axelrad (1989) the effects of indoor air pollution on indoor materials are influenced by a number of factors, including the type of pollutant, its concentration and exposure pattern, the type of material exposed and other environmental factors. These effects are discussed in some detail in a report from the EPA (1987). Table 1 is taken from that report and summarises the effects of a number of pollutants on a variety of materials. Damage may include corrosion of electronic components and electrical current leakage which may eventually result in equipment malfunction (EPA, 1987; Walker and Weschler, 1980). Computing equipment and other electronic devices are also known to be subject to failures caused by indoor air contaminants. The costs of materials and equipment damage by indoor air pollutants include the maintenance, repair, and replacement costs resulting from: soiling or deterioration of a material's appearance and reduced service life for corroded or degraded appliances, furnishings and equipment.

According to Weschler (reported in Axelrad, 1989) the costs of electronic malfunctions caused by indoor air contaminants can be high. Failures in seven regional telephone companies in the USA were reported to cost in the range of $10,000 to $380,000 per event. Bell Communications Research has developed guidelines for preventing such damage, including the use of high efficiency filtration, the constant use of fans, maintaining minimum air changes per hour, and keeping buildings pressurised to prevent infiltration of outdoor contaminants.

In certain circumstances, such as in art museums or galleries, costs associated with installation of environmental controls such as air filtering systems may also be incurred. Dust, soot, tobacco smoke textile fibres and alkaline aerosols from setting concrete have all been encountered in the deterioration of works of art, documents and historic artifacts (Berry, 1989a). Paper, paintings, textiles and wax objects have been identified as especially susceptible to particulate pollution; metals and photographic materials are vulnerable to attack by acid fumes.

Turner *et al* (1990) claim that a healthy modern building, incorporating a comprehensive approach to indoor air quality by source control and good HVAC systems, can be designed without additional cost implications because of savings due to energy efficiency measures.

EVALUATION CRITERIA

A WHO working group (1983) stated that the application of occupational exposure limits to non-industrial occupational spaces is inappropriate. The group recommended that different, more appropriate, guidelines should be developed for such spaces and that further intensive research is needed on methods for the evaluation of subtle medical effects, sensory and stress reactions. Apparently the WHO group considered offices more similar to dwellings than to the industrial workplace when it comes to air quality. They may also have been taking into account the WHO (1961) definition of health as being a "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity".

According to Nathanson (1990) occupational standards do not seem to apply to office requirements. The composition of the work forces is different and perhaps a contributing factor: there are more healthy, younger males in industrial workplaces. Neither does the standard address the hypersensitive individual nor the differences in "environmental expectations" between industrial and office workers.

Occupational exposure limits for industrial situations are typically set to protect nearly all workers against adverse effect. This means that a certain percentage of individuals may suffer adverse effects below these values. In addition, it is known from experience that the presence of many compounds can be perceived at levels well within the occupational exposure limit by factors such as smell or slight irritation.

In a paper on exposure limits for office environments, Lindvall (1985) concludes:

- occupational exposure limit values for offices should reflect the large potential for avoiding air pollution in these spaces. Since office work for many is characterised by high mental performance demands, avoidance of toxicological effects is not an adequate criterion for a suitable environment. In offices, perceived discomfort is a critical effect;

- the air of an office workplace should be non objectionable to at least 80% of the workers. In the absence of health based indoor air quality standards for the non-industrial working environments, ambient air quality standards or guidelines should be used, or the best available control technology;

- the risk management in occupational as well as in public health focuses on the same critical organ symptoms. The difference in views seemingly is largely in the gradings of the effects and in the emphasis given to the specific grades. Since most indoor air pollutants in office spaces are odorous, odour control is attractive not only for reducing discomfort but achieving a reduction of air pollutants in general;

- sensory warnings have a great emotional impact to many people and may cause exaggerated responses, even to buildings with only minor climate problems. They may cause unjustified claims of serious and persistent health effects. Increased sensory irritation, discomfort and fear of more serious persistent health effects easily add up to occupational health problems of a considerable size that makes preventative measures very cost-efficient.

Participants in an International Karolinska Institute Symposium on Environmental Health (Lindvall and Radford, 1973) concluded in consensus that in terms of the numbers affected, annoyance due to exposure to environmental factors is probably much more widespread than overt toxic effects arising from chemical or physical agents. Avoidance of toxicological effects alone is not an adequate criterion for a suitable environment. From the medical point of view the participants declared the term "annoyance" implies an effect which may not be demonstrably pathogenic but which involves a negative factor for the individual's comfort and well-being.

The Swedish Work Environment Commission (1976) stated that the aim of limit values must be to prevent workers being exposed to harmful or unpleasant effects and that perceived discomfort caused, for example, by odour sensation may be of importance.

According to ASHRAE (1989) it has been customary to assume as a first guide that a level of one tenth of the Threshold Limit Value for a compound would not produce complaints in an office environment. It is recognised that this value may not provide a satisfactory environment to individuals who are extremely sensitive to an irritant. It also states that indoor air can be considered acceptably free of annoying contaminants if 80% of a panel of at least 20 untrained observers deems the air to be not objectionable under representative conditions of use and occupancy. It is likely that the latter procedure will be more limiting than the method employing fractions of the Threshold Limit Value. However, the method using observers is only a test for odours. Many harmful contaminants will not be detected for example carbon monoxide and radon are two examples of odourless contaminants.

Molhave (1990a) has proposed tentative guidelines for indoor levels of volatile organic chemicals. A no-effect level of 0.16 milligrammes per cubic metre is suggested. A multifactorial exposure range is said to possibly exist between 0.2 and 3 milligrammes per cubic metre. Above 3 milligrammes per cubic metre discomfort is expected and above 25 milligrammes per cubic metre toxic affects may appear. In controlled exposure experiments, odours were significant at 3 milligrammes per cubic metre.

Seifert (1990b) proposes a guideline figure for total volatile organic chemicals of 0.3 milligrammes per cubic metre. Compounds are assigned to one of seven groups of compounds and the following conditions must also be observed: no individual compound should exceed 50% of the concentration allotted to its own class or 10% of the total concentration. This proposal is not based on toxicological considerations but Seifert concludes that it is achievable taking into account current findings in the literature. The proposal, he also states, does not exclude the fact that additional guideline figures may be needed for individual compounds. The figures recommended are also intended for "normal" operating conditions. If renovation work has been carried out, then for periods of 1 week and 6 weeks, 50 and 10 times these values would be acceptable.

Greenwood (1990) presents information to suggest that a guideline value for isoparaffinic hydrocarbons in indoor air should not be as low as that proposed by Molhave for volatile organic chemicals as a group.

Although many countries have set standards for outdoor (ambient) air pollutants worldwide there are no standards for indoor air pollutants (Seifert, 1990b). Seifert suggests two reasons against the setting of standards for chemicals and microorganisms in indoor air:

- the existence of a standard favours the impression of having a a limit below which there is no reason for concern;

- the enforcement of a standard is virtually impossible due to the large number of closed spaces.

A further difficulty results from the large variety of conditions encountered within buildings. A room may meet the requirements of a standard at 20°C but not at 23°C. However, both temperatures are within the range of thermal comfort and an individual cannot be constrained to live at 20°C simply because the standard would be met at that temperature.

Seifert (1990b) prefers the use of guidelines. He considers that these are less binding than standards and are more likely to be agreed upon by different countries, in contrast to standards, because they generally will not take into account socio-economic or political aspects. A strategy that includes two values can be adopted. While the first value would define the level of hazard, the second would indicate a target value for the future. In the Federal Republic of Germany, this strategy has recently been applied for tetrachloroethene in the air of rooms next to dry-cleaning shops (Federal Health Office, 1988). From toxicological considerations a value of 5 milligrammes per cubic meter has been set below which no immediate action such as closing the shop was considered necessary. However, preventative control measures were recommended to lower the concentration down to a target value of 0.1 milligrammes per cubic metre.

In a paper by Gammage *et al* (1989) a number of empirical guideline figures are given for screening purposes. These include 1000 parts per million of carbon dioxide to screen for outdoor air supply, 500 colony forming units per cubic meter of microorganisms to screen for sanitary conditions and 1 part per million of volatile organic compounds to screen for active sources of these chemicals.

Air quality standards and guidelines are listed in Tables 2-4. Figures such as these are used by investigators to assess levels of indoor contaminants. Ambient air quality standards commonly are designed to protect the general public to within an adequate margin of safety. For the protection of children, the elderly and the disabled, building codes in certain countries prescribe, for dwellings and public spaces, either specific limit values (at that time only radon and formaldehyde) or the use of fractions of occupational exposure limits (Sundell 1982). However, care has to be taken in the application of air quality standards and guidelines. Peterson (1988) undertook an analysis of the data used in the derivation of various ambient air quality standards. From this he concluded that those for carbon monoxide and ozone are based on the toxicology of the materials and thus are suitable for use in evaluating indoor environments. However, those for suspended particulate matter, nitrogen dioxide and sulphur dioxide are strictly empirical and therefore he states that these should not be used for anything but their first, intended purpose. The standards for non-methane hydrocarbons are based on photochemical smog production and therefore have no utility for indoor environment evaluation.

Guideline values and standards should not be taken to represent sharp cut-off values below which no adverse effects will ever occur. In addition, the basis for each guideline should be determined to see whether it is applicable for the situation under investigation. The sampling and analytical techniques employed should, under similar conditions, also give comparable results to those which would obtained if those which were used when the guideline was established.

BUILDING INVESTIGATION PROTOCOLS

Advice on how to carry out building associated investigations is given in two recent reports (Molina *et al*, 1989 and Valbjorn *et al*, 1990a). Both of these documents recommend a stepwise approach and describe how this can be undertaken.

Most large scale investigations of buildings have relied on comparisons between buildings which necessarily involves many confounding factors (Leinster *et al*, 1990). These authors describe an investigation based on the systematic modification of environmental conditions in a building, with simultaneous double blind monitoring of occupants' responses to the changes. The occupants, and the investigators carrying out the occupant surveys, were not informed of the nature of the changes that were introduced nor of when they occurred. Catch trials were also undertaken. In this study different changes were carried out in different rooms in a series of study "modules", including a control module. A double blind study was also used to investigate the effects of changes in the ventilation rate within a building (Menzies *et al*, 1990). In an investigation of the effect of air humidification, a 6 period cross-over was utilised (Reinikainen *et al*, 1990) whilst in a study of air recirculation a double blind four period cross-over study was used (Jaakkola *et al*, 1990). A study which looked at the same population working in both in a naturally ventilated building and in an air conditioned building is repoted in a paper by Robertson *et al* (1988).

Questionnaires used in the study of problems within buildings vary considerably in their definitions of symptoms and in the response scales used. Hedge (1990) reports a comparative analysis of 8 questionnaires and discusses the need for a standardised format. Hansen (1987) states that it is essential to use occupant questionnaires to check that remedial action is effective. Appleby and Bailey (1990) recommend caution in the comparison of building sickness scores obtained by different investigators since there is no accepted standard list of symptoms for use in questionnaires. Occupant surveys and environmental monitoring should be carried out concurrently.

A compendium of measurement methods has been compiled by the EPA to provide standard operating procedures and technical assistance (Berry 1990). Monitoring methods have been recommended for volatile organic chemicals and nicotine (EPA 1990).

Leinster *et al* (1990) found significantly higher levels of airborne contaminants on occasions using personal monitors compared with samplers placed at fixed locations within rooms. This emphasises the need for the actual conditions to which individuals are exposed to be assessed and not just the general background conditions.

AIRBORNE CONTAMINANTS

A summary of contaminants which are commonly found in indoor air together with possible sources, effects and the level at which such effects might be expected is given in Table 5 whilst factors which have an indirect effect on the indoor environment are presented in Table 6. Suggested remedies for potential problems are given in Table 7.

Mant and Muir Gray (1986) summarise the main chemical pollutants found within the indoor environment under the following headings; metabolic products (including water vapour, carbon dioxide and body odour or bioeffluents), combustion products and organic compounds.

Sykes (1988) includes building occupants, building fabric and furnishings, office machinery, and heating, ventilation and air conditioning (HVAC) systems amongst the most important sources of indoor chemical pollutants. Smoking is also considered to be an important source (Mant and Muir Gray, 1986; Knoppel, 1989).

Particulates

No correlation has been shown between levels of total dust and SBS (Molina *et al*, 1989). Harrison *et al*, (1990) point out that while adverse health effects are more commonly reported in buildings with HVAC systems, levels of airborne particulates are generally lower than in naturally ventilated buildings providing the air conditioning system is properly maintained.

Probably the most well known and best documented health risks are associated with asbestos fibres. Asbestos is a naturally occurring mineral fibre known to be carcinogenic and to cause chronic lung disease. It has been widely used in the past in the office environment. Corn (1990) calculated the risk to occupants from background levels of airborne asbestos in non-school buildings to be 0.43 premature deaths per million workers exposed over a twenty year period. He considers that this is insignificant compared to other commonplace risks faced in life.

Man-made mineral fibres (MMMF), manufactured from ceramics, glass and rock are now often used in insulation products, building materials and fabrics as an alternative to asbestos. These have been a cause for concern in some situations especially where they are used within air ducts for noise attenuation purposes due to the eye and skin irritation effects which can be produced by exposure to the fibres.

Tobacco smoking generates significant levels of particulates as well as gas phase pollutants, some of which are known carcinogens. These are typically respirable, but a study of the uptake of pollutants among an exposed population carried out by Scherer *et al* (1990), using several common biomarkers including carboxyhaemoglobin and urinary excretion, suggests that exposure to the particulate fraction of environmental tobacco smoke (ETS) is low. Another study (McAughey *et al*, 1990) found that the dose to the bronchial region of the lung was much less than expected from epidemiological estimates, but that further work is needed to determine the physical and chemical properties of particulate ETS before a risk assessment can be provided. This study indicates that the specific physical and chemical properties of airborne particulates are critical to health effects among an exposed population as well as the total volume inhaled. Clausen *et al* (1987b) found that particle filtration of ETS did not reduce irritation to the eyes, nose and throat.

According to Fishbein and O'Neill (1987) the major sources of metals in indoor environments are cigarettes, fuel consumption, dust and consumer products, with lead, nickel, cadmium and arsenic being of primary toxicological importance. Kulmala *et al* (1987) determined the chemical constituents of particulate samples collected indoors and indicate the proportion of sulphur, potassium, calcium and iron found.

Levels of particulate contamination within the office environment are affected by the ability of the HVAC system to remove particulates from the supply air, by the presence of internal sources and by settled dust becoming airborne. There is evidence that adverse health complaints can be reduced by filtering air as it enters the room, rather than when it enters the air conditioning system. This suggests that there can be significant contamination of the supply and recirculated air by the air conditioning system (Shen, 1990). Dusts can become airborne as a result of the activities of people in the office, the nature of the work undertaken, the office cleaning regime and the activity of the HVAC system. A significant proportion of indoor particulates are external in origin and overall mass concentrations are frequently similar in magnitude (Mant and Muir Gray, 1986). Weschler and Shields (1987) found that particles of different sizes came from different sources. The fine particles infiltrated in from outside whereas the coarse particles were generated within the office environment, probably because coarse particles of external origin were arrested by filtration of the incoming air.

Owen *et al*, (1990a) identified six major source types of indoor particulates in their review of the literature; plant, animal, mineral, combustion, home and personal care and radioactive aerosols. Plant and animal aerosols include pollens, spores, moulds, bacteria, viruses and miscellaneous by-products such as hair and insect parts. Gravesen *et al* (1990) found that there was a high correlation between the quantity of potential immunogenic components in dust and mucosal and general symptoms of SBS.

Mineral aerosols include asbestos, carbons, clays and man-made fibres. Man made mineral fibres can enter the office environment with the outside air or can be generated in ventilation systems or within the office, for example when ceiling boards are damaged. Shumate and Wilhelm (1990) found that both fibreglass and organic fibre filtration media used in air conditioning systems shed fibres, some of which were respirable. The rate of shedding fell over time. However, the rate of shedding, even at its peak, was reported to be negligible compared to the levels of particulates present in unfiltered air.

Sources of combustion aerosols include tobacco smoke, heating appliances and industrial plants. These particles are usually within the respirable range and therefore significant in terms of occupant exposure. Various estimates (Ogden *et al*, 1990) have shown that in areas where smoking is allowed, approximately one half of the respirable dust is from tobacco smoking, although the figures will be heavily dependant on the presence of other sources of particulates. Krafthefer and MacPhaul (1990) and Sammaljarvi *et al* (1990) have shown that particulates are generated by both high and low heat resistance type heaters such as bar heaters. The particles are probably produced when background particulates come into contact with the heated element and are pyrolysed which suggests that the amount produced will depend on the background particulate load. The particles generated are smaller than background particulates and so are more likely to cause adverse health effects.

Office cleaning can be an important source of internally generated particulates and is a function of the frequency, timing and quality of the cleaning techniques and equipment used. If the office is vacuumed daily, the timing of this will have an effect on occupant exposure. Dust stirred up by vacuuming is more likely to settle out before the offices are occupied if cleaning is carried out in the evening whereas there might be a significant residual level of airborne dust during working hours if vacuuming is carried out in the morning. Smith *et al* (1990) found that a standard vacuum cleaner emitted on average 9.1×10^{10} particles per minute in the range 0.01-10 microns during vacuuming. The type of final filters fitted to vacuum cleaners can have a significant effect on the levels of particulates which are generated during cleaning activities.

Gases and Vapours

Combustion products include carbon monoxide, nitrogen dioxide, sulphur dioxide and the gas phase components of environmental tobacco smoke. Carbon monoxide is produced by the incomplete combustion of fuel and can reach levels sufficient to cause death when unvented appliances are used in rooms with inadequate ventilation. This is unlikely to occur in office buildings. Nitrogen dioxide is a minor byproduct associated with the combustion of common fuels and is an irritant. Wanner *et al* (1990) found the frequency of respiratory symptoms in Switzerland was higher if the ambient level of nitrogen dioxide was elevated, but there was no correlation with indoor fluctuations. It has been suggested that nitrogen dioxide may be absorbed onto surfaces in a building and may be converted into nitrogen monoxide (Grundel *et al*, 1987). Nitrogen monoxide has less adverse health effects than nitrogen dioxide (Grundel *et al*, 1987), but it is not clear whether a similar process might result in the generation of significant levels of nitrous acid indoors.

Epidemiological and clinical studies suggest that respiratory health may be damaged by airborne acidity from any source (Brauer *et al*, 1990).

Many of the gaseous components of environmental tobacco smoke, which include organic compounds, carbon monoxide and nitrogen dioxide, have known health effects ranging from irritancy to carcinogenicity. Mant and Muir Gray (1986) report that a number of studies have indicated a positive risk association between exposure to tobacco smoke and an increased relative risk of lung cancer, although the level of significance which can be applied to the findings is currently a matter of debate. SBS is more pronounced in smokers than in non smokers (Skov *et al*, 1987) and people exposed to ETS show more symptoms (Robertson *et al*, 1988). In order to avoid any annoyance or health risk Schlatter and Wanner (1987) consider that it is necessary to separate smokers and non smokers. However, they consider that the avoidance of acute irritating effects in healthy people can be achieved by means of ventilation strategies. Kay *et al* (1990) found that ETS affected non-smokers' breathing patterns and responses to odour strength and that it caused eye and throat irritation and general annoyance.

Concern over ETS, formaldehyde and wood preservatives in particular has focussed attention on organic compounds in general but knowledge of health effects from exposure to organic compounds is sparse. Because of the large number of species reported, researchers usually restrict their work to a fraction of the total range of organic compounds, categorised according to the chemico-physical properties of that fraction into semi-volatile organic compounds (SVOC), which are distributed in air between the particulate and vapour phases and therefore combine characteristics of particulates and gases, volatile organic compounds (VOC), very volatile organic compounds (VVOC) and particulate organic matter (POM). The only documented definition for classification into these different sub-groups is provided by the World Health Organisation (1989b). One estimate suggests that 85% of the organic chemicals in indoor air are usually found in the vapour phase, and 15% in the particulate phase (Oehme and Knoppel, 1987).

The WHO (1989b) publication also provides a review of current knowledge of health effects associated with organic chemicals in the indoor environment. These range from responses to odours and irritation to carcinogenic effects. Humans cannot usually differentiate between an odorant and an irritant effect (WHO, 1989b). Irritancy effects can be a response to an accumulated dose whereas odour perception is usually immediate. Respondents are usually unable to identify a single source of response but eye and nose irritation seem to occur most frequently. The sensation of irritation is influenced by a number of factors such as previous exposures, skin temperature and humidity or diet and medication (WHO, 1989b). Individual sensitivity to the same stimulus can vary by up to one thousand times. Irritancy effects include subjective symptoms and objective signs of conjunctivitis, sneezing, coughing, hoarseness, a feeling of dryness of mucosal membranes, skin erythema or oedema and changes in breathing patterns. There do not at present seem to be any comprehensive studies of the irritation interactions caused by mixtures of chemicals (WHO, 1989b).

The concentrations of organic pollutants found in the indoor environment are usually much closer to the levels at which sensory effects occur rather than systemic toxic effects (WHO, 1989b). The dose response information available for organic compounds suggests that sensory effects have a concentration threshold below which the response does not occur (WHO, 1989b). Acute toxic effects are therefore unusual in the office environment, but organics may cause odours and mucosal and sensory irritation at indoor air levels (WHO, 1990). Sterling *et al* (1987) found no difference in VOC concentration in rooms with or without complaints.

It has been postulated that there may be synergistic relationships between volatile organic chemicals which might lower the level at which health effects occur to well below that measured for single substances. It is possible that low concentrations potentiated by other factors, may become important or that it may be concentration gradients rather than total concentrations that trigger adverse health effects (Molina *et al*, 1989). Morey and MacPhaul (1990) noted that atypical profiles of ranked individual volatile organic compounds were found in buildings with a large number of complainants and concluded that the individual species present should be investigated rather than just the total level of volatile organics. Several authors (Broughton *et al*, 1990; Watanabe *et al*, 1990; Levitas and Gallagher, 1990; Matsushita *et al*, 1990) have reported the usefulness of bioassays for evaluating the mutagenicity of indoor airborne contaminants, especially as it is said to allow an evaluation of health effect or risk to be made without having to consider the individual compounds present. This technique may also enable the synergistic effects of exposure to low levels of a range of contaminants to be determined.

Molhave (1990b) suggests that as only the frequency of irritation of mucosal membranes and headaches seems to differ significantly between sick buildings and non sick buildings and VOCs are known to have a potency to cause these symptoms, it is likely that VOCs are at least a contributory factor to SBS. However, De Bortoli *et al* (1990a) found during an investigation of the indoor air quality in office buildings of the European Parliament that levels of organic vapours and formaldehyde in particular did not correlate with complaint rate. Knoppel (1989) produced a summary of available knowledge on the health effects associated with organic compounds which indicates the limit of current knowledge.

Recent evidence suggests that some of the adverse health effects associated with the office environment may be the result of chemical hypersensitivity. Clinical evidence has suggested that exposure to environmental chemicals is a possible cause of chemical hypersensitivity in some cases (Small, 1990). The evidence does not support, however, the premise that indoor chemical exposures are in all cases the fundamental cause of the hypersensitivity.

Bach *et al* (1987) showed that exposure to formaldehyde at levels of 0.4 and 1.2 milligrammes per cubic metre under controlled conditions may cause acute central nervous system effects. It also appeared to be the case that subjects with long term formaldehyde exposure seemed to have a poorer mental performance than matched control persons. A significant increase in symptoms has been shown to occur at concentrations above 0.3 milligrammes per cubic metre of formaldehyde in indoor air (WHO, 1987). Broughton *et al* (1990) found evidence to suggest that chronic exposure to formaldehyde caused activation of the immune system and suggested that individuals with polysymptomatic health complaints resulting from polluted indoor air may have a subtle but chronic activation of the immune system.

Pollutants can be drawn into the office environment from outside or can be generated from a large variety of sources within a building (Wolkoff and Neilsen, 1987). Baldwin and Farrant (1990) found that occupants and their actions generate substantial amounts of volatile organic compounds within the office environment, and these are strongly affected by energy saving measures and changes in ventilation. Tsuchiya and Stewart (1990) measured volatile organic compounds in the air in Canadian buildings and found that while each building had a different fingerprint of chemicals, in 18 out of 28 buildings, emissions from wet process photocopiers were significant and in 8 buildings, these emissions accounted for 90% of the total volatile organic compounds detected. Ventilation can also increase the level of some contaminants within the office environment by drawing them in from outside. Weschler *et al* (1990) have shown that indoor levels of ozone are dependent on outdoor levels and ventilation rates. While the indoor levels were always lower than those recorded outside, the ratio varied from 20 to 90% of the outdoor level, depending on the ventilation rates used.

The ventilation system itself can also be a significant source of indoor air contaminants. Pasanen (1990) found that where air conditioning filters were heavily contaminated by microbial growth, volatile metabolic products were produced by the microorganisms. Light odorous organic acids and aldehydes were identified as being released from the filters regardless of the filter medium.

Brauer *et al* (1990a) showed that outdoor levels of sulphur dioxide, nitric acid, hydrogen ions and sulphate ions were higher than those recorded inside. They suggest that either external sources are more important than indoor ones or that neutralisation might be occurring indoors. Brauer *et al* (1990b) also pointed out that while levels of nitrogen dioxide in particular have been extensively investigated both inside and outside, little attention has been given to its fate indoors. Continuous monitoring of nitrous acid revealed higher levels indoors than outside, which may suggest indoor production of nitrous acid through heterogeneous reactions involving an external source of nitrogen dioxide. The authors were highlighting the possibility of significant chemical reactions occurring indoors. Ryan and Koutrakis (1990) state that the increased surface to volume ratios, the presence of reactive surfaces and the lower levels of nitrogen dioxide found inside rather than outside suggests that chemical modification of the pollutant mix may occur within a building. Yanagisawa *et al* (1990) showed that three building materials commonly used in offices, gypsum board, masonite and cement, all adsorbed significant amounts of nitrogen dioxide, although the rate depended on the humidity present.

Heating and combustion processes can generate pollutants if poorly ventilated. Naudeix (1987) reports that instant gas water heaters of the type commonly found in offices can, in a confined location reduce the oxygen availability by production of carbon dioxide during combustion to such a level that subsequent combustion generates carbon monoxide instead of carbon dioxide. Convector heaters, in which air comes in contact with the heating element, have also been reported to generate a small amount of oxides of nitrogen and ozone (Sammalijarvi *et al*, 1990).

The variation in levels of pollutants within the office environment over time has been investigated by Wolkoff (1987) as part of the Danish Town Hall study. He found that the levels of total volatile organic compounds were strongly time dependant due to changes in activity during the day. The ratio of maximum to minimum levels of total volatile organics measured during a single day ranged from 2 to 15, the level of formaldehyde varied by 40% and the levels of dust followed a similar pattern. Berglund *et al* (1990a) found that the change in the prevalence of 8 SBS symptoms over the day showed a strong relationship with the mean concentration of 24 VOCs measured in exhaust air.

At night or over weekends, some HVAC systems operate with a minimal level of fresh air intake in order to reduce energy costs. This can allow a significant build-up of pollutants to occur which may result in adverse health effects once the building is reoccupied.

Pesticides

Information on pesticide exposure indoors is sparse (WHO, 1989). A study of pesticide pollution in the home (Camann *et al*, 1990) showed that soil track-in was the source of about half of the pesticide level measured in indoor air. In offices with heavy traffic, this may also be a significant source of a number of pollutants. Barbieri *et al* (1990) showed that where pentachlorophenol (PCP) had been used for wood treatment, it remained a significant source of pollution for a long time.

Biocides

The WHO (1990) concluded that the use of biocides in the cleaning and maintenance of HVAC systems or surfaces in buildings presents adverse health risks. Burge (1990) states that there is increasing evidence that biocides such as thiazolones, glutaraldehyde, chlorhexidine, benzalkonium chloride and chloramine at low concentrations can cause symptoms similar to building sickness.

Radon

Radon, part of the Uranium 238 series, is a gas which is formed as a radioactive decay product of radium, a substance which is widely distributed in the earth's crust and is present in nearly all soils and in building materials derived from them. The release of radon into air leads to a build-up of its short lived radionuclides (*ie* radioisotopes of polonium, bismuth and lead). Most become attached to dust particles, forming radioactive aerosols. A great variability in the concentration of radon and radon daughters is found indoors (Campos Venuti and Piermattei, 1989). However, little has been written on the significance of radon within offices.

According to Campos Venuti and Piermattei (1989) the radiotoxicity of inhaled radon is less than that of inhaled non-gaseous radionuclides such as radon daughters but because of their very short half lives, most radon daughters decay in the respiratory tract giving rise mainly to a radiation dose to the bronchial epithelium. Various authors suggest that the presence of ETS particulates in indoor air results in a longer residence time in air of radon progeny (Moghissi *et al*, 1987; Pritchard and Strong, 1990), but there is disagreement on whether this actually leads to a higher dose to occupants or not. Moghissi *et al* (1987) and Periasamy *et al* (1990) argue that the inhalation of radon progeny attached to indoor aerosols poses a serious health risk.

The effective dose received by exposed persons may therefore depend on the availability of airborne dust particles in indoor air. Removal of indoor aerosols should therefore reduce the health risk. Periasamy *et al* (1990) calculated that the lifetime risk to health from radon and its progeny was reduced by between 32% and 93% by the action of air cleaners, depending on the type of cleaner.

At present it is estimated that at approximately 2 millisieverts per year natural radiation exposures account for about 80% of the average annual effective dose equivalent received by members of the general population in the Member States of the European Communities. The single largest component of this dose, at about 40% of the total, arises from the irradiation of lung tissue following the inhalation of airborne radon daughter products in the indoor environment (McLaughlin, 1988).

The contribution to indoor radon due to building materials is usually minor in comparison to that from ambient sources of the gas itself (McLaughlin, 1988), but this does depend on the building materials used. Battaglia, *et al* (1990) found that in Italy, coal ash and pozzuolanic cements provided a significant source of radon release when used as building materials. Bonetti *et al* (1990) also found that the radon concentration in pozzuol cements was high.

Gammage and Wilson (1990) compared the use of passive mitigation procedures for use in residential buildings, such as the sealing of cracks and services in the basement area with active measures such as installing subslab barriers and de-pressurisation below this.

Reductions of 40-80% in indoor radon levels were achieved in the former case, but sometimes additional, active measures were needed to reduce the level further to within acceptable limits. All the methods were stable over a one year period. Kunz (1990) also found that subslab suction was a very effective because it not only reduced the radon soil content but also caused an air flow out of the basement or lowest level in the building which prevented radon gas entering the occupied space. Brennan *et al* (1990) found that for schools and commercial buildings in the USA, the air conditioning systems were usually far more complex than in residential properties and in the majority of cases, if the ASHRAE ventilation standards were met, then the indoor levels of radon would be acceptable. In the few instances where this would not be the case, it was considered that soil depressurisation (subslab suction) could be used successfully to reduce radon concentrations to within acceptable levels.

Microorganisms and other Biological Contaminants

A WHO working party, set up to consider the state of knowledge regarding suspended viable particles, suspended allergens and other biologically derived suspended material, has produced a review (WHO, 1990). They considered that suspended allergens may be the most significant cause of adverse health effects. Sources of biological contaminants in indoor air and their relative importance are listed in the WHO report (1990).

Biological airborne contaminants include pollens, spores, moulds, bacteria, viruses and miscellaneous by-products. Most pollens, spores and moulds are of outdoor origin but may accumulate or multiply within the office environment. Where there is no significant indoor source and the air filtration system is effective then the levels of fungi will be higher outside than they will be inside. Holt (1990) showed that the ratio of indoor levels of airborne fungi to outdoors was 31% in office blocks in which there were no complaints. Levels of bacteria are usually higher indoors than out because office occupants are a significant source. People continually shed skin cells, most of which will carry resident bacterial populations. Bacteria are also released from the respiratory tract during coughing, sneezing and talking.

Measured levels of total airborne bacteria and fungi may not show a correlation with symptom prevalence because total counts of either may obscure the presence of the causal agent (Burge, 1990). Morey (1990) argues that species identification and ranking is essential in order to correlate symptom prevalence and levels of airborne bacteria and fungi.

A range of adverse health effects which are sometimes associated with, or caused by, biologically derived aerosols as listed and amplified in the WHO publication (1990) is: rhinitis, sinusitis, otitis, conjunctivitis, pneumonia (including Legionnaires' Disease), asthma, alveolitis, humidifier fever, bronchopulmonary aspergillosis, contact dermatitis, atopic eczema, contact uticaria, mycotoxicosis. Possible adverse health effects can be subdivided into those caused by allergic or pseudo-allergic response, infection or toxic response to biological products.

Morey (1990) suggests that microorganisms are found in reservoirs and amplifiers but must be disseminated to the breathing zone to cause illness. Moulds flourish indoors on specific nutrients. Organic material, damp walls, damp leather, cotton, paper, fireproofing material, furniture stuffing, carpets, house dust, house plants and air conditioning units all support abundant growth of *Penicillium* and *Aspergillus* spores and are therefore potential sources of airborne fungi indoors (Terkonda, 1987). Another specific hazard relates to the inhalation of mycotoxins, *ie* toxic compounds produced by certain species of filamentous fungi. Exposure to abnormal concentration of spores, mycelial fragments of toxigenic fungi or substrate particles should be considered hazardous (WHO, 1990).

Martikainen *et al* (1990) demonstrated that the dust collected on ventilation filters provided a readily useable source of nutrients for microbiological colonisation as long as a sufficient source of moisture was available. Staib *et al* (1987) found that the major sources of invasive fungal pathogens were potted plant soil and bird droppings.

Strom *et al* (1990) state that building materials often contain microorganisms before use which cause adverse health effects in occupants after the materials are incorporated into a building, especially if they are kept in humid conditions. Growth is reported to be especially high in plastic sheeting and mineral wool.

Humidifiers and chillers can become contaminated with microorganisms and are an important potential source of them. Experimental exposure of individual symptomatic workers to humidifier antigens can induce headache, rhinitis and lethargy, as well as asthma and alveolitis; similar exposures did not cause symptoms in previously unexposed workers (WHO, 1990). Maroni (1989) reported that there has been a recent interest in the incidence of infectious disease engendered by unhealthy housing conditions as a result of the discovery of new pathogenic organisms which are able to multiply and spread in buildings. Moreover, an increased frequency of illness caused by biologically derived materials through immunological mechanisms has been registered in the population. He suggests that biological contaminants in building air account for a substantial proportion of absenteeism in schools and workplaces. Schata *et al* (1987) state that 38% of all allergic disease in the Federal Republic of Germany is caused by sensitisation to moulds.

Airborne viral infections can also occur in the indoor environment (WHO, 1990). Infection may be introduced to a previously unaffected workforce or infections may be spread within the office environment. It has been shown experimentally that the half life of rhinovirus-14 (causative agent of the common cold) in air following nebulisation of a viral suspension may be as long as 14 hours, which would suggest that it could easily be spread throughout an office building. However, 80% relative humidity was required to achieve this. At 50% RH the infectivity of the airborne virus was quickly lost. All of the viruses found within the indoor environment are reported to come from the human respiratory tract (Terkonda, 1987). The enhanced spread of pathogenic airborne organisms through ventilation systems has been alleged or documented for a number of pathogens (WHO, 1990).

Harrison *et al* (1990) showed that there was a positive correlation between symptom prevalence in office buildings, especially blocked noses, dry throats and dry skin and levels of airborne fungi .

The length of time plant and animal aerosols remain airborne is a critical factor in their potential to cause adverse health effects. Infective effects will only occur whilst the aerosols remain viable but allergic effects do not depend on viability. Pollen and spores tend to be seasonal and generally too large to remain airborne for long. Bacteria and viruses are small and likely to remain airborne for much longer periods of time. Viruses are so small that they can pass through most filters. Yoshizawa and Sugawara (1990) investigated the effect of different parameters on airborne microbiological particle concentration and settlement. Ceiling height and ventilation rates were the most important factors, with ceiling height increasingly significant as particle size increased.

Indoor allergens are usually derived from pollen, microfungi, animal dander, hair and food leftovers. In the office the two major sources of allergens are organic dusts and viable microorganisms. In the 1960s it was recognised that mites which live in bedding, carpets and household dust produce allergens that cause allergic asthma in humans. Recent research has suggested that significant numbers of mites might also be present in the office environment and that these may be a contributory factor to sick building syndrome (Leinster *et al*, 1990). Survival of mites in the natural environment is based on food supply, temperature and humidity. It has been reported that if the average relative humidity is less than 60% then mites are practically absent. However, recent changes in the way offices are furnished may have provided microenvironments in which the mites can survive, such as chairs in which the localised humidity is likely to be much higher than the background level (Leinster and Marshall, 1991).

PHYSICAL FACTORS

A summary of some of the physical factors that affect the indoor environment together with effects, or presumed effects, are given in Table 8 whilst factors which have an indirect effect are presented in Table 9. Suggested remedies for potential problems are given in Table 7.

Ventilation

The ventilation system within a building is often regarded as one of the most significant factors to be considered when undertaking an investigation to ascertain the cause of complaints (Sykes 1988). SBS most often affects buildings which have mechanical ventilation or air conditioning. This can lead to the presumption that lack of fresh air is a major cause of SBS.

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 they allow little personal choice or local control;

- the make-up air supply into mechanical ventilation systems can be restricted, thereby increasing 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.

An adequate fresh air supply is required within the office environment for two reasons. Firstly, a rate of around 0.5 litres per second fresh air is required per person to maintain a satisfactory level of oxygen and carbon dioxide (HSE, 1988). Secondly, a much higher supply rate of fresh air is required to remove bioeffluents, smoking products and other contaminants of the indoor environment. Ventilation although not necessarily fresh air may also be required to maintain personal comfort, ie, for the control of air temperature. Valbjorn *et al* (1990a) state that at least 4 litres per person per second outside air is required and that at ventilation rates of above 8 litres per person per second, adverse health effects seem to be rare. However, the office illness project in northern Sweden found that there was no correlation between ventilation rates and symptoms of SBS, although the ventilation rates recorded were higher than expected and about double the ASHRAE standard (Sundell *et al* 1990). This study did however find significant correlations between air flow and increased symptoms such as fatigue, headaches, eye symptoms, nasal symptoms, throat symptoms and facial skin symptoms among certain subgroups in the office population.

Berglund *et al* (1990b) indicated that the percentage of recirculated air is especially important in controlling airborne concentrations of use related pollutants. When there was a 100% fresh air supply, variations between pollutant levels in the morning and afternoon are small, whereas when only 25% of the air supplied to the occupied space is fresh, there was a two to three fold increase over the course of the day. This is important because adverse health complaints often follow a similar pattern. Jaakkola *et al* (1990) found that 70% recycled air can be used without causing adverse health effects. The level of fresh air intake also affects the level of pollution from background internal sources and often results in elevated levels in winter when the fresh air supply is cut down in order to make space heating more effective.

Berglund and Fobelets (1987a) found that the temperatures preferred by occupants increased with air speed at flow rates of greater than 0.25 metres per second. The same authors (1987b) found that within 2 metres of a cold, unheated, perimeter wall there is the potential that a substantial fraction of the occupants will feel an uncomfortable draft on their feet. Fanger *et al* (1987) found that the percentage dissatisfied due to draught was a function of both the mean velocity and the turbulence intensity of the air movement. Air flow with high turbulence causes more complaints than the same air flow with low turbulence.

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 Institute of Building Services Engineers (1978) and British Standard (BS) 5720 (1979) set a standard which ranges from 5 litres per second per person in general offices up to 25 litres per second per person for personal offices or boardrooms where smoking is heavy. In the USA, the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) standard is most widely accepted. In 1981 the recommended rate was 2.5 litres per second per person (7.5 litres per second per person for offices where smoking was permitted). The latest ASHRAE (1989) standard requires 10 litres per second per person for offices. However, as Appleby and Bailey (1990) conclude, the provision of outdoor air at a rate in compliance with national standards does not guarantee an acceptable quality of inhaled air. They consider that it is essential that the method of creating room air movement is capable of reducing contaminant concentrations in the inhaled air to an acceptable level either by dilution or displacement.

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. Youle (1986) and Waller (1984) detail a number of 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. Collett *et al* (1988) also describe several case studies in which the cause of the health and comfort complaints was traced to correctable problems with the ventilation system. A study in which the same population were compared whilst they were subjected to two types of ventilation is described by Robertson *et al* (1990). There was a significant rise in complaints of SBS on moving from a naturally ventilated to an air conditioned office. There was however only a slight improvement on going from an air conditioned to a naturally ventilated building. It is suggested that the interval for recovery is longer than expected or it may be that once individuals have SBS then even low levels of exposure, such as are found in naturally ventilated buildings, continue to give rise to symptoms.

The goals of achieving acceptable indoor air quality and minimising energy consumption appear to imply a compromise (ASHRAE 1989). The guidance given in ASHRAE (1989) states that the conditions specified must be achieved during the operation of buildings as well as in their design if acceptable indoor air quality is to be achieved. To facilitate this, the standard includes requirements for ventilation design documentation to be provided for system operation. The purpose of the standard is to specify minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to avoid adverse health effects. Therefore, with respect to tobacco smoke and other contaminants, the standard does not, and cannot, ensure the avoidance of all possible adverse health effects, but it reflects recognised consensus criteria and guidance. A study undertaken by Van der Meer *et al* (1990) showed that adjusting the ventilation system in combination with unsealing the windows resulted in a reduction of complaints and an increase in comfort without increasing the energy consumption. However, Yamanaka *et al* (1990) state that the air flow rate through a single open window cannot be predicted because it is determined by the turbulence of natural wind. This makes it difficult to assess the requirements of a ventilation system when it is used in conjunction with natural ventilation.

The ASHRAE standard (1989) specifies alternative procedures to obtain acceptable indoor air quality:

> **Ventilation Rate Procedure:** acceptable air quality is achieved by providing ventilation air of the specified quality and quantity to the space; or
>
> **Indoor Air Quality Procedure:** acceptable air quality is achieved within the space by controlling known and specifiable contaminants. It incorporates both quantitative and subjective evaluation.

Whenever the Ventilation Rate procedure is used, the design will need to be re-evaluated if, at a later time, space use changes occur or if unusual contaminants or unusually strong sources of specific contaminants are to be introduced into the space. If such conditions are known at the time of the original design, the use of the Indoor Air Quality Procedure may be indicated.

The Indoor Air Quality Procedure could result in a ventilation rate lower than would result from the first procedure, but the presence of a particular source of contamination in the space may result in increased ventilation requirements. Change in space use, contaminants, or operation may require a re-evaluation of the design and consequent implementation of changes.

Care should be taken to ensure ventilation air is supplied throughout the occupied zone and that an acceptable air quality is maintained at all locations.

In offices with tight building envelopes the performance of the mechanical ventilation system must be carefully monitored. The reuse of return air from smoking rooms, store rooms, photocopying rooms etc should be prohibited (Lindvall 1985).

A sub-committee of the Nordic Committee for Building Codes released guidelines for building regulations regarding indoor air quality, particularly ventilation (Sundell 1982). It was considered that verification of compliance with concentration limits was virtually impossible. Instead the chosen method was to establish requirements with regard to air flow rates and the quality of the fresh air supplied. In this way the air quality requirements were specified by indirect means. The air flow rates were specified on the basis of current knowledge regarding the types and quantities of indoor air pollutants likely to be present.

Several "temporarily sick buildings" have been reported to be "cured" by increased ventilation, amongst other measures (University of Washington, 1982). Two papers dealing with buildings that appeared to be "permanently sick" were able to show a reduction in symptoms with increased ventilation (Sterling and Sterling, 1983; Taylor *et al*, 1984). In one, the fresh air rate was increased from 6 to 20 cubic feet per minute per person; the fresh air rates were not given in the other.

Temperature

Discomfort is perceived by most people when the ambient temperature is less than 18°C but adverse health effects have not been identified until the temperature drops to below 16°C. Below this temperature, there may be an increased risk of respiratory infection. Below 12°C there is increased strain on the cardiovascular system and these changes increase the risk of myocardial infarction and stroke. The cardiovascular changes become particularly marked below 9°C. These values are based on the assumption that people are wearing clothing which is equivalent to a normal business suit (Mant and Muir Gray, 1986). It has been shown that temperature has an effect on mental activity among office workers. High temperatures can also result in thermal discomfort which may lead to a general dissatisfaction with the quality of the indoor environment. The main thermal conditions causing symptoms in workers are too high a temperature level and heat radiation to the head (Valbjorn *et al*, 1990a).

In practice, it is often useful to know the percentage of people who will be satisfied (or dissatisfied) with a particular thermal environment. Fanger (1972) has produced a comfort equation which enables the influence of various factors, on the comfort of a population, to be determined. Factors affecting the thermal environment include air movement and radiant heat. Where radiant heat is asymmetric, for example due to the presence of a cold window surface, complaints often result. Similarly, large windows facing the sun can cause uncomfortable radiant heat gain. Ikaga and Matsunawa (1990) evaluated the effect of radiant heat gain on the occupants of a room using a computer model. They showed that the percentage of people dissatisfied would be 60% near the windows and 30% in the middle of the room if there were no blinds on the windows, whereas it dropped to 16-18% when sun shades were used. The peak space cooling load was also reduced by 50% by the use of sunshades.

Relative Humidity

Sykes (1988) lists four possible reasons for the increased incidence of infection due to low relative humidity:

- humidity may affect the survival of bacteria and viruses. Airborne microorganisms are least likely to survive when the relative humidity is about 50%, but high humidities cause dampness which may encourage the growth of microorganisms;

- higher humidities encourage larger airborne particles which may be less likely to cause infection than smaller ones;

- dry air may cause microfissures in the upper respiratory tract which act as landing sites for infection;

- increased mucous flow favours rejection of microorganisms, but there is no agreement as to whether mucous flow increases or decreases at high humidity.

Sykes (1988) states that low humidity is known to cause some of the symptoms noted in sick buildings, but Molina *et al* (1989) refer to research carried out by Anderson *et al* which showed that when a population was exposed to clean, dry air, no adverse health effects were found. Reinikainen *et al* (1990) found, in a comparison of humidified and non-humidified rooms in Finland, that workers in humidified rooms reported less sick building and dryness symptoms as well as less of a sensation of air dryness, although there was no difference in the occurrence of respiratory infections. The results were adjusted for tobacco smoke exposure and history of allergic disease, but not sex.

The perceived humidity of indoor air may be more important than actual levels on occupant comfort. Arundel *et al* (1987) found that there was little correlation between low humidity and eye, nose, throat and skin irritation, although respondents reporting symptoms believed that the relative humidity was too low. Breunis and Groot (1987) found that while relative humidity correlated with occular discomfort only for contact lens wearers, the perceived humidity was strongly associated with occular discomfort among other sufferers. Göthe *et al* (1987) showed that perceptions of dry air were not correlated with humidity, but temperature. Respondents thought that the humidity was low when the temperature was high.

As with temperature, the indirect effect of relative humidity and changes in relative humidity may be more important than the direct effects, especially in relation to emission rates from building material and furnishings but also in levels of respirable suspended particulates and the build up of static electricity (Molina *et al*, 1989). Berglund *et al* (1987) stated that VOC concentrations were inversely proportional to relative humidity due to the effect of relative humidity on emission rates and consequently adverse health effects were more common in winter. Excess humidity was also reported to degrade particle board and lead to the release of formaldehyde into the office environment (Valbjorn *et al*, 1990a).

The effects of changes in relative humidity on the thermal response of wool clothing has been examined by de Dear *et al* (1987). Wool adsorbs a significant amount of moisture if transferred from a low humidity environment to a high humidity one. This is then released again, albeit at a slower rate, if the wool is transferred back to a lower humidity environment. Taking into account the buffer effect of clothing, 34% of the heat gain or loss resulting from these moves affects the wearer of the clothes. Relative humidity changes therefore may result in changes in the air temperature requirements of office occupants.

Air conditioners designed to reduce relative humidity using dessicants have been shown to reduce indoor concentrations of nitrogen dioxide, carbon monoxide, sulphur dioxide, total hydrocarbons, airborne microorganisms and particulates (Relwani *et al*, 1987; Novosel *et al*, 1987).

Reinikainen *et al* (1990) state that skin and eye dryness, allergic reactions and sensations of dryness can be alleviated by proper air humidification. Wilson and Hedge (1987) found in their office environment study that humidified buildings had slightly higher rates of symptoms than non-humidified buildings and that buildings with steam humidification had rates of complaint similar to those for buildings with no humidity controls. However, they conceded that their results were somewhat inconclusive. Zweers *et al* (1990) found that the level of humidification was related to some office environment complaints but no difference was found between spray and steam humidification.

OTHER CONSIDERATIONS

Odours

A common observation in buildings where a high prevalence of symptoms occurs is a faint but unpleasant odour. The direct source of the odour can be difficult to detect, but mould growth, new building materials, new furniture, copying machines and accumulated dust are often mentioned as sources. Apart from being an indicator of contamination the odour in itself forms a stress factor, which may contribute to the symptoms. The odour seems often to occur where materials with a large specific surface are used, *eg* fleecy material like floor carpets and hessian wall covering, but also where hygroscopic materials such as paper are present. In these materials the odour can be absorbed instead of being ventilated away and then later be given off when the climate conditions change, *eg* an increase of temperature (Valbjorn *et al*, 1990a). Dust particles can also contribute to odour problems by absorbing odorous substances, especially during periods of total air recirculation such as at night and then act as secondary sources (Valbjorn *et al*, 1990b).

Engen (1987) states that people adapt quickly to an odour, after which the perceived odour intensity is virtually unaffected by duration. First impressions are therefore all important. Background odour can be an important factor often resulting from the air conditioning system itself. However, ventilation standards assume that the occupants are the major pollutants (Lauridsen *et al*, 1987).

Van der Wal *et al* (1987) have shown that odour complaints may be caused by moisture in mineral wool, especially at high temperatures. From laboratory experiments at 50°C, higher aliphatic aldehydes, ketones and aromatic aldehydes were found to be released from moist mineral wool. Similar aliphatic aldehydes were found in rooms where complaints had been made about odour. The mechanism for the release of these chemicals was thought to be accelerated decomposition of the binder material due to moisture and high temperatures.

The derived adverse health effects of odours can include vomiting, escape behaviour, interactions with other sensory or biological systems, triggering of hypersensitivity reactions and changes in breathing patterns (WHO, 1989b). These secondary effects may increase over time if they are dose dependent.

Lighting

Good lighting, whether natural or artificial, has an important role to play. It can reduce the likelihood of visual fatigue and discomfort. Poor lighting, by making the visual system work harder, may lead to visual fatigue (eye strain) although the normal healthy eye cannot actually be "strained" by over use. The symptoms of visual fatigue vary according to the lighting conditions and the task carried out and are likely to occur whenever the visual system has to act at the limits of its capabilities for any length of time. The inadequacies of a person's visual system can also create problems. Common symptoms include:

- irritation such as inflammation of eyes and lids, itchiness;
- breakdown of vision such as blurred or double vision;
- referred symptoms such as headaches, fatigue and giddiness.

Poor lighting conditions can also cause other more indirect effects. The natural response to insufficient illuminance or veiling reflections, for example, is to get closer to the task or to look at it from a different angle. This can mean adopting unusual postures that lead to other forms of strain, such as headaches (HSE, 1987). Irritant eye effects can also be due to causes such as low humidity (CIBSE, 1989). Wilson and Hedge (1987) found that there was a greater number of SBS symptoms among occupants of poorly illuminated buildings.

Wilkins *et al* (1985) found that under conditions of fluctuating illuminance, headaches tended to decrease with the amount of available natural light. Office occupants chose to switch on the fluctuating illumination for less time than a steady illumination source (Mant and Muir Gray, 1986).

Sterling and Sterling (1983) suggested that fluorescent lighting contributes to the symptoms in sick buildings by creating a photochemical smog resulting from the catalytic action of ultraviolet radiation of organic pollutants, but they stated that there was little evidence to support this view. Sterling and Sterling (1983) also noted a reduction in eye symptoms when they varied the quantity of ultraviolet light and the ventilation but no reduction in other symptoms associated with sick building syndrome. Wilson and Hedge (1987) found the greatest number of sick building syndrome 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. Wilkins *et al* (1985) reduced the incidence of eye strain by reducing fluctuation in illumination by means of a solid state high frequency ballast.

Mant and Muir Gray (1986) also note that fluorescent lights can precipitate epileptic seizure in a minority of the population but that they are far less potent precipitants than television.

Noise and Vibration

In terms of annoyance, people vary widely in their response to a given noise situation. This is partly an inherent characteristic in that some people seem to be more sensitive than others, and partly a consequence of the fact that 'annoyance' can be caused by a number of factors and it is difficult to separate noise from the others. When considering interference with work, the effect of background noise on speech communication is the most important factor. Normal speech is carried on at a level of about 60 dB(A), so background noise approaching or above this level will demand some raising of the voice. This is tiring and can lead to difficulty or mistakes, particularly when using telephone or radio communication. In general, a noise level below 60 dB(A) will not affect ability to concentrate, speed or accuracy of mental or manual work, although some people would find levels of close to 60 dB(A) annoying. Experiments tend not to show any significant effect on work efficiency for most people below about 85 dB(A), though almost anyone would find this very annoying and regard it as tiring (Sutton, 1991).

Infrasound (0.1 - 20 Hz) may cause dizziness and nausea, but this is reported to occur at levels above 120 dB. Low frequency noise (20-100 Hz), which is found in buildings with industrial machines or ventilation plant, may cause problems. Noise, although having a relatively low A-weighted level, can contain some pure tones which may cause irritation or other disturbances (Molina *et al*, 1989) .

Vibrations produced in the neighbourhood of buildings (for instance underground railways) have also been accused of being a contributory factor. Hodgson *et al* (1987) found that there was a significant correlation between vibration and adverse health complaints. He observed that irritability and dizziness experienced by a group of secretaries working in new offices correlated significantly with the vibrations measured on their desks.

Ions

Low levels of ions exist in outside air, typically 1 in 10^{16} molecules. However, levels indoors are about one tenth of this level (Sykes, 1988). Ions are claimed to have a number of effects, including neuroticism, the removal of trace gases and the killing of microorganisms (Sykes, 1988). Positive ions are reported to increase air uptake in exercise and there is some conflicting evidence that air ions may be beneficial to asthmatics (Sykes, 1988). However, very few repeatable results have been obtained and different authors have found both positive and negative effects from artificially increasing ion levels in offices.

Chandraker and Benhama (1990) found that the negative ion density drops very quickly beyond about 1.5 meters from ionising units, which restricts the usefulness of ionisers for cleaning room air even if their benefit were proven.

Electrostatic Charge

According to Norbäck and Torgen (1987) electrostatic charge may be a causal factor in the reported high frequency of eye and airway complaints and other symptoms that correlate with the presence of wall to wall carpeting.

Linden and Rolfsen (1981) noted that users of visual display units (VDUs) can suffer from an intense prickling sensation of the skin of the face and those parts of the body not covered by clothing. They also found a number of VDU operators had facial dermatitis, which the authors suggest was probably due to the use of VDUs at work.

In other studies, environmental factors have been associated with such complaints. These include low relative humidity (20 - 30%) and the presence of a static electric field in the vicinity of the VDU (HSE, 1983).

BUILDING DESIGN AND SERVICES

General Considerations

Indoor air quality can be actively managed and improved through good building design. The primary function of good building design with regard to indoor air quality is to ensure that the building systems supply and maintain good quality indoor air and that potential internal sources of pollutants are minimised. Many factors contribute to the quality of the indoor environment and these are dependent on both the design of the building and its services and the way in which these are managed and operated (Warren, 1988).

There are two product based methods for ensuring that emissions of pollutants into the indoor environment are minimised. The first is to exercise source control and the second is artificial ageing of the building furnishings and fabrics. Product control at the design stage is becoming more common and is proving successful. Tucker (1990) outlines approaches for selecting materials and products that are unlikely to have an adverse effect on the indoor environment and states that emission rate testing and exposure modelling of materials and products has become a significant step in the design of some new and renovated office buildings. Such efforts, if coupled with appropriate attention to ventilation system design and operation, aesthetic and ergonomic factors and building maintenance, are almost certain to reduce the types of complaints that characterise sick buildings.

Plehn (1990) describes the Federal Republic of Germany Environmental Labelling Scheme for assuring that paints and varnishes offered as low pollutant products will not have a significant adverse effect on indoor air quality. The author also reports the results of an FRG research programme linked to this scheme which has found that it is possible to assess the environmentally relevant properties of paints from product composition information stored on a computer. Fredericksen (1990) suggests that an alternative to source control by selection of products and materials on criteria such as emission rates or the need for *in situ* artificial product ageing is to ensure that manufactured components are used wherever possible. These combine a number of separate products and materials in a way that is designed to prevent deterioration of the indoor air quality and allows artificial product ageing to be used before installation in a building. He cites as an example the case of internal partitions. If the mineral wool used as insulation is sealed in at the factory, if they are painted, baked and stored in a hyperventilated store room before being installed into a building and if they are provided with a smooth light coloured finish to avoid dust collection and facilitate cleaning, then the likelihood of any adverse effect on indoor air quality can be minimised. Such partitions need to be designed so that they can be fitted without modification and can have doors, windows and shelves added without having to cut the units.

Testa (1990) points out that many of the design ideas used to address indoor air quality concerns, which he identifies as relating to the air supply or to the materials used, can lead to unforseen difficulties. For instance, most "clean" materials such as ceramics and tiles tend to have hard surfaces which do not provide acoustic absorption. They are excellent transmitters of impact sound and vibrations and this may have an adverse effect on the indoor environment. Building design must consider the whole system.

Cole and Sterling (1987) state that five issues must be addressed before a more fundamental architectural response to designing office buildings for improved environmental quality will occur:

- an acceptance and comprehension of the air quality problem;

- a re-assessment of the premises of current environmental design strategies;

- access to and assimilation of reliable information;

- the justification of alternative design solutions and re-definition of costs; and

- the coordination of members of the design team.

Levin (1990) lists the major measures that can be taken to control indoor air quality by design as site planning and design, overall architectural design, ventilation and climate control, materials selection and construction processes and initial occupancy. This overall approach to office design is known as "building ecology" and according to Levin, provides the foundations for theoretical advances in building design. It is more cost effective to incorporate considerations for good air quality at all stages of the design and build than to incorporate them retrospectively.

When the office space is reconfigured, especially if floor to ceiling partitions are introduced or moved and new furnishings are added or if there are more occupants than first envisaged then the existing HVAC equipment may not cope.

Small (1990) discusses the need for, and means of, accommodating a range of human sensitivities in building design. He cites practical evidence that suggests that a combined strategy is effective. This should combine elimination of sources and reduction in individual hypersensitivities by clinical treatment. The author lists a number of measures that can be taken and modifications that can be made in order to provide an immediate decrease in the overall contaminant load for a hypersensitive individual.

Baglioni (1990) argues that source removal is just one of a number of options that need to be taken into account when designing a building. Others include cleaning and maintenance.

Emissions and Control of Sources

The quality of indoor air is a function of indoor and outdoor sources of pollution. There are sinks for air contaminants indoors such as carpets and fabrics, floors, open shelving, and other surface areas that capture and, at various rates, release contaminants into the environment. Risks to health and materials indoors can be reduced by improving air quality through control mitigation strategies.

Building fabric and furnishings can release chemicals over a long period of time. This off-gassing is usually highest immediately after construction and occupation and is usually only significant during the first few months to one year unless some other influence causes a renewed release of chemicals. For example, urea-formaldehyde foam insulation and resin coatings emit formaldehyde after application, but under normal conditions, these emissions drop off quickly. If water is present, however, the emission rates remain high for a much longer period (Rothweiler *et al*, 1987). Water and excess humidity can also degrade particleboard and cause the release of formaldehyde (Valbjorn *et al*, 1990a). Baldwin and Farrant (1990) found that organic compounds attributable to building materials decrease to a stable state within one year whereas Wallace *et al* (1987) found that the levels of total volatile organic vapours decreased after construction with a half life of 2 to 8 weeks. Wallace *et al* (1987) found that this internal release of chemicals resulted in levels of total volatile organics inside new buildings one hundred times higher than those outside. Under extreme conditions, the release of chemicals from the building fabric can continue for much longer. Schriever and Marutzky (1990) found that if wooden parqueted floors were sealed under unfavourable ventilation conditions such as with the windows closed, levels of VOCs were still elevated after 495 days. McLaughlin and Aigner (1990) found that odorous alcohols originating from a carpet migrated into the concrete floor below and were then emitted from the concrete for nine months after the carpet was removed.

Jungers and Sheldon (1987) found that not only was the release of volatile organic compounds highest immediately after construction, in agreement with other authors, but that the major constituents of the off-gassing changed over time. Aliphatic hydrocarbons accounted for greater than 60% of the total immediately after construction, whereas chlorinated hydrocarbons were prominent in older offices, presumably due to the use of solvent based office materials. Wallace *et al* (1987) also noted that levels of some chemicals such as trichloroethylene went up over time due to the activities of occupants and their use of consumer products. When renewal of painted surfaces is required, high concentrations of airborne contaminants can arise unless remedial action is taken. Völkl *et al* (1990) recommended that when coatings based on petroleum solvents are used, elevated temperatures and high air exchange rates should be used in order to minimise the airborne concentrations. Levin (1987) reported that a programme of materials and indoor air quality testing during the design and construction of a new office block in California found that carpet, workstation and office furnishings and fibreglass ceiling tiles were the products most likely to emit significant quantities of toxins and irritants. The testing programme also showed a strong correlation between material ages and emission rates. The emission rates of formaldehyde from the carpets and ceiling tiles for example dropped by ten times over the first three to six weeks of exposure to room air. Temperature, relative humidity, air exchange rates and time were found to have the most important influences on emission rates in a study by Tichenor (1987). NASA have tested emission rates from over five thousand materials used in the space programme and have generated a large data base of results. Many of these products are also used in the office environment so this is a valuable source of information (Ozkaynak *et al*, 1987). The EPA requires emission rate testing data from manufacturers and suppliers of coatings, flooring or wall coverings made from plastics, fibres or fabrics, adhesives, furniture or furnishings with a substantial amount of pressed woods or fabric, non-metallic products used in ventilation and ductwork, office machines, supplies and maintenance materials (Tucker, 1990).

The level of pollutants in the office environment is affected by adsorption onto interior surfaces as well as off-gassing from them. The loss rate of airborne particulates and chemicals to indoor surfaces depends on the diffusivity of the species and the nature of the air circulation pattern within a room (Nazaroff and Cass, 1987). Volatile organics, for instance, are adsorbed onto internal surfaces, but the effect is small. Semivolatile organics on the other hand, especially if introduced as a spray, are readily retained on textiles, and can result in elevated levels in the indoor air for a considerable period due to subsequent desorption (Seifert and Schmahl, 1987). In order to minimise emissions of VOCs from dust settling onto hot surfaces, hot surfaces should be kept below 70°C (Hirvonen *et al*, 1990). A summary of existing work on adsorption of indoor pollutants is presented in Tichenor *et al* (1990). They evaluated the adsorption potential of nylon carpet, painted wallboard, ceiling tile, upholstery and window glass. Only window glass had no sink effect, but both the type of material and the type of VOC affected the sorption rates for the other materials tested. In all cases, higher air temperatures increased both the rate of adsorption and desorption.

According to Berry (1989b) complaints related to start up operations in buildings include off-gassing of products used to construct the building or furnish it and an unbalanced heating and cooling system. Over a period of time, these problems usually are corrected by modifications in the building development, mechanical system, or the time related to off-gassing any materials. Berry (1989b) considers that after the building "break-in" period, most complaints are related to the lack of poor maintenance, cleaning, upkeep, and repair. He also states that virtually all indoor air quality problems can be managed successfully. The only exception might be a situation in which a building has been overtaken so severely by biocontaminants that it must be abandoned. The primary means of controlling and managing indoor air according to Berry (1989b) is simple: remove harmful sources. Emissions of many substances can simply be prevented by removal of the source. Examples include the outright banning of the use of tobacco products; various machines, such as copiers; or certain fabrics on furniture and walls; and carpets that emit gas-phase organic compounds to the indoor air. Another control option, source modification, has also been applied, mainly as the result of consumer demands. Building products that contain formaldehyde, benzene, or other harmful substances have been replaced or modified.

Emission rates of organic pollutants are not available for many materials, due to the complexity and lack of standardisation of their measurement (Knoppel 1989). A test recently carried out amongst several European laboratories on emissions from a single carpet-coated particle board showed the presence of 22 quantifiable compounds and 18 chemicals identified but not quantified. Among the quantified species, a single compound (ethanol,2[2-butoxyethoxy],acetate) accounted for 61% of total emissions.

The strategy for risk assessment and management of organic indoor pollution can be based on single compounds, on source emissions and on indoor air mixtures. Each of these approaches has advantages and disadvantages that should be taken into proper consideration. The following actions are proposed by Knoppel (1989):

- setting imission/emission standards for single compounds (eg formaldehyde);

- agreement on imission/emission guidelines for total VOCs;- banning carcinogens where possible (**eg** asbestos, benzene) and setting emission limits where a ban is not possible (radon);

- choice of low toxicity constituents for mixtures and attribution of "positive" labels to products; and

- avoidance of odorous emissions and attribution of "positive" or "quality" labels to no or low olfactory products;

In designing a strategy for control of organic pollution, efficacy and applicability of the different approaches have to be recognised. With the possible exception of ventilation for environmental tobacco smoke, any remedial strategy has to deal with source removal or source modification. This can be obtained with regulation in some cases (*eg* for formaldehyde, ETS, and pesticides) and with recommendation in other cases (*eg* for VOCs, SVOCs, and POMs).

Walkinshaw (1989) considers that it is apparent from even the limited field studies conducted to date that it will be more cost effective to eliminate and reduce the levels of many of the pollutants being encountered indoors through control at source, rather than through increases in ventilation rates.

Seifert (1990a) describes how the Federal Health Office of West Germany in 1977, convened an ad-hoc commission of experts which proposed a guideline value of 0.1 parts per million for formaldehyde in indoor air. The value was not linked to a time interval. Over the years, the 0.1 parts per million value had been adopted by many other European countries (Seifert, 1990a; Maroni, 1990). The World Health Organisation (1987), in "Air Quality Guidelines for Europe", proposed a value of 100 microgrammes per cubic metre as a 30 minute average. The guideline value was used to develop the formaldehyde emission standard for particle board in West Germany (Committee on Harmonised Technical Prescriptions for Construction 1980). In 1985, a guideline was also issued by the same committee to control formaldehyde emission from urea-formaldehyde foam insulation (Committee on Harmonised Technical Prescriptions for Construction 1985).

The classification of particle board proved to be very useful as a tool for lowering formaldehyde concentrations in indoor air. However, only the use of particle board for construction had been regulated. Low quality particle board, increasingly used in the manufacture of furniture, especially imported items, was not subject to any regulation. Therefore indoor air formaldehyde levels did not decrease as much as had been expected.

When the 0.1 parts per million value was issued in 1977, it was meant as a guideline value. However, over the years, many people, including judges, considered it to be a standard with resulting legal implications. This interpretation did not take into account that the guideline had not provided detailed prescriptions of all the conditions under which the formaldehyde concentration in the air of a room would have had to be measured (eg temperature, relative humidity, ventilation status, and sampling period).

In October 1986, the Ordinance on Hazardous Substances (1986) came into force in West Germany under the Chemical Act (1980). In this ordinance, a number of paragraphs addressed the question of formaldehyde including:

- wood-based products (particle board, coated particle board, block board, veneer plywood, fibre board) must not be marketed if they lead to an equilibrium concentration of formaldehyde of more than 0.1 ppm. The equilibrium concentration is to be determined in a test chamber;

- furniture must not be marketed if it contains wood-based products which do not meet these requirements.

Seifert (1990b) concludes that the best way to achieve good indoor air quality is by source control. This means that acceptable emission values have to be set for compounds. One approach is to start from a tolerable indoor concentration level or guideline value and then make a number of assumptions as to the conditions under which the product will be used in practice (temperature, humidity, air exchange rate, loading factor *etc*). In this way the desired emission rate of a compound can be calculated. Generally emission factors are obtained from test chamber measurements.

Guides published in Europe (Working Group 3, 1989) and in the USA (American Society for Testing Materials, 1989) demonstrate that care has to be taken to ensure that defined conditions are established and maintained during testing if comparable results are to be obtained. The rate of emission of compounds from materials are affected by factors such as type of material, material loading (area of material/volume of room), compound emitted, temperature, humidity and ventilation rate. According to Tichenor and Guo (1988) such relationships are unavailable for most materials and compounds. In a study by Engstrom *et al* (1988) the total emission of volatile organic compounds per material ranged from 0.0016 to 5.2 milligrammes per cubic metre. A building in which care was taken to minimise indoor air quality concerns by choice of materials and operating techniques was compared with two other buildings (Black and Bayer, 1988). Measurements indicated that in general the air quality was superior in this building compared with the others in the study. Not only do the compounds integral to the material of construction have to be considered but so too do decomposition products (Nielson, 1988).

Tucker (1987) concludes a review of the literature regarding emissions from surface materials, the factors that influence those emissions and models that can be used in evaluating emissions data by focusing on indoor air quality control by controlling emissions especially by producing and using low emitting products. A literature review on the emission, adsorption and desorption effects in indoor materials has been undertaken by Berglund, Johanson and Lindvall (1988). The review includes sections on sources and characterisation of indoor organic compounds, aging of materials, aging of buildings and odour. The recommendations in the review include:

- a combination of advanced methods of sampling and analysis is required. Do not expect simple causal relationships in the qualitative and quantitative patterns of volatile organic compounds;

- a new building needs a gassing off-period of at least 6 months. During this period no recirculation of air should be allowed, the outdoor rates should be high and the ventilation ducts be kept clean and dry;

- used materials from a 5 to 10 year old building may still emit pollutants. Thus gassing-off for a period of time does not always help. In such a case surface materials have to be replaced;

- compounds are believed to be adsorbed from the room air by indoor materials and then desorbed again when the materials are ventilated. This exchange of contaminants between room air and room surfaces explains the difficulties encountered when one wants to distinguish between a healthy and a sick building by chemical classification. The adsorption/ desorption process makes it difficult to trace the origin of specific contaminants appearing in the air of sick buildings. The source may be disguised by the simultaneous re-emission from otherwise innocent materials;

- care should be taken to avoid polluting materials but also to avoid surface materials and duct linings which increase the risk of adsorbing/desorbing air pollutants;

- the removal of the prime building (surface) material in a room will require weeks or even months before it can be confirmed to have resulted in a successful improvement in indoor air quality;

- recirculation of return air is not recommended. If it is used repeated checks are required on the functioning of the system and regular maintenance and cleaning should be carried out.

Air Supply Systems

Air can be circulated around an office building by natural or mechanical ventilation. Mechanical ventilation systems can heat, cool and condition air by adding or removing humidity. In the interests of energy efficiency, mechanical ventilation and air conditioning systems typically supply a mixture of outside air and recirculated indoor air to the occupied spaces of the building. The percentage of fresh air can be fixed centrally and remain constant over time, (fixed air volume or FAV) or can vary according to stimuli such as the temperature of the outside air or carbon dioxide levels indoors (variable air volume or VAV). The latter has the advantage that when the ambient temperature is optimal (for a system controlled by the ambient temperature) 100% fresh air will be supplied to the occupied space, but equally under extreme conditions no fresh air might be supplied. The former has the advantage that a certain amount of outside air will be supplied at all times, although this may put an unnecessary load on the heating or cooling systems. It is essential that the minimum fresh air supply level is sufficient where a VAV system is used.

Air supplied by the air handling system can be introduced into the occupied space itself by dilution or mixing flow or by displacement flow. Dilution or mixing flow, as the name suggests, relies on a mixing effect of outside air with room air to keep the level of oxygen up and pollutants down. Displacement flow involves conveying cool air at low velocity into a room at near floor level. This layer of cool air will not mix with existing warm, polluted office air, but gradually rises as it warms, displacing the existing polluted air which can then be extracted at ceiling level. Pollutants generated below the cool air band but which are at a higher temperature can rise through this cool layer to be efficiently extracted (Andegiorgis, 1988). Displacement flow is now reported to be more popular (Fitzner, 1987) because it saves energy, improves comfort and increases ventilation efficiency. However, Andegiorgis (1988) reports that if air disturbance is sufficient to break up the stable underlying layer of clean air, there will be an overall rise in the concentration of dust particles and gases. Palonen *et al* (1988) state that the resulting vertical temperature differences can lead to complaints of heat stress at head level and draught around the feet. Holmberg *et al* (1987) compared the two methods experimentally and found that as well as being less energy efficient, dilution flow with air supplied through wall mounted and floor mounted supply devices resulted in convection currents around a seated person which could result in a high concentration of ETS in their breathing zone.

It has also been reported (Ollson, 1987) that ventilation efficiency can be improved very simply by extracting air at the same point that it is introduced into the occupied space. He points out that when the supply air stream enters a room it will draw secondary air to the outlet by induction. Locating the supply and extract at the same point is therefore a way of increasing the ventilation efficiency. Antti *et al* (1987) state that the most common cause of decreased air exchange efficiency is a short circuiting of air between supply and exhaust ducts. The authors reinforce Ollson's view that the highest air exchange efficiencies are achieved when the supply and exhaust ducts are located on the same wall, providing that the velocity of the incoming supply air is sufficient.

Wyon (1988) has investigated the use of ventilated floor systems with independent room air terminals as the basis for producing a healthy office environment. He states that available field tests of three of this type of installation confirms that the system performs extremely well the three functions that are basic for a healthy office environment: individual room control under very different loading; the supply of requisite quantities of air of high quality; adequate distribution of air within restrictions due to draughts or thermal gradients. In addition, ventilated floor systems of this type have been shown to offer new possibilities for providing a room with air under the day to day control and supervision of the occupants themselves, without the cost penalties or delays normally associated with changing ventilation systems to adapt to new requirements or user complaints.

Carbon dioxide is often used as a surrogate for evaluating ventilation and can be used as a way of determining the volume of outside air supplied by a VAV system. However, in several problem buildings, levels of less than 1000 parts per million (ASHRAE Standard 62-1989) have been found which suggests that it is not a good method for ascertaining fresh air requirements (Putnam *et al* 1990). Janssen and Hill (1982) describe an air supply system which is set to operate at 2,500 parts per million of carbon dioxide, *ie* the system would not draw in fresh air until the carbon dioxide level reached 2,500 parts per million. However, since carbon dioxide levels did not rise above 1800 parts per million the system did not draw in fresh air. Tanaka and Masumoto (1987) found that good temperature and air distribution was maintained even when a VAV system was heavily throttled down, but that dust levels increased correspondingly. No relationship between occupant comfort and VAV air volume was detected so long as temperature, relative humidity and air velocity were maintained at a constant level, so the authors concluded that the volume of outside air supplied by a VAV unit should be set according to indoor dust levels in order to maximise energy efficiency and indoor air quality. Guttman (1987) has proposed a practical methodology for calculating the required percentage of outside air needed for either a FAV or VAV system.

Forced ventilation is often incorporated into buildings because it is seen as the only way that the internal areas of a building can be effectively ventilated. However, ventilation can be provided to rooms in the middle of a block with no access to windows by the use of ventilation shafts (Fail and Pauzhauser, 1987). Air is drawn into the room, by infiltration through the building envelope, as air moves across the outside face of the shaft.

Clausen *et al* (1987a) found that when people were exposed to ETS in a test chamber, if an air scrubber was in operation, the odour intensity did not decrease but the air was perceived to be cleaner. The use of air washers therefore could allow a reduction in fresh air supply rates in areas affected by ETS without increasing occupant discomfort. Lauridsen *et al* (1987) found that a ventilation rate of 12 cubic metres per cigarette kept eye, nose and throat irritation to an acceptable level. Other authors have suggested that air cleaners are useful in reducing the health risk from radon progeny in the indoor environment as progeny attached to particulates can be removed from the air by a variety of air cleaners (Periasamy *et al*, 1990).

Chiang and Chang (1987) tested reclaimed spent grain from a brewery as an absorbent for removing VOCs and found that the results were roughly equivalent to those from filters made with coconut shell activated carbon.

Graham and Bayati (1990) investigated the effectiveness of activated carbon in air cleaning devices for the control of VOCs. They report that granular activated carbon has been successfully used to remove trace air pollutants in a number of public buildings in the United States of America and laboratory experiments have shown that it is effective at removing part per billion levels of benzene from air, despite its effectiveness, according to Graham and Bayati (1990), being questioned recently by the US EPA. Liu (1990) also supports these findings.

One simple form of indoor air cleaning discussed in the literature relies on convection. Fibre filters placed on top of radiators provide some filtration of air moved through the filter by convection (Erdlinger *et al*, 1990).

Commissioning Tests and Building Bake-Outs

Meckler (1990) stated that the most important factors in maintaining indoor air quality are commissioning and building operations. He proposed the "Building Systems Approach" as offering the best structure for ensuring that effective commissioning is achieved. This involves establishing suitable design criteria, providing complete descriptions of the HVAC system selected, its intended control, operation and maintenance and developing a commissioning plan and subsequent verification procedures.

Artificial product ageing can be carried out by manufacturers or suppliers of products or used within the building immediately prior to occupancy. The process employed within a building is termed a "bake-out" and involves artificial ageing by increasing office temperatures and ventilation rates to well above those normally experienced in the office environment. Office bake-outs appear to be beneficial to some degree and may result in reduced rates of off-gassing and levels of indoor contaminants. However, there is disagreement as to the procedures needed to obtain optimum efficiency and results. There are effectively three parameters that can be varied during the implementation of a building bake-out. These are duration, air temperature and ventilation rates during and after the procedure. Bayer (1990) tested the principle of off-gassing in a chamber study and found that for partition boards and particle boards baked at 90° - 120°F at 0.5 to 1.0 air changes per hour, the VOC emission rates were not significantly reduced, although formaldehyde emissions from the particle board were reduced. Hicks *et al* (1990) concluded from their study of a new five-storey hospital that baking out a building does not appear to reduce the concentration of all VOCs. Formaldehyde showed a considerable reduction, as did 1,4 dioxane, but the levels of VOCs generally were low before and after the bake-out which may explain the lack of significant improvement. The aim of this bake-out was to raise the building temperature to 35°C for at least 48 hours. Girman *et al* (1990) reviewed the specific techniques and results from bake-outs in five different buildings in the United States. The authors concluded that it was necessary to continue the treatment for several days to achieve air temperatures of greater than 32°C and for the process to be effective. Material damage was recorded in one building at these levels, but in retrospect it was considered to be minimal or that it could have been avoided. Building bake-outs are not a simple process. They may require modification to the HVAC system, disconnection of thermostats and de-activation of sprinkler systems.

Cleaning and Maintenance

Provided that a building is capable of achieving the required conditions for adequate indoor air quality, then the main factors involved in operation are control and maintenance. Adequate maintenance, both of the fabric and services, is essential to ensure that buildings continue to provide a safe, healthy and comfortable environment over their lifetime (Warren, 1988). Burge *et al* (1990) found in a study of 6 offices that there was a relationship between standards of maintenance and the prevalence of building sickness.

Davidge and Kerr (1990) state that it is not enough for indoor air to be clean, but it must also seem clean. This means that maintenance needs to be preventative. If the quality of the indoor air drops, even if it is subsequently returned to its original state, the air may not then be perceived to be as satisfactory. Approaches for ensuring that the air quality is not allowed to or be perceived to deteriorate and that problem areas are quickly and easily identified have been suggested (Lane *et al*, 1990). These tend to rely on feedback from individual members of staff on an organised basis and involve ensuring that remedial actions are seen to be taken when necessary. The role of high visibility maintenance and cleaning as an important panacea for air quality complaints is also documented by Davidge and Kerr (1990).

Cleaning of offices is also an important factor and vacuum cleaners appear to be a significant source of indoor aerosol particles (Smith *et al*, 1990). Abildgaard (1990) found that better planning of carpet maintenance could result in a healthier indoor climate. Norback and Torgen (1987) suggest that the dust collecting effects of carpets may lead to an increase in symptoms. Flatheim (1990b) states that the indoor environment can be upgraded through better and more frequent cleaning whilst Skov and Valbjorn (1990) reported that work related mucous irritation and general symptoms were related to the quality of cleaning. Gravesen (1987) states that in Denmark, increased office complaints seemed to be connected to a reduction in public sector finances and hypothesises that they could be due to static effects resulting from a move towards using cheaper synthetic carpets or due to an increase in airborne levels of microorganisms and organic dust as a result of cuts in cleaning budgets.

Leinster *et al* (1990) have shown that intensive office cleaning can improve occupants perception of the indoor environment, reduce the population of mites in a building and reduce the number of symptoms experienced.

Indoor pollution by biological contaminants may be controlled with strategies based on the avoidance of conditions which provide substrate for the growth of viable particles and the containment or removal of any growth. Air filtration is of limited efficacy, but the control of moisture (Maroni, 1989) and nutrients (Morey, 1990) are the most important ways of controlling the growth of microorganisms. Maroni has produced a table summarising the effectiveness of control methods, which vary according to source and level of importance.

According to Morey (1990) causes of contamination in office buildings include poor maintenance of the HVAC system, disregard for maintenance in the design of the HVAC system, the use of porous man-made insulation in mechanical systems, excessive humidity or flooding in the occupied space and the location of the building air intake near an external source of contaminants. Consideration should be given to maintenance at the design stage in order to ensure that the planned indoor air quality is preserved throughout the building's life (Fredericksen, 1990).

While maintenance is an important factor in ensuring satisfactory indoor air quality, many aspects of it in practice are determined by cost rather than cost effectiveness (Beck, 1990).

Morey *et al* (1987) suggests that where microbiological contamination is shown to be present in a building, sources of water in the building and HVAC system should be removed, porous contaminated surface such as ceiling tiles should be removed altogether and non porous surfaces should be washed down with bleach. Bencko *et al* (1990) suggest ways of reducing microbiological fouling in the recirculation water in humidifiers. They concluded that humidifiers should be constructed in such a way that they can be easily cleaned, that they should be built to withstand high pH during radical disinfection, and that water quality should be tested regularly. It is important that the emission of chemicals into the occupied space from such activities is considered and health effects minimised.

Building Management Systems

Flemming *et al* (1990) concluded that a system designed to control indoor air quality must integrate information on pollutant sources and concentrations, building parameters and weather conditions and that continuous evaluation of this information may improve the energy efficiency and cost effectiveness of indoor air quality control. They presented results of a field test of a system that monitors radon, carbon dioxide, relative humidity and temperature on a continuous basis.

Cowan (1990) states that energy management is usually accused of causing poor indoor air quality, but counters that it is only bad energy management that does this. He considers that both indoor air quality and energy management programmes have a common interest in good design, operation and maintenance of building systems. Many activities involved in energy management programmes are identical to those required to ensure good indoor air quality, with both focussed on accuracy of controls and air distribution.

According to Meckler (1990) building management systems can best be developed by ensuring that appropriate documentation is required at the commissioning stage or on completion of the building and that this documentation is then used to formulate a systems manual and to train the personnel that will operate and maintain the building. The same author gives procedures for ensuring that indoor air problems are avoided both during initial occupancy and during the continued operation and maintenance of the building. One occupant on each floor of the building is appointed to fill out a daily indoor air quality appraisal form and report any subjective evaluations of the indoor environment. This enables the air quality to be monitored whilst the extraordinary ventilation requirements needed immediately after occupation are gradually reduced to the normal level.

Prezant *et al* (1990) suggest that the terms of a lease can be set so as to maximise indoor air quality. Tenants influence indoor air quality by the way they alter the use of space in the building and by introducing contaminants into the building. Owners influence indoor air quality through the design, maintenance and operation of the building. The authors suggest that contracts could be negotiated between the two parties which address the quality of ventilation delivered to the occupied spaces, contaminants generated, design limits and maintenance and operational practices for the HVAC.

Owen *et al* (1990b) modelled the respective benefits of local and central controls for indoor air quality. They concluded that both can be effective, but the choice of strategy must be based on the individual situation.

ACTIVITIES WITHIN THE COMMISSION OF THE EUROPEAN COMMUNITIES

Much of the information in this section is based on the paper by De Bortoli *et al* (1990b).

Various parts of the Commission of the European Communities are involved in aspects of indoor air quality:

- Directorate-General III (Internal Market and Industrial Affairs) is in charge of regulating properties of building materials;

- Directorate-General V (Employment, Industrial Relations and Social Affairs) is responsible for occupational health and hygiene and public health and is in charge of community legislation on smoking prevention; and

- Directorate-General XI (Environment, Nuclear Safety and Civil Protection) is in charge of defining and implementing preventive measures against indoor pollution from a growing number of substances;

- Directorate-General XII (Science, Research and Development) undertakes research activities through its Joint Research Centre (Ispra);

- The Consumer Protection Service is preparing its first action programme which may consider the impact of consumer products on indoor air quality.

As stated in the 4th Policy and Action Programme on the Environment (1987-1992) of the European Community, approved by the Council of Ministers on 19 October 1987, scientific research is an essential preparatory activity for almost any political action in the field of environmental protection. Moreover, under the title "actions in specific sectors, atmospheric pollution" the programme specifies that a major objective of an overall longer-term strategy to reduce air pollution is "to identify the atmospheric pollutants (outdoor and indoor)....of greatest concern from the standpoint of the protection of human health".

The Institute for the Environment of the Commission of the European Communities Joint Research Centre (Ispra) acts as leader of the COST (Cooperation Europeenne dans le Domaine de la Recherche Scientifique et Technique) Project 613 Indoor Air Quality and the Impact on Man.

COST Project 613 has the following objectives:

- identification and characterisation of pollutants and sources;

- assessment of population exposure;

- assessment of health effects;

- investigations into complaints of air quality in office buildings (including SBS);

- development and validation of guidelines, reference methods and other research tools;

- collation, synthesis and dissemination of data.

Three working groups have already achieved their tasks:

WG 1 has prepared the report "Sick building syndrome - a practical guide", which gives advice to people faced with air quality complaints in buildings (Molina *et al*, 1989);

WG 2 has prepared the report "Strategy for sampling chemical substances in indoor air"; the report addresses the questions when, how often, for what period of time and where to take samples when investigating indoor air pollution. It has been adopted by ASTM sub-committee D22.05 on Indoor Air as first draft for an ASTM guideline;

WG 3 has prepared the report "Formaldehyde emission from wood based materials: guideline for the determination of steady state concentrations in test chambers"; this guideline is presently under evaluation by CEN (Comite Europeen de Normalisation) (Working Group 3, 1989).

At present seven working groups are charged with the following tasks:

WG 4 preparation of a discussion document on health effects of indoor air pollutants;

WG 5 preparation of a guideline or standard procedure for the determination of microbiological pollutants;

WG 6 preparation of a guideline on ventilation requirements based on perceived air quality;

WG 7 Sick building syndrome research; this group is a follow up of WG 1 and is preparing guidance on how to perform longitudinal studies in buildings;

WG 8 preparation and validation of a method for the characterisation of VOC emitted from indoor materials and products; this group is reviewing a guideline prepared by the US EPA;

WG 9 preparation and validation of protocols for VOC measurements in indoor air (follow-up of WG2);

WG10 review of the state of knowledge of sensory stimulation by indoor air pollution and resulting sensory, neurological and psychological effects.

In the attempt to overcome the increasing difficulty of having essential information in a concise form, the Concertation Committee, through the Secretariat and the Working Groups, issues summary reports on single pollutants of high priority. Two such reports have been published: Radon in Indoor Air (McLaughlin, 1988) and Indoor Pollution by NO_2 in European Countries (COST Project 613, 1989). A third report on Indoor Air Pollution by Formaldehyde in European Countries is in press.

Of particular importance is an inventory of investigations and research projects in the field of indoor air quality going on in the countries participating in COST Project 613 (Knoppel *et al* 1989).

Regulations and recommendations relating to indoor air quality developed or under preparation are briefly described:

Environment, Nuclear Safety and Civil Protection (DG XI). The 4th "Policy and Action Programme on the Environment (1987-1992)", approved by the Council of Ministers on 19 October 1987, includes as one of the major objectives the development of "an overall longer-term strategy to reduce air pollution" and as part of this strategy "to define and implement preventive measures against indoor pollution from a growing number of substances".

As a further preventive measure, an information booklet for the general population on potential hazards of indoor air pollution and on possibilities how to avoid or reduce them is under preparation.

Internal Market and Industrial Affairs (DG III). Since March 1987 Directive 87/217/EEC regarding asbestos has been in force. Although it makes no explicit reference to indoor air pollution, it introduces measures to prevent and reduce air and other environmental pollution by asbestos. It also specifies rules to be observed during removal of asbestos containing materials from buildings.

Of particular relevance for indoor air pollution by building products is Directive 89/106 on the "approximation of laws, regulations and administrative provisions of the Member States relating to construction products", approved by the Council in December 1988. This Directive applies to all works, including buildings and civil engineering works where such works are subject to regulation. One of the essential requirements in the directive relates to "hygiene, health and environment" and specifies: "The construction work must be designed and built in such a way that it will not be a threat to the hygiene or health of the occupants or neighbours, in particular as a result of any of the following:

- the giving off of toxic gas;

- the presence of dangerous particles or gases in the air;

- the emission of dangerous radiation..".

One of the draft Interpretative Documents to the Construction Products Directive identifies aspects of work where hygiene, health and the environment may be concerned.

For the purpose of establishing the suitability of products, Appendix 1 of the Directive gives the following definition of the Essential Requirement which is applicable where the works are subject to regulations containing such a requirement:

> The construction work must be designed and built in such a way that it will not be a threat to the hygiene or health of the occupants or neighbours, in particular as a result of any of the following:
>
> - the giving-off of toxic gas
> - the presence of dangerous particles or gases in the air- the emission of dangerous radiation
> - pollution or poisoning of the water or soil
> - faulty elimination of waste water, smoke, solid or liquid wastes
> - the presence of damp in parts of the works or on surfaces within the works.

A summary of some of the specific requirements is given in Appendix 1.

Limiting the emission of formaldehyde from wood-based materials is presently under consideration as a first case in relation to the essential requirement.

Employment, Industrial Relations and Social Affairs (DG V). In the framework of the programme "Europe against Cancer" the Council of Health Ministers adopted in May 1989 a resolution to ban smoking in public places, except in clearly defined areas reserved for smokers.

Consumer Policy (Consumer Policy Service). The impact of consumer products on indoor air quality is presently under consideration as a subject to be included in a new action programme in the field of consumer protection.

Present and proposed actions adopt the approach of reducing exposure to indoor pollutants through the reduction or appropriate manipulation of the source.

The European Parliament, in October 1988, adopted a resolution on air quality in buildings, in which it was stated that "more attention should be devoted in Community environmental policy to the problem of the quality of air in indoor environments, reiterates the request already made with regard to bans on smoking...considers...that the Commission should promote further in depth research into the possible causes and effects of air pollution inside buildings in human health." Moreover, the resolution invited the Commission to prepare a directive on the subject, which should include:

- a list of substances whose use in construction works and in cleaning should be regulated or prohibited;
- quality standards to be applied to air in indoor environments;
- rules governing the planning, building, management and maintenance of air conditioning and ventilation systems; and
- minimum rules for the maintenance of buildings open to the public, in order to ensure the highest standard of hygiene and cleanliness."

Council Directive 89/654 (1989) concerning the minimum safety and health requirements for the workplace also has implications for indoor air quality. It contains requirements relating to:

- ventilation: sufficient fresh air must be provided; systems must be maintained; draughts causing discomfort must not be produced; any deposit or dirt must be removed without delay;
- temperature: must be adequate for the purpose; excessive effects of sunlight should be avoided;
- lighting: must be adequate for the purpose.

ACTIVITIES IN THE USA

Much of the information in this section is based on papers by Axelrad (1990) and Berry (1990).

In 1986, Congress enacted Title IV of the Superfund Amendments and Reauthorisation Act (SARA) to establish an effective research effort aimed at characterising the extent of the indoor air pollution problems and to begin to take steps to enhance the quality of the indoor air. Title IV (the Radon Gas and Indoor Air Quality Research Act) gave EPA clear authority for the first time to begin to address indoor air quality problems on a more comprehensive basis.

In order to fulfil the mandate of SARA Title IV the EPA proposed: to adequately characterise and understand the risks to human health which pollutants pose in indoor environments, and to reduce these risks by reducing exposure to indoor pollutants.

The EPA stated that "sufficient evidence exists to conclude that indoor air pollution represents a major portion of the public's exposure to air pollution and may pose serious acute and chronic health risks. This evidence warrants an expanded effort to characterise and mitigate this exposure." They indicated that indoor air research and policy programmes have not yet sufficiently characterised indoor air quality problems and solutions to be able to determine whether additional regulatory approaches to indoor air quality problems are needed. Nevertheless, EPA made a number of recommendations intended to develop the necessary information to make such determinations:

- research to better characterise exposure and health effects of chemical contaminants and pollutant mixtures commonly found indoors should be significantly expanded;

- a research programme to characterise and develop mitigation strategies for biological contaminants in indoor air should be developed;

- research to identify and characterise significant indoor air pollution sources and to evaluate appropriate mitigation strategies should be significantly expanded;

- a programme is needed to develop and promote, in conjunction with appropriate private sector organisations, guidelines covering ventilation, as well as other building design, operation, and maintenance practices for ensuring that indoor air quality is protective of public health;

- a programme of technical assistance, and information dissemination, similar in scope to the Agency's radon programme, is needed to inform the public about risks and mitigation strategies, and to assist state and local governments and the private sector in solving indoor air quality problems. Such a programme should include an indoor air quality clearing house;

- the Federal government should undertake an effort to characterise the nature and pervasiveness of the health impacts associated with indoor air quality problems in commercial and public buildings, schools, health care facilities, and residences, and develop and promote recommended guidelines for diagnosing and controlling such problems;

It was also the EPA intention to:

- initiate a process to establish a consensus-based system for accrediting private sector indoor air quality diagnostic and mitigation firms;

- initiate an assessment of multiple chemical sensitivity issues to determine what is currently known, and what research needs to be done to address indoor air issues relevant to sensitive individuals and populations (this assessment will be used to develop a long-range research and analysis agenda).

Development of targeted guidance programs, information dissemination and training tailored to building owners and managers, design engineers, and architects and covering public and commercial buildings, schools, and residential structures is viewed as a high priority. A number of guidance documents are in development.

Another high priority is said to be the need for the development of baseline data on the scope of the indoor air problem nationwide and of appropriate guidelines for conducting building investigations. An effort to develop such guidelines and protocols was expected to get underway in 1990.

The pollutant/source programme initially focused on the risks associated with environmental tobacco smoke.

As a predominantly non-regulatory programme, developing and disseminating both technical and non-technical information is considered to be fundamental including communicating with the general public.

THE WAY AHEAD

All the evidence in the literature points to the fact that within certain buildings circumstances exist which can have a real and adverse effect on some of the occupants. Much of the available information has remained in the research community and has not been communicated to those involved in the design, construction and running of buildings. One of the reasons that problems to do with the indoor environment should be of concern is the very large number of people that potentially can be involved. In the countries of the European Community alone many millions of people work in offices. It would appear that problems within buildings have an adverse effect on productivity and increases absenteeism. Therefore if action can be taken to improve and safeguard the indoor environment in general and indoor air quality in particular, many will benefit and substantial cost savings will be made. It would also appear that solutions can be found for the majority of buildings with problems.

Although the Commission of the European Communities is undertaking work in the field of indoor air quality there is no overall coordination of the effort. Much of the activity is being coordinated by the Joint Research Centre at Ispra through COST Project 613 but other Directorates do not seem to be fully aware of the scope of this work. Indoor air quality affects people at work and therefore it would appear that Directorate-General V has an important role to play in the Commission's activities within this area.

There are many areas to do with the study of this subject in which further information is required. Indeed much of the subject appears to be in a preliminary or formative stage of development. According to Hansen (1990) the study of indoor air quality has been largely a problem driven activity.

It is considered that in the light of current knowledge of indoor air quality problems and solutions additional regulatory requirements would not be appropriate at this time. As stated earlier in the review the setting of guidelines rather than standards would appear to be more appropriate in most cases. The information is not available in the literature to enable any judgement to be made as to how, or if, design guidelines should be modified to take account of the climatic conditions encountered in different countries.

On the basis of current knowledge it should be possible to take a pragmatic approach and alleviate a large number of the problems which are encountered within buildings. The available information needs to be interpreted and translated into basic guidelines and then communicated to those involved in the design, construction and refurbishment of buildings so that factors known to cause problems are not repeated. In addition those involved in running buildings need to be informed of the ways in which they can maintain acceptable working conditions.

From the reports in the literature a number of factors appear to have an effect on conditions within buildings and some of these are given in the section of this review entitled Common Features of Buildings With Problems. Although definitive statements cannot yet be made, sufficient information is available to allow consensus guidelines to be formulated which would gain widespread support. Directorate-General V could take a lead in this area by convening a meeting of experts with the express purpose of devising consensus guidelines. These may not be the final solution but if they were incorporated into new or refurbished buildings they would be an improvement on much of the current practice and should significantly reduce the numbers of problems which occur. Factors which could be included in the guidelines include:

- ventilation rates including the use of natural ventilation and openable windows;
- temperature;
- humidity including advice on types of humidifiers;
- air movement;
- lighting, including the provision of natural lighting;
- standards of construction;
- depth of office space *ie* distance of occupants from windows;
- airborne pollutants including means for controlling levels;
- selection and use of materials and procedures so as to minimise the emission of chemicals;
- control of processes known to emit chemicals;
- local control of environmental conditions;
- standards of decoration;
- standards of cleaning and maintenance;
- type of glazing;
- commissioning tests;
- ongoing testing of parameters which describe the indoor environment.

In addition to guidelines related to the physical environment, working practices and management styles also have a major impact on the way in which individuals view their workplace.

It is clear that a considerable effort is required if there is to be significant progress in the understanding of many of the aspects affecting indoor air quality. This effort has to be coordinated in some way if research effort is not to be needlessly duplicated and if consensus, which is required for example in design parameters and evaluation criteria, is to be achieved amongst the many interested parties. The need for further clarification, investigation and research work arising from the review of the literature is outlined in the following paragraphs. The papers by Maroni (1989) and Berry (1990) and the WHO publications (WHO, 1989b; WHO, 1990) all include a number of recommendations and these have been incorporated as considered appropriate:

Building Investigation Protocols

Although certain authors have made recommendations regarding how investigations should be carried out there is no protocol which has gained widespread acceptance. Consensus protocols are required and these should include:

- details of the range of parameters which can be measured and assistance in determining what is appropriate in a particular situation;
- how many measurements should be taken in a given space and the ratio between fixed and personal samples;
- duration and frequency of sampling;
- standardised questionnaire surveys and frequency of application;
- personal activity logs;
- procedures relating exposures to individual source strengths;
- standardised formats for the reporting of results for example the use of 10th, 50th and 90th percentiles.

Monitoring Techniques

There are a number of methods available but there is no agreement on which is most appropriate. This aspect of the work is complicated by the fact that there are discrepancies between for example what constitutes volatile organic chemicals or total particulates in different reports. Such definitions have to be tied into agreed and validated sampling and analytical procedures. People tend to measure what it is possible to measure rather than necessarily what should be measured. Guidance is required on the parameters to be measured and also on the fraction of the collected material which may be important for example; a specific proportion of the total dust or a particular group of volatile organics.

Many of the procedures used in assessing the indoor environment are occupational hygiene techniques. These may not be appropriate from the point of view of the weight and noise of equipment or the limits of detection may not be low enough for use in office environments. Both the specificity and the sensitivity of the methods used may provide reasons why changes in environmental factors are not indicated even when there is a reduction in the occupant symptoms following an intervention in a building.

As in other areas of work quality assurance reference methods are required.

Exchange of Information and Data Bases

There needs to be an adequate and rapid exchange of information. A clearing house approach has been suggested. It is considered that the following data bases are required both as a source of information and to avoid duplication of effort:

- data from buildings in which complaints occur and from those in which there are no complaints. This information should be obtained using standardised procedures. This would provide a basis for the setting of guidelines and assessment criteria;

- information on sources and emissions. The data should again be obtained using standardised procedures.

Modelling Techniques

Procedures for modelling building performance and predicting occupant exposures are required.

Multidisciplinary Studies

The majority of studies reported have not involved multidisciplinary investigative teams. However, it is generally recognised that the problems associated with indoor air quality and the indoor environment requires input from many different disciplines. Studies need to be undertaken that take into account all currently recognised factors which may be pertinent.

Building Design Guidelines

The information gathered on all aspects of indoor air quality and the indoor environment such as ventilation strategies, materials of construction, thermal environment, humidity, air movement, lighting, layouts and control over the environment need to be interpreted and translated into design guidelines. These then need to be communicated to and implemented by those involved in building design, construction and refurbishment so that best practice is adopted.

Control Measures

Although it may be possible to affect future building design it is evident that there will be the need for effective remedial action in existing buildings.

Maintenance and cleaning regimes have a significant impact on the quality of the indoor environment. Various techniques and regimes should be evaluated and then guidelines developed. These should include aspects such as types of vacuum cleaner to use, chemicals to be employed and a procedure to determine how effective the cleaning is in a particular area.

Air cleaning technologies need to be developed and then evaluated to determine their ability to reduce the levels of specific airborne contaminants. Means of controlling existing factors known to affect the indoor environment should be developed.

Emissions from Materials

Many materials used within building emit chemicals. Standardised and validated method are required in order to assess emissions and models should be developed which will enable exposures to be predicted from such data. The rate of change of emissions with time should also be determined. Further understanding of the sorption and re-emissions from "sinks" is required.

Evaluation Guidelines and Standards

There are few generally agreed guidelines or standards against which physical, chemical and biological factors within the indoor environment can be assessed. Such guidelines and standards are essential if sense is to be made of the measurements that are taken.

Health Effects

The majority of identified needs relate to chemical and biological factors. It may be that there is sufficient knowledge relating to physical factors such as ventilation rates, the thermal environment, humidity, air movement, lighting and layouts. If this is the case then there should be no barrier to the setting of guidelines and if not the gaps in knowledge should be identified and investigated. The following needs relating to chemical and biological factors have been identified in the literature:

- the identification or development of sensitive functional or physiological measures to characterise the health effects of exposure to indoor air pollutants;

- the determination of the comparative irritancy and response-thresholds of indoor air pollutant chemicals and mixtures;

- the identification and characterisation of chemically sensitive individuals and population subgroups susceptible to SBS;

- the development of methods for directly measuring sensory irritation from sources;

- the development and application of biomarkers of inflammation and allergy in upper airways following exposure to indoor air pollutants;

- the characterisation of the mutagenicity and carcinogenicity of complex mixtures of indoor pollutants and the identification of major sources;

- the development of assessment methods for multiple pollutants and non-cancer endpoints.

Commissioning Tests

Tests are required to ensure that design parameters are actually achieved in practice and that the required conditions are maintained throughout the occupied space both on commissioning and in normal operation on a continuing basis.

It is also necessary to ensure that building systems are able to cope with any modifications made to the layout of the building or the changes in the load placed on them. The effectiveness of building bake out procedures should be evaluated.

Other Factors

Other factors which have been identified as requiring further investigation include:

- the risks associated with newly built offices;

- methods to estimate exposure to environmental tobacco smoke;

- the determination of indoor spatial and temporal concentration gradients;

- information on biological contaminants and their effects;

- the relative importance of peak and long term exposures;

- an assessment of indoor exposure to pesticides and herbicides;

- the identification of major sources of pollutants within the indoor environment.

APPENDIX 1

The following is a summary of some of the guidance contained in a draft guidance note relating to the Construction Products Directive (89/106/EEC) that will have implications for the indoor environment:

General Hygiene and Cleanliness

The requirement is concerned with unhygienic conditions in works where normal cleaning is carried out and includes floor surfaces and building services such as ventilation systems where access for cleaning and maintenance is important.

Indoor Environment

The requirement should take into account:

- thermal environment including humidity and air movement;
- lighting;
- air quality;
- dampness; and
- noise.

Air Quality

The requirement is concerned with the elimination or control of pollutants in the indoor environment taking into account pollutants including:

- metabolic products;
- combustion products;
- tobacco smoke;
- volatile organic compounds;
- non-viable particulates;
- viable particulates including microorganisms;
- radon and radioactive substances emitting gamma radiation;
- emission from electric and electronic equipments.

Although only products incorporated permanently in construction works are the subject of the Directive, pollutants from other sources need to be taken into account in providing methods for controlling air quality, such as ventilation.

Unhealthy indoor air can be caused by pollutants generated by:

- building materials;
- building services, including combustion appliances;
- furnishings and fittings;
- sources in the outside air;
- the soil beneath the building;
- processes and activities being undertaken within the building;
- human, animal occupation and plants;
- hot water systems.

Methods which are given for the control of pollutants include:

- control of sources: eliminating or limiting the use of materials which may emit pollutants; eliminating or limiting the emission of pollutants into the air; by design and adequate maintenance of appliances;

- control of air by ventilation, filtration or absorption;

- control of exposure of people by procedural controls, *eg* excluding re-entry for a specified time after repainting.

Dampness

The requirement is concerned with factors which include the indirect effects of dampness inducing mould growth on surfaces and inside products and the potential for increased numbers of house dust mites.

Contact Allergy

Contact allergy can be controlled by the prohibition, limitation of use or limitation of diffusion of named substances.

Solid Wastes

The hazards may arise from:

- the presence of disgusting or nauseating smells;
- disease vectors, pests and vermin.

Disease vectors include: house flies, stable flies, mosquitoes, cockroaches, bedbugs, fleas. Pests and vermin include: wasps, ants, Feral pigeons, rats and mice, house mites, bird mites, house dust mites.

TABLE 1 Air Pollution Effects on Materials

Materials	Type of Damage	Principal Pollutants	Other Environmental Pollutants
Metals	Corrosion, tarnishing	Sulphur oxides and other acid gases	Moisture, air, salt, microorganisms, particulate matter
Paint and organic coatings	Surface erosion, discolouration, soiling	Sulphur oxides, hydrogen sulphide, particulate matter	Moisture, sunlight, ozone, microorganism
Textiles	Reduced tensile strength, soiling	Sulphur oxides, nitrogen oxides, particulate matter	Moisture, sunlight, ozone, physical wear
Textile dyes	Fading, colour change	Nitrogen oxides, ozone	Sunlight
Paper	Embrittlement, soiling	Sulphur oxides, particulate matter	Moisture, physical wear
Magnetic storage media	Loss of signal	Particulate matter	Moisture, heat, wear
Photographic materials	Microblemishes, "sulphiding"	Sulphur oxides, hydrogen sulphide	Moisture, sunlight, heat, other acid gases, particulate matter, ozone and other oxidents
Rubber	Cracking	Ozone	Sunlight, physical wear
Leather	Weakening, powdered surface	Suphur oxides	Physical wear
Ceramics	Changes surface appearance	Acid gases, hydrogen fluoride	Moisture, micro-organisms

Source : US EPA 1987

TABLE 2 **Air Quality Guideline Values for Individual Substances Based on Effects other Than Cancer or Odour and Annoyance**[a]

Substance	Time-weighted Average	Averaging Time	Chapter
Cadmium	1- 5 ng/m^3	1 year (rural areas)	19
	10-20 ng/m^3	1 year (urban areas)	
Carbon disulfide	100 g/m^3	24 hours	7
Carbon monoxide	100 mg/m^3 [b]	15 minutes	20
	60 mg/m^3 [b]	30 minutes	
	30 mg/m^3 [b]	1 hour	
	10 mg/m^3	8 hours	
1,2-Dichloroetyane	0.7 mg/m^3	24 hours	8
Dichloromethane (Methylene chloride)	3 mg/m^3	24 hours	9
Formaldehyde	100 g/m^3	30 minutes	10
Hydrogen sulfide	150 g/m^3	24 hours	22
Lead	0.5-1.0 g/m^3	1 year	23
Manganese	1 g/m^3	1 year[c]	24
Mercury	1 g/m^3 [d] (indoor air)	1 year	25
Nitrogen oxide	400 g/m^3	1 hour	27
	150 g/m^3	24 hours	
Ozone	150-200 g/m^3	1 hour	28
	100-120 g/m^3	8 hours	
Styrene	800 g/m^3	24 hours	12
Sulphur dioxide	500 g/m^3	10 minutes	30
	350 g/m^3	1 hour	
Tetrachloroethylene	5 mg/m^3	24 hours	13
Toluene	8 mg/m^3	24 hours	14
Trichloroethylene	1 mg/m^3	24 hours	15
Vanadium	1 g/m^3	24 hours	31

[a] Information from this Table should not be used without reference to the rationale given in the chapters indicated.

[b] Exposure at these concentrations should be for no longer than the indicated times and should not be repeated within 8 hours.

[c] Due to respiratory irritancy it would be desirable to have a short-term guideline, but the present data base does not permit such estimations.

[d] The guideline value is given only for indoor pollution, no guidance is given on outdoor concentrations (via deposition and entry into the food chain) that might be of indirect relevance.

Source : WHO 1987

TABLE 3 National Primary Ambient-Air Quality Standards for Outdoor Air as Set by the US Environmental Protection Agency

Contaminant	Long term Concentration $\mu g/m^3$	ppm	Averaging	Short term Concentration $\mu g/m^3$	ppm	Averaging
Sulphur dioxide	80	0.03	1 year	365	0.14	24 hours
Total Particulate	75[a]	-	1 year	260	-	24 hours
Carbon monoxide				40,000	35	1 hour
Carbon monoxide				10,000	9	8 hours
Oxidants (ozone)				235[b]	0.12[b]	1 hour
Nitrogen dioxide	100	0.055	1 year			
Lead	1.5	-	3 months[c]			

[a] Arithmetic mean

[b] Standard is attained when expected number of days per calendar year with maximal hourly average concentrations above 0.12 ppm (235 $\mu g/m^3$) is equal to or less than 1, as determined by Appendix H to subchapter C, 40 CFR 50.

[c] Three-month period is a calendar quarter.

Source : ASHRAE, 1989

Table 4 Guidelines for Selected Air Contaminants of Indoor Origin

Contaminant	Concentration	ppm	Exposure Time
Carbon Dioxide	1.8 g/m^3	1000*	Continuous
Chlordane	5 ug/m^3	0.0003	Continuous
Ozone	100 ug/m^3	0.05	Continuous
Radon gas	0.027 WL		Annual Average

*This level is not considered a health risk but is a surrogate for human comfort (odour)

Source : ASHRAE, 1989

Table 5 Factors Associated with Airborne Contaminants in Non-Industrial Buildings and Their Effect or Presumed Effect on People.

Factor	Area for Possible Effects	Proved Effect	Presumed Effect	Source Amongst Others
Organic gases and vapours	5-20 mg/m^3 in	Dryness mucous membrane	Mucous membrane irritation	Paint Glue Plastic
Formaldehyde (and other aldehydes)	0.1-0.4 ppm 0.12-0.5 mg/m^3	Mucous membrane irritation Dry skin Eczema		Paint, acid hardening lacquer Glue (in chipboards) Tobacco smoke
Amines	Unknown		Mucous membrane irritation	Paint
Phthalates	c.0.5 mg/m^3		Mucous membrane irritation	Plasticiser
Fluorides	Unknown		Mucous membrane irritation Headache	Wood impregnated
Nitrogen dioxide	0.1-0.3 ppm 0.2-0.5 mg/m^3	Reduced lung function	Mucous membrane irritation	Gas Cooker Unvented gas or petroleum oven
Hydrogen chloride	1.3 ppm 1.4-4 mg/m^3		Mucous membrane irritation	Acid washed brick walls
Carbon-dioxide	1500-5000 ppm 2.7-9 g/m^3 (0.15-0.5%)	Indicator of human bio-effluents	Fatigue Headache	People Unvented combustion

Table 5 Continued

Factor	**Area for Possible Effects**	**Proved Effect**	**Presumed Effect**	**Source Amongst Others**
Carbon-monoxide	c.10 ppm c.12 mg/m^3		Fatigue Headache	Tobacco smoke Unvented combustion Exhaust gas from automobiles
Ozone	0.05-0.1 ppm 0.1-0.2 mg/m^3	Mucous membrane irritation		Copying machines Electrofilters
Inorganic dust	c.1 mg/m^3 (in the air)		Mucous membrane irritation	Dirt from outside and from building materials
Man made mineral fibres	1.000-20.000 $fibres/m^3$		Mucous membrane irritation Eczema	Acoustic ceilings (Insulating materials)
Organic dust	c.1 mg/m^3 (in the air) 3-6 mg/g *) (in floordust)		Mucous membrane irritation Fatigue	Paper Textiles
Organic biological dust **)	Micro fungi c. 100-1.000 colony forming units/ m^3 air	Asthma Allergy	Fatigue Eczema Reduced lung function	House dust mites Animal dander Mould
Metabolic products of micro-organisms	Unknown		Fatigue Headache Mucous membrane irritation	Mould

*) Macromolecular organic dust

**) Specific conditions for development of allergies and release of symptoms in people suffering from allergies.

Only exposures and effects relevant to mucosal or general symptoms are dealt with. The expression "mucous membrane irritation" also covers the expression "dry mucous membrane".

Source : Valbjorn *et al*, 1990

Table 6 Factors Having an Indirect Effect on the Indoor Environment

Factor	**Process of Influence**	**Possible Effects**
Dust and gases	Gases are absorbed in dust which is transmitted to skin and mucous membranes	Rash and mucous membrane irritation

Source : **Valbjorn** *et al*, 1990

Table 7 Factors which are Suspected of Causing Symptoms, Probable Indicators and Suggested Remedies

Factor	Indicator/Cause	Remedy Proposed
Human bioeffluents	Carbon dioxide concentration > 1000 ppm Odour	Check and adjust operation and maintenance of ventilation system. Adjust to new requirements Increase the outdoor air rate Airing instructions
High temperature	Complaints or temperatures above 23-24°C	Lower heat load (from lighting, sun and apparatus) Control and maintenance of heating plant
Radiation of heat against the head	Ceiling heating (surface temperature above 35°C)	Change incandescent lamp to fluorescent lighting Replace ceiling heating with radiator
Mould spore	Visible mould Odour (sometimes) Water damage Low air change Condensation Many plants (Spore content in the air)	Wash away the mould Reduce humidity load Deal with leaks in roofs and walls Increase the ventilation
Organic dust in carpeting	Visible dirt Carpet 5-10 years old not cleaned annually Analysis of vacuum-cleaned dust	Try thorough cleaning Change to "hard" flooring

Table 7 Continued

Factor	Indicator/Cause	Remedy Proposed
Microorganisms from humidifiers	Stagnant water in the humidifier (eg in the night and at weekends) Visible growth	Clean humidifier Check maintenance and operation Switch off or change to a steam model
Levelling compound in the floor structure	Casein filler Discoloured floors Odour	Remove casein and dry out the construction
High dust concentration in air	Visible dust on floors, shelves or in the air Much paper-handling and high activity	Improve cleaning
House dust mites (particularly in homes)	High relative humidity (> 40% RH) in winter months in homes Condensation on double glazing Counts of dust mites	Reduce the water evaporation or increase ventilation rate Clean mattress and remove carpets in bedroom
Tobacco smoke	Odour Carbon monoxide Questionnaire	Check smoking in proportion to odour transfer between rooms (stop recirculation) Check ventilation rate Avoid smoking
Man-made mineral wool fibres (non asbestos)	Sound absorption lining made of soft mineral wool with unprotected surface or hard mineral wool with water based glue Fibres in air or dust on surfaces (measured)	Clean lining and room Change or cover lining
Off-gassing from building materials	New materials installed Odour which can be related to a specific material (Solvent, formaldehyde)	Check and adjust operation and maintenance of ventilation system Increase ventilation Heat and ventilate when rooms are not in use (bake out) Change materials

Table 7 Continued

Factor	**Indicator/Cause**	**Remedy Proposed**
Off-gassing from furniture etc.	New furniture Odour which can be related to specific furniture	Move or remove furniture Heat and ventilate when rooms are not in use
Off-gassing from copying machines, laser printers	Odour which can be attributed to the copying process Old filters (Saturated)	Place the machine away from working places preferably in ventilated rooms Connect local exhaust Adjust ventilation to negative pressures in the copying room
Exhaust gases from cars Flue gases	Odour Carbon monoxide from eg garage and boiler room via staircase and corridor or from parking via outdoor air intake	Move outdoor air intake Prevent infiltration
Pollution from other activities in the building (laboratories, big kitchens, workshops *etc*)	Odour Infiltration Return air used	Check the ventilation rates and pressure conditions Stop use of return air Control short-circuit from exhaust to outdoor air intake
Electrostatic charges	Unpleasant discharge (shock) Non-antistatic carpeting or chair covering	The floor is treated with antistatic material Replace floor material or chair covers

Source : Valbjorn *et al*, 1990

Table 8 Physical Factors in Non-Industrial Buildings and Their Effect or Presumed Effect on People.

Factor	**Area for Possible Effects**	**Proved Effect**	**Presumed Effect**	**Source Amongst Others**
High temperature	24-30^{o}C	Lack of concentration	Fatigue Headache Sensation of dryness	Sun radiation Lighting Heat-emitting apparatus
Low frequency sound	70-120 dB in frequency area 20-100 Hz		Fatigue Heavy in the head	Ventilators Machines Compressors
Noise	60-80 dB (L_{Aeq}) equivalent noise level		Fatigue Headache	Machines Ventilation system Traffic
Lighting: Glare Reflection Contrast low			Eye-Irritation Headache	Daylight Artificial lighting Visual display

Source : Valbjorn *et al*, 1990

Table 9 Factors Having an Indirect Effect on the Indoor Environment

Factor	**Process of Influence**	**Possible Effects**
High temperature and/or high humidity	Increases the rate of offgassing from building materials and furniture	Mucous membrane irritation
	Increases microbial growth	Mucous membranes irritation and fatigue
Fleecy and hygroscopic materials (carpets, textiles, paper)	Changes the off-gassing conditions in a room by adsorption and desorption of pollutants	Mucous membrane irritation and fatigue
	Increases the risk of accumulating sources of biological activity released by high humidity	Increases the risk of mucous membrane irritation and fatigue
High temperature and noise	The ability to concentrate is reduced by high temperature but increased by simultaneous noises (stresses the organism)	Increases the risk of headache and fatigue (stresses the organism)
High temperature and low level of lighting	The ability to concentrate is reduced	Where the ability of high concentration is needed the risk of headache and fatigue is increased (stress)
Static electrical charge and dust	Dust is transmitted to the skin	Flush and facial skin and rash
Inadequate lighting conditions	Distorted working postures result in muscular tensions	Headache
Draughts and low temperature	Increases muscular tensions locally	Headache

Source : Valbjorn *et al*, 1990

REFERENCES

ABILDGAARD, A. (1988) The Interaction Between Dust, Microorganisms and the Quality of Cleaning. *Healthy Buildings '88* **3**, 19-23. Swedish Council for Building Research, Stockholm.

AMERICAN SOCIETY FOR TESTING MATERIALS (1989) *Standard Guide for Small-Scale Environmental Determinations of Organic Emissions from Indoor Materials/Products*. Draft, Subcommittee D 22.05 on Indoor Air.

AMERICAN SOCIETY OF HEATING, REFRIGERATION AND AIR-CONDITIONING ENGINEERS (ASHRAE) (1989) *Ventilation for Acceptable Indoor Air Quality, ASHRAE Standard 62-1989*. ASHRAE, Atlanta, USA.

ANDEGIORGIS, T. (1988) Ventilation Employing Displacement Flow. *Healthy Buildings '88* **3**, 31-37. Swedish Council for Building Research, Stockholm.

ANTTI, M., TAPIO, H. and SEPPÄNEN, O. (1987) Air Quality and Ventilation Efficiency in Residential and Office Buildings. *Indoor Air '87* **3**, 301-306. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

APPLEBY, P.H. and BAILEY, M.R. (1990) Indoor Air Quality in Brussels Meeting Rooms. *Indoor Air '90* **4**, 41-46. International Conference on Indoor Air Quality and Climate, Ottawa.

ARUDEL, A,. COLLET, C., STERLING, E. and STEEVES, J. (1987) Low Relative Humidity and Eye, Nose, Throat and Skin Irritation. *Indoor Air '87* **2**, 650-654. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

AXELRAD, R. (1989) Economic Implications of Indoor Air Quality and its Regulation and Control. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, The Implications of Indoor Air Quality for Modern Society, CCMS Report No. 183,* 89-116. NATO/CCMS.

AXELRAD, R. (1990) EPA and Indoor Air Quality. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, Managing Indoor Air Quality Risks,* 41-54. United States Environmental Protection Agency EPA/400/7-90/005, Washington DC.

BACH, B., MOLHAVE, L and PEDERSEN, O.F. (1987) Human Reactions During Controlled Exposures to Low Concentrations of Formaldehyde, Performance Tests. *Indoor Air '87* **2**, 620-624. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

BAGLIONI, A. (1990) New Parameters For Design and Evaluation of Buildings. *Indoor Air '90* **3**, 283-287. International Conference on Indoor Air Quality and Climate, Ottawa.

BALDWIN, M.E. and FARRANT, J-P. (1990) Study of Selected Volatile Organic Compounds in Office Buildings at Different Stages of Occupancy. *Indoor Air '90* **2**, 665-670. International Conference on Indoor Air Quality and Climate, Ottawa.

BANSAZAK, E.F., THIEDE, W.H. and FINK, J.N. (1970) Hypersensitivity Pneumonitis due to Contamination of an Air Conditioner. *New England Journal of Medicine* **283**, 271-276.

BARBIERI, F., COLOSIO, C., ALCINI, D. and MARONI, M. (1990) Assessment of Indoor Exposure to Pentachlorophenol (PCP) from Home and Occupational Sources. *Indoor Air '90* **2**, 671-676. International Conference on Indoor Air Quality and Climate, Ottawa.

BATTAGLIA, A., CAPRA, D., QUEIRAZZA, G. and SAMPAOLO, A. (1990) Radon Exhalation Rate in Building Materials and Fly Ashes in Italy. *Indoor Air '90* **3**, 47-52. International Conference on Indoor Air Quality and Climate, Ottawa.

BAYER, C.W., (1990) An Investigation Into the Effect of "Building Bakeout" Conditions on Building Materials and Furnishings. *Indoor Air '90* **3**, 581-586. International Conference on Indoor Air Quality and Climate, Ottawa.

BECK, E.M. (1990) Filter Facts. *Indoor Air '90* **3**, 171-176. International Conference on Indoor Air Quality and Climate, Ottawa.

BENCKO, V., MELICHERCIK, J., MELICHERCIKOVA, V. and WIRTH, Z. (1990) Indoor Air Microbial Pollution Control Measures in Health Facilities. *Indoor Air '90* **3**, 207-212. International Conference on Indoor Air Quality and Climate, Ottawa.

BERGLUND, B., JOHANSSON, I. and LINDVALL, T. (1988) Adsorption and Desorption of Organic Chemicals in Indoor Materials. *Healthy Buildings '88* **3**, 299-309. Swedish Council for Building Research, Stockholm.

BERGLUND, B., BERGLUND, U. and ENGEN, T. (1987) Do Sick Buildings Affect Human Performance ? How Should One Assess Them ? *Indoor Air '87* **2**, 477-481. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

BERGLUND, L.G., and FOBELETS. A.P. (1987a) Occupant Acceptance of Air Motion and Asymetric Radiation in Neutral and Cool Environments. *Indoor Air '87* **3**, 419-423. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

BERGLUND, L.G., and FOBELETS. A.P. (1987b) Floor Drafts from Cold Walls. *Indoor Air '87* **3**, 439-442. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

BERGLUND, B., JOHANSSON, I., LINDVALL, T. and LUNDIN, L. (1990a) A Longitudinal Study of Percieved Air Quality and Comfort in a Sick Library Building. *Indoor Air '90* **1**, 489-494. International Conference on Indoor Air Quality and Climate, Ottawa.

BERGLUND, B., JOHANSSON, I., LINDVALL, T. and LUNDIN, L. (1990b) A Longitudinal Study of Airborne Chemical Compounds in a Sick Library Building. *Indoor Air '90* **2**, 677-682. International Conference on Indoor Air Quality and Climate, Ottawa.

BERGLUND, B. and LINDVALL, T. (1990) Sensory Criteria for Healthy Buildings. *Indoor Air '90* 5, 65-79. International Conference on Indoor Air Quality and Climate, Ottawa.

BERRY, M.A. (1989a) Impact of Indoor Air Quality on Health and Welfare: State of the Art and Research Needs. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, The Implications of Indoor Air Quality for Modern Society, CCMS Report No. 183*, 5-26. NATO/CCMS.

BERRY, M.A. (1989b) Strategies for Prevention/Mitigation for Specific Categories of Indoor Pollutants. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, The Implications of Indoor Air Quality for Modern Society, CCMS Report No. 183*, 27-35. NATO/CCMS.

BERRY, M.A. (1989c) Population Risk Assessment for Indoor Air Pollutants. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, The Implications of Indoor Air Quality for Modern Society, CCMS Report No. 183*, 77-88. NATO/CCMS.

BERRY, M.A. (1990) A Response to Legislation. EPA's Indoor Air Research Program. *Indoor Air '90* 5, 193-201. International Conference on Indoor Air Qualiity and Climate, Ottawa.

BLACK, M.S. and BAYER, C.W. (1988) Measurement of Indoor Air Quality in Office Building Environments in Relation to Construction Materials. *Healthy Buildings '88* 3, 311-326. Swedish Council for Building Research, Stockholm.

BONETTI, R., CAPRA, L., FACCHINI, U., VALLI, G., CARRERI, V., ANVERSA, A., BLANCO, G., GUALDI, R., SGORBATI, G. and DE CRESCENZO, S. (1990) Development of Radon Surveys in Lombardia, Italy. *Indoor Air '90* 3, 53-58. International Conference on Indoor Air Quality and Climate, Ottawa.

BRAUER, M., KOUTRAKIS, P., KEELER, G.J. and SPENGLER, D. (1990a) Indoor and Outdoor Concentrations of Acidic Aerosols and Gases. *Indoor Air '90* 3, 447-452. International Conference on Indoor Air Quality and Climate, Ottawa.

BRAUER, M., RYAN, P.B., SUH, H.H., KOUTRAKIS, P., SPENGLER, J.D., LESLIE, N.P., and BILLICK, I.H. (1990b) Measurement and Modelling of Nitrous Acid in Indoor Air. *Indoor Air '90* 2, 293-298. International Conference on Indoor Air Quality and Climate, Ottawa.

BRENNAN, T., TURNER, W.A. and FISHER, G. (1990) Building HVAC/Foundation Diagnostics for Radon MitigAtion in Schools and Commercial Buildings: Part 1. *Indoor Air '90* 3, 439-444. International Conference on Indoor Air Quality and Climate, Ottawa.

BREUGNON, N., CLEMENT, P., MARTIN, E., MASSERAND, R. and MOLINA, N. (1986) Perception Des Conditions De Travail En Atmosphere Climatisee. Maladies Des Climatiseurs Et Des Humidificateurs. In INSERM (Eds), 117-125. INSERM, Paris

BREUNIS, K. and de GROOT, J.P. (1987) Relative Humidity of the Air and Occular Discomfort in a Group of Susceptible Office Workers. *Indoor Air '87* **2**, 625-629. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

BRITISH STANDARD (BS) 5720 (1979) *Code of Practice for Mechanical Ventilation and Air Conditioning in Buildings*. BSI, London.

BRODER, I., PILGER, C. and COREY, P. (1990) Building Related Discomfort is Associated with Perceived Rather than Measured Levels of Indoor Environmental Variables. *Indoor Air '90* **1**, 221-226. International Conference on Indoor Air Quality and Climate, Ottawa.

BROUGHTON, A., THRASHER, J.D. and MADISON, R. (1990) Biological Monitoring of Indoor Air Pollution: A Novel Approach. *Indoor Air '90* **2**, 145-150. International Conference on Indoor Air Quality and Climate, Ottawa.

BURGE, P.S. (1990) Building Sickness - A Medical Approach to the Causes. *Indoor Air '90* **5**, 3-14. International Conference on Indoor Air Quality and Climate, Ottawa.

BURGE, P.S., JONES, P. and ROBERTSON, A.S. (1990) Sick Building Syndrome - Environmental Comparisons of Sick and Healthy Buildings. *Indoor Air '90* **1**, 479-484. International Conference on Indoor Air Quality and Climate, Ottawa.

CAMANN, D.E., HARDING, H.J. and LEWIS, R.G. (1990) Trapping of Particle-Associated Pesticides in Indoor Air by Polyurethane Foam and Exploration of Soil Track-in as a Pesticide Source. *Indoor Air '90* **2**, 621-626. International Conference on Indoor Air Quality and Climate, Ottawa.

CAMPOS VENUTI, G. and PIERMATTEI, S. (1989) Behaviour of Radon in Indoor Air and Possible Strategies for Controlling Indoor Pollution. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, The Implications of Indoor Air Quality for Modern Society, CCMS Report No. 183*, 37-54. NATO/CCMS.

CHANDRAKER, K. and BENHAMA, A. (1990) Ion Counter for Atmospheric Air. *Indoor Air '90* **3**, 231-236. International Conference on Indoor Air Quality and Climate, Ottawa.

CHARTERED INSTITUTE OF BUILDING SURVEYORS AND ENGINEERS (CIBSE) (1978) *Guide A1, Environmental Criteria for Design*. CIBSE, London.

CHARTERED INSTITUTE OF BUILDING SURVEYORS AND ENGINEERS (CIBSE) (1989) *Lighting Guide LG3: Areas for Visual Display Terminals*. CIBSE, London.

CHIANG, P-U. and CHANG, P. (1987) Low Cost Control Technology for VOC Emissions. *Indoor Air '87* **3**, 261-266. Institut für Wasser-, Boden-und Lufthygiene, Berlin.

CHEMICALS ACT OF 16 SEPTEMBER (1980) *Bundesgesetzblatt* I, 1718

CLAUSEN, G.H., MÖLLER, S.B. and FANGER, P.O. (1987a) The Impact of Air Washing on Environmental Tobacco Smoke Odour. *Indoor Air '87* 2, 47-51. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

CLAUSEN, G.H., NEILSEN, K.S, SAHIN, F. and FANGER, P.O. (1987b) Sensory Irritation from Exposure to Environmental Tobacco Smoke. *Indoor Air '87* 2, 52-56. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

COLE, R.J.and STERLING, E.M. (1987) Designing Office Buildings For Improved Environmental Quality. *Indoor Air '87* 3, 175-179. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

COLLETT C.W., STERLING, E.M. and ARUNDEL, A.V. (1988) Changing Sick Buildings into Healthy Buildings: Improving the Ventilation System. *Healthy Buildings '88* 3, 55-60. Swedish Council for Building Research, Stockholm.

COMMITTEE ON HARMONISED TECHNICAL PRESCRIPTIONS FOR CONSTRUCTION (1980) Guideline On The Use Of Particleboard With Regard To The Avoidance Of Unacceptable Formaldehyde Concentrations In Indoor Air. *Beuth Verlag*, Berlin.

COMMITTEE ON HARMONISED TECHNICAL PRESCRIPTIONS FOR CONSTRUCTION (1985) Guideline to Limit the Formaldehyde Emmission into Indoor Air From Urea-Formaldehyde Foam Insulation. *Beuth Verlag*, Berlin.

CORN, M. (1990) Airborne Concentrations of Asbestos-In-Air In Buildings and Exposures of Occupants: Risk and Regulatory Implications. *Indoor Air '90* 2, 459-464. International Conference on Indoor Air Quality and Climate, Ottawa.

COST PROJECT 613 (1989) *European Concerted Action COST Project 613, Indoor Air Quality and Its Impact on Man. Environment and Quality of Life Report No. 3, Indoor Air Pollution by NO_2 in European Countries.* Commission of the European Communities, Directorate-General Information, Market and Innovation, Luxembourg.

COUNCIL DIRECTIVE 87/217/EEC (1987) Council Directive on Prevention and Reduction of Environmental Pollution by Asbestos. *Official Journal of the European Communities No L 085.*

COUNCIL DIRECTIVE 89/106/EEC (1989) Council Directive on Construction Products. *Official Journal of the European Communities.*

COUNCIL DIRECTIVE 89/654/EEC (1989) Council Directive Concerning the Minimum Safety and Health Requirement for the Workplace. *Official Journal of the European Communities* **No L 393/1-393/12.**

COWAN, J.D. (1990) The Partnership of Indoor Air Quality and Energy Management. *Indoor Air '90* 3, 431-436. International Conference on Indoor Air Quality and Climate, Ottawa.

DAVIDGE, B. and KERR, G. (1990) Suggestions for Avoiding Indoor Air Air Quality Complaints. *Indoor Air '90* 3, 343-347. International Conference on Indoor Air Quality and Climate, Ottawa.

DE DEAR, R.J., TANABE, S., KNUDSEN, H.N., PEJTERSEN, J.H., MACKEPRANG, J. and FANGER, P.O. (1987) Thermal Response of Wool Clothing During Humidity Transients. *Indoor Air '87* 3, 399-403. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

DE BORTOLI, M., KNOPPEL, H., PEIL, A., PECCHIO, E., SCHLITT, H. and DE WILDE, H. (1990a) Investigation on the Contribution of Volatile Organic Compounds to Air Quality Complaints in Office Buildings of The European Parliament. *Indoor Air '90* 2, 695-700. International Conference on Indoor Air Quality and Climate, Ottawa.

DE BORTOLI, M., KNOPPEL, H. and SEIFERT, B. (1990b) Orientations and Actions of the European Community in the Assessment and Prevention of Indoor Air Pollution. *Indoor Air '90* 5, 203-211. International Conference on Indoor Air Quality and Climate, Ottawa.

ENGEN, T. (1987) Adaptation to Odours. *Indoor Air '87* 2, 671-675. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

ENGSTROM, K., NYMAN, L., HAIKOLA, M. and SAARNI, H. (1988) Organic Compounds Released from Building Materials and Furnishings. *Healthy Buildings '88* 3, 333-337. Swedish Council for Building Research, Stockholm.

ENVIROMENTAL PROTECTION AGENCY (EPA) (1987) *Indoor Air Quality Implementation Plan, Appendix* A. EPA, Washington D.C.

ENVIROMENTAL PROTECTION AGENCY (EPA) (1990) *Compendium of Methods for the Determination of Air Pollutants in Indoor Air. EPA 610/1990*. EPA, Washington D.C.

ERDLINGER, L., SONNTAG, H-G. and HAMMES, K-H. (1990) Performance of a Simple Fibre-Filter System for Indoor Air Purification by Convection. *Indoor Air '90* 3, 163-168. International Conference on Indoor Air Quality and Climate, Ottawa.

ETO, J.H. and MEYER, C. (1988) The HVAC Costs of Fresh Air Ventilation in Office Buildings. *ASHRAE Transactions* **94 (II)**. ASHRAE, Atlanta, USA.

FAIL, A. and PANZHAUSER, E. (1987) Natural Shaft Ventilation - Measuremment, Simulation, Contribution to Basic Ventilation. *Indoor Air '87* 3, 342-346. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

FANGER, P.O. (1972) *Thermal Comfort*. McGraw-Hill, London.

FANGER, P.O. (1987) Perceived Quality of Indoor and Ambient Air. *Indoor Air '87*, 365-376. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

FANGER, P.O. (1988) Introduction of the Olf and the Decipol Unit to Quantify Air Pollution Perceived by Humans Indoors and Outdoors. *Energy and Buildings* 12, 1-6.

FANGER, P.O., BREUM, N.O and JERKING, E. (1977) Can Colour and Noise Influence Man's Thermal Comfort ? *Ergonomics* 20, 11-18.

FANGER, P.O., MELIKOW, A.K. and HANZAWA, H. (1987) Draught and Turbulence. *Indoor Air '87* 3, 404-408. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

FANGER, P.O., LAURIDSEN, J., BLUYSSEN, P. and CLAUSEN, G. (1988) Air Pollution Sources in Offices and Assembly Halls Quantified by the Olf Unit. *Energy and Buildings* 12, 7-19.

FEDERAL HEALTH OFFICE, WEST GERMANY (1977) Criteria For Formaldehyde In Indoor Air. *Press Release Number* 19/77, 12 October. Federal Health Office, Bonn.

FEDERAL HEALTH OFFICE, WEST GERMANY (1988) Recommendation concerning tetrachloroethene in Indoor Air. *Bundesgesundheitsblatt* 31, 99-101.

FINNEGAN, M.J. and PICKERING, A.C. (1987) Prevalence of Symptoms of Sick Building Syndrome in Buildings Without Expressed Dissatisfaction. *Indoor Air '87* 2, 542-546. Institut für Wasser-, Boden-und Lufthygiene, Berlin.

FISHBEAN, L and O'NEAL, I.K. (1987) Metals in Indoor Environments: Sources and Aspects of Bioavailability and Interactions. *Indoor Air '87* 1, 501-508. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

FITZNER, K. (1987) Air Outlets for Displacement Flow and Their Influence on Flow Patterns with Various Kinds of Heat Sources. *Indoor Air '87* 3, 347-351. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

FLATHEIM, G. (1990a) Energy Consequences of Upgrading Indoor Air Quality. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, Managing Indoor Air Quality Risks*, 107-128. United States Environmental Protection Agency EPA/400/7-90/005, Washington DC.

FLATHEIM, G. (1990b) IAQ Upgrades do not Ruin Budgets. *Indoor Air '90* 4, 59-64. International Conference on Indoor Air Quality and Climate, Ottawa.

FLEMMING, W.S., HESSE, B.J. and CARLSON, S.W. (1990) IAQ Variables - Determining Cause and Effect. *Indoor Air '90* 3, 495-500. International Conference on Indoor Air Quality and Climate, Ottawa.

FREDERICKSEN, E. (1990) Practical Attempts to Predict Indoor Air Quality. *Indoor Air '90* 3, 239-244. International Conference on Indoor Air Quality and Climate, Ottawa.

GAMMAGE, R.B., HANSEN, D.L. and JOHNSON, L.W. (1989) Indoor Air Quality Investigations: A Practioner's Approach. *Environment International* **15**, 503-510.

GAMMAGE, R.B. and WILSON, D.L. (1990) Performance Experience With Radon Mitigation Systems. *Indoor Air '90* **3**, 507-512. International Conference on Indoor Air Quality and Climate, Ottawa.

GIRMAN, J.R., ALEVANTIS, L.E., PETREAS, M.X. and WEBBER, L.M. (1990) Building Bake-Out Studies. *Indoor Air '90* **3**, 349-354. International Conference on Indoor Air Quality and Climate, Ottawa.

GÖTHE, C-J., ANCKER, K., BJURSTRÖM, R., HOLM, S. and LANGWORTH, S. (1987) Relative Humidity, Temperature and Subjective Perception of "Dry Air". *Indoor Air '87* **3**, 443-447. Institut für Wasser-, Boden-und Lufthygiene, Berlin.

GRAHAM, J.R. and BAYATI, M.A. (1990) The Use of Activated Carbon for the Removal of Trace Organics in the Control of Indoor Air Quality. *Indoor Air '90* **3**, 133-138. International Conference on Indoor Air Quality and Climate, Ottawa.

GRAVESEN, S. (1987) Microbiological Studies on Carpets Versus Hard Floors in Non-Industrial Occupations. *Indoor Air '87* **1**, 668-672. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

GRAVESEN, S., SKOV, P., VALBJORN, O. and LOWENSTEIN, H. (1990) The Role of Potential Immunogenic Components of Dust (MOD) in the Sick Building Syndrome. *Indoor Air '90* **1**, 9-15. International Conference on Indoor Air Quality and Climate, Ottawa.

GREENWOOD, M.R. (1990) The Toxicity of Isoparaffinic Hydrocarbons and Current Exposure Practices in the Non-Industrial (Office) Indoor Air Environment. *Indoor Air '90* **5**, 169-175. International Conference on Indoor Air Quality and Climate, Ottawa.

GRUNDEL, L.A., SOMORJAI, N. and NOVAKOV, T. (1987) The Interaction of Nitrogen Oxides With Particles: Chemical Transformation on Activated Carbon and Alumina Surfaces. *Indoor Air '87* **1**, 330-332. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

GUNNARSEN, L. and FANGER, P.O. (1988) Adaptation to Indoor Air Pollution. *Healthy Buildings '88* **3**, 157-167. Swedish Council for Buidling Research, Stockholm.

GUTTMANN, K. (1987) Proposed Method of Indoor Air Pollution Control by Dilution With Outside Air. *Indoor Air '87* **3**, 198-202. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

HANSEN, L. (1987) Monitoring of Symptoms as a Control of the Effect of Intervention in the Sick Building Syndrome. *Indoor Air '87* **2**, 459-464. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

HANSEN, S.J. (1990) Quality Indoor Air Through Preventative Strategies. *Indoor Air '90* 3, 407-412. International Conference on Indoor Air Quality and Climate, Ottawa.

HARRISON, J., PICKERING, A.C., FINNEGAN, M.J. and AUSTWICK, P.K.C. (1987) The Sick Building Syndrome: Further Prevalence Studies and Investigation of Possible Causes. *Indoor Air '87* **2**, 487-491. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

HARRISON, J., PICKERING, C.A.C., FARAGHER, E.B. and AUSTWICK, P.K.C. (1990) An Investigation of the Relationship Between Microbial and Particulate Indoor Air Pollution and the Sick Building Syndrome. *Indoor Air '90* **1**, 149-154. International Conference on Indoor Air Quality and Climate, Ottawa.

HEALTH AND SAFETY EXECUTIVE (HSE) (1983) *Visual Display Units*. HMSO, London.

HEALTH AND SAFETY EXECUTIVE (HSE) (1987) *HS(G) Series No. 38: Lighting at Work*. HMSO, London.

HEALTH AND SAFETY EXECUTIVE (HSE) (1988) *Guidance Note EH22, Ventilation of the Workplace*. HMSO, London.

HEDGE, A., WILSON, S., BURGE, P.S., ROBERTSON, A.S. and HARRIS-BASS, J. (1987a) Indoor Climate and Employee Health in Offices. *Indoor Air '87* **2**, 492-496. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

HEDGE, A., STERLING, E.M., COLLET, C.W., MUELLER, B. and ROBSON, R. (1987b) Indoor Air Quality Investigation as a Pyschological Stressor. *Indoor Air '87* **2**, 552-556. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

HEDGE, A. (1990) Questionnaire Design Guidelines for Investigations of "Sick" Buildings. *Indoor Air '90* **1**, 605-610. International Conference on Indoor Air Quality and Climate, Ottawa.

HICKS, J., WORL, K. and HALL, K. (1990) Building Bake-Out During Commissioning: Effects on VOC Concentrations. *Indoor Air '90* **3**, 413-418. International Conference on Indoor Air Quality and Climate, Ottawa.

HIRVONEN, A., SAVOLAINEN, T., RUUSKANEN, J., TARHANEN, J. and PASANEN, P. (1990) Thermal Desorption of Settled Household Dust. *Indoor Air '90* 3, 743-746. International Conference on Indoor Air Quality and Climate, Ottawa.

HODGSON, M.J., PERMAR, E., SQUIRE, G., CAGNEY, W., ALLEN, A. and PARKINSON, D.K. (1987) Vibration as a Cause of "Tight Building Syndrome" Symptoms. *Indoor Air '87* **2**, 449-453. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

HOLMBERG, R.B., FOLKESSON, K., STENBERG, L-G. and JANSSON, G. (1987) Experimental Comparison of Indoor Climate Using Various Air Distribution Methods. *Indoor Air '87* 3, 307-312. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

HOLT, G.L. (1990) Seasonal Indoor/Outdoor Fungi Ratios and Indoor Bacteria Levels in Non-Complaint Office Buildings. *Indoor Air '90* 2, 33-38. International Conference on Indoor Air Quality and Climate, Ottawa.

HONEYWELL TECHANALYSIS (1985) *Indoor Air Quality: A National Survey of Office Worker Attitudes*. Minneapolis, Minnesota.

HUDNELL, K.H., OTTO, D.A., HOUSE, D.E. and MOLHAVE, L. (1990) Odour and Irritation Effects of a Volatile Organic Compound Mixture. *Indoor Air '90* 1, 263-268. International Conference on Indoor Air Quality and Climate, Ottawa.

HYGYE, S. (1987) Interactions of Noise and Thermal Factors on Human Behaviour. *Indoor Air '87* 3, 452-456. Institut für Wasser-, Boden-und Lufthygiene, Berlin.

IKAGA, T. and MATSUNAWA, K. (1990) Evaluation of Building Design Based on Thermal Comfort and Space Heat Load. *Indoor Air '90* 3, 295-300. International Conference on Indoor Air Quality and Climate, Ottawa.

IWASHITA, G., KIMURA, K., DOI, S., SATO, T., YOSHIZAWA, S., IKEDA, K. and TANABE, S. (1990) Indoor Air Quality Assessment Based on Olfactory Sensation. *Indoor Air '90* 1, 355-360. International Conference on Indoor Air Quality and Climate, Ottawa.

JAAKKOLA, J.J.K., MIETTINEN, O.S., KOMULAINEN, K., TUOMAALA, P. and SEPPANEN, O. (1990) The Effect of Air Recirculation on Symptoms and Environmental Complaints in Office Workers. A Double Blind, Four Period Cross-over Study. *Indoor Air '90* 1, 281-286. International Conference on Indoor Air Quality and Climate, Ottawa.

JANSSEN, J.E. and HILL, T.J. (1982) Ventilation for Control of Indoor Air Quality: A Case Study. *Environment International* 8, 487-496.

JOHNSEN, C.R., HEINIG, J.H., SCHMIDT, K., ALBRECHTSEN, O., NIELSEN, P.A., NIELSEN, G.D., HANSEN, L.F., WOLKOFF, P.and FRANK, C. (1990) Controlled Human Reactions to Building Materials in Climatic Chambers. Part I: Performance and Comfort. *Indoor Air '90* 1, 269-274. International Conference on Indoor Air Quality and Climate, Ottawa.

JUNGERS, R.H. and SHELDON, L.S. (1987) Characterisation of Volatile Organic Chemicals in Public Access Buildings. *Indoor Air '87* 1, 144-148. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

KAY, D.L.C., HEAVNER, D.L., NELSON, P.R., JENNINGS, R.A., EAKER, D.W., ROBINSON, J.H., DELUCA, P.O. and RISNER, C.H. (1990) Effects of Relative Humidity on Nonsmoker Response to Environmental Tobacco Smoke. *Indoor Air '90* **1**, 275-280. International Conference on Indoor Air Quality and Climate, Ottawa.

KJAERGAARD, S., MOLHAVE, L. and PEDERSEN, O.F. (1990) Changes in Human Sensory Reactions, Eye Physiology and Performance when Exposed to a Mixture of 22 Indoor Air Volatile Organic Compounds. *Indoor Air '90* **1**, 319-324. International Conference on Indoor Air Quality and Climate, Ottawa.

KNOPPEL, H. (1989) Organic Compounds in the Indoor Environment. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, The Implications of Indoor Air Quality for Modern Society, CCMS Report No. 183*, 55-65. NATO/CCMS.

KNOPPEL, H., DE BORTOLI, M. and SEIFERT, B. (1989) *European Concerted Action COST Project 613, Indoor Air Quality and Its Impact on Man. Environment and Quality of Life Report No. 5, Project Inventory*. Commission of the European Communities, Directorate-General Information, Market and Innovation, Luxembourg.

KRAFTHEFER, B.C. and MACPHAUL, D. (1990) Ultrafine Particle Emission From Baseboard and Other Resistance-Type Heaters. *Indoor Air '90* **3**, 659-664. International Conference on Indoor Air Quality and Climate, Ottawa.

KULMALA, M., SAARI, H., RAUNEMAA, T. and OLIN, M. (1987) Indoor Air Aerosols: Outdoor Air Influence on Indoor Air. *Indoor Air '87* **1**, 564-568. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

KUNZ, C. (1990) Radon Mitigation With Subslab Suction: Effect on Air and Soil-Gas Infiltration. *Indoor Air '90* **3**, 463-468. International Conference on Indoor Air Quality and Climate, Ottawa.

LANE, C.A., PUTNAM, V.L., WOODS, J.E. and RASK, D.R. (1990) A Procedure to Identify "Zones of Maximum Potential Exposure" in Commercial Buildings. *Indoor Air '90* **3**, 355-360. International Conference on Indoor Air Quality and Climate, Ottawa.

LAURIDSEN, J., PEJTERSEN, J., MITRIC, M., CLAUSEN, G. and FANGER, P.O. (1988) Addition of Olfs for Common Indoor Pollution Sources. *Healthy Buildings '88* **3**, 189-195. Swedish Council for Building Research, Stockholm.

LAURIDSEN, J., MUHAXHERI, M., CLAUSEN, G.H. and FANGER, P.O. (1987) Ventilation and Background Odour in Offices. *Indoor Air '87* **2**, 640-644. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

LEINSTER, P. and MARSHALL, J. (1991) Dust Mites: "A Plague O' Both Your Houses... and Office". *Health and Safety Practitioner, May 1991*. Paramount Publishing Ltd., Borehamwood, Herts.

LEINSTER, P., RAW, G., THOMSON, N., LEAMAN, A. and WHITEHEAD, C. (1990) A Modular Longitudinal Approach to the Investigation of Sick Building Syndrome. *Indoor Air '90* 1, 287-292. International Conference on Indoor Air Quality and Climate, Ottawa.

LEVIN, H. (1987) A Procedure Used to Evaluate Building Materials and Furnishings for a Large Office Building. *Indoor Air '87* 1, 54-58. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

LEVIN, H. (1990) Critical Building Design Factors for Indoor Air Quality and Climate: Current Status and Predicted Trends. *Indoor Air '90* 3, 301-306. International Conference on Indoor Air Quality and Climate, Ottawa.

LEVITAS, J and GALLAGHER, J. (1990) Comparison of Bioindicators of Exposure to Genotoxic Indoor Air Pollutants. *Indoor Air '90* 2, 237-242. International Conference on Indoor Air Quality and Climate, Ottawa.

LINDEN, V. and ROLFSEN, S. (1981) Video Computer Terminals and Occupational Dermatitis. *Scandinavian Journal of Workplace and Envrionmental Health* 7, 62-67.

LINDVALL, T.I. (1985) Exposure Limits for Office Environments. *Annals of the American Conference of Industrial Hygiene* 12, 99-108.

LINDVALL, T and RADFORD. T (1973) Measurement of Annoyance due to Exposure to Environmental Factors. *Environmental Research* 6, 1-36.

LIU, R.T. (1990) Removal of Volatile Organic Compounds in IAQ Concentrations With Short Carbon Bed Depths. *Indoor Air '90* 3, 177-182. International Conference on Indoor Air Quality and Climate, Ottawa.

MCAUGHTEY, J.J., PRITCHARD, J.N. and STRONG, J.C. (1990) Respiratory Deposition of Environmental Tobacco Smoke. *Indoor Air '90* 2, 361-366. International Conference on Indoor Air Quality and Climate, Ottawa.

MCLAUGHLIN, J.P. (1988) *European Concerted Action COST Project 613, Indoor Air Quality and Its Impact on Man. Environment and Quality of Life Report No. 1, Radon in Indoor Air*. Commission of the European Communities, Directorate-General Information, Market and Innovation, Luxembourg.

MCLAUGHLIN, P. and AIGNER, R. (1990) Higher Alcohols as Indoor Air Pollutants: Source, Cause, Mitigation. *Indoor Air '90* 3, 587-591. International Conference on Indoor Air Quality and Climate, Ottawa.

MANT, D.C. and MUIR GRAY, J.A. (1986) *Building Regulation and Health*. Department of the Environment, Building Research Establishment, Watford, England.

MARONI, M. (1989) Biological Contaminants: New Issues for an Old Problem. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, The Implications of Indoor Air Quality for Modern Society, CCMS Report No. 183*, 67-75. NATO/CCMS.

MARONI, M. (1990) The Approach to Control Indoor Air Quality in Italy. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, Managing Indoor Air Quality Risks*, 95-102. United States Environmental Protection Agency EPA/400/7-90/005, Washington DC.

MARTIKAINEN, P.J., ASIKAINEN, A., NEVALAINEN, A., JANTUNEN, M., PASANEN, P. and KALLIOKOSKI, (1990) Microbial Growth on Ventilation Filter Materials. *Indoor Air '90* 3, 203-206. International Conference on Indoor Air Quality and Climate, Ottawa.

MATSUSHITA, H., GOTO, S., ENDO, O., TANABE, K., KOYANO, M., TAKAGI, Y., MURATA, M. and LEWITAS, J. (1990) Biological and Chemical Methodologies for Assessing Human Exposure to Airborne Mutagens Indoors. *Indoor Air '90* 2, 225-230. International Conference on Indoor Air Quality and Climate, Ottawa.

MECKLER, M. (1990) Role of Commissioning and Building Operations in Maintaining Acceptable Indoor Air Quality. *Indoor Air '90* 3, 383-388. International Conference on Indoor Air Quality and Climate, Ottawa.

MENZIES, R.I., TAMBLYN, R.M., TAMBLYN, R.T., FARANT, J.P., HANLEY, J. and SPITZER, W.O. (1990) Sick Building Syndrome: The Effect of Changes in Ventilation Rates on Symptom Prevalence: The Evaluation of a Double Blind Experimental Approach. *Indoor Air '90* 1, 519-524. International Conference on Indoor Air Quality and Climate, Ottawa.

MOGHISSI, A.A., SEILER, F.A. and DELLARCO, M.J. (1987) Enhancement of Exposure to Radon Progeny as a Consequence of Passive Smoking. *Indoor Air '87* 2, 330-364. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

MOLHAVE, L. (1990a) Volatile Organic Compounds, Indoor Air Quality and Health. *Indoor Air '90* 5, 15-33. International Conference on Indoor Air Quality and Climate, Ottawa.

MOLHAVE, L. (1990b) The Sick Building Syndrome (SBS) Caused by Exposure to Volatile Organic Compounds (VOCs). In Weeks, D.M. and Gammage, R.B. (Eds.) *The Practitioner's Approach to Indoor Air Quality Investigations*, 1-18. American Industrial Hygiene Association, Akron, Ohio.

MOLINA, C., PICKERING, C.A.C., VALBJORN, O. and DE BORTOLI, M. (1989) *European Concerted Action COST Project 613, Indoor Air Quality and Its Impact on Man. Environment and Quality of Life Report No. 4, Sick Building Syndrome, A Practical Guide*. Commission of the European Communities, Directorate-General Information, Market and Innovation, Luxembourg.

MOREY, P.R. (1990) Bioaerosols in the Indoor Environment: Current Practices and Approaches. In Weeks, D.M. and Gammage, R.B. (Eds.) *The Practitioner's Approach to Indoor Air Quality Investigations*, 51-72. American Industrial Hygiene Association, Akron, Ohio.

MOREY, P. and MACPHAUL, D. (1990) Rank Order Assessment of Volatile Organic Compounds in Indoor Air Quality Evaluations. *Indoor Air '90* 2, 735-739. International Conference on Indoor Air Quality and Climate, Ottawa.

MOREY, P., BURGE, H., CHATIGNY, M., FEELEY, J., KREISS, K. and OTTEN, J. (1987) Assessment of Non-Pathogenic Bioaerosols in Indoor Environments. *Indoor Air '87* 1, 622-626. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

MORRIS, L. and HAWKINS, L. (1987) The Role of Stress in the Sick Building Syndrome. *Indoor Air '87* 2, 566-571. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

NATHANSON, T. (1990) Indoor Air Quality Building Surveys Case Studies. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, Managing Indoor Air Quality Risks*, 145-156. United States Environmental Protection Agency EPA/400/7-90/005, Washington DC.

NAUDEIX, D (1987) Limits of Carbon Monoxide and Dioxide from Unvented Instantaneous Water Heaters. *Indoor Air '87* 1, 349-353. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

NAZAROFF, W.W. and CASS, G.R. (1987) Mass-Transfer Aspects of Pollutant Removal at Indoor Surfaces. *Indoor Air '87* 3, 244-248. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

NIELSEN, P.A. (1987) Potential Pollutants - Their Importance to the Sick Building Syndrome - and Their Release Mechanism. *Indoor Air '87* 2, 598-602. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

NIELSEN, P.A. (1988) The Importance of Building Materials and Building Construction to the 'Sick Building Syndrome'. *Healthy Buildings '88* 3, 391. Swedish Council for Building Research, Stockholm.

NORBACK, D. and TORGEN, M. (1987) A Longitudinal Study of Symptoms Associated With Wall-to-Wall Carpets and Electrostatical Charge in Swedish School Buildings. *Indoor Air '87* 2, 572-576. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

NOVOSEL, D., RELWANI, S.M. and MOSCHANDREAS, D.J. (1987) Development of a Desiccant Based Air Conditioner With Indoor Pollution Control Capabilities. *Indoor Air '87* 3, 283-287. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

OEHME, M and KNOPPEL, H. (1987) Analysis of Low Volatile ($>C_{15}$) and Particle Bound Indoor Pollutants: Assessment of a Sensitive Method and First Result. *Indoor Air '87* **1**, 210-214. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

OGDEN, M.W., MAIOLO, K.C., OLDAKER, G.B. and CONRAD, F.W. (1990) Evaluation of Methods for Estimating the Contribution of ETS to Respirable Suspended Particles. *Indoor Air '90* **2**, 415-420. International Conference on Indoor Air Quality and Climate, Ottawa.

OLSSON, H. (1987) Increased Ventilation Efficiency in Rooms. *Indoor Air '87* 3, 383-387. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

ORDINANCE ON HAZARDOUS SUBSTANCES (1986) *Bundesgesetzblatt* **I**, 1470-1467, 26 August

OWEN, M.K., ENSOR, D.S. and SPARKS, L.E. (1990a) Airborne Particle Sizes and Sources Found in Indoor Air. *Indoor Air '90* **2**, 79-84. International Conference on Indoor Air Quality and Climate, Ottawa.

OWEN, M.K., LAWLESS, P.A., ENSOR, D.S. and SPARKS, L.E. (1990b) A Comparison of Local and Central Controls for Indoor Air Quality. *Indoor Air '90* **3**, 193-198. International Conference on Indoor Air Quality and Climate, Ottawa.

OZKAYNAK, H., RYAN, P.B., WALLACE, L.A., NELSON, W.C. and BEHAR, J.V. (1987) Sources and Emission Rates of Organic Chemical Vapours in Homes and Buildings. *Indoor Air '87* **1**, 3-7. Institut für Wasser-, Boden-und Lufthygiene, Berlin.

PALONEN, J., MAJANEN, A. and SEPPANEN, O. (1988) Performance of Displacement Air Distribution System in a Small Office Room. *Healthy Buildings '88* **3**, 103-112. Swedish Council for Building Research, Stockholm.

PASANEN, P., TARHANEN, J., KALLIOKOSKI, P. and NEVALAINEN, A. (1990) Emissions of Volatile Organic Compounds From Air Conditioning Filters of Office Buildings. *Indoor Air '90* 3, 183-186. International Conference on Indoor Air Quality and Climate, Ottawa.

PERIASAMY, R., ENSOR, D. and SPARKS, L.E. (1990) Effect of Indoor Aerosol Control on the Health Risk from Exposure to Radon and it's Progeny. *Indoor Air '90* **3**, 531-536. International Conference on Indoor Air Quality and Climate, Ottawa.

PETERSON, J.E. (1988) Use and Abuse of Ambient Air Quality Standards to Evaluate Indoor Environments. *Healthy Buildings '88* **3**, 697-695. Swedish Council for Building Research, Stockholm.

PICKERING, A.C., FINNEGAN, M.J., ROBERTSON, A. and BURGE, S. (1984) Sick Building Syndrome. *Indoor Air 3*, 321-325. Swedish Council for Building Research, Stockholm.

PLEHN, W. (1990) Solvent Emission From Paints. *Indoor Air '90* **3**, 563-568. International Conference on Indoor Air Quality and Climate, Ottawa.

PRELLER, L., ZWEERS, T., BRUNEKREEF, B. and BOLEIJ, J.S.M. (1990) Sick Leave due to Work Related Health Complaints Among Office Workers in the Netherlands. *Indoor Air '90* **1**, 227-230. International Conference on Indoor Air Quality and Climate, Ottawa.

PREZANT, B., BEARG, D. and TURNER, W. (1990) Tailoring Lease Specifications, Proposals and Work Letter Agreements to Maximise Indoor Air Quality. *Indoor Air '90* **3**, 371-376. International Conference on Indoor Air Quality and Climate, Ottawa.

PRITCHARD, J.N. and STRONG, J.C. (1990) The Influence of Environmental Tobacco Smoke on Radon Dosimetry. *Indoor Air '90* **3**, 33-38. International Conference on Indoor Air Quality and Climate, Ottawa.

PUTNAM, V.L., WOODS, J.E. and RASK, D.R. (1990) A Comparison of Carbon Dioxide Concentrations and Indoor Environmental Acceptability in Commercial Buildings. *Indoor Air '90* **3**, 365-370. International Conference on Indoor Air Quality and Climate, Ottawa.

RAW, G.J., ROYS, M.S. and LEAMAN, A. (1990) Further Findings from the Office Environment Survey: Productivity. *Indoor Air '90* **1**, 231-236. International Conference on Indoor Air Quality and Climate, Ottawa.

REINIKAINEN, L.M., JAAKKOLA, J.J.K., HELENIUS, T. and SEPPANEN, (1990) The Effects of Air Humidification on Symptoms and Environmental Complaints in Office Workers. A Six Period Cross-Over Study. *Indoor Air '90* **1**, 775-780. International Conference on Indoor Air Quality and Climate, Ottawa.

RELWANI, S.M., MOSCHANDREAS, D.J. and BILLICK, I.H. (1987) Indoor Air Quality Control Capabilities of Desiccant Materials. *Indoor Air '87* **3**, 236-240. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

ROBERTSON, G. (1988a) Source Nature and Symptomology of Indoor Air Pollutants. *Healthy Building '88* **3**, 507-516. Swedish Council for Building Research, Stockholm.

ROBERTSON, H. (1988b) Use of Occupant Complaint in an Air Quality Investigation. *Healthy Buildings '88* **3**, 235-241. Swedish Council for Building Research, Stockholm.

ROBERTSON, A.S., ROBERTS, K.T., BURGE, P.S. and RAW, G. (1990) The Effect of Change in Building Ventilation Category on Sickness Absence Rates and the Prevalence of Sick Building Syndrome. *Indoor Air '90* **1**, 237-242. International Conference on Indoor Air Quality and Climate, Ottawa.

ROTHWEILER, H., KNUTTI R. and SCHLATTER, C. (1987) Formaldehyde in Indoor Air. *Indoor Air '87* 1, 69-73. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

RYAN, P.B. and KOUTRAKIS, P. (1990) Indoor Air Chemistry: An Emerging Field. *Indoor Air '90* 2, 489-494. International Conference on Indoor Air Quality and Climate, Ottawa.

SAMMALIJARVI, E., LAAKSONEN, A. and RAUNEMMAA, T. (1990) Aerosol and Reactive Gas Effects by Electric Heating Units. *Indoor Air '90* 3, 653-658. International Conference on Indoor Air Quality and Climate, Ottawa.

SCHATA, M., JORDE, W., ELIXMANN, J.H. and LINSKENS, (1987) Allergies to Moulds Caused by Fungal Spores in Air-Conditioning Plants. *Indoor Air '87* 2, 777-780. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

SCHERER, G., CONZE, C., SCHMID, E.R., PACHINGER, A. and ADLKOFER, F. (1990) Importance of Gas Phase and Particulate Phase Constituents in Exposure to Environmental Tobacco Smoke (ETS). *Indoor Air '90* 2, 201-206. International Conference on Indoor Air Quality and Climate, Ottawa.

SCHLATTER, J. and WANNER, H-U. (1987) Strategies to Avoid Negative Health Effects of Passive Smoking. *Indoor Air '87* 2, 161-166. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

SCHRIEVER, E. and MARUTZKY, R. (1990) VOC Emissions of Coated Parqueted Floors. *Indoor Air '90* 3, 551-555. International Conference on Indoor Air Quality and Climate, Ottawa.

SEIFERT, B. (1990a) Formaldehyde Emission Standards In The Federal Republic Of Germany. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, Managing Indoor Air Quality Risks*, 13-24. United States Environmental Protection Agency EPA/400/7-90/005, Washington DC.

SEIFERT, B. (1990b) Regulating Indoor Air. *Indoor Air '90* 5, 35-49. International Conference on Indoor Air Quality and Climate, Ottawa.

SEIFERT, B. and SCHMAHL, H-J. (1987) Quantification of Sorption Effects for Selected Organic Substances Present in Indoor Air. *Indoor Air '87* 1, 252-256. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

SHEN, J. (1990) Fresh Air is Provided Into Air Conditioned Room Directly. *Indoor Air '90* 3, 199-201. International Conference on Indoor Air Quality and Climate, Ottawa.

SHUMATE, M.W and WILHELM, J.E. (1990) Fiber Shedding Characteristics of Commercial Air Filtration Media. *Indoor Air '90* 3, 157-162. International Conference on Indoor Air Quality and Climate, Ottawa.

SKOV, P. and VALBJORN, O. (1987) The "Sick" Building Syndrome in the Office Environment. *Indoor Air '87* 1, 439-443. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

SKOV, P. and VALBJORN, O. (1990) The Danish Town Hall Study, A One-Year Follow-Up. *Indoor Air '90* 1, 787-791. International Conference on Indoor Air Quality and Climate, Ottawa.

SMALL, B.M. (1990) Accomodating a Range of Human Sensitivities in Building Design. *Indoor Air '90* **3**, 319-324. International Conference on Indoor Air Quality and Climate, Ottawa.

SMITH, D.D., DONOVAN, R.P., ENSOR, D.S. and SPARKS, L.E. (1990) Quantification of Particulate Emission Rates from Vcuum Cleaners. *Indoor Air '90* 3, 647-652. International Conference on Indoor Air Quality and Climate, Ottawa.

STAIB, F., SEIBOLD, M. and HEISSENHUBER, M. (1987) Indoor Air Mycology: Aspergillosis, Mucormycosis and Cryptococcosis Caused by Fungal Spores from Indoor Air. *Indoor Air '87* 1, 694-698. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

STELLMAN, J.M., KLITZMAN, S., GORDON, G.C. and SNOW, B.R. (1985) Air Quality and Ergonomics in the Office: Survey Results and Methodological Issues. *American Industrial Hygiene Association Journal* **46**, 286-293.

STENBERG, B. (1987) Skin Complaints in Sick Buildings. *Indoor Air '87* 2, 530-534. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

STROM, G., PALMGREN, U., WESSEN, B., HELLSTROM, B. and KUMLIN, A. (1990) The Sick Building Syndrome: An Effect of Microbial Growth in Building Constructions ? *Indoor Air '90* 1, 173-178. International Conference on Indoor Air Quality and Climate, Ottawa.

STERLING, D.A., MOSCHANDREAS, D.J. and RELWANI, S.M. (1987) Office Building Investigation. *Indoor Air '87* 2, 444-448. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

STERLING, E and STERLING, T (1983) The Impact Of Different Ventilation Levels and Fluorescent Lighting on Building Illness : An Experimental Study. *Canadian Journal of Public Health* **74**, 385-392.

SUNDELL, J. (1982) Guidelines For Nordic Building Regulations Regarding Indoor Air Quality. *Environment International* **8**, 17-20.

SUNDELL, J., LONNBERG, G., STENBERG, B. and ZINGMARK, P-E. (1990) The Office Illness Project in Northern Sweden Part III: A Case - Referent Study of SBS in Relation to Building Characteristics and Ventilation. *Indoor Air '90* **4**, 633-638. International Conference on Indoor Air Quality and Climate, Ottawa.

SUTTON, P. (1991) Noise Control. *Kluwer's Handbook of Occupational Hygiene* **3**, 6.8.

SWEDISH WORK ENVIRONMENT COMMISSION (1976) *Work Environment Act* SOU 1976. 1 Liber, Stockholm (English Summary)

SYKES, J.M. (1988) *Sick Building Syndrome: A Review*, Health and Safety Executive Technology Division Specialist Inspector Report No. 10. Health and Safety Executive, Bootle, England.

TANAKA, T, and MASUMOTO, T. (1987) Evaluation of Performance of VAV System in Super Energy Conservation Building. *Indoor Air '87* **3**, 214-218. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

TAYLOR, P.R., DELL'ACQUA, B.J., BAPTISTE, M.S., HWANG, H-L. and SOVIK, R.A. (1984) Illness in an Office Building With Limited Fresh Air Access. *Journal of Environmental Health* **47**, 24-27.

TAYLOR, A.N. (1987) Background to Building Related Illnesses. *Building Related Illnesses*, A1-A12. Crown Eagle Communications Ltd, London.

TERKONDA, P.K. (1987) Sources and Effects of Microbiological Indoor Pollutants. *Indoor Air '87* **1**, 713-718. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

TESTA, C. (1990) Indoor Air Pollution: Remedies and Pitfalls. *Indoor Air '90* **3**, 325-327. International Conference on Indoor Air Quality and Climate, Ottawa.

TICHENOR, B.A. (1987) Organic Emission Measurements via Small Chamber Testing. *Indoor Air '87* **1**, 8-15. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

TICHENOR, B.A. and GUO, Z. (1988) The Effect of Ventilation on Emission Rates of Wood Finishing Materials. *Healthy Buildings '88* **3**, 423-432. Swedish Council for Building Research, Stockholm.

TUCKER, W.G. (1990) Buildings with Low-Emitting Materials and Products: Where do we Stand ? *Indoor Air '90* **3**, 251-256. International Conference on Indoor Air Quality and Climate, Ottawa.

TICHENOR, B.A., GUO, Z., MASON, M.A. and DUNN, J.E. (1990) Evaluation of Indoor Air Pollutant Sinks for Vapour Phase Organic Compounds. *Indoor Air '90* **3**, 623-628. International Conference on Indoor Air Quality and Climate, Ottawa.

TSUCHIYA, Y. and STEWART, J.B. (1990) Volatile Organic Compounds in the Air of Canadian Buildings with Special Reference to Wet Process Photocopying Machines. *Indoor Air '90* **2**, 633-638. International Conference on Indoor Air Quality and Climate, Ottawa.

TURNER, W.A., THOMPSON, J.G., BLAISDELL, E.L., GREIM, C.W., MISSELL, J.A. and MORRISSETTE, P.R. (1990) Design of a Healthy Modern Office Building. *Indoor Air '90* **3**, 269-274. International Conference on Indoor Air Quality and Climate, Ottawa.
UNIVERSITY OF WASHINGTON CONFERENCE (1982) *Indoor Air Problems - The Office Environment - A National Epidemic.* December 7-9.

VALBJORN, O., HAGEN, H., KUKKONEN, E. and SUNDELL. J. (1990a) *Indoor Climate and Air Quality Problems: Investigation and Remedy.* SBI Report 212, Danish Building Research Institute.

VALBJORN, O., NIELSEN, J.B., GRAVESEN , S. and MOLHAVE, L. (1990b) Dust in Ventilation Ducts. *Indoor Air '90* **3**, 361-364. International Conference on Indoor Air Quality and Climate, Ottawa.

VALBJORN, O. and SKOV, P. (1987) Influence of Indoor Climate on the Sick Building Syndrome Prevalence. *Indoor Air '87* **2**, 593-598. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

VAN DER MEER, A., LEITJEN, J.L. and KURVERS, S.R. (1990) The Effects of Unsealing the Windows on Comfort and Energy Consumption (A Case Study). *Indoor Air '90* **1**, 663-668. International Conference on Indoor Air Quality and Climate, Ottawa.

VAN DER WAL, J.F., MOONS, A.M.M. and STEENLAGE, R. (1987) Thermal Insulation as a Source of Air Pollution. *Indoor Air '87* **1**, 79-84. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

VOLKL, S., GEBEFUGI, I.L. and KORTE, F. (1990) Emission of Volatile Organic Compounds From Coatings into Indoor Air. *Indoor Air '90* **3**, 701-706. International Conference on Indoor Air Quality and Climate, Ottawa.

WALLACE, L., JUNGERS, R., SHELDON, L. and PELLIZZARI, E. (1987) Volatile Organic Chemicals in 10 Public-Access Buildings. *Indoor Air '87* **1**, 188-192. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

WALKER, M. and WESCHLER, C. (1980) Water Soluble Components of Size Fractionated Aerosols Collected After Hours in a Modern Office. *Building Environmental Science and Technology* **14**, 594-597.

WALKINSHAW, D.S. (1989) Energy, Building Science, and Indoor Air Quality. *NATO/CCMS Workshop, Pilot Study on Indoor Air Quality, The Implications of Indoor Air Quality for Modern Society, CCMS Report No. 183,* 117-121. NATO/CCMS.

WALLER, R.A. (1984) *Case Study of a Sick Building.* Indoor Air **1**, Swedish Council for Building Research.

WANNER, H.U., BRAUM, C. and MANN, C. (1990) Measurement of Nitrogen Dioxide Indoor and Outdoor Concentrations with Passive Sampling Devices. *Indoor Air '90* **2**, 503-507. International Conference on Indoor Air Quality and Climate, Ottawa.

WARREN, P.R. (1988) Principles for Operating Buildings to Achieve Optimal Occupant Health and Comfort. *Healthy Buildings '88* 3, 189-197. Swedish Council for Building Research, Stockholm.

WATANABE, T., MATSUKI, H., MISAWA, K. and KASUGA, H. (1990) Enzyme-Linked Immunosorbent Assay (ELISA) for Urinary Desmosine. *Indoor Air '90* 2, 219-224. International Conference on Indoor Air Quality and Climate, Ottawa.

WESCHLER, C.J. and SHIELDS, H.C. (1987) A Detailed Study of the Effects of Ventilation, Filtration and Outdoor Air on the Composition of Indoor Air at a Telephone Office Building. *Indoor Air '87* 3, 142-146. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

WESCHLER, C.J., SHIELDS, C.J. and NAIK, D.V. (1990) Indoor Ozone: Further Observations. *Indoor Air '90* 2, 613-618. International Conference on Indoor Air Quality and Climate, Ottawa.

WILKINS, A.J., NIMMO-SMITH, N.I., SLATER, A. and BEDOES, L. (1985) *Fluorescent Lighting, Headaches and Eye-Strain.* Department of the Environment, Building Research Establishment, Watford, England.

WILSON, S and HEDGE, A. (1987) *The Office Environment Survey, A Study of Building Sickness.* Building Use Studies Ltd, London

WOLKOFF, P. (1987) Sampling of VOC Indoor Under Condition of High Time Resolution. *Indoor Air '87* 1, 126-129. Institut für Wasser-, Boden-und Lufthygiene, Berlin.

WOLKOFF, P. and NIELSEN, G.D. (1987) Carbonless Copy Paper as a Potential Non-Building Indoor Irritant. *Indoor Air '87* 1, 89-93. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

WORKING GROUP 3 (1989) *European Concerted Action COST Project 613, Indoor Air Quality and Its Impact on Man. Environment and Quality of Life Report No. 2, Formaldehyde Emission From Wood Based Materials: Guideline for the Determination of Steady State Concentrations in Test Chambers.* Commission of the European Communities, Directorate-General Information, Market and Innovation, Luxembourg.

WORLD HEALTH ORGANISATION (WHO) (1961) *Constitution of the World Health Organisation: Basic Documents.* 15th Edition, Geneva.

WORLD HEALTH ORGANISATION (WHO) (1983) *Indoor Air Pollutants: Exposure and Health Effects.* EURO Reports and Studies No 78 WHO Regional Office for Europe, Copenhagen.

WORLD HEALTH ORGANISATION (WHO) (1986) *Indoor Air Quality Research.* EURO Reports and Studies No 103, WHO Regional Office for Europe, Copenhagen.

WORLD HEALTH ORGANISATION (WHO) (1987) *Air Quality Guidelines for Europe.* European Series No 23, WHO Regional Office for Europe, Copenhagen.

WORLD HEALTH ORGANISATION (WHO) (1989a) *Formaldehyde.* Environmental Health Criteria 89. Geneva.

WORLD HEALTH ORGANIZATION (WHO) (1989b) *Indoor Air Quality: Organic Pollutants.* EURO Reports and Studies No 111, WHO Regional Office for Europe, Copenhagen.

WORLD HEALTH ORGANIZATION (WHO) (1990) *Indoor Air Quality: Biological Contaminants,* report on a WHO meeting. WHO Regional Publications European Series No 31, Copenhagen.

WYON, D.P. (1988) Ventilated Floor Systems with Independent Room Air Terminals as the Basis of a Healthy Office Environment. *Healthy Buildings '88* 3, 127-136. Swedish Council for Building Research, Stockholm.

YAMANAKA, T., NARASAKI, M. and DAIKOKU, T. (1990) Ventilation Rate of an Enclosure with a Single Opening Exposed to Natural Wind. *Indoor Air '90* **4**, 479-484. International Conference on Indoor Air Quality and Climate, Ottawa.

YAGLOU, C.P., RILEY, E.C. and COGGINS, D.I. (1936) Ventilation Requirements. *HP & AC*, 65-76.

YANAGISAWA, Y., FASANO, A.M., SPENGLER, J.D., RYAN, P.B. and BILLICK, I.H. (1990) Removal of Nitrogen Dioxide by Interior Materials. *Indoor Air '87* **1**, 376-380. Institut für Wasser-, Boden- und Lufthygiene, Berlin.

YOSHIZAWA, S. and SUGAWARA, F. (1990) Relation of Airborne Microbiological Particle Concentration and Settlement. *Indoor Air '90* **2**, 85-90. International Conference on Indoor Air Quality and Climate, Ottawa.

YOULE, A. (1986) Occupational Hygiene Problems in Office Environments: The Influence of Building Services. *Annals of Occupational Hygiene* **30**, 275-287.

ZWEERS, T., PRELLER, L., BRUNEKEEF, B. and BOLEIJ, J.S.M. (1990) Relationships Between Health and Indoor Climate Complaints and Building, Workplace, Job and Personal Characteristics. *Indoor Air '90* **1**, 495-500. International Conference on Indoor Air Quality and Climate, Ottawa.

ZYLA-WISENSALE, N.H. and STOLWIJK, J.A.J. (1990) Indoor Air Quality as a Determinant of Office Worker Productivity. *Indoor Air '90* **1**, 249-254. International Conference on Indoor Air Quality and Climate, Ottawa.

European Communities — Commission

EUR 14029 — A review of indoor air quality and its impact on the health and well-being of office workers

Dr P. Leinster, E. Mitchell

Luxembourg: Office for Official Publications of the European Communities

1992 — IX, 109 pp., num. tab., fig. — 21.0 × 29.7 cm

Health and safety series

ISBN 92-826-4279-8

Price (excluding VAT) in Luxembourg: ECU 12

A review of the literature has been undertaken concerning problems related to indoor air quality and other factors which affect the indoor environment in offices. Within some buildings the causative agent is readily apparent. However, in others complaints of ill health are more common than might reasonably be expected and yet there is no readily discernible reason. This latter condition is commonly known as sick building syndrome.

There are a number of features commonly found in buildings in which complaints arise and these are described. Problems associated with the indoor environment are widely spread and include chemical contaminants, physical parameters and human factors such as management style. These problems can have a significant effect on productivity and can also cause material damage. There are few standards and guidelines against which conditions in offices can be assessed. However, if action can be taken to improve and safeguard the quality of the indoor environment many will benefit and substantial cost savings will be made.

Even though the study of this subject is in its formative stages and few definitive answers can be given, it should be possible to take a pragmatic approach and alleviate a large number of the problems encountered. The information from the scientific literature needs to be interpreted and communicated to those responsible for the design, construction, refurbishment and maintenance of buildings so that factors known to cause problems are not repeated.

Venta y suscripciones • Salg og abonnement • Verkauf und Abonnement • Πωλήσεις και συνδρομές
Sales and subscriptions • Vente et abonnements • Vendita e abbonamenti
Verkoop en abonnementen • Venda e assinaturas

BELGIQUE / BELGIË

Moniteur belge / Belgisch Staatsblad
Rue de Louvain 42 / Leuvenseweg 42
B-1000 Bruxelles / B-1000 Brussel
Tél. (02) 512 00 26
Fax (02) 511 01 84

Autres distributeurs / Overige verkooppunten

Librairie européenne/ Europese boekhandel
Rue de la Loi 244/ Wetstraat 244
B-1040 Bruxelles / B-1040 Brussel
Tél. (02) 231 04 35
Fax (02) 735 08 60

Jean De Lannoy
Avenue du Roi 202 /Koningslaan 202
B-1060 Bruxelles / B-1060 Brussel
Tél. (02) 538 51 69
Télex 63220 UNBOOK B
Fax (02) 538 08 41

Document delivery:

Credoc
Rue de la Montagne 34 / Bergstraat 34
Bte 11 / Bus 11
B-1000 Bruxelles / B-1000 Brussel
Tél. (02) 511 69 41
Fax (02) 513 31 95

DANMARK

J. H. Schultz Information A/S
EF-Publikationer
Ottiliavej 18
DK-2500 Valby
Tlf. 36 44 22 66
Fax 36 44 01 41

DEUTSCHLAND

Bundesanzeiger Verlag
Breite Straße
Postfach 10 80 06
D-W 5000 Köln 1
Tel. (02 21) 20 29-0
Telex ANZEIGER BONN 8 882 595
Fax 2 02 92 78

GREECE/ΕΛΛΑΔΑ

G.C. Eleftheroudakis SA
International Bookstore
Nikis Street 4
GR-10563 Athens
Tel. (01) 322 63 23
Telex 219410 ELEF
Fax 323 98 21

ESPAÑA

Boletín Oficial del Estado
Trafalgar, 29
E-28071 Madrid
Tel. (91) 538 22 95
Fax (91) 538 23 49

Mundi-Prensa Libros, SA
Castelló, 37
E-28001 Madrid
Tel. (91) 431 33 99 (Libros)
431 32 22 (Suscripciones)
435 36 37 (Dirección)
Télex 49370-MPLI-E
Fax (91) 575 39 98

Sucursal:

Librería Internacional AEDOS
Consejo de Ciento, 391
E-08009 Barcelona
Tel. (93) 488 34 92
Fax (93) 487 76 59

Llibreria de la Generalitat de Catalunya
Rambla dels Estudis, 118 (Palau Moja)
E-08002 Barcelona
Tel. (93) 302 68 35
302 64 62
Fax (93) 302 12 99

FRANCE

Journal officiel
Service des publications des Communautés européennes
26, rue Desaix
F-75727 Paris Cedex 15
Tél. (1) 40 58 75 00
Fax (1) 40 58 75 74

IRELAND

Government Supplies Agency
4-5 Harcourt Road
Dublin 2
Tel. (1) 61 31 11
Fax (1) 78 06 45

ITALIA

Licosa Spa
Via Duca di Calabria, 1/1
Casella postale 552
I-50125 Firenze
Tel. (055) 64 54 15
Fax 64 12 57
Telex 570466 LICOSA I

GRAND-DUCHÉ DE LUXEMBOURG

Messageries Paul Kraus
11, rue Christophe Plantin
L-2339 Luxembourg
Tél. 499 88 88
Télex 2515
Fax 499 88 84 44

NEDERLAND

SDU Overheidsinformatie
Externe Fondsen
Postbus 20014
2500 EA 's-Gravenhage
Tel. (070) 37 89 911
Fax (070) 34 75 778

PORTUGAL

Imprensa Nacional
Casa da Moeda, EP
Rua D. Francisco Manuel de Melo, 5
P-1092 Lisboa Codex
Tel. (01) 69 34 14

Distribuidora de Livros Bertrand, Ld.ª

Grupo Bertrand, SA
Rua das Terras dos Vales, 4-A
Apartado 37
P-2700 Amadora Codex
Tel. (01) 49 59 050
Telex 15798 BERDIS
Fax 49 60 255

UNITED KINGDOM

HMSO Books (PC 16)
HMSO Publications Centre
51 Nine Elms Lane
London SW8 5DR
Tel. (071) 873 2000
Fax GP3 873 8463
Telex 29 71 138

ÖSTERREICH

Manz'sche Verlags- und Universitätsbuchhandlung
Kohlmarkt 16
A-1014 Wien
Tel. (0222) 531 61-0
Telex 112 500 BOX A
Fax (0222) 531 61-39

SUOMI

Akateeminen Kirjakauppa
Keskuskatu 1
PO Box 128
SF-00101 Helsinki
Tel. (0) 121 41
Fax (0) 121 44 41

NORGE

Narvesen information center
Bertrand Narvesens vei 2
PO Box 6125 Etterstad
N-0602 Oslo 6
Tel. (2) 57 33 00
Telex 79668 NIC N
Fax (2) 68 19 01

SVERIGE

BTJ
Tryck Traktorwägen 13
S-222 60 Lund
Tel. (046) 18 00 00
Fax (046) 18 01 25

SCHWEIZ / SUISSE / SVIZZERA

OSEC
Stampfenbachstraße 85
CH-8035 Zürich
Tel. (01) 365 54 49
Fax (01) 365 54 11

CESKOSLOVENSKO

NIS
Havelkova 22
13000 Praha 3
Tel. (02) 235 84 46
Fax 42-2-264775

MAGYARORSZÁG

Euro-Info-Service B.T.
Rádáy u. 24/B
H-1092 Budapest
Tel. (1) 36 1 118
Fax (1) 36 1 72 83

POLSKA

Business Foundation
ul. Krucza 38/42
00-512 Warszawa
Tel. (22) 21 99 93, 628-28-82
International Fax&Phone
(0-39) 12-00-77

CYPRUS

Cyprus Chamber of Commerce and Industry
Chamber Building
38 Grivas Dhigenis Ave
3 Deligiorgis Street
PO Box 1455
Nicosia
Tel. (2) 449500/462312
Fax (2) 458630

TÜRKIYE

Pres Gazete Kitap Dergi Pazarlama Dağitim Ticaret ve sanayi AŞ
Narlibahçe Sokak N. 15
Istanbul-Cağaloğlu
Tel. (1) 520 92 96 - 528 55 66
Fax 520 64 57
Telex 23822 DSVO-TR

CANADA

Renouf Publishing Co. Ltd
Mail orders — Head Office:
1294 Algoma Road
Ottawa, Ontario K1B 3W8
Tel. (613) 741 43 33
Fax (613) 741 54 39
Telex 0534783

Ottawa Store:
61 Sparks Street
Tel. (613) 238 89 85

Toronto Store:
211 Yonge Street
Tel. (416) 363 31 71

UNITED STATES OF AMERICA

UNIPUB
4611-F Assembly Drive
Lanham, MD 20706-4391
Tel. Toll Free (800) 274 4888
Fax (301) 459 0056

AUSTRALIA

Hunter Publications
58A Gipps Street
Collingwood
Victoria 3066

JAPAN

Kinokuniya Company Ltd
17-7 Shinjuku 3-Chome
Shinjuku-ku
Tokyo 160-91
Tel. (03) 3439-0121

Journal Department
PO Box 55 Chitose
Tokyo 156
Tel. (03) 3439-0124

RUSSIA

CCEC (Centre for Cooperation with the European Communities)
9, Prospekt 60-let Oktyabria
117312 Moscow
Tel. 007 095 135 52 87
Fax 007 095 420 21 44

ISRAEL

ROY International
PO Box 13056
41 Mishmar Hayarden Street
Tel Aviv 69865
Tel. 00972 3 496 108
Fax 00972 3 544 60 39

SINGAPORE

Legal Library Services Ltd
STK Agency
Robinson Road
PO Box 1817
Singapore 9036

AUTRES PAYS
OTHER COUNTRIES
ANDERE LÄNDER

Office des publications officielles des Communautés européennes
2, rue Mercier
L-2985 Luxembourg
Tél. 499 28 1
Télex PUBOF LU 1324 b
Fax 48 85 73/48 68 17

5 15

CE-NA-14029-EN-C

NOTICE TO THE READER

All scientific and technical reports published by the Commission of the European Communities are announced in the monthly periodical **'euro abstracts'**. For subscription (1 year: ECU 110) please write to the address below.

Price (excluding VAT) in Luxembourg: ECU 12

ISBN 92-826-4279-8

9 789282 642795

OFFICE FOR OFFICIAL PUBLICATIONS
OF THE EUROPEAN COMMUNITIES

L-2985 Luxembourg