Chemical, Microbiological, Health and Comfort Aspects of Indoor Air Quality – State of the Art in SBS

EURO

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Chemical, Microbiological, Health and Comfort Aspects of Indoor Air Quality – State of the Art in SBS

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PREFACE

Interest in indoor air quality (IAQ) is growing at a public, a political and a scientific level. Complaints about poor IAQ associated with acute symptoms such as mucous irritation, headaches and bad odour occur frequently and are of particular concern in the office environment where typical patterns of symptoms often occur and this has been termed "Sick Building Syndrome" (SBS) by a Working Group of the World Health Organization.

It is anticipated that over the next few decades, significantly more than the current percentage of 50% of the work force will be occupied in a non-industrial environment.

Although research into the causes for IAQ problems has increased over the past two decades, only some of the factors involved have actually been identified because of the complex, multifactorial nature of the problems. The knowledge of how to deal with and solve situations in which complaints arise is far from complete because of a lack of detailed information on the mechanisms leading to symptoms and also a lack of understanding of the dynamics of the indoor environment.

This book contains the lecture notes of a seminar aimed at presenting in depth state-of-the-art knowledge on factors presumably involved in SBS complaints to researchers who are actively involved in assessing and investigating IAQ problems related to SBS. Internationally known experts address the following issues:

- the dynamics of the indoor environment and strategies for indoor measurements
- chemical and microbiological pollution, important species, sources and detection methods
- effects of indoor pollution and in particular
  - sensory irritation including odour
  - airway, eye and skin irritation by organic indoor pollutants and assays for their assessment
  - immune effects including allergic sensitization
  - chemical hyper-responsiveness
- controlled human reactions to organic pollutants
- building investigations, approaches and results
- source characterization and source control
- criteria, norms and techniques against indoor pollution and regulatory aspects.

Studies into the causes and remedies of complaints on poor IAQ, in buildings, as seen from the above listing, are - probably more than any other research - dependent on multidisciplinary collaboration. Experts from very diverse fields such as construction engineering, architecture, ventilation/air conditioning, chemistry, biology, occupational hygiene, psychology, toxicology, epidemiology, environmental and occupational medicine must all contribute if progress is to be made. It is evident that communication between researchers coming from such diverse disciplines, all speaking their own language, is a difficult task. Communication however, is a prerequisite for collaboration. Therefore the seminar, the lectures of which are reproduced in this book was also aimed at promoting mutual understanding between researchers coming from different disciplines and, hopefully thereby stimulating future collaboration.

It is the editors' wish that this book, like the seminar, may provide state-of-the-art knowledge to the many experts involved in investigations of 'sick' buildings and how to make them 'healthy' and it may simultaneously help develop mutual understanding and collaboration between them.

H. Knöppel
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THE SICK BUILDING SYNDROME - OVERVIEW AND FRONTIERS

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ABSTRACT. The paper presents an overview on terms such as 'problem building', 'sick building' and 'sick building syndrome', and on the various unwanted effects on the health and well-being of occupants of buildings which may be caused by either the buildings themselves or by equipment and systems within these buildings. Allergies and other hypersensitivity reactions, adverse sensory effects and neurotoxic effects are identified as being particularly relevant. The factors which need to be controlled to obtain 'healthy buildings' and the control options available are briefly discussed.

1. The Sick Building Syndrome

There is no generally agreed upon definition of a "sick building". A common and historically maybe the most appropriate definition is: "Sick buildings" are modern buildings in which occupants show symptoms similar to those caused by formaldehyde exposure (Andersen, Lundquist & Mølhave, 1975) although the concentrations of formaldehyde many times are far below the reaction thresholds. Occupants complain of deteriorated air quality (adverse environmental perceptions) and of subtle medical symptoms (adverse body perceptions) that may be related to the indoor air (Stolwijk, 1984; Berglund & Lindvall, 1985; Berglund & Lindvall 1990). A fairly specific set of reported body perceptions (symptoms) is called the "Sick Building Syndrome".

The symptoms reported in the sick buildings vary widely but some salient features may be recognized. The main symptoms reported seem to be (cf. Akimenko et al., Stolwijk, 1984)

- irritation of the eyes, the nose, and the throat
- sensation of dryness in the mucosa and the skin
- erythema of the skin
- mental fatigue
- weak but persistant odors.

2. The Purpose of Buildings

Buildings are erected for mainly three reasons. They are:

- to provide protection of people and their belongings against outdoor climate, illegal entry and destruction,
- to ensure that adequate functional requirements are met for indoor activities, as a home or as a work, public or leisure space, and
- to constitute a value in economical, social as well as psychological terms.

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Sick buildings fail to satisfy two of the three purposes above. Of course it is imperative that a building used for habitation does not cause a disease in any of its occupants. Unfortunately, though, we are facing a number of building related illnesses in society, like lung cancer due to radon and allergic asthma due to dust mites. It is still debated whether SBS may be part of a defined disease state, and commonly SBS is looked upon as distinguished from building related illness. However, health is more than absence of disease. To construct a building that is healthy rather than sick means more than simply avoiding indoor climate problems. We need positive criteria that surpass the mere avoidance of negative effects on occupants and buildings (Berglund and Lindvall 1990). We then need to talk in terms of comfort/discomfort, satisfaction/dissatisfaction, non-adverse/adverse effects, and precursors/manifestations of disease.

The first priority in health promotion is to protect the sensitive individuals and the groups at high risk. The second is to protect the general population. Thus it is essential to identify and characterize the sensitive groups or the groups at high risk, and to specify their specific needs. Methods for measuring health effects should reflect this demand. Measures in the building to promote health should involve both general measures directed to the whole population as well as individual measures to support the very sensitive persons.

3. Technologically Defined Problem Buildings

Indoor climate problems are common. It is estimated that in buildings built or remodelled during the sixties and later up to one third may present indoor climate problems (WHO 1986; Swedish National Allergy Committee 1989). All types of buildings are affected - i.a. residential, office, school, hospital and kindergarten buildings. In some Swedish communities during the seventies every fourth kindergarten were reported a problem building.

The increase in problem buildings seems to have coincided with energy economizing and building codes which have emphazised energy savings. However, during the same time period the "load" on the interior environment has changed. An increasing number of new chemicals and products have been introduced in building construction and system solutions as well as in interior furnishings. Many occupants have changed considerably their use of the building utility area, of office and home appliances, but also of tobacco.

3.1. BUILDINGS AT RISK

Many buildings have a less than perfect performance from the strict engineering point of view. Because of that they are often accompanied by an increased risk of health or comfort problems among their occupants. In the SBS context the main risk factors for producing problem buildings are high humidity, insufficient materials control and insufficient ventilation (Berglund et al. 1991).

30-50% of the Swedish non-residential, non-industrial buildings display engineering failures in ventilation performance (G. Andersson 1990). In high rise residential buildings 15% may have insufficient air exchange rates, and in small homes 20% (Lyberg, Boman and Skogberg 1989).

In Sweden 5-10% of all buildings need remodelling because of humidity problems from the ground, the building structure or leakage (Tolstoy & Svennerstedt 1984). About 3-5% of small homes are believed to have serious mould problems.

Comparative studies of failures in building construction do not indicate any large difference between Belgium, England and Sweden (Bergström 1989). The main cause of a failure is building design (51%), construction (26%), materials (10%), occupant use (9%), and maintenance etc (3%).

According to Woods (1990) 20-30% of non-industrial buildings in Europe and North America may be classified as problem buildings. Only 50-70% would be persistently healthy buildings.

4. Occupant Defined Problem Buildings

Problems in buildings may not be observed until the occupants are affected. Also the most ambitious building or ventilation engineer may fail to identify deficiencies of the building since available chemical-physical measurement techniques often are inadequate or insensitive. The occupant reactions may range from a simple detection of a peculiar odor (environment perception), the experience of an adverse symtom (body perception), spontaneous complaints, annoyance reactions, and performance impairments, to aggravation of existing diseases in single occupants or causation of a specific building related illness.

4.1. BODY PERCEPTIONS (SYMTOMS) IN SBS AND IN GENERAL

A number of reports the world over indicate that 10-25% of modern or remodelled non-industrial buildings cause, or will eventually cause, symtom prevalences in occupant groups typical in character and size of the so-called Sick Building Syndrome (SBS) (WHO 1986; Woods 1990). Some believe that 5-10% of all non-industrial building eventually will cause building related disease among individual occupants (Woods 1990).

4.1.1.SBS-like symtoms in the general population. The same symtoms as in SBS are common in the general public and may not always be just building related. In Danish and Swedish studies on samples of the adult general population eye irritation were reported by 11-16%, nose or throat irritation by 16-19%, fatigue by 25-30% and headache by 10-19% (Valbjörn and Kousgård 1986; Norbäck and Edling 1990). Parts of these symtom prevalences may be building related, but probably not all of them.

4.1.2.Symtoms and complaints in sick buildings. In the North American and the European countries a number of case studies of sick buildings have been reported by occupational safety and health control agencies. Investigations usually fail to isolate a specific chemical, a physical or an infectious agent that may be responsible for the problems. The symptoms related to "sick buildings" have also been investigated for possible psychogenic origins.

The extensity of mucosal irritation symptoms among occupants of large buildings is never at zero level. The sick building is commonly characterized by the higher prevalence of just the same symptoms as are reported in the non-sick building but at a lower frequency.

The prevalence of sick buildings varies by country. Up to 30 % of new or remodelled buildings may have unusually high rates of complaints (Akimenko et al., 1985). For example, in the City of Stockholm indoor air quality problems have been reported in 9 - 26 % of the 600 day care centers built 1977 -1981 (Hult, 1983).

Complaints on detoriated indoor climate seemingly have become more frequent over the last 10-15 years. At first building owners and building/ workplace managers disclaimed the complaints. Sometimes occupants were accused of being nonreliable or hysterical. A large number of systematic building investigations performed since then show that the vast majority of complaints do have adequate reasons (NIOSH ; Andersson and Stridh 1991). Furthermore, if the problem is not taken seriously from the start the terms between building owners and tenants may quickly turn hostile and leave the building vacant. When facing a possible SBS-case the rule is simple: Good management pays off!

5. Exposure and Dose

Human exposure to environmental factors (chemical, physical or biological) can be through inhalation, ingestion and skin contacts, and may vary much between homes, workplaces, public spaces, vehicles and outdoors. The links beteween air, food and water pollution are getting increasing interest. For example, in terms of total body exposure a toxic compound may reach the body by several routes, not just by air. For many hazardous compounds all routes of exposure have to be taken into account jointly. Some exposures (by cosmetics or food) may change the occupant's mucosal sensitivity to airborne irritants.

There has also been a shift from the one-substance one-effect view to the acknowledgement of interactions that may lead to amplified or attenuated effects. Interactions

may occur between compounds in complex, real-life mixtures of air pollution. The sum of the volatile organic compounds in the indoor air may cause eye irritation but not the single components. Also various body responses to environmental exposures may interact. High room temperature will increase the skin temperature which makes it more sensitive to chemical irritants in the air.

Not surprisingly, we still have large difficulties in predicting health effects from chemicals as they appear naturally, especially the early, subtle and reversible effects. We need biological indicators for environmental health monitoring that will identify

- adverse health effects at realistic exposure levels (low dose effects),
- the vulnerable portions of the general population, and
- the interaction effects of pollutants and other environmental factors, and of physiological and toxicological reactions in the human body.

Traditional methods of pollution measurements often lack sufficient environmental health relevance. Althogh they express concentrations of substances e.g. in air, they provide little or no indication of how well they represent the relevant exposure spectrum, of how much ends up in the human body, or of which, after conversion in cells or organs, give rise to health and comfort effects. The effect is further complicated by the complex patterns of human behavior, which must be taken into account when assessing total exposure.

Concentration in air, water, food

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Biological dose in organs, tissues and fluids

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Biological dose in cells or on receptors

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Interaction with cell chemistry and cell componets

In some sense the concentrations of pollutants in air, water and food have the least biological relevance. The biological dose in organs, tissues and fluids may be more relevant since it includes the impact of a number of background factors like lifestyle and exposure pattern. Still more relevant is the biological dose in cells or on receptors which is influenced by additional background factors like biodistribution, metabolism and excretion. The most relevant dose measure may be of the biological dose to the cell components, e.g. as reflected by electro-chemical cell reactions or interaction with DNA in the cell nucleus, including the impact of immune defence and repair mechanisms.

Thus, in addition to measure pollutants in the air combined with forecasting individual exposures from activity patterns we often gain from measurements, when possible, of concentrations in biological tissues and fluids (mucous, blood, hair, urine, milk). Biotests may be used, such as tests of chromosome aberrations as a measure of mutagenicity, and sensory measurements with panels of human observers to assess pollution concentration in terms of odor or mucosal irritation potency.

6. Adverse Effects on Health and Wellbeing

Of the health effects caused by air pollution cancer is of major concern. However, equally important from a health point of view are long and short term effects on the respiratory system and possibly the nervous system (especially in children), interactions with infectious agents, allergies and other hyperreactivities. Sensory reactions are important since they, among other things, are widespread in the population. In the following some of the more recently acknowledged effects will be discussed. For some of these the building relationship is evident, for others it is suspected or deemed to be important from a total exposure perspective.

6.1. ALLERGIES AND OTHER HYPERSENSITIVITY REACTIONS

Persons suffering from allergy or other hypersensitivity reactions are important risk groups in SBS-related problem environments. "Hypersensitivity" is an umbrella term used to describe conditions in which the sensitivity of organs in the body to different substances is pathologically increased. This increased sensitivity is due to either immunological (allergy) or non-immunological (non-allergic hypersensitivity) mechanisms.

The number of hypersensitive or allergic individuals appears to have increased substantially in recent years. One of the causes is believed to be shortcomings in the environments within and around buildings (Swedish Allergy Committee 1989). The relationship between hypersensitivity and air quality is thus one of the major contemporary problems encountered in buildings.

6.1.1 Allergy. Allergy means that the hypersensitivity is of an immunological nature. The reaction is caused by special antibodies or by blood cells after contact with a foreign substance (antigen).

The substances (allergens) which are the prime causers of allergies are pollen and animal hair or dender. Consequently, the allergies are often conditional on seasonal and environmental factors. Dust mites are also increasingly common causes of allergy, highly suspected to be building related. The common hypersensitivity to "dust" is usually caused by mites and animal epithelia. A large number of species of airborne mould spores have also proved to be capable of causing allergic reactions. However, the latter are not frequent.

Pollen allergies are seasonally bound. Tree pollen is present in the air during the spring, grass pollen during the early summer and herbaceous pollen until the late summer. There are also differences in dispersion. Tree pollen travels a long way, whereas the spread of grass pollen is limited.

The ability to produce antibodies after exposure to natural concentrations of certain substances (atopy) is highly hereditary. The proportion of the population suffering from allergies of the type mentioned here is estimated at about 15 per cent. However, almost 50 per cent of the population react to one allergen or another when tested.

6.1.2 Non-allergic hypersensitivity reactions. Hyperreactivity is defined as an increased tissue sensitivity to such things as smoke, dust, chemicals, odours, cold and moisture. Hyperreactivity usually occurs in the respiratory passages but can also appear in the gastrointestinal tract. The biological mechanisms are largely unknown. As a rough estimate, at least half of the hypersensitivity reactions are unrelated to allergies. The symptoms and their gravity may be the same as in cases of allergically induced hypersensitivity.

Even normally healthy individuals can display increased sensitivity of the bronchi in conjunction with diseases of the respiratory passages or upon exposure to high contents of air pollutants such as ozone. The protective barrier afforded by the mucous membranes in the respiratory passages can be weakened in different ways by exposure to tobacco smoke or large amounts of air pollutants.

6.1.3 Asthma. Asthma is a temporary condition of breathing difficulty caused by contraction of the bronchi. Among children, asthma is commonly induced by allergic factors, whereas two-thirds of asthma cases among adults have other causes such as infections,

irritating substances, side effects of pharmaceutical drugs, physical exertion and psychological stresses. Although the asthmatic reaction is temporary the triggering causes are often so frequently occurring in and around buildings that the disease becomes virtually chronic. Most asthma sufferers notice a direct deterioration in their bronchi when they come into contact with substances that bring on the disease. Acute attacks can be fatal.

The incidence of asthma is 3-4 percent among children below school age and about 2-3 percent among adults. Among 18-year-old conscripts (upon signing on) the incidence of asthma has been shown to increase from 1.9 percent in 1971 to 2.8 percent in 1981 (Åberg 1988). The corresponding figures for hay fever were 4.4 percent in 1981 and 8.4 percent in 1981. The increasing incidence of asthma and hay fever was more striking in northern Sweden than in other parts of the country. This may possibly be due to differences in the built environment.

Increased mortality due to asthma has been suspected in recent years in reports from New Zealand, Britain and the U.S. Despite the substantial variations in asthma mortality with time there is a strong suspicion that the long-term trend is an increase. The cause of this is unclear but environment pollution is a suspect.

6.2. ADVERSE SENSORY EFFECTS

As pointed out in the WHO Air Guality Guidelines for Europe (1987) many substances in the outdooor and indoor environments may cause sensory effects at concentrations far below those at which toxic effects occur. As an example, odor annoyance may not by all be regarded as an adverse health effect but it is commonly viewed as adversely affecting the quality of life. As criteria for acceptability and annoyance the WHO Guidelines use 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 say, cannot be defined on the basis of concentration alone.

Outspoken criteria for adverse sensory effects are given in a WHO document on indoor air quality (WHO 1989). It is recommended for non-industrial indoor environments that unwanted odorous compounds should not be detectable by more than half of the occupants and then just barely (ED_{50} detection threshold), and similarly that sensory irritants should not be detectable by more than one tenth of the occupants (ED_{10} detection threshold).

In the WHO document on environmental health criteria for formaldehyde (WHO 1989), the evaluation of human health risks is partly based on sensory criteria. The argument applied is that human exposure to formaldehyde should be minimized, not only for its probable carcinogenic effect, but also for its potential for irritant effect. Recommendations are given to avoid strong sensory reactions in the workplace environment (peak max 1.0 and mean max 0.3 mg/m^3) as well as a much lower value to avoid odor and sensory irritation for the general population in the outdoor and the non-industrial indoor environments (max 0.1 mg/m^3). Even a very low guideline value is given intended to support the specially sensitive groups that show hypersensitivity reactions without immunological signs (max 0.01 mg/m^3).

The established practice in ventilation engineering in the US (ASHRAE 1989) is that the air of a space can be considered acceptably free of annoying contaminants if 80% of a panel of at least 20 untrained observers immediately after entering deems the air to be not objectionable under representative conditions of use and occupance. Users of the method are cautioned that the metod is only a test for odors. Many harmful contaminants will not be detected by this test (e.g. carbon monoxide and radon).

6.3. NEUROTOXIC EFFECTS

It is well known that environmental pollution can influence the nervous system. Although inhalation is not the major route of exposure in comparison with ingestion of food, for example, neurological effects of exposure to air pollution are not to be neglected; the effects of occupational exposure to organic solvents is one example, that of residential exposure to carbon monoxide is another. Foetuses and children are particularly at risk for neurotoxic effects as a result of the higher lifetime exposure and of the sensitivity of the brain during its

growth stages. A wide spectrum of effects might be of importance, from those at molecular level to behavioral abnormalities.

Nervous system disorders are one of the leading causes of work-related diseases. In the United States (U.S. Congress 1990) a significant number of workers have potential for exposure to neurotoxic substances. neurotoxic substances are prominent among the top 25 chemicals emitted into the air. Neurotoxic substances may play a role in the occurrence of some neurological and psychiatric disorders such as Parkinson's disease and Alzheimer's disease. It is deemed that neurotoxicity may be a neglected non-cancer risk since few chemicals have been evaluated adequately for neurotoxicity.

Chemically induced neurotoxicity and carcinogenesis have some similarities but also major differences (Bonnefoi et al. 1990). Carcinogens will often lead to malignant cancer and death while the neurotoxins will lead to a large variety of effects from the very subtle (e.g., abberant social behavior) to the severe (e.g., paralysis). It is often very difficult to demonstrate evidence of neurotoxicity and scientists disagree on the definition of what is an adverse effect on the nervous system. Considerable research will be required in order to develop methods of measurement, and to clarify the size of the problem in different populations and the reponsible mechanisms in the nervous system.

7. Outdoor Air Pollution

Outdoor air pollution affects the indoor environment in various ways. To a large extent the chemical pollutants are about the same outdoors and indoors but at diffent concentrations levels and with different time patterns. Already from its "start" the intake air of a building may carry a large pollution load of outdoor origin. The capacity of such an intake air may be much reduced for diluting pollutants originating from indoor sources. Sometimes the building have to be sealed off from the polluted outdoor air, and the indoor air be filtered and recirculated. Gaseous pollutants, dust, pollen, animal dender from the outside may be transferred into the building by shoes, clothings etc. Inspite of the generally higher concentrations of most air pollutants indoors compared to outdoors, and of the much longer time spent indoors many general population studies of health effects of air pollutants have referred to exposures only met outdoors.

It has been demonstrated that ambient air pollutants can have an acute effect on the respiratory system of sensitive individuals, including asthmatics. The effects of prolonged exposure are, however, not fully known. Examples of air pollutants that can irritate or damage the mucous membranes include nitrogen dioxide, sulfur dioxide and photochemical oxidants (substances such as ozone and aldehydes formed in photochemical smog; aldehydes are also present in vehicle exhaust). It is also suspected that other hydrocarbons irritate the mucous membranes. Particles, particularly acid ones, are formed on combustion and in the atmosphere and are major sources of irritation. Particles also carry various chemical substances which in themselves may be irritants.

In the densely populated areas several diseases deemed to be related to prolonged exposure to air pollution are over-represented. Chronic bronchitis is one. Even if the over-representation is largely attributable to other causes such as tobacco smoking, there are nevertheless indices that air pollution may be a contributory factor. It has also been established that the air in densely populated areas contains several mutagenic or carcinogenic substances. This affords at least part of the explanation why cancer of the lungs is more common in urban than in rural areas.

It is evident from epidemiological studies of annoyance reactions to motor vehicle exhausts (Ewetz and Camner 1983) that a large proportion of the urban population report annoyance. Considerable groups of sensitive persons are particularly inclined to experience annoyance, and air pollution seemingly can aggravate some respiratory tract symtoms, although clinical tests are negative.

The guideline values for ambient air pollution are based on "minimum effect" levels which are frequently uncertain and have small margins of safety. With but few exceptions, it has not been possible to make allowance for the interactive effects of, for instance, different chemical substances. Recommendations are lacking of the requirements in quantative terms of the quality of the outdoor air when it is used as intake air to a ventilation system.

8. Indoor Air Pollution

8.1. ENVIRONMENTAL TOBACCO SMOKE

One of the most important sources of air pollution indoors is tobacco smoking. The smell of tobacco smoke is far stronger than that from other common sources indoors. It also persists for a longer time. This means that the amount of smoking is directly decisive for the ventilation need insofar as odor is concerned. Discomfort caused by tobacco smoke is also indicative of generally poor ventilation and consequently, that other, unnoticed substances may be present.

The adverse effects on health of exposure to tobacco smoke in the environment (passive smoking) have been increasingly observed in recent years (U.S.National Research Council 1986). The health effects that are the most common and which make their presence felt most quickly are sensory reactions: irritation in the mucous membranes of the eyes, nose and throat, and an annoying smell.

Users spending any length of time in premises in which people are permitted to smoke or where the ventilation has return air containing tobacco smoke from other parts of the building do not perceive odors as strongly because their sense of smell becomes dulled (olfactory fatigue). Instead, the dominating trouble is irritation of the mucous membranes and particularly of the eyes. These symptoms are aggravated by both increasing concentration and longer exposure time.

Precisely which substances in tobacco smoke cause the sensory reactions has not been determined. Almost 4000 substances - in both gaseous and particulate form - have been identified. The composition of the smoke gases varies with the manner of smoking, chemical reactions in the smoke, separation of particles upon inhalation (tiny particles reeach deep respiratory passages more easily) etc.

Both laboratory studies and field trials indicate that tobacco smoke resulting in CO contents in excess of 1-2 ppm lead to eye irritations or other discomfort among about 20 per cent of those exposed.

Certain individuals are particularly sensitive. Children of smokers suffer more often than others from diseases of the lower respiratory passages, bronchitis and asthma. Further research is needed in order to describe in more exact terms the relations between exposure to tobacco smoke and different states of hypersensitivity. The current level of knowledge nevertheless justifies vigorous measures against smoking - particularly in environments occupied by children and other sensitive persons.

In buildings which use return air, tobacco smoke is returned to all spaces embraced by the ventilation system. Properly functioning filters are capable of removing solid particles but not gaseous substances. Whether or not return air should be permitted is a matter that has been under discussion in recent years. The Swedish Building Codes do not contain any prohibition of the use of return air in offices and similar premises. The Swedish Allergy Committee has proposed that the use of return air ventilationg systems be prohibited in new buildings and that smoking be prohibited in all old buildings with return air systems.

8.2. SICK BUILDINGS

Sensory reactions are typical for the "sick building" syndrome but usually no single irritant can be held responsible. More complex causal mechanisms are probably at work. From the literature on sensory research it is evident, that a number of interactions are taking place in the senses. The sick building symptoms may involve not only the specialized chemical senses but also the cutaneous senses. Many skin receptors respond to at least two classes of environmental stimuli. Warming and cooling the skin can affect the sensitivity to touch and vibrotactile stimulation. This does not mean that every receptor respond to the full range of all environmental stimuli.

The sensory thresholds also depend on the stimulus duration and the total stimulus amount. A series of subthreshold stimuli directed to the same skin spot may result in the sensation

threshold being passed. The threshold is influenced by general factors like age, anxiety, attention, and other sensitivity variations.

The symptoms (body perceptions) appearing in sick buildings are at present best characterized as multisensory perceptions. For example, dryness sensation of the mucosa and feeling of thirst may becaused by low humidity, by thermal stimulation of exposed parts of the body and by chemical pollution, e.g., formaldehyde. Perceived eye irritation may be caused by chemicals, draft, dust, dry and warm air, thermal radiation, as well as by adverse lighting conditions that strain the eye muscles.

Another important factor may be the interaction between volatile chemicals and particulate matters. Adsorption to particles may concentrate gaseous irritants so that locally at the mucosa, the sensation threshold is passed. It is not known whether the electrical charges of the airborne particles indoors affect their deposition on the body surfaces.

8.3. THERMAL FACTORS

There is no doubt that improved insulation and tightness in the last decade have made the indoor climate more comfortable from a thermal point of view, at least in cold climate areas. The diminished economic margins in heating and cooling have caused an increased interest in research on the combined effects of environmental factors, including cultural determinants. The emphasis in today's thermal climate research seemingly is on the impact of air velocity, humidity, asymmetric heat radiation and cold floors in the build-up of the thermal discomfort sensation. Heating and cooling systems must be planned and installed so that they can be adjusted and checked regularly to ensure that the required performance in the occupant zone is maintained. There is a need to develop instruments and methods that will permit the end user to check the climatic conditions, and climate control systems and instructions that will allow the end user to control her own local climate conditions.

8.4. HUMIDITY

Indoor mould growth is a recurrent problem in dwelling hygiene. The indoor air is never free from mould spores. There is a large variety of species which requires expert knowledge in measuring and interpretation of results. In "clean" rooms up to 25 mould spores/m^3 have been found, and in dwellings with mould problems up to 12 000 spores/m^3 of potentially pathogenic mould organisms. Common causes of mould problems are capillary water transport to a concrete slab from the ground, use of contaminated construction material, water vapour producing household activities, use of unflued combustion appliances, and insufficient ventilation and heating. In most cases there is a combination of several factors.

There is little field study evidence of casual relationships between moulds in dwellings and allergy. But, for sensitive persons a number of irritating symtoms are associated with exposure to indoor moulds, their spores or metabolites. The salient effect on the occupants of many "mould buildings" is the persistent and annoying odor which frequently causes psychosocial problems.

A common indoor allergen is protein from dust mites which is associated with asthma. The most important indoor factor leading to the growth of house-dust mites in dwellings is a high indoor humidity.

Low indoor humidity in centrally heated buildings during the winter time is often said to cause dry nasal symptoms and respiratory illnesses. Controlled observations in climate chamber have not been able to demonstrate that ambient air humidity is significant for nasal symptoms in healthy persons. The complaints by healthy persons of dry air during winter periods may be caused by one or several other factors occuring simultaneously with low air humidity, e.g., higher levels of dust and irritating pollutants. For hyperreactive patients (perennial allergic rhinitis) clinical observations indicate that artificial humidification may be beneficial during the winter time.

General air humidification is not recommended for hygienic reasons. Humidification can result in side-effects such as the growth of dust mites, humidifier-fever and other allergies. "Dry air" symtoms should be countered preferably by other means than air humidification. Selective humidification may be required for special individuals/environments/processes; it is then important that a "safe" method is selected.

8.5. VENTILATION

A basic requirement for a healthy building is that the room air must not cause illness or discomfort during normal use. The building must also be able to withstand a fair amount of misuse by its occupants without giving rise to health hazards. Ventilation, for example, must have some surplus capacity, and be "forgiving" in its operation. Basically indoor air quality can be controlled by

- controlling emissions from various sources,
- guidelines or standards for air pollutant concentrations,
- prescribed outdoor air flow and quality requirements, and
- specific design requirements which research or practical experience have shown to be essential for a good indoor climate.

A combination of these requirements is always needed. The requirements on ventilating air is a function of the pollution loads. The chemical loads in combination with knowledge of the maximum permissible levels commonly determine the minimum ventilation rates from the health point of view. By using biotests (mutagenicity potency tests, odor assessment tests, etc.) a relative characterization of the pollution load can be made (mutagenic load, sensory load, etc.) and ventilation rates be proposed for different levels of ambitions (genotoxic risk, level of intended comfort, etc.).

Maximum permissible values should be specified for commonly encountered and well-researched pollutants such as humidity, formaldehyde, man-made mineral fibres, radon, asbestos, nitrogen oxides, sulphur oxides, carbon monoxide and total volatile organic substances. Maximum values should also be given for indicators such as carbon dioxide (presence of occupants and their emissions) and carbon monoxide (presence of tobacco smoke or traffic exhausts). In a recent publication on Air Quality Guidelines for Europe WHO (1987) has proposed a guide for 28 major chemical compunds in the outdoor and indoor general environments. However, we lack adequate toxicological knowledge of all the other several hundred low-level pollutants and their possible interactions.

Requirements for maximum, permissible emission levels of selected types of pollutants must be specified. Standard test methods should be developed.

Air recirculation is not recommended in public premises as a normal method on account of the risk of spreading gases and fumes, and in light of the practical experience of shortcomings in application and maintenance. Air from "polluted" rooms, such as rooms used by smokers, should not be recirculated. In existing systems, air recirculation may have to be used, but the conditions of filters and settings of fresh air supply systems must be checked at frequent intervals. For new systems it is recommended that other means of heat/cool recovery be employed. Air recirculation can be used as a method of mixing fresh air and room air when this is justified in practical terms, e.g. for thermal reasons. If air recircualtion is used in new building developments, special requirements must be fulfilled in respect of adjustment, regular performance checking and cleaning of ducting systems.

8.6. MATERIALS

For healthy buildings it is essential to choose building materials with a minimum pollutants emission to the indoor air. Materials to be recommended are ones that are

- proven and found to be low-emittant,
- accompanied by a statement of contents in respect of pollutant emissions,
- stable, lasting and durable under the conditions likely to be encountered, and
- free from heavy metals, asbestos, biocides, radioactivity, etc.

Purchasers/users of buildings must learn to express quantified requirements that can be checked, and also to check that the requirements have been fulfilled. Maintenance and operational aspects must be considered throughout the building process. The working environment of the operational and maintenance personnel, as well as their need for training, must not be forgotten. Technical descriptions and instructions for the user must be prepared towards completion of the building process.

9. Management to avoid SBS

In view of the complexity of pollutant sources and exposures indoors as well as in composition of the exposed population there is a need for an overall view of action for source control. This should include a screening of chemicals, a specific control of selected compounds, an evaluation of design and system solutions, an evaluation of occupant/environment interactions and the establishment of guidelines incorporating adequate safety margins.

9.1. SCREENING OF CHEMICALS

The ever increasing number of new chemicals and materials in building construction, installations, furnishings, maintenance and home activities indoors require some sort of a screening system to avoid the potentially harmful or otherwize adverse compounds. Andersen et al. (1982) suggested a strategy to reduce the exposure to the major groups of toxic indoor pollutants in non-industrial spaces. By a notification system products are to be selected with the least impact on human health and comfort, focusing on the reduction of three groups of substances:

- genotoxic substances,
- eye-airway irritants, and
- odorous chemicals.

The first are few in numbers and cause severe diseases, the second are numerous and have great prospects for substitution, and the third should in general be avoided because they are annoying.

There are at present a number of screening methods developed for the testing of genotoxicity of chemicals. Many of these tests are in use already for product control in some countries.

More than 2/3 of all threshold limit values for occupational health purposes are based on the irritant properties of the chemicals. The occupational limit values are set high since they are aiming only to protect most workers but not all. However, the approach shows that screening for sensory irritation effects among building products would be an acceptable method consistent with other areas of health control.

Since 50 years ventilation requirements have been set from the odor criterion, first to compensate for occupancy emissions only but later to indicate ventilation performance and to be used as an early warning of indoor non-human pollutants. The odor criterion is not only a sensitive and relevant basis for decision by its own value but is also consistent with decades of practical experience as reflected in most building codes in the world.

Since most indoor air pollutants in office spaces and dwellings are odorous, odor control would result also in a reduction of air pollutants in general. Provided no non-ethical manipulation of the sensory capabilities of the occupants is introduced (like odor masking), the efficiency of the odor control measures are easily checked. Furthermore, sensations are the integrated net response of the body to a large number of interacting components, and the effects appear at an early stage. A few pollutants lack sensory warnings and behave differently from the odorants, precluding the use of odor as an indicator effect. These substances must be controlled by other means.

9.2. SPECIFIC CONTROL OF SELECTED COMPOUNDS

For some chemicals and environment factors society knows the need for specific control actions. Major urban air pollutants such as sulfur oxides, nitrogen oxides, carbon monoxide and ozone are controlled for by air quality guidelines and surveillance programs, nowadays also directed to the indoor environment. Pollutants originating mostly indoors such as radon, formaldehyde, certain pesticides and some heavy metals are controlled for in specific ways. The resources in society and research, however, will remain too limited to manage to identify and specifically control for the majority of compounds. For these more general solutions must be searched.

9.3. EVALUATION OF SYSTEMS

Buildings and ventilation installations are complex systems whose performance not always can be predicted however close they are to the building codes and practice handbooks. Especially in times which favour innovations in energy saving the designer/constructor may abandon the old rules and the long experience. Scientific evaluations of the new systems are badly needed - from technical, economical, and human points of view. The health implications of new system solutions, positive and negative, deserve special attention in such evaluations: air quality characterization, toxicity evaluations of exposures from the knowledge of dose-effect relationships, sensory evaluations of indoor air quality and climate by human observers, and biotests using biological indicators.

10. Conclusions and Recommendations

1. The hygienic and climatic requirements have been disregarded far too often in designing and managing the built environment. "Healthy buildings" require a combination of proven experience and scientifically founded knowledge.
2. In the assessment of risks and realities of adverse health effects priority should be given to effects of major concern, such as building related cancer and allergy and other hypersensitivity reactions. However, since sensory reactions, climate discomfort reports and annoyance reactions are frequent, widespread and early signs of technical systems malfunction and of human strain, they are important parts of the health assessment.
3. The target is to control human exposure and should be reached primarily by source control. Dilution is not the main solution to pollution.
4. A ranking system is needed for building and consumer products based on harmonized test procedures. Fast screening procedures should be developed for appropriate endpoints of health and comfort. Test facilities will be needed to assist governments, manufacturers, builders and consumers.
5. The physical planning is critical. If buildings are erected on poor ground or close to sources of hazardous or annoying emissions, greater care and special solutions will be needed. This should be reflected in the building documents.
6. Feedback of experience must not be neglected. Warning signals of poor designs and materials, and working environment problems at the construction place, indicating later problems for the users, must be fed back to avoid further mistakes.

7. Technical systems in the built environment should either be very simple and self-explaining or be so automated that the need of maintenance and control is virtually eliminated. The rule of thumb is: Keep it simple!

Bibliography

Åberg N. Allergic diseases in childhood and adolescence in relation to background factors. Doctoral thesis. University of Gothenburg, 1988.

Akimenko V, Andersen I, Lebowitz M and Lindvall T. Report of a WHO subgroup on the "sick building" syndrome. In B. Berglund, U. Berglund, T. Lindvall & J.Sundell (Eds.) INDOOR AIR, Volume 6. Stockholm: Swedish Council for Building Research D13:1986, 87-97.

Andersen I, Lundquist G R and Molhave L. Indoor air pollution due to chipboard used as a construction material. Atmospheric Environment 9:1121-1127, 1975.

Andersen, I., Lundqvist, G.R., and Proctor, D.F. Human perception of humidity under four controlled conditions. Archives of Environmental Health, 1973, 26, 22-27.

Berglund B, Berglund U, Johansson I. and Lindvall T. Formaldehyde - absolute odor threshold and perceived odor intensity. In B. Berglund, T. Lindvall & J. Sundell (Eds.) INDOOR AIR, Volume 3: Sensory and hyperreactivity reactions to sick buildings. Stockholm: Swedish Council for Building Research D18:1984, p. 89-96.

Berglund, B., Berglund, U., and Lindvall, T. Psychological processing of odor mixtures. Psychological Review, 1976, 83, 432-441.

Berglund B and Lindvall T. Sensory reactions to sick buildings. Environment International, 12, 147-159, 1986.

Berglund B. and Lindvall T. (Eds). Healthy Buildings: State of the art reviews. Swedish Council for Building Research, Stockholm, D:19, 1988.

Bonnefoi M, Bolon B, Davenport C J and Morgan K T. Neurotoxicology at CIIT. CIIT Activities 10(6):1-7, 1990.

Cain, W.S. Olfaction and the common chemical sense: some psychological contrasts. Sensory Processes, 1976, 1, 57-67.

Colligan, M.J. The psychological effects of indoor air pollution. Bulletin of the New York Academy of Medicine, 1981, 57, 1014-1026.

Dawidowicz N., Lindvall T. and Sundell J. The healthy building. Swedish Council for Building Research, Stockholm, G:14, 1988.

Green, G.H. The health implications of the level of indoor air humidity. In (B. Berglund, T. Lindvall & J. Sundell, eds.) Indoor Air, volume 1: Recent advances in the health sciences and technology. Stockholm: Swedish Council for Building Research, 1984, p. 71-78.

Johnson B G, Kronvall J, Lindvall T, Wallin A, Weiss-Lindencrona H. Buildings and health (Hus och hälsa). Stockholm: Swedish Council for Building Research T4:1990. (In Swedish).

Korsgaard J. Demands of the allergic and hypersensitive populations. In (Berglund B. and Lindvall T., Eds) Healthy Buildings: State of the art reviews. Swedish Council for Building Research, Stockholm, D:19, 1988.

Lindvall T et al. An environmental health monitoring system based on biological indicators. Stockholm: National Environmental Protection Board Informs, 1989.

Platts-Mills T.A.E. and de Weck A. Mite allergy - a world-wide problem. In de Weck A. and Todt A. (Eds): Mite Allergy. The UCB Institute of Allergy, Brussels, 1988.

Sale, C.E. Humidification during the cold weather to assist perennial allergic rhinitis patients. Annals of Allergy, 1971, 29, 256-357.

Stevens, J.C. Thermo-tactile interactions: Some influences of temperature on touch. In D. Kenshalo (Ed.), Sensory Functions of the Skin of Humans. New York: Plenum, 1979, pp. 207-222.

Stolwijk, J.A.J. The "sick building" syndrome. In (B. Berglund, T. Lindvall & J. Sundell, eds.) Indoor Air, volume 1: Recent advances in the health sciences and technology. Stockholm: Swedish Council for Building Research, 1984, p.23-29.

Swedish Allergy Committee. To prevent allergy and hypersensitivity. Stockholm: Allmänna Förlaget. In Swedish only. 1989.

U.S. Congress, Office of Technology Assessment. Neurotoxicity: Identifying and controlling poisons of the nervous system. Washington, D.C.:U.S. Government Printing Office, 1990.

U.S. National Research Council. Environmental tobacco smoke. Washington, D.C. National Academy Press, 1986.

World Health Organization. Noise. WHO Environmental Health Criteria Document No. 12, 1980.

World Health Organization. Recommended health-based occupational exposure limits for respiratory irritants. WHO Technical Report Series No. 707, 1984 b.

World Health Organization. Air Quality Guidelines for Europe. WHO Regional Publications, European Series No. 23, 1987.

World Health Organization. Guidelines for Healthy Housing. Environmental Health Series, Regional Office for Europe, No. 31, 1988.

World Health Organization. Indoor Air Quality: organic pollutants. EURO Reports and Studies No. 111, 1989.

World Health Organization. Formaldehyde. Enviromental Health Criteria 89, 1989.

THE DYNAMICS OF THE INDOOR ENVIRONMENT AND SOME STRATEGICAL ASPECTS OF INDOOR MEASUREMENTS

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ABSTRACT. The indoor environment is characterized by a dynamic nature in particular from various emission sources contributing with volatile organic compounds. An understanding and consideration of all potential indoor pollution sources, their emission characteristics, and the interrelationship of various indoor air quality parameters are prerequisite for the design and development of a sampling strategy. This includes parameters like the time of sampling, sampling duration and frequency, and selection of the sampling location. The field measurements of various studies show the importance of considering time as well as on a long-term as on a short-term basis.

1. INTRODUCTION

Imagine an old train smoking comparment with six heavy smokers and you entering it from the fresh outdoor air. You will experience a pronounced irritation in the eyes. It is decided to measure the mean concentration of aldehydes over one hour. It is not possible to relate the results with the experienced symptoms. On the other hand if the short-term peak concentrations in the plumes from the smokers are measured, then the concentrations do correlate with your experience of annoyance (Ayer and Yeager 1982). This is the indoor air situation in a nutshell. You have to understand your indoor environment and you have to know how to carry out an investigation of a problem or non-problem building. Although the sampling method applied for an indoor pollutant measurement has a large influence upon the result, some indoor air quality factors may also have a marked influence upon the measured pollutant concentration because of the dynamic character of the indoor chemical environment.

Although sampling strategy is a well-known concept in traditional occupational hygiene the sampling strategy of an indoor environment must in addition be based upon a careful definition of the sampling objective and with due consideration of all indoor air quality parameters, their possible interrelationships, and the dynamic character of indoor pollutants. An understanding of all these parameters will also be a requisite for the evaluation of the measurements.

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This paper deals with volatile organic compounds (VOC) as an example of indoor air pollutants because of their ubiquitous presence in the indoor environment. Their dynamic nature will be discussed in relation to strategical sampling aspects such as selection of sampling location, sampling time, duration, and frequency. Parts of this paper have been discussed in Report no. 6 (CEC 1989), by Working Group 9 (1991-1992), further by Seifert (1987), Seifert et al. (1986), Thorsen and Mølhave (1987), and Wolkoff (1990).

2. INDOOR AIR POLLUTANTS

The energy crisis in the seventies demanded a need for tighter buildings and reduced ventilation requirements (Mage and Gammage 1985). At the same time the use of synthetic building materials increased together with the introduction of modern office technology like photocopying machines, computers, video display terminals, laser printers, carbonless copy paper, etc. These changes resulted in an increase of new organic indoor air pollutants. Indoor/outdoor concentration ratios of typical indoor pollutants were found to be significantly greater than one.

The indoor air quality is *inter alia* influenced by the universe of indoor air pollutants. These are characterized by the following:

- Concentration levels are generally sub threshold limit values by a factor $10\text{-}10^3$.
- They present a multitude and complex matrix of pollutants.

The pollutants may be divided into the following three types:

1. Gases and vapours (inorganic and organic)
2. Particulate matter inclusive radioactive particles and environmental tobacco smoke
3. Biological air contaminants

Several hundred organic compounds have been found in the indoor environment. The volatile organic compounds (VOC) (b.p. = 50 - 300 °C) are ubiquitous in the indoor air and by far the largest group of pollutants. They are further characterized by that their indoor/outdoor concentration ratios generally are larger than one.

The origin of VOC is a plethora of various emission sources. The major sources can be put into three different emission type categories: building related (Levin 1989; Wallace 1987), human related activities (Wallace 1989), and outdoor sources. Generally the emission from building related materials including inventory, consumer and, household related products are dominating, cf. Table 1 in CEC (1989). Some sources may even dominate depending upon the sub-microenvironment, human activities, and the sampling objective itself, e.g. the sampling location. Some examples of emissions are shown in Table 1.

3. THE DYNAMICS OF THE INDOOR ENVIRONMENT

The total indoor air pollution of VOC is a combination of continuous and discontinuous emission sources as described by Seifert and Ullrich (1987) and pointed out in the CEC report (1989). The emissions may further be subdivided into those behaving in a regular or irregular mode as shown below in Scheme 1.

Pollutant
- **Continuous**
  - **Regular** (constant emission factor)
  - **Irregular** (variable emission factor)
- **Discontinuous**
  - **Regular** (constant time pattern)
  - **Irregular** (variable time pattern)

SCHEME 1

The duration of the continuous type is either continuous or in the order of days to weeks while it may proceed within hours to minuttes for the discontinuous type as exemplified in Table 1. The concentration time profile of VOC in (public) buildings with activities may vary significantly during the working hours (Wolkoff 1990), more closer the emission source. Table 1 also shows some examples of typical source emission characteristics together with their major emitted pollutants, predominantly VOC. Any emission profile of VOC, whether it is building or human activity related, will depend upon the volatility of the VOC and the air exchange rate. The emission characteristic of a source may further be prolonged if the source acts as sink which adsorb other VOC from the indoor air and later desorb depending upon the climatic conditions and the air exchange rate.

The above illustrates the dynamic behaviour of VOC in the indoor environment in their variability expressed by the following: the concentration ranges encountered indoors; the plethora of source types; the variability of emission characteristics; the multitude of different building types and spaces; different ventilation conditions, and in addition to the variability of outdoor sources. The profile of measured VOC or VOC pattern may change from space to space and concentrations of a particular VOC may change within the space. These factors are further to some extent interrelated, e.g. a certain type of VOC are found in office spaces due to the use of office machines, etc, while different types will dominate in a kindergarten or kitchen, and some may originate from outdoor sources via the HVAC system. Another factor is the sink effect of materials and surfaces as mentioned above. The dynamic impact of this effect may be reflected in a typical office in which emitted pollutants from human activities and persons during the workday are adsorbed on fleecy surfaces and shelfs like textiles and paper. During the night while the HVAC system is turned off re-emission of VOC will occur and a VOC concentration is built up of which the workers are exposed to the next morning. Conversely, if the HVAC system is turned on overnight with heating the VOC can be

removed (Nielsen 1988).

Table 1. Duration of indoor air pollutants, some VOC emission characteristics, and pollutants emitted.
(taken from WG9 (1991-1992))

Emission type	Duration[1] of emission and its characteristics				Pollutant Emitted
	mins → hours	hours → days	days → weeks	Continuous[3]	
Building related materials, furniture, inventory:					
Carpets				R	solvents, 4-phenylcyclohexene
Vinyl floor				R	solvents, 2,4,4-trimethyl-1,3-pentanediol diisobutyrate 2-ethylhexanol
Wood products				R	terpenes, aldehydes, wood preservatives
Human related activities:					
Man	R,I				Bioeffluents
Smoking	I				ETS
Cleaning		I			solvents, limonene, odorants
Hobby work[4] - glueing	R,I				solvents, reactants
Office work[3]		I	I		ozone, solvents
Painting			I		solvents, co-solvents, aldehydes
Outdoor sources:					
Traffic[5]	R,I	R,I	R,I	R,I	aliphatic and aromatic hydrocarbons

1) Not counting sink effects. 2) The duration is greater than one month. 3) In case of frequent change in the number of occupants. 4) Depends upon the solvent volatility. 5) Depends upon ventilation habits. R = regular, I = irregular.

4. THE IMPORTANCE OF TIME and LOCATION

Time and location are parameters which have multifunctional relations with regard to the sampling strategy thus leading to the important questions: when, where, how often, and for how long to sample. How these two parameters are interrelated is shown in Table 2. The sampling time should be considered together with the sampling duration. For example, until recently field measurements combined with questionnaire techniques have not been able to identify VOC as a causative agent, because the measurements and the self-reporting of sick building syndrome (SBS) symptoms have not been carried out simultanously. However, Hodgson et al. (1991) have performed simultaneous total VOC measurements and self-reporting of SBS and found that VOC correlated with mucous irritation and general symptoms.

Table 2. The interrelationship between different indoor parameters showing the dynamics of the indoor environment (taken from Report no. 6 (CEC 1989)).

Parameter	Outdoor source	Air exchange rate	Air exchange efficiency	Source strength	Sinks
Sampling related:					
time of sampling	+			+	
sampling duration	+	+		+	
sampling frequency	+			+	
sampling location	+		+	+	+
Building related:					
age of building		+		+	+
source strenght		+	+	+	
temperature				+	
relative humidity	+			+	
Human activity related:					
activity pattern		+		+	
number of persons		+	+	+	+
Miscellaneous:					
Season	+	+			

The interrelationship of several indoor air quality parameters further reflects the overall dynamicity of the indoor environment as discussed in Report no. 6 (CEC 1989) and of which are important for the sampling objective, design, strategy, and the evaluation of the results. These are shown in Table 2, see above.

The time should also be considered on a long-term basis, i.e. the lifetime of a building. Because of the dynamicity of the emission sources of which several are point sources and strongly time dependent, like a photocopying machine, the position of the sampler is crucial. Concentration gradients of indoor specific VOC and their relation to sick building symptoms have been discussed by Noma et al. (1988). In addition, low or inefficient ventilation may lead to inhomogenous mixing of indoor pollutants and strong concentration gradients near the breathing zone may occur (Rodes et al. 1991). Further examples will be discussed below.

5. EXAMPLES

The importance of the time factor and the location/position of the sampler is shown in Table 3 and will further be discussed in the following examples.

Table 3. Indoor parameters influencing the measurement.

Parameter		Building related:	Impact upon
Time	long-term	age of building seasonal variation	sampling time sampling duration
		migration + infiltration	
		sink effect	
		decomposition	
		emission rate	
	short-term	**Activity related:** activities indoors source status ventilation	sampling frequency
		activities outdoors	
Location		activities source status emission characteristic	sampling time sampling duration sampling position

In the Danish Town Hall study (Skov et al. 1989, 1990) TVOC was measured using a high time resolution of 40 min sampling duration and using stationary sampling (Wolkoff 1990). The results showed:

a) The measured TVOC concentration some days changed a factor 2 up to 30 at noon and afternoon compared with the morning value. In one case this could be assigned to specific activities.
b) In a later investigation it was found that TVOC decreased twofold from the morning and five persons present to the afternoon and only one person working.
c) Annual measurements in the same office in a new building showed a tenfold decrease between first and second measurement, and again a fivefold decrease the third year.

Other studies have similarly showed that the TVOC level can change markedly depending upon shower activity Pleil et al. (1989), McKone (1989) and daily activities Wallace et al. (1989). In a recent climatic chamber study with office machines under controlled conditions it was found that TVOC concentration changed significantly from morning to afternoon due to activities (Wolkoff et al. 1992).

The Danish twin apartment study showed that formaldehyde and some VOC concentrations in two new apartments had strong seasonal variations while other VOC exhibited a decline over 130 days (Wolkoff et al. 1991) as similarly found for VOC in a new preschool (Berglund et al. 1982). The study concluded that important details concerning the construction of a building, the age of the building, temperature and humidity, air exchange, and the occupants' activity pattern all are prerequisite in order to draw conclusions based upon measured mean long-term concentrations. The seasonal variation of VOC has further been studied by Lebret et al. (1986), Gammage and Matthews (1988), Seifert et al. (1989) and for formaldehyde Reponen et al. (1991).

The infiltration of VOC from crawl space, a garage, an elevator, and a printing house, and factories into surrounding buildings have been reported by Wolkoff et al. (1991), Gammage and Matthews (1988), Weschler et al. (1990), and Verhoff et al. (1988, 1989).

6. CONCLUSION

The indoor environment is a dynamic situation rather than static in particular with regard to VOC. The most important step in designing and developing a sampling strategy is the definition of the sampling objective and in particular because of the multitude of factors and their interrelationship influencing the indoor pollutant concentration. The sampling objective could be, e.g., average or maximum exposure of a population, in search of acute or chronic effects in a complaint building and the impact of specific pollutants, identification of potential sources, evaluation of mitigation measures, and test for compliance. This leads to the key questions *why* sample and *what* to sample. The sampling objective, sampling strategy, and the data quality objective (quality control and assurance) should be considered jointly in the final sampling protocol (Keith 1990).

As a rough guide short-term sampling should reflect acute effects and long-term

sampling chronic effects.

Future indoor air sampling and in particular VOC should apart from the present guides focus upon source specific VOC, and apply statistical methods to identify VOC patterns and other indoor air quality parameter as possible causative agents of SBS (Berglund et al., 1990; Wallace et al. 1991).

7. REFERENCES

Ayer, H.E. and Yeager,D.W. (1982) 'Irritants in Cigarette Smoke Plumes', *American Journal of Public Health*, **72**, 1283-1285.

Berglund, B., Johansson, I. and Lindvall, T. (1982) 'A longitudinal study of air contaminants in a newly built preschool', *Atmospheric Environment* **8**, 111-115.

Berglund, B., Johansson, I., Lindvall, T. and Lundin, L. (1990) 'A longitudinal study of airborne chemical compounds in a sick library building', in D.S. Walkinshaw (ed.), Proceedings of the Fifth International Conference of Indoor Air Quality and Climate, Toronto, vol. 2, pp 677-682.

Gammage, R.B. and Matthews, T.G. (1988) 'Volatile Organic Compounds in Indoor Air: Types, Sources, and Characteristics', *Environmental Progress* **7**, 279-283.

CEC, European Concerted Action. (1989) 'Report No. 6 Strategy for Sampling Chemical Substances in Indoor Air', European Concerted Action Indoor air Quality & Its Impact on Man. Commision of the European Communities, Brussels-Luxembourg.

Hodgson, M.J., Frohliger, J., Permar, E., Tidwell, C., Traven, N.D., Olenchock, S.A. and Karpf, M. (1991) 'Symptoms and Microenvironmental Measures in Nonproblem Buildings', *Journal of Occupational Medicine* **33**, 527-533.

Keith, L.H. 1990. 'Environmental sampling: A Summary. *Environmental Science Technology* **24**, 610-617.

Lebret, E., Van de Wiel, H.J., Bos, H.P., Noij, D. and Boleij, J.S.M. (1986) 'Volatile Organic Compounds in Dutch Homes', *Environment International* **12**, 323-332.

Levin, H. (1989) 'Building Materials and Indoor Air Quality', *Occupational Medicine: State of the Art Reviews* **4**, 667-693.

Mage, D. and Gammage, R.B. (1985) 'Evaluation of Changes in Indoor Air Quality Occuring Over the Past Several Decades', in R.B. Gammage and S.V. Kaye (eds.), Indoor Air and Human Health, Lewis Publishers, Chapter 2.

McClenny, W.A., Oliver, K.D. and Pleil, J.D. (1989) 'A Field Stategy for Sorting Volatile Organics into Source-Related Groups', *Environmental Science Technology* **23**, 1373-1379.

McKone, T.E. (1987) 'Human Exposure to Volatile Organic Compounds in Household Tap Water: The Indoor Inhalation Pathway', *Environmental Science Technology* **21**, 1194-1201.

Nielsen, P.A. (1988) 'The importance of building materials and building construction to the sick building syndrome', in B. Berglund and T. Lindvall (eds.), *Healthy Buildings*, Stockholm, vol 3 pp. 391-399.

Noma, E., Berglund, B., Berglund, U., Johansson, I., Baird, J.C. (1988) 'Joint Representation of Physical Locations and Volatile Organic Compounds in Indoor Air from a Healthy and a Sick Building', *Atmospheric Environment* **22**, 451-460.

Pleil, J.D., McClenny, W.A., Oliver, K.D. (1989) 'Temporal Variability Measurement of Specific Volatile Organic Compounds', *International Journal of Environmental Analytical Chemistry* **37**, 263-276.

Reponen, T., Raunemaa, T., Savolainen, T. and Kalliokoski, P. (1991) 'The effect of material ageing and season on formaldehyde levels in different ventilation systems', *Environment International* **17**, 349-355.

Rodes, C., Kamens, R. and Wiener, R.W. (1991) 'The Significance and Characteristics of the Personal Activity Cloud on Exposure Assessment Measurements for Indoor Contaminants. *Indoor Air* **1**, 123-145.

Seifert, B. (1987) 'Meßtechnik im Umweltschutz', VDI-Verlag, Düsseldorf, February, M61-M65.

Seifert, B. and Ullrich, D. (1987) 'Methodologies for Evaluating Sources of Volatile Organic Chemicals (VOC) in Homes', *Atmospheric Environment* **21**, 395-404.

Seifert, B., Ullrich, D., Mailahn, W. and Nagel, R. (1986) 'Flüchtige organische Verbindungen in der Innenraumluft', *Bundesgesundhbl* December, 417-424.

Seifert, B., Mailahn, W., Schultz, C. and Ullrich. D. (1989) 'Seasonal Variation of Concentrations of Volatile Organic Compounds in Selected German Homes', *Environment International* **15**, 397-408.

Skov, P., Valbjørn, O., Pedersen, B.V. and DISG. (1990) 'Influence of indoor air quality on the sick building syndrome in an office environment', *Scandinavian Journal of Work, Environment & Health* **16**, 363-371.

Skov, P., Valbjørn, O. and DISG. (1987) 'The sick building syndrome in the office environment: The Danish town hall study', *Environment International* **13**, 339-349.

Thorsen, M.A. and Mølhave, L. (1987) 'Elements of a standard protocol for measurements in the indoor atmospheric environment', *Atmospheric Environment* **21**, 1411-1416.

Verhoeff, A.P., Wilders, M.M.W., Monster, A.C. and Van Vijnen, J.H. (1987) 'Organic solvents in the indoor air of two all factories and surrounding houses', International *Archives of Occupational Environmental Health* **59**, 153-163.

Verhoeff, A.P., Suk, J. and Van Wijnen, J.H. (1988) 'Residenial indoor air contamination by screen printing plants', *International Archives of Occupational Environmental Health* **60**, 201-209.

Wallace, L.A., Pellizzari, E.D., Leaderer, B., Zelon, H. and Sheldon, L. (1987) ' Emissions of Volatile Organic Compounds from Building Materials and Consumer Products', *Atmospheric Environment* **21**, 385-393.

Wallace, L.A., Pellizzari, E.D., Hartwell, T.D., Davis, V., Michael, LC. and Whitmore, R.W. (1989) 'The Influence of Personal Activities on Exposure to Volatile Organic Compounds' *Environmental Research* **50**, 37-55.

Wallace, L.A., Nelson, C.J. and Dunteman, G. (1991) 'Workplace Characteristics Associated with Health and Comfort Concerns in Three Office Buildings in Washington, DC', IAQ 91 *Healthy Buildings*, pp. 56-60.

Weschler, C.J., Shields, H.C. and Rainer, D. (1990) 'Concentrations of Volatile Organic Compounds at a Building with Health and Comfort Complaints', *American Industrial Hygiene Association Journal* **51**, 261-268.

Wolkoff P. (1990) 'Some Guides for Measurements of Volatile Organic Compounds Indoors', *Environmental Technology* **11**, 339-344.

Wolkoff, P., Clausen, P.A., Nielsen, P.A. and Mølhave L. (1991) 'The Danish Apartment Study. Part I: Formaldehyde and Long-Term Measurements of VOC', *Indoor Air* **1**.

Wolkoff, P., Johnsen, C.R., Franck, C, Wilhardt, P., and Albrechtsen, O. (1992) 'A Study of Human Reactions to Office Machines in a Climatic Chamber', submitted.

Working Group 9. (1991-1992) 'Strategies for VOC measurements in Indoor Air', European Concerted Action - Indoor Air Quality & Its Impact on Man. Community COST 613 Concertation Committee.

ORGANIC INDOOR POLLUTANTS: SOURCES, SPECIES, AND CONCENTRATIONS

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ABSTRACT. The major sources of organic indoor air pollution can be divided into three categories: (a) outdoor air penetrating indoor spaces via infiltration or ventilation, (b) man and his activities, (c) materials and equipment. Examples are given for all three types of sources. In view of the large variety of these sources it is not amazing that hundreds of organics have been identified in indoor air. For methodological reasons, special attention has been payed to non-polar volatile organic substances (VOC). From a number of large studies conducted in several countries, sufficient information is available to characterize average VOC concentration levels in the air of private homes. In the case of individual situations, however, prediction of concentrations remains difficult due to the variability of ventilation conditions, source strength, etc. For polar VOC, semi-volatile organics and particle-bound organics much less information is available even for the average situation although interest in getting the respective data is growing.

1. INTRODUCTION

Indoor air, like other compartments of the environment, can be polluted by a large variety of compounds which are generated from many different sources. Depending on the quality of these sources and their strength, the air inside enclosed spaces contains mixtures of pollutants which vary in terms of both their composition and concentration. Among the pollutants, organic compounds play a much more important role for the indoor than for the outdoor air: as a matter of fact, the concentrations of many organic compounds are higher indoors than outdoors (Seifert 1982; Pellizzari et al. 1986; Shah and Singh 1988), even in heavily industrialized areas (Cohen et al. 1989). In the following text the existing knowledge with regard to sources, species and concentrations of selected organic indoor air pollutants is summarized.

H. Knöppel and P. Wolkoff (eds.),
Chemical, Microbiological, Health and Comfort Aspects of Indoor Air Quality – State of the Art in SBS, 25–36.

2. SOURCES OF INDOOR AIR POLLUTANTS

For a better understanding of indoor air pollution, it is useful to characterize the sources of indoor air pollutants. Table 1 gives an overview of the most important sources as far as they can be made responsible for the emission of organic compounds. The sources can be divided into three categories: outdoor air, man and his activities, and materials and equipment.

TABLE 1. Important sources of organic indoor pollutants and the major organics of concern possibly emitted by them

Source	Emitted compounds or classes of compounds
Outdoor environment	
Air	Common outdoor air pollutants,
Soil	Volatile organic compounds
Water	Volatile organic compounds
Man and his activities	
Man himself	Body odours
Energy production	Volatile organic compounds, semi-volatile organic compounds
Smoking	Nicotine and many other volatile and semi-volatile organic compounds
Household and hobby products	Volatile organic compounds, semi-volatile organic compounds
Materials and equipment	
Building and renovation materials	Volatile organic compounds, fungicides
Furnishings	Volatile organic compounds
HVAC systems	Odoriferous compounds, mycotoxins

2.1. Outdoor environment

All buildings exhibit a more or less pronounced exchange between outdoor and indoor air. In buildings with natural ventilation this exchange is highest if windows/doors are open, but takes also place - although at a reduced level - if they are closed (infiltration through cracks and interstices). In the case of mechanically ventilated build-

ings, the ventilation system forces outdoor air (unless indoor air is recirculated) into the building shell to guarantee the air exchange. Hence, outdoor air cannot be neglected as a source of contaminants in indoor air if it has an elevated level of pollution.

For mechanically ventilated buildings provisions should be taken to clean the incoming air as much as possible. However, experience shows that this is not always done to the extent needed. Due to malfunctioning of the ventilation system or an unfavourable location of the air inlet (e.g., close to parking garages or loading docks) polluted outdoor air may become a noticeable contributor to indoor air pollution. This contribution may be especially important under certain meteorological conditions (high pollution episodes). As has been shown (Seifert and Schmahl 1987b; Borrazzo et al. 1990), adsorption of pollutants on walls, material surfaces, etc. may lower concentrations to a certain extent, especially in the case of polar organics. However, desorption may occur at a later stage and, thus, the removal of a prime polluting surface or material may not always result in a rapid decrease of the concentration level of the compound in question (Berglund et al. 1989).

A special case of indoor contamination originating from outdoors is the migration of gaseous substances into the building from the surrounding soil. Although radon is the most prominent example for such migration, a number of organic compounds may also play a role in the case of buildings constructed on waste sites.

Finally, the outdoor environment may indirectly contribute to indoor air pollution through organic substances resulting from the use of drinking water. In fact, chloroform and other volatile halogenated hydrocarbons have been found to reach non-neglectable concentration levels during showering (Andelman 1985).

2.2. Man and his activities

In addition to carbon dioxide and water vapour human beings emit a large number of organic compounds, many of which contribute to the body odour.

Energy production, e.g. the use of kerosene heaters, gas appliances or open fireplaces for cooking and heating, causes the presence of many indoor air pollutants among which nitrogen dioxide and carbon dioxide have been widely studied (e.g., CEC 1989a, Lebret 1985, Harper 1988). Combustion processes also generate suspended particulate matter, volatile organic compounds (VOC) and semi-volatile organic compounds (SVOC).

Smoking is a special case of combustion and one of the most important sources of indoor air pollution (NRC 1986). Interestingly enough, side stream smoke contains more pollutants and at a higher level than main stream smoke (Klus and Kuhn 1982). In addition to the compounds generally formed in combustion processes, tobacco smoke generates nicotine which can be considered as an indicator substance for tobacco smoke.

The large variety of existing household and hobby products makes it impossible to give a comprehensive overview of their components.

Among the most important VOC are those belonging to the classes of normal and halogenated hydrocarbons (solvents), aldehydes and esters. The use of special products, such as those for pest control, causes the lasting presence of certain SVOC in indoor air.

An excellent compilation of the composition of household and hobby products including information on adverse health effects has been prepared by Velvart (1989). Table 2 is a summary of the table of contents of his book and gives an impression of the wide spectrum of existing products most of which are potential emitters of organic compounds.

TABLE 2. Consumer products potentially contributing to indoor air pollution (adapted from Velvart 1989)

Household and Cleaning Products	Body Care Products
air freshener	alcohol-containing cosmetics
automatic dishwashing soap	hair care products
bathtub + sink cleaner	nail care products
bleach	skin care products
carpet and upholstery cleaner	
dishwashing soap	Gardening & Pest Control
drain cleaner	
floor care products	ant killer
furniture polish	fertilizer
household cleaner	fungicide
laundry detergent	herbicide
metal polishes, degreasers	insecticide
mold + mildew remover	mothballs
oven cleaner	rodenticide
paint stripper	
rust remover	Leisure Time and Hobby
shoe care products	
stain remover	glue
toilet bowl cleaner	home repair and maintenance
toilet bowl deodorizer	insect repellents
waterproofing agents	office supplies
window + glass cleaner	photofinishing chemicals
wood preservative	swimming pool chemicals

2.3. Materials and equipment

While most of the human activities mentioned in section 2.2 cause short term intermittent emissions (Seifert and Ullrich 1987a), the use of building and renovation materials in a room generally results in a long-term, more or less continuous pollution of indoor air.

In the past, much attention has been paid to formaldehyde which can be emitted from materials such as wood products, carpets, textiles, but also from glues and sealants. Besides formaldehyde, a large number of VOC are emitted from such materials, especially shortly after their installation.

As many paints and lacquers today are produced using water as the basic solvent, they do no more emit important amounts of organic solvents. However, a number of new compounds are now being added to these products (van Faassen and Borm 1990). As some of these have higher boiling points, they may significantly contribute to the occurrence of SVOC in the indoor environment. A large portion of these SVOC is bound to dust particles.

The information on organics emitted from equipment, materials and products is increasing. At the 5th International Conference on Indoor Air Quality and Climate, the respective sessions comprised nearly 40 papers (Walkinshaw 1990). Among these papers was one on a database of indoor air pollutant sources (Lawless et al. 1990). This computerized database (dBase III^{+}) has two parts with the same structure: one contains data extracted from the literature and cannot be altered, the other can be edited by the user.

The existence of such a database demonstrates the difficulty of condensing the full body of available information into one table. Therefore, Table 3 gives only those classes of materials that are supposed to have the most important impact on indoor pollution by organic substances.

TABLE 3. The most important sources of organic indoor pollutants with regard to materials and equipment

Adhesives
Caulks
Floor covering
Floor sealants
Furniture
HVAC system
Insulation materials
Lacquers
Office machines
Paints
Particleboard
Wall covering

Under certain circumstances, HVAC installations in an air-conditioned building may be a vehicle for, or even a source of, organic indoor air pollution. In the first case, organic substances resulting from emissions or spills in one rom may be transported into other rooms of the percentage of recirculated air is high. In the latter case, growth of mold in a badly maintained HVAC system may produce odoriferous substances. In addition, the formation and spread of mycotoxins cannot be excluded in such cases (Miller 1990).

As many air-conditioned buildings are being used as offices, a number of organics related to office work and office machines can be encountered in the air of such buildings.

3. ORGANIC SPECIES IN INDOOR AIR

In view of the multitude of existing organic compounds, it is difficult to establish a full list of those relevant to indoor air. Recently, however, Berglund et al. (1986) have screened the indoor literature for publications on organics. According to their search, more than 300 organics have been identified over the years. Most of these were volatile organic compounds (VOC) which, according to a classification given by WHO (1989), comprise compounds with boiling points of 50-100 °C to 240-260 °C. Although very volatile organic compounds (VVOC; <0 °C to 50-100 °C), semi-volatile organic compounds (SVOC; 240-260 °C to 380-400 °C) and particle-bound organics (POM; >380 °C) can also be found in indoor air, VOC probably cover the bulk of organic compounds.

TABLE 4. Organic compounds frequently observed in indoor air

Very volatile organic compounds

Dichloromethane
Chloroform

Volatile organic compounds

C_6 - C_{12} Alkanes	Ethanol
Benzene	Butanol
Toluene	Chloroethanes
Styrene	Chloroethenes
Xylenes	p-Dichlorobenzene
Trimethylbenzenes	α-Pinene
Ethylacetate	Limonene
Butylacetate	Formaldehyde
Acetone	Acetaldehyde
Methylisobutylketone	Acrolein
Nicotine	Hexanal

Semi-volatile organic compounds and particulate organic matter

Pesticides
- Chlordane
- Chlorpyrifos
- Diazinon
- Dichlorvos
- Heptachlor
- o-Phenylphenol
- Propoxur

Polychlorinated biphenyls
Polycyclic aromatic compounds

Table 4 gives examples of organic compounds frequently determined in indoor air, as classified according to the WHO definition.

The likelihood of occurrence of organics in indoor air can be estimated from work carried out by Engström et al. (1988). The authors tested the emissions of 200 materials used indoors, among which were 66 floor, wall and ceiling coverings, 43 insulation materials, 28 textiles, 19 paints, and 18 furnishings. Table 5 shows that about 50 compounds were observed which belonged to 11 chemical classes. Aldehydes, especially formaldehyde, aromatic hydrocarbons, and alcohols were observed most frequently.

TABLE 5. Organic emissions from 200 building products and furnishings (adapted from Engström et al., 1988)

Chemical class	Number of individual compounds observed per class	Number of products emitting
Acids	4	6
Alcohols	4	39
Aldehydes	5	74
Alkanes	4	18
Aromatic hydrocarbons	15	49
Esters	3	7
Glykol ethers and esters	5	7
Halocarbons	3	16
Ketones	5	28
Siloxanes	3	3
Miscellaneous	5	5

It is clear that according to the objectives of individual studies and to the analytical procedure used, compounds other than those mentioned in Tables 4 and 5 may be observed. As a matter of fact, some "exotic" organics have been considered now and then due to the health effects associated with their presence. As an example, TXIB may be mentioned (2,2,4-trimethyl-1,3-pentanediol-diiso-butyrate). TXIB which is a semi-volatile ester used as a plasticizer, e.g. in vinyl flooring (Gasking 1988) has been found at concentrations far above 100 $\mu g/m^3$ in buildings whose occupants complained about the sick building syndrome (Rosell 1990).

4. CONCENTRATIONS OF INDOOR AIR POLLUTANTS

In indoor spaces - especially in private rooms - there is a large variety of situations with regard to the ventilation status, the presence or absence of sources and the source strength. Thus, the concentration of indoor air pollutants may vary widely as a function of both

time and space. In addition, the sampling strategy used to determine the concentration level together with the boundary conditions encountered or set on purpose before and after the measurement will have a marked influence on the final result (CEC 1989b).

In contrast to inorganic pollutants, organic compounds occur at a much larger number of species in indoor air and not all of those potentially involved in the generation of indoor air problems can even be measured. For methodological reasons, most research work in the past has been focussed on non-polar VOC. The review of studies on VOC carried out in Italy (De Bortoli 1985), the Netherlands (Lebret et al. 1986), the USA (Wallace 1987), and the Federal Republic of Germany (Krause et al. 1987) led a WHO working group to establish a set of data for VOC concentrations to be expected in homes (WHO 1989). Table 6 summarizes these data for the most frequently encountered compounds.

TABLE 6. Percentiles of the frequency distribution of VOC concentrations in the air of private homes (adapted from WHO 1989)

Pollutant	Concentration ($\mu g/m^3$)	
	Median	90-Percentile
Dichloromethane	<10	<10
Chloroform	3	15
Formaldehyde	25	60
Hexanal	1	5
Decane	10	50
Undecane	5	25
Benzene	10	20
Toluene	65	150
Styrene	1	5
Naphthalene	2	5
1,1,1-Trichloroethane	5	20
Trichloroethene	5	20
Tetrachloroethene	5	20
p-Dichlorobenzene	5	20
Butanol	<1	3
α-Pinene	10	20
Limonene	15	70
Ethylacetate *)	5 - 10	10 - 50
n-Butylacetate *)	2 - 5	5 - 50

*) Values not given by WHO (1989) but based on the author's personal judgment.

The large number of VOC makes it difficult to deal with each of them individually if it comes to limiting their concentration. Thus, the concept of total VOC (TVOC) has been developed (Mølhave 1990).

Although TVOC is an ill-defined entity (Seifert 1990) because two VOC mixtures giving rise to the same TVOC value may have different composition and health implications, and measured TVOC concentrations depend critically on the analytical method used (without there being a standardised method), the concept merits further consideration. In fact, limiting the TVOC concentration which may reach dozens of mg/m^3 especially in new or newly renovated buildings, may lead to a general reduction of organic pollutants and, thus, reduce the number of complaints from the occupants. Proposals to limit TVOC concentrations in indoor air have been made recently (Mølhave 1990, Seifert 1990).

As to concentrations of semi-volatile and particle-bound organics, much less information is available. However, data on pesticides were collected in the NOPES project conducted in the USA (Immerman and Schaum 1990). In this project several hundred air samples were collected in randomly sampled households in two urbanized areas. Table 7 gives medians and 90-percentiles of concentrations found for the seven pesticides indicated in Table 4.

TABLE 7. Percentiles of the frequency distribution of concentrations of 7 selected pesticides (NOPES project)

Pollutant	Concentration (ng/m^3)			
	Jacksonville FL		Springfield MA	
	50 %	90 %	50 %	90 %
Chlordane	85	1000	30	540
Chlorpyrifos	180	900	nd	20
Diazinon	75	675	nd	20
Dichlorvos	nd	565	nd	nd
Heptachlor	10	700	3	230
o-Phenylphenol	70	190	25	125
Propoxur	110	900	nd	110

nd = not detectable (individual detection limits variable by factors of up to 20 depending on location and season)

5. CONCLUSION

Organic substances can be present in indoor air at levels much higher than in outdoor air. In most cases source apportionment is difficult as many products and materials may be responsible for the emission of one and the same compound. However, for certain activities emissions can be specified. While indoor concentration levels to be expected on average can be given for a considerable number of volatile organic compounds

(VOC), concentration levels for individual situations are difficult to be predicted because of the wide variety of possible boundary conditions (ventilation status of the room, source strength, etc.). For most semi-volatile and particle-bound organics much less information on their occurrence both at a qualitative and quantitative level is actually available than for VOC.

6. REFERENCES

Andelman, J.B. (1985) Inhalation exposure in the home to volatile organic contaminants of drinking water, Sci. total environ. 47, 443-460.

Berglund, B., Berglund, U. and Lindvall, T. (1986) Assessment of discomfort and irritation from the indoor air, Proc. ASHRAE Conference IAQ '86, 20-23 April 1986, Atlanta, GA, pp. 138-149.

Berglund, B., Johansson, I. and Lindvall, Th. (1989) Volatile organic compounds from used building materials in a simulated chamber study, Environ. Intern. 15, 383-387.

Borrazzo, J.E., Davidson, C.I. and Andelman, J.B. (1990) Sorption of organic vapors to indoor surfaces of synthetic and natural fibrous materials, in D. Walkinshaw (ed.), INDOOR AIR '90, Prec. 5th Internat. Conf. Indoor Air Quality and Climate, Toronto, 29 July-3 August 1990, Vol. 3, Canada Mortgage and Housing Corp., Ottawa, pp. 617-622.

CEC (Commission of the European Communities) (1989a) Indoor pollution by NO_2 in European countries, Report No. 3, European Concerted Action "Indoor Air Quality and its Impact on Man" (COST Project 613), EUR 12219 EN, Luxembourg.

CEC (Commission of the European Communities) (1989b) Strategy for sampling chemical substances in indoor air, Report No. 6, European Concerted Action "Indoor Air Quality and its Impact on Man" (COST Project 613), EUR 12617 EN, Luxembourg.

Cohen, M.A., Ryan, B.P., Yanagisawa, Y., Spengler, J.D., Özkaynak, H. and Epstein, P.S. (1989) Indoor/outdoor measurements of volatile organic compounds in the Kanawha Valley of West Virginia, JAPCA 39, 1086-1093.

De Bortoli, M., Knöppel, H., Pecchio, E., Peil, A., Rogora, L., Schauenburg, H., Schlitt, H. and Vissers, H. (1985) Measurements of indoor air quality and comparison with ambient air. Report EUR 9656 EN, CEC, Luxembourg.

Engström, K., Nyman, L., Haikola, M. and Saarni, H. (1988) Organic compounds released from building materials and furnishings, in B. Berglund and T. Lindvall (eds.), Healthy Buildings '88, Vol. 3, Swedish Council for Building Research, Stockholm, pp. 333-337.

Gasking, D.I. (1988) Texanol isobutyrate and other additive chemicals - environmental contaminants or laboratory artifacts?, Intern. J. Environ. Anal. Chem. 34, 1-15

Harper, J.P. (1988) Combustion Processes and the Quality of the Indoor Environment, Transactions Intern. Specialty Conf., Air & Waste Management Assoc., Niagara Fall, NY.

Immerman, F.W. and Schaum, J.L. (1990) Nonoccupational Pesticide Exposure Study (NOPES). Report EPA/600/3-90/003, Environment Protection Agency, Washington, DC.

Klus, H. and Kuhn, H. (1982) Verteilung verschiedener Tabakrauchbestandteile auf Haupt- und Nebenstromrauch (Eine Übersicht), Beitr. Tabakforsch. 11, 229-265.

Krause, C., Mailahn, W., Nagel, R., Schulz, C., Seifert, B. and Ullrich, D. (1987) Occurrence of volatile organic compounds in the air of 500 homes in the Federal Republic of Germany, in B. Seifert, H. Esdorn, M. Fischer, H. Rüden and J. Wegner (eds.), INDOOR AIR '87 - Proc. 4th Internat. Conf. Indoor Air Quality and Climate, Berlin (West), 17-21 August 1987, Vol. 1, Institute for Water, Soil and Air Hygiene, Berlin, pp. 102-106.

Lawless, P.A., Michaels, L.D. and White, J. (1990) Demonstration of EPA's database of indoor air pollutant sources (DIAPS), in D. Walkinshaw (ed.), INDOOR AIR '90, Prec. 5th Internat. Conf. Indoor Air Quality and Climate, Toronto, 29 July-3 August 1990, Vol. 3, Canada Mortgage and Housing Corp., Ottawa, pp. 673-675.

Lebret, E. (1985) Air pollution in Dutch homes, Thesis, Univ. of Wageningen, The Netherlands.

Lebret, E., van de Wiel, H.J., Bos, H.P., Noij, D. and Boleij, J.S.M. (1986) Volatile organic compounds in Dutch homes. Environ. Intern. 12, 323-332.

Miller, J.D. (1990) Fungi as contaminants in indoor air, in D. Walkinshaw (ed.), INDOOR AIR '90, Prec. 5th Internat. Conf. Indoor Air Quality and Climate, Toronto, 29 July-3 August 1990, Vol. 5, Canada Mortgage and Housing Corp., Ottawa, pp. 51-64.

Mølhave, L. (1990) Volatile organic compounds, indoor air quality and health, in D. Walkinshaw (ed.), INDOOR AIR '90, Prec. 5th Internat. Conf. Indoor Air Quality and Climate, Toronto, 29 July-3 August 1990, Vol. 5, Canada Mortgage and Housing Corp., Ottawa, pp. 15-33.

National Research Council (1986) Environmental Tobacco Smoke - Measuring Exposures and Assessing Health Effects, National Academy Press, Washington, DC.

Pellizzari, E.D., Hartwell, T.D., Perritt, R.L., Sparacino, C.M., Sheldon, L.S., Breen, J.J. and Wallace, L. (1986) Comparison of indoor and outdoor residential levels of volatile organic chemicals in five U.S. geographical areas, Environ. Intern. 12, 619-623.

Rosell, L. (1990) High levels of a semi-VOC in indoor air due to emission from vinyl flooring, in D. Walkinshaw (ed.), INDOOR AIR '90, Prec. 5th Internat. Conf. Indoor Air Quality and Climate, Toronto, 29 July-3 August 1990, Vol. 3, Canada Mortgage and Housing Corp., Ottawa, pp. 707-712.

Seifert, B. (1982) Vergleich der innerhalb und außerhalb geschlossener Räume auftretenden Konzentrationen anorganischer und organischer Verbindungen, in K. Aurand, B. Seifert and J. Wegner (eds.), Luftqualität in Innenräumen, Gustav Fischer Verlag, Stuttgart-New York, pp. 41-74.

Seifert, B. and D. Ullrich (1987a) Methodologies for evaluating sources of volatile organic chemicals VOC in homes, Atmos. Environ. 21, 395-404.

Seifert, B. and Schmahl, H.-J. (1987b) Quantification of Sorption Effects for Selected Organic Substances Present in Indoor Air, in B. Seifert, H. Esdorn, M. Fischer, H. Rüden and J. Wegner (eds.), INDOOR AIR '87 - Proc. 4th Internat. Conf. Indoor Air Quality and Climate, Berlin(West), 17-21 August 1987, Vol. 1, Institute for Water, Soil and Air Hygiene, Berlin, pp. 252-256.

Seifert, B. (1990) Regulating indoor air, in D. Walkinshaw (ed.), INDOOR AIR '90, Prec. 5th Internat. Conf. Indoor Air Quality and Climate, Toronto, 29 July-3 August 1990, Vol. 5, Canada Mortgage and Housing Corp., Ottawa, pp. 35-49.

Shah, J.J. and Singh, H.B. (1988) Distribution of volatile organic chemicals in outdoor and indoor air, Environ. Sci. Technol. 22, 1381-1388.

Van Faassen, A. and Borm, P.J.A. (1990) Indoor air pollution and health hazard by waterborne construction paints (wpc), in D.S. Walkinshaw (ed.), INDOOR AIR '90, Prec. 5th Internat. Conf. Indoor Air Quality and Climate, 29 July-3 August 1991, Vol. 3, Toronto, Canada Mortgage and Housing Corp., Ottawa, pp. 695-700.

Velvart, J. (1989) Toxikologie der Haushaltsprodukte, 2nd ed., Hans Huber Verlag, Bern.

Walkinshaw, D.S. (ed.) (1990) INDOOR AIR '90, Prec. 5th Internat. Conf. Indoor Air Quality and Climate, 29 July-3 August 1991, Vol. 3, Toronto, Canada Mortgage and Housing Corp., Ottawa, pp. 551-775.

Wallace, L. (1987) The Total Exposure Assessment Methodology (TEAM) Study: summary and analysis. Report EPA/600/6-87/002a, Environment Protection Agency, Washington, DC.

WHO (World Health Organization) (1989) Indoor air quality: Organic pollutants, EURO Reports and Studies 111, WHO Regional Office for Europe, Copenhagen.

SAMPLING AND ANALYSIS OF ORGANIC INDOOR AIR POLLUTANTS

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ABSTRACT. A wide range of organic compounds including aldehydes, VOC and VVOC have been shown or suspected to play a role as one of the multiple causes of the 'Sick Building Syndrome'. Methods for their measurement consist of a sampling step and a separation and identification step. Of these steps sampling needs to be designed according to the specific requirements of the indoor environment, whereas separation and identification methods are common to many fields of environmental analysis. This paper discusses mostly sorbent sampling, gives some information on whole air sampling and describes methods for sample transfer to the separation and identification equipment.

1. Introduction

The design of sampling and analytical methods for the measurement of indoor air pollutants depends on the nature of the pollutants and on the objective of the measurement.

A wide range of organic compounds including aldehydes, volatile organic compounds (VOC) and very volatile organic compounds (VVOC), defined by a working group of the World Health Organization (WHO, 1989) and discussed by Seifert (this volume), are the most important indoor air pollutants that have been shown or suspected to be a co-factor for the occurrence of the so-called "Sick Building Syndrome" (Knöppel and De Bortoli, 1991). Therefore this paper will focus on sampling and analytical methods for these compound classes.

The objective of pollution measurements influences the choice of the detection and in particular of the sampling method because it determines whether

- the presence and concentration of pre-selected "target" compounds has to be determined or a survey is requested of which pollutants are present at which concentrations,
- short term peak values or long term averages of the pollutant concentrations have to be detected or
- a local pollutant concentration (or an environmental sample), the concentration in the breathing zone of a person (or a personal sample) or the emissions from indoor materials have to be measured.

Most of the analytical methods currently available have been developed for analysing outdoor or workplace air pollutants and, where necessary, have been adapted for the measurement of indoor pollutant concentrations or exposures. They are usually designed to cope with the following conditions:

- Typical indoor (and outdoor) concentrations of most air pollutants (organic compounds in particular) are too low for direct analysis with most of the detection

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methods currently available. Therefore, during the sampling procedure the pollutants are usually preconcentrated. Preconcentration is particularly important for identifying unknown compounds, i.e. for survey analysis.

- The indoor environment consists of a large number of separate spaces with different pollution patterns and levels. Therefore, many measurements need to be taken for a representative characterization of indoor pollution. The necessity of taking many measurements calls for simple, lightweight and inexpensive equipment.
- Indoor spaces are usually occupied by people. If the occupants of these spaces are to be disturbed as little as possible, the analytical instrumentation should be small and silent.

For VOC, VVOC and aldehydes the answer to these characteristics of the indoor environment are analytical methods which are composed of two steps:

(1) *Sampling.* This step is performed by lightweight, small, silent, and inexpensive equipment. During sampling the pollutants are usually separated from the bulk of the air thereby achieving a preconcentration.

(2) *Separation and identification.* This step is typically performed in the laboratory and therefore also complex and expensive instrumentation may be used. It includes separating the often complex mixtures of indoor pollutants by high resolution gas chromatograghy (HRGC) or high performance liquid chromatography (HPLC), and their identification by chromatographic retention times, by mass spectrometry (MS) or by a combination of both methods.

The chemical characterization of source emissions is usually performed under controlled, standardized environmental conditions in the laboratory (De Bortoli and Colombo, this volume) and may be performed at higher than environmental concentrations. Consequently the reasons for dividing the sampling/analysis procedure into two separate steps apply to a lesser degree than for field studies.

Whereas the sampling procedures have to be adapted to the specific requirements of the indoor environment, the methods for separating and identifying organic indoor air pollutants are also used in other fields of organic environmental analysis such as outdoor air and water analysis (Knöppel 1977). Therefore, this paper will focus mainly on sampling procedures.

An important part of the analysis of organic indoor pollutants is the procedure for transferring the pollutants from the sampling equipment to the separation and identification instruments. This procedure has a strong influence on the volume of air which has to be sampled and on the sensitivity of the overall analytical method as will be discussed below.

2. Sampling Methods for Organic Indoor Air Pollutants

Three different principles have been applied to the sampling of volatile organic pollutants from ambient or indoor air as schematically indicated in Figure 1:

(1) The *GRAB* method takes a whole-air sample by either opening the valve of an evacuated cylinder or pumping air into it (using e.g. a membrane pump).

(2) During *ACTIVE* sampling an appropriate amount of air is drawn by a pump through a solid or liquid sorbent where the pollutants are trapped. For indoor air sampling usually small and silent so-called personal pumps are used.

(3) P*ASSIVE* sampling is based on the diffusion of pollutants from the entrance opening (surface area A) of a sampling cylinder (where the pollutant concentration is assumed to be that of the surrounding or bulk air) to the surface of a sorbent (usually solid, but also liquid) which has a well defined distance L from the entrance and where the pollutant concentration is assumed to be negligible compared to the bulk air concentra-

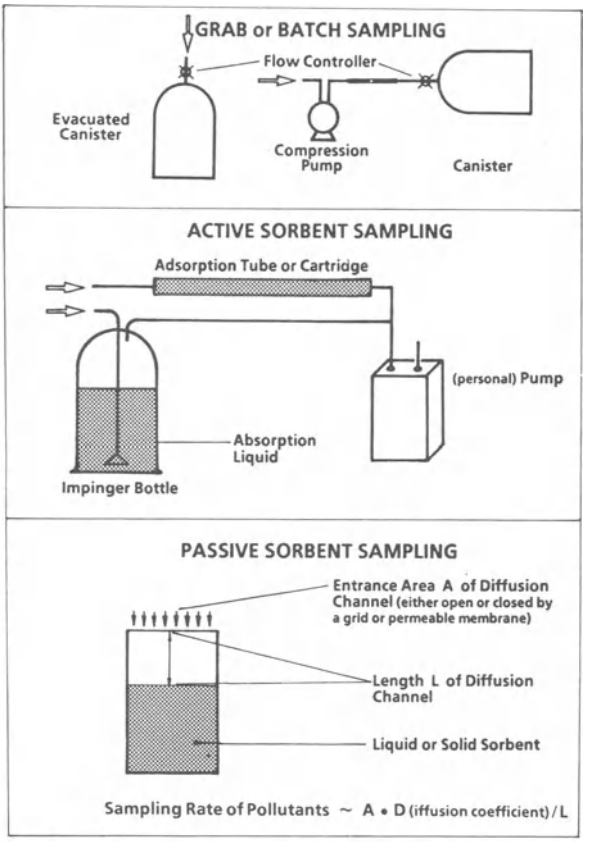

Figure 1. Illustration of sampling principles for organic indoor pollutants

tion. Ideally the sampling rate follows Fick's first law of diffusion and is determined by the geometry of the sampler and the diffusion coefficient of the pollutants according to the equation given at the bottom of Figure 1. It is important that no air turbulences disturb the diffusion process in the space between the sampler opening and the sorbent surface since this is a prerequisite for the determination of bulk air concentrations. Therefore either the diameter of the entrance area A must be small in comparison to the diffusion length L or the entrance opening must be closed by a permeable diaphragm.

Table 1 summarizes some basic features of the three sampling principles.

Grab sampling allows high sampling velocities and short sampling times. It is therefore particularly suitable for the determination of short term peak values of concentrations but can also be adapted to the measurement of longer term average concentrations.

For *active sampling* the sample flow is limited since the organic molecules must be sufficiently long in contact with the sorbing medium in order to allow for diffusion from the air to the sorbent. Moreover the sorbent bed acts as a flow resistance.

The useful sampling rate of *passive samplers* is limited by the air velocity at the entrance area of the sampler. At low air velocities the pollutant concentration in the vicinity of the entrance of the diffusion channel decreases compared to the bulk air concentration since there is no complete replacement of the molecules diffused into the sampler. This leads to an apparent increase of the diffusion channel length and to a reduction of the sampling rate compared to the theoretically expected one. The effect of the air velocity on the sampling rate can be reduced using samplers with small entrance areas (and, hence, low sampling rates). Such samplers are most useful for the determination of longer term (1-2 weeks) average concentrations (see section 5.2).

Grab or whole-air sampling can be used for the determination of *environmental concentrations* whereas active sampling with lightweight silent personal pumps and, even more easily, passive sampling can also be used for *personal monitoring.*

TABLE 1. Characteristics of different sampling approaches for organic indoor air pollutants

type	sampling principle	typical sample volume	typical sampling velocity
grab, batch or whole air sampling	- vacuum - compression pump - cryo-condensation	1 ℓ - 6 ℓ 1 ℓ - 20 ℓ 1 ℓ - 50 ℓ	≤ 30 ℓ/min (smaller velocities with flow restrictor)
active sampling (solid or liquid sorbent)	(personal) aspiration pump	0,5 ℓ - 2 ℓ (thermal elution) 50 ℓ - 600 ℓ (solvent elution)	4 mℓ/min - 4 ℓ/min (smaller velocities with intermittent sampling)
passive sampling (solid or liquid sorbent)	molecular diffusion	0,5 ℓ - 2 ℓ (thermal elution) 50 ℓ - 600 ℓ (solvent elution)	0.5 mℓ/min - 100 mℓ/min* (depending on geometry)

* The higher the sampling velocity the stronger its dependence on air movement

4. Sample Transfer to the Separation/Identification Equipment

There are essentially three ways used to transfer samples to the separation and identification equipment:

(1) *direct injection* of part of a grab sample or an aliquot of an absorption liquid into a HRGC or HPLC system;

(2) *solvent extraction* of the trapped pollutants from an absorption liquid or a solid sorbent and injection of an aliquot of the extract into the HRGC or HPLC;

(3) *thermal elution* of adsorbed VOC or VVOC from a solid sorbent by means of a pure carrier gas, usually helium; in this case the desorbed compounds are cryogenically re-concentrated in a capillary which is directly connected with the analytical HRGC column. Cryo-concentration may also be used to introduce larger amounts of a grab sample into the HRGC column. The cryotrap is flash heated in order to guarantee a rapid injection of the compounds into the gas chromatograph.

The sample transfer method has an important influence on the overall sensitivity of the analytical method. Sorption on a solid sorbent and *thermal elution* is the most sensitive method and therefore most often applied. Using this method all compounds collected from an air sample are available for *one* analysis. In principle the same is true if a whole air sample is cryo-concentrated prior to HRGC separation. However, the water contained in the air sample may block the cryotrap (see section 6).

Several thermal elution/cryo-concentration units are commercially available. There are models for manual (e.g. Thermal Desorption Cold Trap Injector (TCT), Chrompack, Middelburg, The Netherlands) and for an automatic change of sample tubes (e.g. Thermal Desorption Autosampler model TDAS 5000, Carlo Erba Strumentazione, Rodano (Milano), Italy).

Solvent extraction leeds to a dilution of the sampled compounds in the solvent, of which usually only a small fraction (typically 1 ‰ to 1 %) can be injected in the HRGC or HPLC system. Evaporation of the solvent would lead to losses of the sampled compounds.

A particular case results, if an absorption liquid contains a reagent which reacts specifically with a single compound or compound class. In indoor air analysis this technique is mostly applied to the detection of aldehydes using dinitrophenylhydrazine (DNPH) as a reactant. In this case non volatile reaction products (dinitrophenyl hydrazones) are formed and the absorption liquid (e.g. acetonitrile) or the extraction solvent may be vaporized without sample loss leeding to a considerable gain in detection sensitivity. As an alternative to this procedure more recently reversed phase cartridges (e.g. SEP-PAK®, Waters Associates, Milford, MA) impregnated with DNPH have been used for sampling aldehydes. Sampling about 30 ℓ of air (1 ℓ/min), extracting the hydrazones with about 2 mℓ acetonitrile and injecting an aliquot of 5 $\mu\ell$ directly on the HPLC column (acetonitrile is also used as liquid phase) yields sensitivities down to few $\mu g/m^3$ of air.

Some additional features of the different sampling methods including sample transfer aspects have been summarized in Table 2

TABLE 2. Additional features of more frequently used sampling methods for organic indoor pollutants

Method	Preconcentration during sampling	Elution method	Preconcentration before chromatogr. separation	Typical application
whole air sampling (e.g. in stainless steel canisters)	no	direct transfer to GC interface	yes (cryogenic)	- survey and target compound analysis, - peak concentrations - determination of the variation of concentrations - sampling of VVOC
liquid absorption	yes	direct transfert to HPLC or solvent extraction	no (however yes, in case low volatile reaction products are formed in the sorption liquid)	analysis of target compounds or compounds classes (e.g. aldehydes)
active or passive sorption on:				
Tenax®TA	yes	thermal elution	yes (cryogenic)	survey and target compound analysis of VOC
Carbotrap™	yes	thermal elution	yes (cryogenic)	survey and target compound analysis of VOC
Carbosieve™ S-III	yes	solvent extraction	no (or very little)	mostly target compound analysis of VOC
	yes	thermal elution	yes (cryogenic)	survey and target compound analysis of VVOC

5. Sorbent Sampling

5.1 ACTIVE SORBENT SAMPLING AND THERMAL ELUTION

The most widely used procedure for sampling volatile organic compounds from ambient or indoor air is to pass a suitably large air volume through a solid sorbent material that retains the compounds of interest (Namieśnik, 1988). Silent, relatively small and light weight battery driven pumps are available which maintain an adjustable constant sample flow (e.g. models ALPHA, E.I. du Pont de Nemour & Co., Wilmington, Delaware 19898, U.S.A. or model CHRONOS, Zambelli s.r.l., I-20010 Bareggio-Milano). The flow of these pumps has to be calibrated. Pumps of this type are available for sample flows from a few milliliter to a few liter per minute and may be used for both personal and environmental sampling. There are pumps using a diaphragm and rotary pumps. The latter ones usually feature lower short term fluctuations of the sampling flow. For environmental and emission sampling alternatively larger silent pumps with integrated sample volume measurement are available (e.g. models GS 212 and GS 312, DESAGA, D-6900 Heidelberg).

There are many types of solid sorbents most of which fall into one of three categories: *organic polymer resins* (e.g. Tenax TA, XAD), *carbon based sorbents* (e.g. Carbotrap, Carboxen, Carbosieve, activated charcoal) and *inorganic sorbents* (e.g. silica gel, alumina, Florisil, molecular sieves). Of these, inorganic sorbents are normally not used for VOC sampling because they are thermally not very stable, are hydrophilic and have therefore a high affinity for water which makes thermal elution impossible. Carbon based sorbents are hydrophobic and have a high thermal stability. However, only graphitized carbon black (like Carbotrap) has a sufficiently low sorbent-air distribution coefficient (or adsorption strength) to allow thermal elution of the full range of VOC at temperatures which do not induce thermal degradation of some compounds. For VVOC also Carboxen and Carbosieve can be used. Tenax TA has a good thermal stability, a low affinity for water and allows thermal elution of a wide range of VOC (i.e. from C_6- up to C_{15}-alkanes) at a temperature of 250°C. Sorption on Tenax TA has therefore been used most widely for sampling of VOC.

TABLE 3. Characteristics of more frequently used solid sorbents

Sorbent	Sorbent type	Appropriate specific sampling area [m^2/g]	Maximum elution temperature [°C]	Useful range for n- alkanes
Carbotrap C	graphitized carbon black	12	400	C_7 — >C_{15}
Tenax®TA	organic porous polymer resins (poly-m-terphenyl ether)	35	250 — 300	C_6 — >C_{15}
Carbotrap™	graphitized carbon black	100	400	C_5 — >C_{15}
Carbosieve™ S-III	spherical carbon molecular sieve	550	>400	≥C_2 (mostly VVOC)
Charcoal (mostly for passive samplers)	charcoal	>1000	—	(>C_2)

Table 3 summarizes the physical characteristics of a few of the most commonly used sorbents for active sampling of VOC from indoor air. For equal weights of sorbent (typically 100 mg - 1 g) the break-through volume of a volatile organic compound (i.e. the air volume which passes through the sampling cartridge before the compound starts to escape from it) is the smaller, the smaller the specific surface area of the sorbent is. Similarly, the higher the specific surface area of a sorbent is, the more volatile compounds are retained on the cartridge at a given air sample volume. On the other hand, the higher the specific surface area is, the higher the required elution temperature. Due to these limitations none of the sorbents allows to trap and thermally elute the whole range of VOC and VVOC as indicated in table 3. From this point of view a combination of sorbents gives the best promise for efficient sampling and thermal desorption of a wide range of volatile organic compounds provided the sample air passes through sorbents with increasing specific surface area. It should be noted, however, that extending the volatility range of a sample to highly volatile compounds is only useful, if the HRGC separation is appropriate, i.e. if the temperature program can start at sufficiently low (subambient) temperatures.

When starting work with a new type of sorbent it should always be tested if no break-through of a compound of interest occurs at the desired sample volume. This is usually achieved by using two sorbent cartridges in series and making sure, that the second cartridge does not contain significant amounts of the interesting substances.

5.2 PASSIVE SORBENT SAMPLING

Passive sampling devices do not require a pump and flow regulation system and are therefore considerably smaller, less costly and less obstrusive than active sampling devices. They are therefore ideally suited for personal sampling and a number of commercially available versions have been developed for industrial hygiene applications. These samplers use active charcoal as sorbent. Due to the strong sorption capacity of charcoal the gas phase concentration C_s of sorbed compounds at the surface of the sorbent is negligible, even for most VVOC. However, charcoal requires solvent elution of the sampled compounds with its inherent lower sensitivity compared to thermal elution. An interlaboratory comparison test of a commercially available sampler (De Bortoli et al., 1986) has shown that about 500 ℓ of air had to be sampled in order to detect VOC concentrations at the 1-2 $\mu g/m^3$ level, a value that corresponds to the 50 percentiles of the concentrations of many indoor pollutants (WHO, 1989). At a sample flow of 25 mℓ/min typical for this sampler a sampling time of about 14 days is required.

In order to increase the sensitivity of passive samplers Lewis et al. (1985), have developed a passive sampling device which uses Tenax GC as sorbent and can be thermally eluted. In addition the length of the diffusion channel was reduced yielding sample flows up to 80 mℓ/min (chloroform), thereby increasing the analytical sensitivity 400 to 500 fold compared to the above mentioned charcoal sampler. Using this device, 1 ng of an indoor pollutant at an air concentration of 1 ng/ℓ can be made available for analysis in about a quater of an hour compared to 14 days using the charcoal based device. A specially designed oven has to be used for thermal desorption of the Tenax passive sampler.

For longer term sampling and more volatile compounds, however, the vapour phase concentration C_s at the Tenax surface is no longer neglible and the sample flow decreases with time.

Apart from this drawback, both described designs need fairly high surface air velocities in order to reach their theoretical (maximum) sample flows. For the sampler of Lewis et al. (1985) sampling rates between 67 and 80 mℓ/min were reduced to 64 % of these values when the air velocity at the entrance area of the sampler was reduced from

50 cm/sec to 5 cm/sec and at lower surface air velocities a further steep decrease of the sample flow has been predicted based on theoretical considerations. On the other hand, the overall frequency distribution of air velocities measured in six occupied houses maximized at 0 to 2.5 cm/sec (Matthews et al., 1989).

In order to avoid the dependence of the sampling rate from the surface air velocity, De Bortoli et al. (1989) used a glass tube with an internal diameter of 3 mm and a diffusion channel length of 25 mm, filled with a 2.5 cm plug of Tenax TA or Carbotrap as passive sampling device for thermal elution. In view of the geometry of the sampler only small sampling rates are achieved in the order of 0.6 mℓ/min or 1 ℓ/week so that in one week 1 ng of a compound is sampled if its air concentration is 1 ng/L. This is about two times the sensitivity which can be achieved with the above mentioned commercial charcoal sampler. As a consequence of the non negligible C_s values, however, this sampler has a lower than theroretical sampling rate for more volatile VOC (about 50 % for n-hexane, 100 % for xylene) and may loose these compounds upon exposure to zero air (40% loss of n-hexane, no loss of xylene after one week).

5.3 CLEANING AND STORAGE OF TENAX AND CARBOTRAP SAMPLING TUBES

Cleaning of sorbent samplers usually is achieved by thermal elution under the same conditions as or at slightly higher temperatures than used for sample elution. Elution temperatures of 260°C-280°C are appropriate for Tenax TA and of 280°C-320°C for Carbotrap. Thermal elution is repeated until acceptable blanks are obtained. Schmidbauer and Oehme (1988) have proposed special cleaning procedures for new Tenax and Carbotrap which may contain larger quantities of impurities.

It is important to use clean helium for the elution of sampling tubes. A convenient way to clean helium is to pass it through a charcoal trap at liquid N_2 temperature.

A convenient and efficient way to conserve clean sampling tubes is to close them with Teflon caps or Swagelock stoppers, enclose them into culture vials closed with screw caps and Teflon lined silicon septa and store them at -15°C to -20°C in a freezer. Even after two months storage time acceptable blank values are obtained which show only traces of freons from the cooling system of the freezer. It is important that Teflon caps are mashined without the use of antigripping liquids.

Loaded samplers stored in the same way did not show alterations if analyzed after two weeks in the author's laboratory.

5.4 ARTIFACTS OF SORBENT SAMPLING

Even after careful cleaning of sorbent samplers artifacts may occur either due to impurities or thermal decomposition of the sorbent or due to reactions of sampled species among themselves or with the sorbent.

Tenax. For more than 15 years Tenax has been most extensively used for sorbent sampling of VOC from ambient air and most knowledge about artifacts has been accumulated during this work. All of the following artifacts have been reported using Tenax GC: formation of benzaldehyde, phenol, acetophenone and benzoic acid when sampling zero air containig 100 ppb of ozone (Schlitt et al., 1980); reaction of ozone, NO_x, SO_2/SO_3 and Cl_2 with Tenax yielding benzaldehyde, acetophenone and phenol (Pellizzari and Krost, 1984); reaction of ozone and Cl_2 with styrene and cyclohexene adsorbed on Tenax yielding various reaction products (Pellizzari et al., 1984).

In addition to these reactions observed during sample collection also reactions of mixtures of bromotrichloromethane and pentachloroethane during thermal elution from Tenax have been observed (Walling et al., 1986).

Walling (1984) has proposed distributed air sampling as a method to reveal the presence of complications when using sampling on solid sorbents and in particular on Tenax. The method is based on the simple notion that the amount of a substance adsorbed on Tenax should be a linear function of the sampled air volume. If this is the case, then the concentration of a substance will be independent of the sample volume. If, however, the concentration of a substance apparently depends on the sample volume and no breakthrough occurrs, then an artifact has to be supposed. Using this method Walling has found on several occasions inconsistencies for Tenax samples of outdoor air.

For the time being none of the above described artifacts has been observed for Tenax sampling of indoor air. Spicer (1986) applied the technique of distributed air sampling in a test house and obtained perfectly consistent data comparing canister and Tenax sampling. It is noteworthy that most indoor air analyses are currently performed using Tenax TA, a more recent and stable version of Tenax. Anyway, there are some compounds (1,1,1-trichloroethane, t-butanol, t-butylacetate) which for not well understood reasons have shown inconsistent recovery from Tenax TA (Health and Safety Executive, 1991).

In view of the above reported artifacts caused by oxidants, attention should be payed when sampling in the vicinity of photocopiers or other appliances which may release oxidants. The appearence of benzaldehyde and acetophenone in such samples may be indicative of a Tenax reaction.

Attention should also be payed to the elution temperature of Tenax cartridges. Although Tenax TA is reported to be thermally stable beyond 300°C, increasing amounts of benzene and toluene appear in blank runs at elution temperatures above 250°C.

Other sorbents. Little is known about artifacts of other sorbents. Rothweiler et al. (1991) compared Tenax TA and Carbotrap and observed losses of acrolein, hexanal and α-pinene when desorbing these compounds from Carbotrap. The loss of α-pinene was accompanied by the formation of additional terpenes. In view of the high elution temperature (320°C) thermal decomposition may be the reason for these losses. This hypothesis is supported by the observation of increasing losses of aldehydes from Carbotrap with increasing desorption temperature by De Bortoli et al. (1989). Similarly an increasing loss of bromoalkanes from Carboxen/Carbopack samplers with increasing desorption temperature has been observed (Shirey et al., 1991). A loss of pentanal from charcoal passive samplers which increased with storage time before analysis has also been reported (De Bortoli et al., 1986).

5.5 SAMPLING OF POLAR COMPOUNDS

Tenax and Carbotrap are usually assumed to perform well for sampling unpolar compounds but to be less or not appropriate for sampling polar compounds. However, only little work has been reported on the sampling of polar compounds with Tenax and Carbotrap. From the work reported by Rothweiler et al. (1991) it appears that at comparable boiling points, polar hydrophilic compounds such as acetonitrile, diethylamine, acetic acid, tetrahydrofuran, 1,2-ethanediol, and mercaptoethanol have considerably smaller retention volumes than unpolar compounds. To a smaller degree such an effect can also be observed for polar lipophilic compounds such as chlorobenzene (Health and Safety Executive, 1991).

Irregular responses of polar hydrophilic compounds such as methoxy- and ethoxyethanol observed in the author's laboratory when analyzing Tenax tubes could be attributed to the interference of water with the HRGC separation on an apolar column (OV-1). Perfect results were obtained when a Carbowax column was used instead.

The limited available experience shows that more work is needed in order to evalute the usefulness of sorbent sampling and thermal elution for the analysis of polar and in particular of hydrophilic compounds.

6. Grab or Whole Air Sampling

Grab or whole air sampling is mostly used for the analysing VVOC. Whole air samples are collected in stainless steel canisters with highly polished inner walls to prevent adsorption of impurities and degradation of collected compounds (Oliver et al., 1986). Canister volumes range from about 1 ℓ to 6 ℓ.

Sampling is carried out either by allowing the sample to enter a pre-evacuated canister or by pressurizing the canister. The first method is preferred for instantaneous sampling whereas pressurized sampling is normally used when long-term integrated samples or higher volume samples are required. In order to pressurize canisters a compression pump has to be used. Since the sample air passes through the pump it is important that the pump does not introduce impurities or absorb VOC. Schmidbauer and Oehme (1988) used successfully a metal-bellow pump with a teflon-covered viton diaphragm (Metal-Bellow Corp. M41, Sharon, MA, U.S.A.) for sampling low molecular weight hydrocarbons. Introducing a flow restrictor between pump and canister allows to adjust the sample integration time.

Samples are recovered for analysis by passing an appropriate sample volume through a cryogenic trap where the organic compounds are efficiently collected whereas the main components of air are not retained (McLenny et al. 1984). After cryofocussing, the sample is thermally desorbed onto a high resolution gas chromatograph.

Canisters are cleaned by repeatedly filling them with clean air and emptying them. Schmidbauer and Oehme (1988) propose a vacuum cleaning procedure for heaviliy contaminated canisters which provides for blanks free of any traces of C_2-C_8 hydrocarbons.

The major advantages of the canister technique are that contamination problems are reduced, a wide range of nonpolar compounds can be characterized, and consistent recoveries are generally obtained. Oliver et al. (1986) have shown that unpolar VOC can be stored in the canisters for up to 30 days without significant losses.

However, the co-collection of water vapour can cause clogging of the cryogenic trap during cryofocussing. A perfluorinated ionomer membrane (Nafion) tube (McLenny et al., 1984) and a drying tube filled with potassium carbonate (Schmidbauer and Oehme, 1988) in front of the cryogenic trap have been used in order to eliminate water. Whereas these approaches gave satisfactory results for the analysis of C_2-C_6 hydrocarbons even at ppt level, polar compounds or less volatile hydrocarbons may be partially retained on the drying tube.

To date, insufficient experience is available on the stability of polar compounds in canister samples. The method is not appropriate for the collection of personal samples. Therefore, and in view of the results of Spicer (1986) showing good agreement of Tenax and canister sampling in indoor air applications, it appears that canister sampling has more advantages for outdoor than for indoor air analysis.

7. References

De Bortoli, M., Mølhave, L., Thorsen, M. A., and Ullrich, D. (1986). 'European interlaboratory comparison of passive samplers for organic vapour monitoring in indoor air', Report nr. EUR 10487 EN, Commission of the European Communities, Luxembourg.

De Bortoli, M., Knöppel H., Pecchio, E., and Vissers, H. (1989). 'Performance of a thermally desorbable diffusion sampler for personal and indoor air monitoring', Environ. Int. 15, 427-434.

De Bortoli, M., and Colombo, A. (1992). 'Characterization of organic emissions from indoor sources', this volume, pp.

Health and Safety Executive, (1991). 'Methods for the determination of hazardous substances: Volatile organic compounds in air; Laboratory method using pumped solid sorbent tubes, thermal desorption and gas chromatography', MDHS 72, HSE, London.

Knöppel, H. (1982). 'Mass spectrometry in environmental organic analysis', Europ. Spetroscopy News 40, 29-34.

Knöppel, H., and De Bortoli, M. (1992). 'Organic indoor pollution and complaints on indoor air quality', in G. Abritti and G. Muzi (eds.), Indoor Air Quality and Health, Monduzzi Editore, Bologna, pp. 181-189.

Lewis, R. G., Mulik, J. D., Coutant, R. W., Wooten, G. W., and McMillin, C. R. (1985). 'Thermally desorbable passive sampling device for volatile organic chemicals in ambient air', Anal. Chem. 57, 214-219.

Matthews, T. G., Thompson, C. V., Wilson, D. L., and Hawthorne, A. R. (1989). 'Air velocities inside domestic environments: an important parameter in the study of indoor air quality and climate', Environ. Int. 15, 545-550.

McLenny, W. A., Pleil, J. D., Holdren, M. W., and Smith, R. N., 1984. 'Automated cryogenic preconcentration and gas chromatographic determination of volatile organic compounds in air', Anal. Chem. 56, 2947-2951.

Namieśnik, J. (1988). 'Preconcentration of gaseous organic pollutants in the atmosphere', Talanta 35, 567-587.

Oliver, K. D., Pleil, J. D., and McClenny, W. A. (1986). 'Sample integrity of trace level volatile organic compounds in ambient air stored in SUMMA® polished canisters', Atmos. Environ. 20, 1403-1411.

Pellizzari, E. D., Demian, B., and Krost, K. J. (1984). 'Sampling of organic compounds in the presence of reactive inorganic gases with Tenax-GC', Analy. Chem. 56, 793-798.

Pellizzari, E. D., and Krost, K. J. (1984). 'Chemical transformations during ambient air sampling for organic vapors', Anal. Chem. 56, 1813-1819.

Rothweiler, H., Wäger, P. A., and Schlatter, C. (1991). 'Comparison of Tenax TA and Carbotrap for sampling and analysis of volatile organic compounds in air', Atmos. Environ. 25B, 231-235.

Schlitt, H., Knöppel, H., Versino, B., Peil, A., Schauenburg, H., and Vissers, H. (1980). 'Organics in air: sampling and identification', in Sampling and Analysis of Toxic Organics in the Atmosphere, American Society for Testing and Materials, Philadelphia, Pa., pp. 22-35.

Schmidbauer, N., and Oehme, M. (1988). 'Comparison of solid adsorbent and stainless steel canister sampling for very low ppt-concentrations of aromatic compounds ($\geq C_6$) in Ambient Air from Remote Areas', Fres. Z. Analy. Chem. 331, 14-19.

Seifert, B. (1992). 'Organic indoor pollutants: sources, species, and concentrations', this volume

Shirey, R. E., Hazard, S., and Cole, S. B. (1991). 'A systematic comparison of trap adsorbents for analyses of volatile organics in drinking water and wastewater', Pittsburgh Conference.

Spicer, C. W. (1986). 'Intercomparison of sampling techniques for toxic organic compounds in indoor air', in Proc. of the EPA/APCA Symposium on Measurement of Toxic Air Pollutants, EPA Report No. 600/9-86-013, pp. 45-60.

Walling, J. F. (1984). 'The utility of distributed air volume sets when sampling ambient air using solid sorbents', Atmos. Environ. 18, 855-859.

Walling, J. F., Bumgarner, J. E., Driscoll, D. J., Morris, C. M., Riley, A. E., and Wright, L. H. (1986). 'Apparent reaction products desorbed from tenax used to sample ambient air', Atmos. Environ. 20, 51-57.

World Health Organization. (1989). 'Indoor air quality: organic pollutants', EURO Reports and Studies No. 111, WHO, Regional Office for Europe, Copenhagen.

CHARACTERIZATION OF ORGANIC EMISSIONS FROM INDOOR SOURCES

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ABSTRACT. Following a short survey of the sources of organic compounds which exist in the indoor environment, this paper describes instruments and methods for the characterization of their emissions. With the aim of obtaining consistent results in different laboratories, it also suggests the use of recently issued guidelines and practical ways of data quality control.

1. Introduction

The investigations carried out in recent years on the pollution of indoor air (dwellings, offices, schools, etc.) have shown the presence of hundreds of organic compounds, including several irritating and toxic ones (e.g., formaldehyde and other aldehydes, benzene, etc.) [1]. Further research allowed for the identification of the materials or activities emitting certain compounds; we now have the knowledge and means of measuring qualitatively and (although some uncertainties still exist) quantitatively, the emissions of the majority of the organic vapours coming from the above mentioned sources.

This paper is an outline of the concepts and instruments developed for the above mentioned aim.

2. Sources

The sources we are dealing with are a variety of objects and activities which may be grouped according to different criteria, their importance depending on the context.

One criterion is the use of the material: e.g., construction or furnishing, cleaning, office work, do-it- yourself, etc.; a second criterion is the emission-time pattern: continuous or intermittent, constant (or very slowly decreasing) or rapidly decreasing; a third criterion which is very important when dealing with models, is the emission mechanism, i.e., surface evaporation, diffusion through a thick layer, decomposition (e.g., of a polymer, like those releasing formaldehyde). As pointed out before, there are sources emitting continuously, independent of any other activity, such as a wood panel and then there are sources emitting only when used, like a cigarette or a photocopying machine.

Frequently sources are complicated or composited (e.g., a wood panel consisting of wood particles bound with a glue may have a finishing coat of paint or something else; a carpet may be fixed to the floor with an adhesive). A further complicating factor is the phenomenon of surface sorption through which organic vapours may be sorbed from the

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air onto walls, carpets, etc. and successively released. This fact, highlighted through a few recent investigations [2, 3], results in a smoothing of concentration peaks but also in bringing about a longer persistence of sorbed pollutants in the air.

3. Source Characterization

In order to characterize a source, it must be isolated from other sources or potential sources. This operation is accomplished through environmental test chambers, containers where the principal environmental conditions can be reproduced. Once the source is in the chamber, the chamber air must be analyzed in order to identify and possibly quantify the vapours emitted. Finally, the results of the quantitative analysis may be used as input for a model which will yield figures describing the emission.

Let us go through these three steps of chambers, analyses and models.

3.1. CHAMBERS

The word "chamber" may designate a great variety of devices, with sizes (internal volume) extending over six orders of magnitudes, namely 50 cm^3 to 50 m^3. However, most source characterization work is carried out using "small" test chambers, i.e., chambers of capacity ≤ 1 m^3. For instance, the 25 chambers used by the participants in the International Chamber Comparison Experiment, organized by our Institute in 1991 and briefly described later, have capacities ranging from 4 liters to 1.47 m^3.

The materials used in the construction of the chambers are mainly stainless steel (3/4 of the chambers above) and glass (1/4). An essential requirement is that the walls be smooth and chemically inert: therefore stainless steel walls are normally electropolished. Despite all precautions even chambers that appear "perfect" give, to a certain extent, a "*sink*" effect, i.e., some vapours (especially for the higher boiling compounds) "plate out" on the walls and are entirely released only when the source is removed from the chamber or is exhausted (this is qualitatively identical with the sorption effect mentioned above). Chamber sink effect is dealt with more extensively further on.

The chamber, in order to control and measure some environmental parameters, is equipped with suitable devices. Controlling of the following parameters is essential: temperature (±0.5-1°C), air flow rate (±1-2%), relative humidity (±5-10%). Though not usually controlled in a straightforward way, effective mixing inside the chamber must be assured. The air velocity on the surface of the source may also be very important because if it is too low the emission rate of the source could be reduced. Usually a value of roughly 0.3 m s^{-1} is considered sufficient to avoid this effect and a device to measure it, at least occasionally, should be available.

The matter of air velocity brings us onto a broader topic which has the potential of being misunderstood. The pollutant "concentrations observed in the chambers should not be used as substitute for concentrations expected in full-scale indoor environments because, even if product loading (i.e., area of source/chamber volume) and air exchange rate (i.e., air flowrate/chamber volume) can be given realistic values, the (sorption) effect of walls, floor, ceiling and furniture is not given in the test chamber" [4]. In fact, the conditions needed in test chambers should be those which enable one to obtain accurate and reproducible experimental results: as far as surface air velocity is concerned, this requires values higher than those occurring in indoor environments, at least for some materials.

A similar problem arises with fluid (liquid or paste) sources which have to be spread onto a solid support: the emission rate also depends on the nature of this support

and hence a "neutral" support, like stainless steel or glass, should be adopted for chamber testing.

A final feature of test chambers worth mentioning here is the possibility of generating known concentrations of vapours inside the chamber, in order to check the correct operation of the whole procedure. This is normally obtained through permeation or diffusion devices, whose emission rate is determined by weighing and hence is known with a high degree of accuracy.

An example chamber test facility is given in Figure 1.

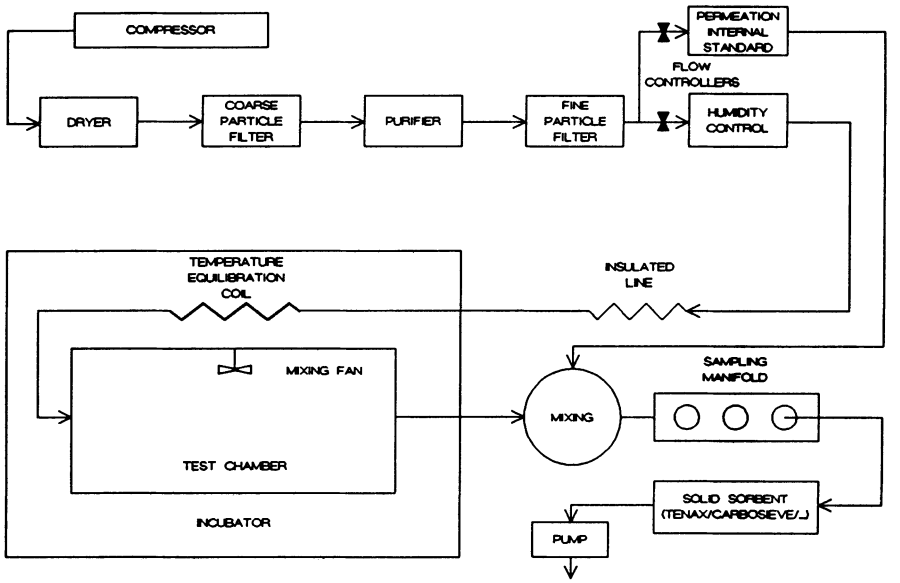

Figure 1. Schematic diagram of an example of a small chamber test facility.

3.2. ANALYSIS

This topic, including sampling, is dealt with thoroughly in another contribution to this course [5] and hence only a few comments have to be made here. In fact, the same instruments and procedures used for surveys in buildings are valid for concentration determination in chambers. They basically consist of sampling cartridges with solid adsorbents and instruments for carrying out gas or liquid chromatography and mass spectrometry.

One aspect particular to chamber investigations is the time scale of sampling: integrating samplers are of no interest if the time profile of emission is to be observed.

The characterization of the vapours emitted from a source may be very easy if only a few compounds are emitted but may become a heavy task if the emission is complex. In this case the question rises of how many of the compounds observed should be identified and quantified, also taking the cost of such work into consideration. One approach is to determine the more prominent compounds (e.g., the first 5 or 10) but, in view of the great

differences in toxicity of compounds, it may happen that a minor compound is more important from a toxicological viewpoint than a major one. There are no general solutions to this problem. A global parameter usually reported in experimental results is "total volatile organic compounds" (TVOC), which is obtained by converting the sum of all the gas chromatographic peaks into a concentration, using the response factor of a single compound (generally toluene). Despite the many criticisms on this parameter, it has the advantage of giving an indication of the emission which is both easily obtainable and synthetic.

3.3. MODELS

We may identify three levels of models of increasing complexity.

The first level, involving only simple hand calculations, may require one single measurement if the source is emitting constantly and the equilibrium concentration has been attained. In this case, multiplying the concentration (mg m^{-3}) by the air flowrate through the chamber (m^3 h^{-1}) yields the emission rate (mg h^{-1}). The procedure is repeated for all the compounds of interest. If the source has a decreasing emission rate no equilibrium concentration will be attained and several measurements are required for minimum knowledge of the phenomenon. Figure 2 shows an example of concentration-time profile obtained from a decreasing source, a sample of spray cleanser for carpets. In such cases the amount of a pollutant emitted in each time interval (mg) can be derived by calculating the area of each trapezoid (mg h m^{-3}) defined by two consecutive measurements and multiplying it by the air flowrate (m^3 h^{-1}). Also the total amount emitted as well as the mean emission rate are easily obtained.

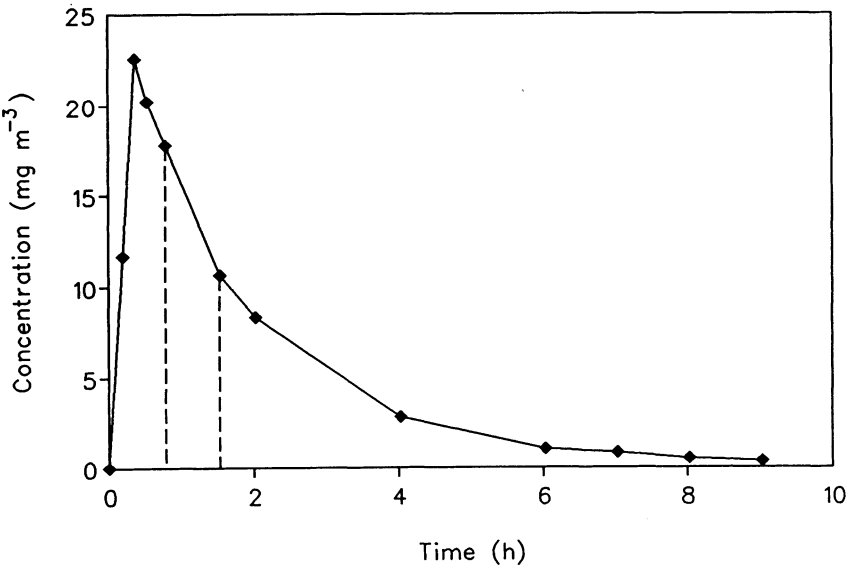

Figure 2. Concentration - time profile of 1-methoxy-2-propanol from a spray cleanser for carpets

A more complex approach may be based on an *empirical model* and requires a personal computer and some skill, which nevertheless is quickly attainable. The model described below simply relies on the mathematical properties of the exponential. It does not depend on the type of source being tested and has been successfully fitted to concentration data obtained from a variety of emission processes and materials. That is, to data which starting from zero increase with time reaching an asymptotic equilibrium value or to data which pass through a maximum and then decline towards zero or some equilibrium value [4, 6, 7].

The time dependence of the concentration of a compound in the chamber is described by the double exponential equation:

$$c = a\,[1 - \exp(-k_1 t)] - b\,[1 - \exp(-k_2 t)]$$

where c (mg m^{-3}) and t (h) indicate concentration and time, a and b (mg m^{-3}) are the linear parameters and k_1 and k_2 (h^{-1}) the rate parameters of the equation. The four empirical constants a, b, k_1, k_2 can be obtained through a non-linear least square regression routine implemented on a personal computer. By differentiation or integration and taking air flowrate and chamber volume into account, this model can yield emission rates as well as chamber mass balances at any time. However, because it does not explicitly rely on physical effects, it can reasonably describe but not entirely interpret, the experimental data. Figure 3 is an example of data treated with this model.

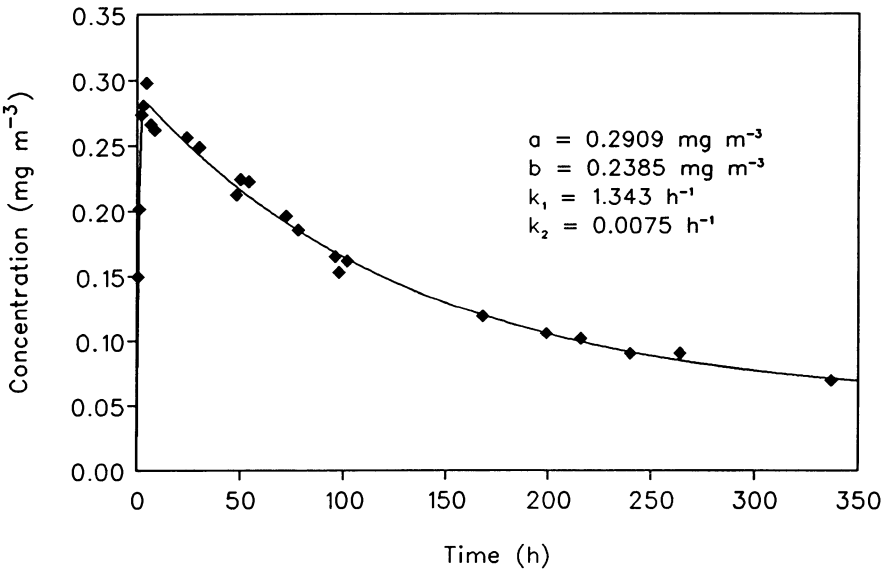

Figure 3. Empirical concentration curve of longifolene from particle board

The third more complex type of model, the *physical model*, attempts to take the fundamental mass transfer processes involved in the emission phenomenon into account. The physical model described below in principle applies to thin film sources, i.e., sources the emission of which may be considered as a pure surface phenomenon (e.g., household

products spread on inert supports). It may be extended to bulk sources if these behave as a thin film from the emission standpoint (e.g., a cake of moth crystal, under certain experimental onditions).

This model considers both the effects of chamber concentration on evaporative mass transfer and of sorption and re-emission from sinks [8].The somewhat complex analytical equation (not reported here) which expresses the concentration of a compound as a function of time originates from the solution of a set of ordinary differential equations which, taking the above mentioned effects into account, describe the compound mass balance in the chamber over a small time increment dt. As based on equation parameters of a physical meaning, this model is more informative than the empirical one. Its implementation, however, requires sophisticated non-linear regression tools and data analysis experience that are not generally available.

4. Guidelines

The results obtained from source characterization in test chambers must be comparable, in order to be useful in the reduction of indoor air pollution, through, e.g., selection of less emitting materials for construction, furnishing, etc. Obtaining comparable results demands that people carrying out source characterization adopt the same experimental conditions, at least in so far as such conditions influence the results. For example Tichenor and Guo [9] have recently shown the pronounced effect of the chamber air flowrate and of the loading factor on the emission rate of a wood stain. Three guidelines, contributing towards this, have been recently issued:

1) "Guideline for the characterization of volatile organic compounds emitted from indoor materials and products using small test chambers" [4].

2) "Formaldehyde emissions from wood based materials: guideline for the establishment of steady state concentrations in test chambers" [10] both by the European Concerted Action "Indoor Air Quality and Its Impact on Man", and

3) "Standard guide for small-scale environmental chamber determinations of organic emissions from indoor materials/products" [11] by the American Society for Testing and Materials.

This paper owes much to them.

An important aspect of normalization is data reporting: in particular which parameters are to be reported to consider a source characterized? This topic assumes great importance when data bases for sources, i.e., containing data on emission from various materials, become available for use. We are currently approaching this as the US Environmental Protection Agency has prepared a prototype of such a database and similar initiatives are ongoing in Europe.One of the guidelines cited gives a recommendation on which results to report to characterize a source: "for predominant compounds, additional compounds and TVOC report: a) emission factor at time zero (i.e., at introduction into the chamber); b) time needed to attain 1/2 of a); c) time needed to attain 1/100 of a); d) time of last sampling; e) emission factor at last sampling. In addition, report fraction identified and quantified of TVOC." [4].

5. Quality Control: Sinks, Interlaboratory Comparison

The system we have outlined above, composed of a test chamber, an analytical sub-system and a model for the treatment of the data, is rather a complex one, where quality control may become a challenge.

5.1. SINKS

We have already mentioned the possibility of checking the correct operation of the chamber by producing in it known concentrations of certain compounds. In fact, this is the tool for an overall quality control of the system, because it enables us to compare, on one side, the concentration of the test compound measured in the chamber through sampling and analysis and, on the other side, the expected concentration on the basis of the weight loss of the permeation or diffusion device and of the air flowrate through the chamber. If the two concentrations are in good agreement, the system may be considered as working correctly for the compound tested. The complication arises that the procedure should be repeated for each compound of interest. A simpler solution, however, is possible: it consists in the fact that if one compound (e.g., dodecane) has been tested, we may reasonably consider that other compounds of the same chemical class (alkanes, in the example) should behave similarly in the system. This solution, however, bears a warning: compounds of the same class but with remarkably different boiling point may behave differently due to differences in their sink effect, this effect being in general more pronounced for the highest boiling compounds.

How can the presence of a sink in a well mixed chamber be detected? The sink may be reversible (as described above) or, more seldom, irreversible, i.e., the sorbed compound is no longer released.

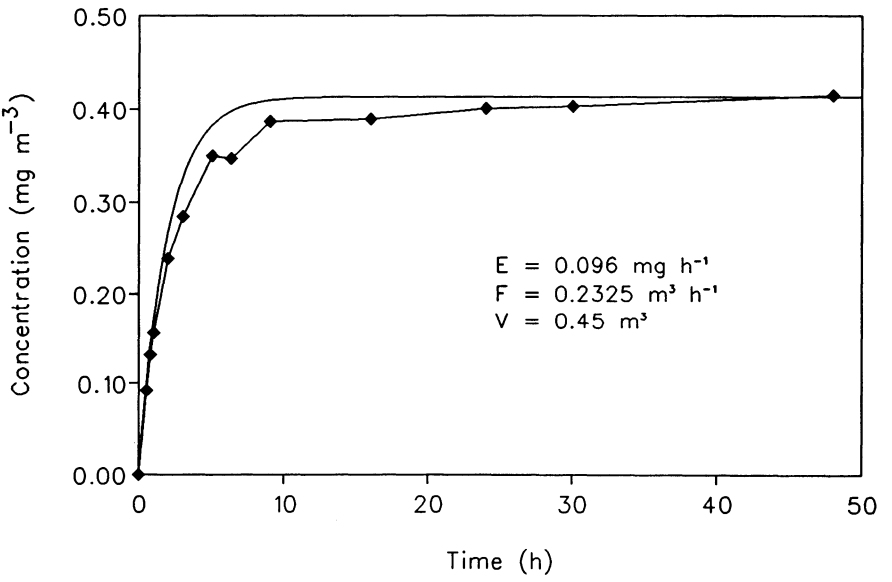

Figure 4a. Chamber sink effect of n-dodecane in the rising curve case (the upper curve is the theoretical one)

In an experiment with a suitable permeation or diffusion device where the weight loss rate of the compound being tested is E (mg h^{-1}), its concentration rising curve is theoretically described by

$$c = E/F\,[1 - \exp(-Ft/V)]$$

where c (mg m^{-3}), t (h) have the usual meaning and F (m^3 h^{-1}), V (m^3) are the chamber air flowrate and volume, respectively, the ratio E/F representing the concentration which one should achieve in the chamber at equilibrium. A reversible sink flattens the rising curve so that the theoretical equilibrium condition is approximated in a time which is longer than expected (Fig. 4a). An irreversible sink does not in any way allow us to attain the above condition and the curve levels off at a concentration value lower than expected.

Similarly, if a source is removed and there is an initial concentration c_o (mg m^{-3}) in the chamber, we may theoretically expect the concentration to decay as per the following equation:

$$c = c_o \exp(-Ft/V)$$

A reversible sink would show up with a delay in attaining the zero concentration as compared to theory (Fig. 4b). A really irreversible sink, however, will yield to decay faster than expected.

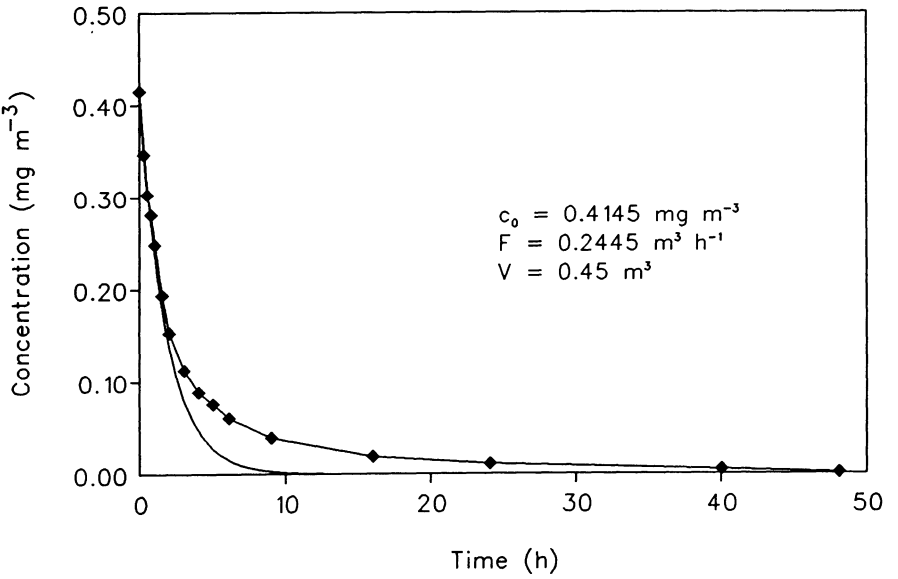

Figure 4b. Chamber sink effect of n-dodecane in the decay curve case (the lower curve is the theoretical one)

Figures 4a and 4b are a typical representation of the above for reversible sinks. One should bear in mind that whereas a chamber air leak is included in the air flowrate value, provided the latter is measured at the chamber inlet and hence causes no problems, it acts as an irreversible sink as long as the flowrate is measured at the outlet.

5.2. INTERLABORATORY COMPARISON

One of the most effective ways to detect errors in an analytical system is comparing the results obtained by different laboratories on the same material. In order to obtain an assessment of the agreement by different laboratories on source characterization through small chambers and also to test practically the Guideline mentioned above [4], in 1991 the Environment Institute at the JRC Ispra organized an International Chamber Comparison Experiment. In all, 22 laboratories (25 chambers) in Europe and in the USA participated. The experiment included three steps of increasing complexity, requiring the determination of the emission rate:

1) of a single compound source (n-dodecane) whose emission rate could also be determined by weighing (constant source)
2) of the four main compounds and TVOC emitted from a PVC tile sample (slowly decreasing source)
3) of four compounds and TVOC emitted from a wax sample (rapidly decreasing source). This third step requested several measurements and employing a model.

At the moment of writing this text, only the results of the first step are available from most laboratories. They show that agreement between the emission rate expected from weight loss and that mesured from concentration is within 25% for 8 out of 16 laboratories, between 25 and 50% for 6 laboratories and greater than 50% for 2 laboratories. The discrepancies, except for two laboratories, are all negative, i.e., the emission rate determined from the measured concentration is less than the emission rate expected on the basis of the weight loss. A reasonable explanation for this discrepancy has still to be found; among the possible hypotheses, that of heavy sinks cannot be ruled out and should be investigated.

6. References

1. Berglund B., Berglund U. and Lindvall T. (1986) "Assessment of discomfort and irritation from the indoor air", in Proceedings from AIQ '86 "Managing Indoor Air for Health and Energy Conservation", Atlanta (GA), American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE), pp. 138-149

2. Seifert B. and Schmahl H.S. (1987) "Quantification of sorption effects for selected organic substances present in indoor air", in Proceedings of the 4th Intern. Conf. on Indoor Air Quality and Climate, Indoor Air '87, Berlin, Vol.1, pp. 252-256

3. Tichenor B.A., Guo Z., Dunn J.E., Sparks L.E. and Mason M.A. (1991) "The interaction of vapour phase organic compounds with indoor sinks", Indoor Air 1, 23-35

4. Commission of the European Communities (1991) "Guideline for the characterization of volatile organic compounds emitted from indoor materials and products using small test chambers", Report EUR 13593 EN

5. Knöppel H. (1992) "Sampling and analysis of organic indoor air pollutants", this volume

6. Colombo A., De Bortoli M., Pecchio E., Schauenburg H., Schlitt H. and Vissers H. (1990) "Chamber testing of organic emission from building and furnishing materials", The Science of the Total Environment 91, 237- 249

7. Colombo A., De Bortoli M.,.Knöppel H., Schauenburg H., and Vissers H. (1991) "Small chamber tests and headspace analysis of volatile organic compounds emitted from houshold products", Indoor Air 1, 13-21

8. Dunn J.E. and Tichenor B.A. (1988) "Compensating for sink effects in emission test chambers by mathematical modeling", Atmospheric Environment 22, 885-894

9. Tichenor B.A. and Guo Z. (1991) "The effect of ventilation on emission rates of wood finishing materials", Environment International 17, 317-323

10. Commission of the European Communities (1989) "Formaldehyde emissions from wood based materials: guideline for the establishment of steady state concentrations in test chambers" Report EUR12196 EN

11. American Society for Testing and Materials (1990) "Standard guide for small-scale environmental chamber determinations of organic emissions from indoor materials/products", ASTM D 5116-90

SENSORY CHARACTERIZATION OF AIR QUALITY AND POLLUTION SOURCES

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ABSTRACT. The present paper maintains that the principal reason for the complaints of poor indoor air quality in many buildings are superfluous, hitherto neglected pollution sources. The sensory sources are quantified by the olf unit while perceived air quality is expressed by the decipol unit. Methods to identify and measure the hidden sensory pollution sources in a building are presented. A practical strategy to improve the perceived air quality in a building by reducing the superfluous pollution sources is outlined.

INTRODUCTION

Visiting a "sick building" is often a frustrating experience for the professional. He may analyze the indoor air chemically and will typically find that all concentrations of components are way below any existing limits. He may measure the ventilation rate and find that it is well above that which is required in any existing ventilation standard. Still 20%, 40%, or 60% of the occupants may complain of stale, stuffy, and irritating air. What is the matter with the building? What can the professional do? It seems to be an effect without a cause reported in thousands of buildings in Europe, Japan and North America (1-12). The present paper maintains that hidden, superfluous and hitherto neglected pollution sources are the principal reason for the complaints of bad air. The sensory pollution sources can be quantified by the olf unit and the perceived air quality by the decipol unit (13). To cure a sick building, it is essential that the hidden pollution sources be identified and removed. Recommendations on how this is done in practice are given.

AIR QUALITY

Many people think that air quality is merely a list of the components of the air. They tend to forget the most important point, namely the impact of the air on the occupants in the building. I suggest that the same definition of quality, common in other fields, be applied to air quality: quality is the extent to which human requirements are met. If people are satisfied with the air, it is high quality, if they are dissatisfied, it is poor quality. It is the customers

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breathing the air who should judge whether or not the air provided is good.

But is it not possible to predict how air will be perceived from its composition? This method works well in industry where specific chemicals are involved in the production. Concentrations of these chemicals in the air are measured and compared to threshold limit values. Unfortunately, this method does not work in nonindustrial buildings. In such places there will typically be thousands of chemicals in the air, but in low concentrations, perhaps a thousand times lower than existing limits. Judged one by one, all chemicals would be acquitted. There are usually no scapegoats present. But still the combined effect of the thousands of pollutants may make the air irritating, stale, and stuffy.

Air is perceived by two senses. The general chemical sense is situated all over the mucous membrane of the nose and it is sensitive to more than one hundred thousand chemicals (irritants). The olfactory sense is situated in a small area of the nasal cavity and is sensitive to around half a million chemical compounds. With these two senses, air is judged to be fresh and pleasant or irritating, stale, and stuffy. It is normally the perception that causes people to complain. How about health? Do people get sick when they occupy sick buildings? No, the risk of disease is usually low in nonindustrial buildings. The dominating reason why people complain is irritation and discomfort.

Unfortunately, information on the chemical composition does not allow one to predict how the air will be perceived. It is too complicated. An obvious analogy is food and taste. Chemical analysis is insufficient to predict whether food will taste good or bad. Ventilation engineers well know that chemistry is a poor predictor of air quality. Consequently, chemistry has rarely been involved in the design of nonindustrial buildings or in ventilation standards.

WHAT IS WRONG?

Yaglou et al. (16) knew already in 1936 that ventilation standards for nonindustrial buildings could not be based on chemistry. He was a professor of occupational hygiene at Harvard University when he performed his classic studies on ventilation requirements. He did not, and could not, analyze chemically the thousands of bioeffluents emitted from the human body. Pragmatically, he determined the ventilation rate required per person to make the air acceptable to a panel of judges. Later he did the same thing for tobacco smoking. Yaglou's research results have since been used in standards in many countries.

Why does the ventilation rate prescribed by Yaglou and the standards existing today no longer ensure good air quality? Because they assume implicitly that humans are the only indoor polluters. They assume that building materials, furniture, and ventilation systems do not pollute. This may have been a reasonable assumption 50 years ago when traditional materials such as bricks, wood, and steel were dominant. But with all the new materials used in modern buildings, this is certainly no longer the case. All materials pollute, some a little, some a lot, but they all contribute to a deterioration of the air quality.

The olf unit (13), introduced a few years ago, makes it possible for the first time to measure all sensory pollution sources by the same yardstick.

THE olf UNIT

One olf (from Latin "olfactus" = olfactory sense) is the emission rate of air pollutants (bioeffluents) from a standard person (Figure 1) (13). Any other pollution source is expressed by the number of standard persons (olfs) required to cause the same dissatisfaction as the actual pollution source (Figure 2).

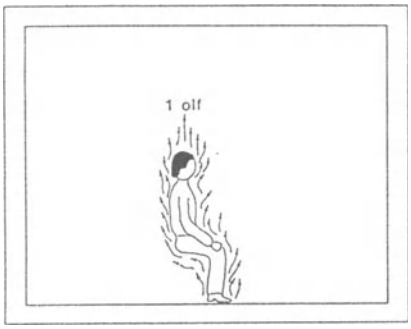

Figure 1 One olf is the air pollution from one standard person, i.e. from an average adult working in an office or a similar nonindustrial work place, sedentary and in thermal comfort with a hygienic standard equivalent of 0.7 bath/day.

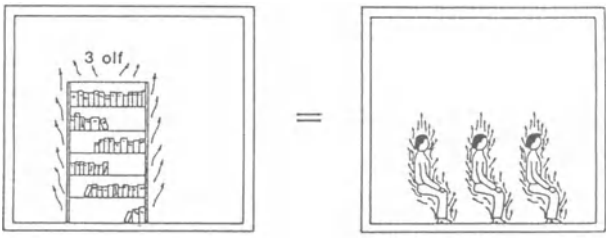

Figure 2 A pollution source has a strength of 3 olf if the pollution from 3 standard persons causes the same dissatisfaction as the source.

The pollution from a human being was chosen as the reference because it is well known and because considerable data are available as to how bioeffluents are perceived by other human beings. Recent data on the impact of bioeffluents are given in Figure 3 which shows how air polluted by one standard person (one olf) is perceived at different ventilation rates. The figure identifies the percentage of dissatisfied, i.e. those who perceive the air as unacceptable just after entering the room. The curve is based on bioeffluents from over 1000 subjects judged by 168 men and women. One standard person is an average adult who works in an office or in a similar nonindustrial workplace, sedentary and in thermal comfort. Table 1 lists the sensory pollution load caused by other occupants with different activities and ages and with different percentages of smokers present.

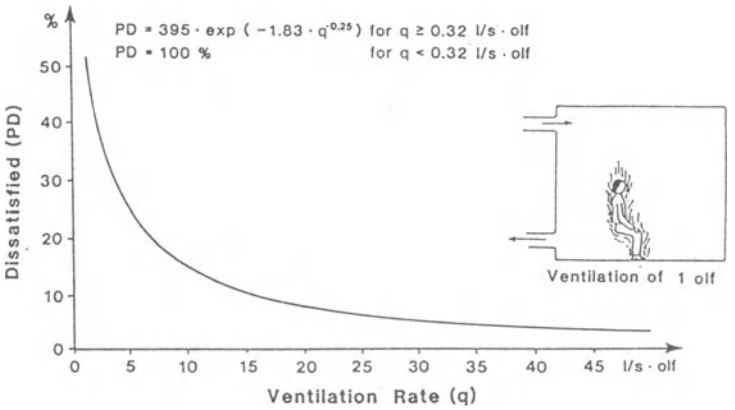

Figure 3 Dissatisfaction caused by one olf at different ventilation rates. The dissatisfied are the persons who, when entering the space, find the air unacceptable. The curve is based on bioeffluents from more than 1000 persons judged by 168 subjects (13).

Table 1 Pollution load caused by occupants

	sensory pollution load olf/occupant	carbon dioxide l/(h · occupant)	carbon monoxide** l/(h · occupant)
*Sedentary, 1-1.2 met**			
0% smokers	1	19	
20% smokers***	2	19	$11 \cdot 10^{-3}$
40% smokers***	3	19	$21 \cdot 10^{-3}$
100% smokers***	6	19	$53 \cdot 10^{-3}$
Physical exercise			
Low level, 3 met	4	50	
Medium level, 6 met	10	100	
High level (athletes), 10 met	20	170	
Children			
Kindergarten, 3-6 years, 2,7 met	1.2	18	
School, 14-16 years, 1-1.2 met	1.3	19	

* 1 met is the metabolic rate of a resting sedentary person (1 met = 58W/m² skin area, i.e. approx. W for an average person).
** from tobacco smoking
*** average smoking rate 1.2 cigarettes/hour per smoker, emission rate 44 ml CO/cigarette

THE decipol UNIT

The concentration of air pollution depends on the pollution source and the dilution caused by ventilation. The perceived air pollution is defined as that concentration of human bioeffluents which would cause the same dissatisfaction as the actual air pollution (13). One

decipol (pol from Latin "pollutio" = pollution) is the pollution caused by one standard person (1 olf) ventilated by 10 l/s of unpolluted air (Figure 4). That is,

$$1 \text{ decipol} = 0.1 \text{ olf/(l/s)}$$

Figure 5 shows the percentage of dissatisfied as a function of the perceived air quality in decipol. Figure 5 is derived from the same data as Figure 3.

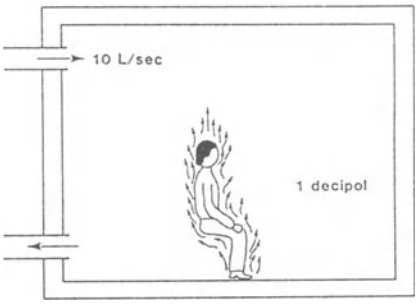

Figure 4 One decipol is the perceived air pollution in a space with a pollution source of 1 olf ventilated by 10 l/s of unpolluted air. Steady-state conditions and complete mixing are assumed.

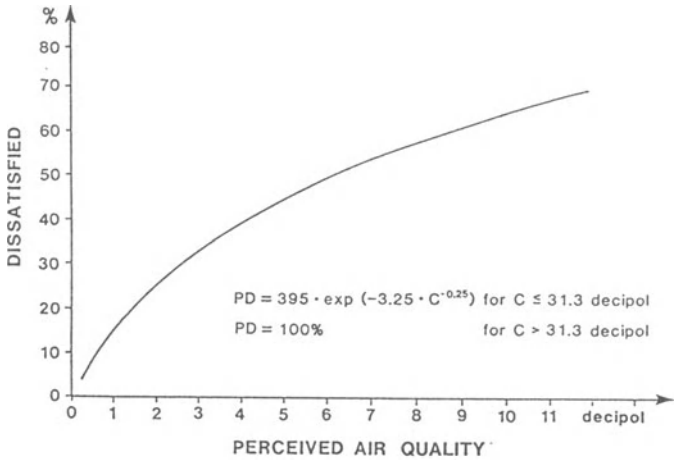

Figure 5 Percentage of dissatisfied as a function of the perceived air pollution in decipol.

In many well-ventilated buildings with low pollution sources the perceived air quality is around 1-2 decipol or 20% dissatisfied ("healthy" buildings). Spaces with a low ventilation rate and extensive pollution sources may easily have a perceived air quality of around 10 decipol or 60% dissatisfied. An air quality below 0.5 decipol or 10% dissatisfied is rather hard to establish in indoor environments. Figure 6 shows the decipol scale and indicates typical levels of perceived air quality.

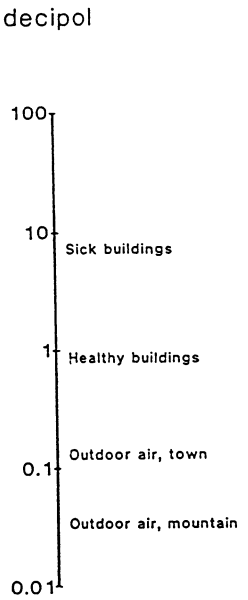

Figure 6 The decipol scale for perceived air quality with typical examples shown.

ANALOGY TO LIGHT AND NOISE UNITS

The two new sensory units for air quality, the olf and the decipol, correspond to analogous sensory units for light and noise.

As listed in Figure 7, the olf corresponds to lumen for light. Lumen is the unit for light emitted from a source. Only electromagnetic radiation sensitive to the human eye is considered, i.e. with wave lengths between 380 and 720 nm. Within this range the impact of the different wave lengths is weighted according to the sensitivity of the eye. For noise the source strength is given by the sound power measured in watt. Only power sensitive to the human ear is considered, i.e. with frequencies between 20 and 20 000 hertz (Hz). In a similar way the olf unit integrates the emitted pollutants according to their impact on the human nose and the perceived annoyance.

Sensory Units

	Light	Noise	Air Quality
Source Strenght	lumen	watt	olf
Perceived Quality	lux	decibel (A)	decipol

Figure 7 Comparison between the new sensory units for perceived air quality and analogous units for light and noise.

The decipol expresses the air quality perceived by the nose like the lux expresses the light perceived by the eye and the decibel(A) expresses the sound perceived by the ear. Both lux and decibel express the perceived level independent of the annoyance. A given dB(A) may for example be caused by traffic or by chamber music. Here there is a deviation in relation to decipol; defining the decipol by the annoyance rather than by the perceived level or intensity was found to be more usefull. A decipol level expresses a constant annoyance, i.e. a constant percentage of dissatisfied, independent of the type of air pollution.

In the beginning, light and noise could only be measured using man as a meter. Later, instruments were developed with built-in information about the sensitivity of the eye and the ear depending on the wave length. Similarly, at the moment olf and decipol can be measured only by using man as the meter. This means using a panel of judges.

HEALTH RISK

It should be emphasized that the decipol level expresses how the air is perceived by humans, not whether the pollution is a health risk. Any such risk should be considered separately. Still, peoples' senses - with a few exceptions - are also influenced by many harmful pollutants. The senses have an important warning function against dangers in the environment. Therefore the perceived air quality in decipol may in many cases also provide a first indication of a possible health risk.

MEASUREMENT OF PERCEIVED AIR QUALITY AND SENSORY POLLUTION SOURCES

An instrument is not yet available which can measure directly the perceived air quality in percent dissatisfied or in decipol. And, unfortunately, one cannot predict the perceived air quality from an analysis of the thousands of chemicals typically occurring in indoor air. Today the only proper way is to use panels of people to judge the air quality. An obvious analogy is perceived food quality. Chemistry is usually inadequate for predicting how food tastes and for years panels have therefore been used systematically in food science and industry to judge the quality of food.

Panels have also been used previously to judge air quality both outdoors (14) and indoors (16,17,21). A panel is also prescribed in ASHRAE's ventilation standard (18). Perceived indoor air quality can be measured by an untrained or a trained panel, judging the air just after entering the space (19,21).

UNTRAINED PANEL

The panel comprises a random group of preferably more than 20 independent persons, unrelated to the building under study. They may be students or people working in offices etc., but not industrial or agricultural workers. Each panel member is asked to judge the acceptability by answering the question in Figure 8.

Imagine that you would be exposed
to the air quality in this room during
your daily work.

Is the air:

☐ Acceptable

☐ Not acceptable

Figure 8 Questionnaire for untrained panel.

The percentage of dissatisfied is calculated and the corresponding perceived air quality in decipol is found from Figure 5. A slightly more sophisticated method is to have each panel member use the acceptability scale in Figure 9 (20).

Imagine that you would be exposed
to the air quality in this room during
your daily work. How acceptable is
the air? Please mark on the scale.

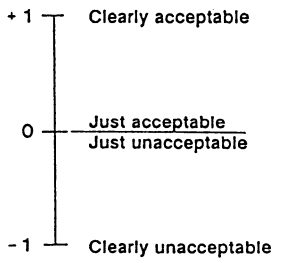

Figure 9 Scale for untrained panel. From the mean acceptability vote (MAV) of the panel the perceived air quality in percent dissatisfied (PD) is calculated by the equation PD = 50 - 97 · MAV (26).

TRAINED PANEL

A panel, preferably of more than five persons, judges the air compared to references with known levels of perceived air quality, e.g., 1, 5, 10 and 20 decipol, see Figure 10. The reference gas may be propanone where the relation between concentration and decipol is known (21). The panel members are trained for several hours to judge unknown levels of the reference gas and other types of pollution.

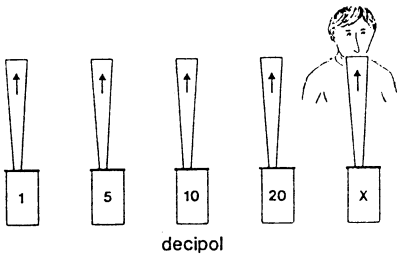

Figure 10 References for judging perceived air quality by a trained panel. Each panel member is trained to judge the unknown air quality X by a comparison to known references of 1, 5, 10 and 20 decipol. A reference gas is generated in each jar to pollute the air flow of min. 0.8 l/s moving through the jar and diffusor. For propanone as reference gas this is the relation between air quality (C) in decipol and gas concentration (P) in ppm:
$C = 0.8 + 0.22 \cdot P$

MEASUREMENT OF SENSORY POLLUTION LOAD IN A BUILDING

The sensory pollution load on the air in a building is the sum of the pollution load from the occupants (including possible smoking) and from the building (including furniture, carpets and the ventilation system). The sensory pollution load in a space may be calculated from this equation:

$$G = 0.1 \cdot Q\,(C_i - C_o) \cdot \varepsilon_v \qquad [1]$$

where
- G = sensory pollution load (olf)
- Q = ventilation rate (l/s)
- C_i = perceived indoor air quality (decipol)
- C_o = perceived outdoor air quality (decipol)
- ε_v = ventilation effectiveness

The perceived indoor air quality is measured as discussed above, the outdoor air quality may either be measured by a panel or estimated. The ventilation rate, i.e., the rate of outdoor air supply to the space, may be measured by a tracer gas method or may be calculated from a CO_2 measurement in the space and a counting of persons present in the building. The ventilation effectiveness is usually close to one, it may be estimated or measured (22).

Equation [1] applies for steady-state conditions so measurements should preferably be taken after the system has been operating for many hours.

The pollution load caused by the occupants may be estimated from Table 1 or calculated from measurements of CO_2 (indicator of bioeffluents) and CO (indicator of tobacco smoke) above outdoor level (17). Substracting the occupant pollution load from the total pollution load provides the load from the building itself. This is an important characteristic of a building. Table 2 shows results of field measurements in more than forty buildings.

Table 2 Pollution load caused by the building, including furnishing, carpets and ventilation system

	sensory pollution load olf/(m² floor)	
	mean	range
Existing buildings		
Offices	0.3	0.02-0.95
Schools (class rooms)	0.3	0.12-0.54
Kindergartens	0.4	0.20-0.74
Assembly halls	0.5	0.13-1.32
Low-polluting buildings (target values)		0.05-0.1

It is obvious that there are large variations from one building to another. If the pollution caused by the building is significant, it will usually be important to spot where the pollution sources are situated. Different methods to split up the load caused by ventilation system and building for studying components in the system is provided in refs. (19) and (23).

As an example Figure 11 shows the average sources in 15 offices. In the average office with a floor area of 230 m² 17 occupants were working. The surprising result is that materials in the space had an average source strength of 28 olfs and the ventilation system polluted 58 olfs. Tobacco smoking contributed 35 olfs to the pollution load in the offices. Although there were only 17 occupants in the space, there were in all 138 olfs present.

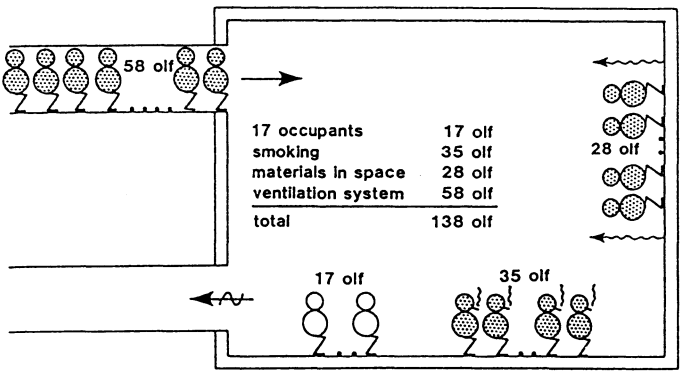

Figure 11 Average pollution sources in 15 offices (average floor area 230 m^2) in Copenhagen. (19) An average of 17 occupants worked in each office. The extensive hidden olfs (grey) in the space and ventilation system are the likely explanation of the sick building syndrome.

For each occupant there were thus 6 to 7 hidden olfs present, polluting the air in the space (Figure 12): 1 to 2 olfs were hidden in the materials in the space, 3 olfs were hidden in the ventilation system and 2 olfs were caused by tobacco smoking.

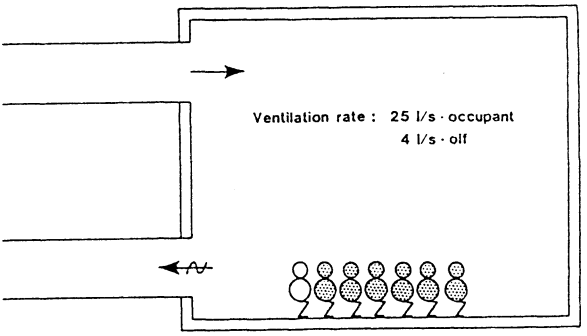

Figure 12 For every occupant (1 olf) in the 15 office buildings there were 6 to 7 hidden olfs present (grey). This is in contrast to ventilation standards over more than a century, which have assumed human beings to be the principal or exclusive polluters in offices and similar spaces. Prevention and cure of sick buildings require removal of the superfuous hidden pollution sources.

These results and studies in other types of buildings (Table 2) are in contrast to ventilation standards applied over more than a century which have assumed that human beings are the principal or exclusive polluters. Standards have implicitly assumed that spaces and ventilation systems are clean and do not contribute to the indoor air pollution.

The hidden pollution sources found in many buildings ruin the air, making it stuffy, stale and unacceptable. Why were these hidden pollution sources not identified earlier? Probably because previously no method of quantification existed except the chemical method, which was usually inadequate. Probably because many pollution sources are spread over large areas in spaces or are hidden in the HVAC systems.

The judges assessed the air just after entering each space. Is this immediate impression of the air sufficient to give a fair assessment of the air quality? The irritants and odorants in the air immediately stimulate the chemical and olfactory senses (24). This means that the stale and stuffy air and the irritated mucous membranes, characteristic of the sick building syndrome, are perceived at once. With time, odour intensity will decrease, while irritation may remain constant. (24,25,26). The total impression of air quality will normally be strongest in the beginning and a judgment made then, therefore, will tend to be conservative. In ventilation theory (16) the aim traditionally has been to provide air quality which is felt acceptable from the first moment a person enters a space. Although some adaptation may take place later, it has always been considered essential to avoid a negative first impression of the air quality in a space.

Are the hidden pollution sources also contributing to other symptoms like headache, lethargy, etc., claimed to be part of the sick building syndrome? Several recent studies indicate that this is the case (27, 28), i.e. that there is a relation between perceived air quality and the frequency of symptoms. Characteristically the symptoms of the sick building syndrome disappear when people leave the building and are exposed to fresh air. If the

hidden pollution sources in the building are removed so that the air indoors is perceived as fresh and pleasant, it seems likely that the other symptoms of the sick building syndrome will be reduced simultaneously.

PRACTICAL RECOMMENDATIONS

The essential point is to identify the hidden pollution sources and remove or reduce them, if possible. Detailed studies using a panel may be performed. Furthermore, the ventilation rate may be measured and the pollution load may be determined in each space. But usually a much simpler method is required during inspection of a building, namely the use of one's own nose. An attempt should be made to identify the sources. One should be suspicious of all materials: floor materials including carpeting, suspended ceilings, furniture, drapes, etc. The ventilation should be turned off. This makes it easier to identify pollution sources when the ventilation system is inspected in detail.

An immediate renovation of the entire building should not be prescribed at once. First a couple of small rooms should be changed by substituting materials. One's nose should be used when selecting the new materials. Use of one's own senses for a few seconds may improve conditions for thousands of occupants of the building over the next ten years.

When the small rooms have been renovated, some of the occupants should be asked to judge the air in the new spaces compared with the unchanged spaces. If they find that the air is significantly better in one of the renovated spaces, that renovating scheme should be used for the entire building. Many unsuccessful investments could have been avoided if such small-scale studies had been performed before the full-scale renovation.

"Olf hunting" is quite a rewarding experience. With some training one can recognize the pollution from numerous typical materials alone and when they occur together in a space. This is similar to an experienced cook who tastes a soup and is able to identify the most important ingredients. But one should never forget that both the cook and the "olf hunter" are there to satify human requirements. The extent to which these requirements are met is a measure of success, a measure of indoor air quality.

REFERENCES

1. Andersen, I. and Lundquist, G.R. (1966) 'Indoor Climate in Schools', Copenhagen: Danish Building Research Institute.
2. Berglund, B., Johansson I., and Lindvall, T. (1982) 'A Longitudinal Study of Air Contamninants in a Newly Built Preschool', Environ. Int. 8, 111-115.
3. Sterling, J.D., Sterling, E. and Dimich-Ward, H.D. (1983) 'Air Quality in Public Buildings with Health Related Complaints', ASHRAE Trans., 89 (2A), 198.
4. Melius, J., Wallingford K., Keenlyside, R. and Carpenter, J. (1984) 'Indoor Air Quality - the NIOSH Experience', Ann. Am. Gov. Ind. Hyg. 10, 3-7.
5. Finnegan, M.J., Pickering, C.A.C. and Burge, P.S. (1985) 'The Sick Building Syndrome: Prevalence Studies', Br. Med. J. 289, 1573-1575.
6. Stolwijk, J.A.J. (1984) 'The Sick Building Syndrome', in B. Berglund, T. Lindvall and J. Sundell (eds.), Indoor Air 1, Stockholm: Swedish Council for Building Research, 23-29.
7. Kröling, P. (1985) 'Gesundheits- und Befindensstörungen in klimatisierten Gebäuden', Munich: W.Zuckschwerdt Verlag. (In English: Health Risks and Discomfort in Air

Conditioned Buildings).
8. Robertson, A.S. Burge, P.S., Hedge, A., Simms, J., Gill, F.S., Finnegan, M., Pickering, C.A.C. and Dalton, G. (1985) 'Comparison of Health Problems Related to Work and Environmental Measurements in Two Office Buildings with Different Ventilation Systems, Br. Med. J. 291, 373-376.
9. Valbjørn, O. and Skov, P. (1987) 'Influence of Indoor Climate on the Sick Building Syndrome Prevalence' in B. Seifert, et al. (eds.), Indoor Air '87 Vol. 2, Berlin: Institute of Water, Soil and Air Hygiene, 593-597.
10. Komine, H., Yoshizawa, S., and Tochihara, Y. (1987) 'The Investigation on IAQ and Subjective Evaluations of Occupants for Indoor Environments in Japanese Office Buildings' in B. Seifert, et al. (eds.), Indoor Air '87, Vol. 3. Berlin, 123-128.
11. Wilson, S. and Hedge, A. (1987) 'The Office Environment Survey. A Study of Building Sickness', London: Building Use Studies Ltd.
12. Rajhans, G.S. (1989) 'Findings of the Inter-Ministerial Committee on Indoor Air Quality (Ontario). Proc. IAQ '89 ASHRAE, Atlanta.
13. Fanger, P.O. (1988) 'Introduction of the olf and the decipol Units to Quantify Air Pollution Perceived by Humans Indoors and Outdoors', Energy & Buildings 12(1), 1-6.
14. VDI 3881/Part 2 (1987) 'Olfactometry - Odour Threshold Determination. Sampling', Verein Deutscher Ingenieure, Düsseldorf.
15. Fanger, P.O. (1990) 'New principles for a future ventilation standard', Proc. of Indoor Air '90, Toronto. Vol. 5, 353-364.
16. Yaglou, C.P., Riley, E.C. and Coggins, D.I. (1936) 'Ventilation Requirements', ASHVE Trans. 42, 133-162.
17. Cain, W.S. et al. 'Ventilation requirements in buildings. - I. Control fo occupancy odor and tobacco smoke odor', Atmos. Environ. Vol. 6, 1183-1197.
18. ASHRAE Standard 62-1989 'Ventilation for acceptable indoor air quality', American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta.
19. Fanger, P.O., Lauridsen, J., Bluyssen, P. and Clausen (1988) 'Air Pollution Sources in Offices and Assembly Halls, Quantified by the olf Unit', Energy & Buildings, 12(1), 7-19.
20. Gunnarsen, L., Fanger, P.O. (1988) 'Adaptation to indoor air pollution', Proc. of Healthy Buildings '88, Stockholm, Vol. 3, 39-51.
21. Bluyssen, P., Kondo, H., Pejtersen, J., Gunnarsen, L., Clausen, G. and Fanger, P.O. (1989) 'A trained panel to evaluate perceived air quality', Proc. of CLIMA 2000, Sarajevo, 25-30.
22. Skaaret, E., Mathiesen H.M. (1982) 'Ventilation efficiency', Environ. Int. 12, 473-481.
23. Pejtersen, J., Bluyssen, P., Kondo, H., Clausen, G., Fanger, P.O. (1989) 'Air pollution sources in ventilation systems', Proc. of CLIMA 2000, Sarajevo, 139-144.
24. Engen, T. (1986) 'Perception of Odor and Irritation', Environ. Int. 12, 177-187.
25. Mølhave, L., Bach B., and Pedersen, O.F. O.F. (1986) 'Human Reactions to Low Concentrations of Volatile Organic Compounds', Environ. Int. 12, 167-175.
26. Gunnarsen, L. (1990) 'Adaptation and ventilation requirements', Proc. of Indoor Air '90, Toronto, Vol. 1, 757-761.
27. Thorstensen E., Hansen, Ch., Pejtersen, J., Clausen, G. and Fanger, P.O. (1990) 'Air pollution sources and indoor air quality in schools', Proc. of Indoor Air '90, Toronto, Vol. 1,531-536.
28. Zweers, T., Skov, P., Valbjørn, O. and Mølhave, L. (1990) 'The effect of ventilation and air pollution on perceived Indoor air quality in five town halls', Energy and Buildings 14, 175-181.

INDOOR MICROBIOLOGICAL POLLUTANTS - SOURCES, SPECIES, CHARACTERISATION AND EVALUATION

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ABSTRACT. Bacteria and fungi growing saprotrophically on damp surfaces in buildings, and in humidifiers and HVAC systems, contribute to the air spora of indoor air, which is dominated by the moulds *Penicillium* and *Cladosporium* and bacteria in the the Micrococcaceae. Actinomycetes and xerophilic fungi are among those micro-organisms in indoor air which are associated with rhinitis and asthma. Some organisms cause humidifier fever and extrinsic allergic alveolitis, but pathogens such as *Aspergillus fumigatus* and *Legionella* are seldom abundant. In investigating possible relationships between the air spora and symptoms of building-related illnesses such as SBS, the choice of sampling and cultural methods is critical. Although viable samplers make identification of organisms possible, they underestimate the total numbers of airborne spores and bacteria, but liquid impingers and filtration samplers enable viable counts and total counts to be made from the same sample. Since mycotoxins in inhaled fungal spores may seriously affect macrophage and other functions in the lung, more research on the effects of toxigenic fungi on respiratory health is required. Another area requiring investigation is production of microbial volatile compounds and their possible role in health.

1. Types of Micro-Organism and Their Ecology

1.1. BIOLOGICAL PARTICULATES

Although this paper is concerned with microbiological pollutants in indoor air, it must be remembered that other biotic factors have also to be taken into account in the search for the causes of building-related disease. Airborne biological particulates which produce allergic symptoms are pollen, insect-derived material, mites and their faeces, and furred animal dander. Most pollen-related allergies are, however, mainly associated with the higher concentrations of pollen found outside buildings. Insect-related allergy is relatively uncommon, although problems associated with cockroach particulates in homes are increasing and may be of appreciable significance among socially disadvantaged groups (Mathews, 1989). On the other hand, it is well known that housedust mites are a widespread cause of respiratory allergy among all socioeconomic groups. Housedust

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Chemical, Microbiological, Health and Comfort Aspects of Indoor Air Quality – State of the Art in SBS, 73–98.

mite-induced allergy is generally associated with the home. However, an investigation of an air-conditioned office block (Leinster *et al.*, 1990) showed that steam cleaning reduced mite levels, especially on hard surfaces and in seat covers, improving environmental rating by occupants and also reducing SBS symptoms. Additional work is obviously needed to confirm that these improvements were due to mite removal, and not to other alterations caused by cleaning. For example, measures which reduce mite numbers, such as are observed in carpets in houses with underfloor heating (Schata *et al.*, 1990), are also known to reduce numbers of colony forming units (CFU), or propagules, of *Aspergillus* and other moulds. Moulds and other fungi (including yeasts) comprise one major category of microbial particulates in indoor air, the others being bacteria (including Actinomycetes), Protozoa (e.g. *Acanthamoeba* and *Naegleria*) which grow in humidifiers, and viruses.

It has been found that viruses may be spread in recirculating air of HVAC systems (Brundage *et al.*, 1988), and rates of infection may be higher in those buildings with such systems than those without. It is also evident that rates of infection by the common cold and influenza virus are likely to be higher in crowded premises because of the increased possibility of inhaling aerosols generated by coughing or sneezing. Nevertheless, person-to-person contact is the predominant means of transmission of these obligately parasitic micro-organisms. The remainder of this review will therefore concentrate on bacteria and fungi.

1.2. SAPROTROPHIC BACTERIA AND FUNGI

A diverse range of saprotrophic bacteria and fungi is to be found in buildings. The bacteria include filamentous types which produce aerially dispersed spores, the Actinomycetes, in addition to unicellular types. The fungi comprise yeasts, moulds, and wood-rotting and plaster fungi in the Ascomycetes and Basidiomycetes, many of which produce distinctive macroscopic sporing bodies. Buildings provide a broad range of ecological niches for these saprotrophs. Provided that there is sufficient moisture, growth and multiplication can be sustained by materials such as wood; paper, paint and other surface coatings; soft furnishings such as upholstered furniture, curtains and carpets; soil in plant pots; dust; and cooked foods and their raw ingredients. Though there may be some "free" nutrients in such materials, other nutrients and energy sources can only be obtained as a result of the breakdown of polymers by the micro-organisms. For example, degradation of cellulose in paper and wood by microbial enzymes provides glucose as a source of energy for growth. Some micro-organisms cause only minor damage to materials and structures, but others cause considerable biodeterioration (Flannigan, 1991). For example, the strongly cellulolytic mould *Stachybotrys atra* causes extensive damage to wallpaper and straw-based constructional materials, and the dry-rot fungus *Serpula lacrymans* is the cause of serious timber decay in buildings.

Although *S. lacrymans* has the exceptional characteristic of being able (once it is well-established) to produce enough moisture by degrading wood to make it independent of an external source of water, the availability of moisture in a material is a determining factor for growth of bacteria and fungi. The water activity (a_w) of the material is a measure of the moisture available to micro-organisms. It is defined as the partial pressure of water in the material relative to that of pure water. The a_w of a substrate in a closed system is directly related to the relative humidity (RH) of the ambient atmosphere. Depending on its initial moisture status, the substrate will lose to, or gain from, the atmosphere that amount

of moisture which will bring it into equilibrium. For example, a cellulose furnishing fabric with an a_w of 0.40 placed in an atmosphere with a RH of 80% will gradually absorb moisture until it reaches a_w 0.8. Therefore, placing initially dry, but susceptible, material in a damp atmosphere makes the growth and spread of micro-organisms possible.

Nearly all saprotrophic micro-organisms grow well when the a_w is close to 1.0, but there are marked differences between species as regards the minimum a_w allowing growth. However, the minimum is modified both by temperature and nutrient availability. In general, there is an inverse relationship between ambient temperature and minimum a_w for growth (Table 1). Coating wallpaper with emulsion paint or carboxymethyl cellulose paste to provide a more readibly degradable source of nutrients has also been found to lower the minimum a_w for growth of a range of moulds (Grant *et al.*, 1989).

TABLE 1. Minimum water activity for growth of moulds on woodchip paper coated with emulsion paint (after Grant *et al.*, 1989)

	Minimum a_w	
Species	12°C	18°C
Aspergillus versicolor	0.87	0.79
Penicillium brevicompactum	0.87	0.83
P. chrysogenum	0.87	0.85
Cladosporium sphaerospermum	0.93	0.92
Ulocladium consortiale	0.94	0.92
Stachybotrys atra	0.98	0.97

As a result of field observations and laboratory studies by Grant *et al.* (1989), it became evident that moulds which grow on damp surfaces can be divided into three types:

(a) Primary colonisers such as *Aspergillus repens, A. versicolor* and *Penicillium brevicompactum*, which show xerophilic characteristics in being able to grow at an a_w <0.80.

(b) Secondary colonisers such as *Cladosporium* spp., which have a minimum a_w of 0.80-0.90 for growth.

(c) Tertiary colonisers such as *Phoma herbarum, Ulocladium* spp. and *Stachybotrys atra*, which only grow at a_w >0.90 and can therefore be classed as hydrophilic.

It can therefore be expected that in poorly insulated buildings, where condensation increases over the winter and the internal surface layers of walls become progressively moister, the range of moulds able to colonise the walls will increase. A succession of moulds will develop, progressing from primary colonisers tolerant of lower a_w to secondary and finally tertiary colonisers when the wall has a very high a_w. Since very few moulds will grow at a_w <0.70, and then only very slowly, it is often stated that reducing the RH in a room or building to <70% will control mould growth. While this might be true in a well-insulated building, it will not be so when any surface is at a temperature lower than the dewpoint, e.g. a poorly insulated wall or a cooling coil.

Wood-rotting fungi generally require an a_w >0.85 for growth, and the minimum a_w for most yeasts and bacteria is generally >0.90. However, some yeasts are able to grow in jams or syrups at much lower a_w, and some bacteria, including some staphylococci, can grow at a_w <0.90. Where mould patches develop on walls under very damp conditions, it can be expected that yeasts and bacteria will be growing in juxtaposition with the mould mycelium.

TABLE 2. Frequency of isolation and abundance of principle genera of filamentous airborne fungi in houses (after Hunter *et al.*, 1988)

Genus	Frequency*	Abundance†
Penicillium	96	35
Cladosporium	89	15
Aspergillus	75	7
Ulocladium	62	1
Sistotrema	51	22

* Percentage of houses

† Percentage of total colonies on isolation plates

2. The Microflora of Indoor Air

2.1. FUNGI

The nature of the air spora in houses has recently been reviewed by Flannigan *et al.* (1991) and the resemblances and differences between indoor and outdoor air noted. The predominant filamentous fungi in both houses (Table 2) and non-industrial workplaces (Tables 3 and 4) are generally the mould genera *Penicillium* and *Cladosporium*, but the Basidiomycete *Sistotrema brinkmannii* has been found in abundance in houses in UK (Table 2). Species of *Aspergillus,* including those which are more correctly allocated to the Ascomycete genus *Eurotium,* form a smaller but note-worthy part of the air spora. Although *A. versicolor* has been reported to be the most prominent of the aspergilli, for example by Hunter *et al.*(1988), Verhoeff *et al.* (1992) found that the strongly xerophilic species *A. penicillioides* may be more prevalent, as can another xerophilic mould, *Wallemia sebi.* It is known that these xerophilic fungi are part of the microflora of housedust, but *W. sebi* and various xerophilic aspergilli have also been found among the fungi growing in damp air-conditioning filters and releasing spores into the indoor air (Elixmann *et al.*, 1990). In summer, counts of airborne mould indoors are usually markedly lower than outdoors (see Flannigan *et al.*,1991). Keeping windows and doors shut reduces the contribution made to the indoor air by outdoor phylloplane fungi, as does air-conditioning (Table 3). During all seasons in Europe, the phylloplane fungi *Alternaria* and *Epicoccum* (Tables 3 and 4) may be found in indoor air, but even in the summer months when growth is greatest they still form only a minor part of the air spora.

Cladosporium spp. are also phylloplane fungi, but may comprise as much as 90% of the outdoor air spora. However, as with *Penicillium* (Fradkin *et al.*, 1987), there are differences in the relative abundance of different species in the air outdoors and indoors. For example, *C. herbarum* is more prevalent outdoors (Verhoeff *et al.*, 1992). In winter, when counts of phylloplane fungi are low outdoors, numbers indoors may be amplified by growth of *Cladosporium* on damp walls, etc. Despite marked differences between species (Fradkin *et al.*, 1989), airborne penicillia and aspergilli in indoor air are generally regarded as originating indoors. Like *Cladosporium* and *Ulocladium*, species in these genera can grow on damp walls and other surfaces, forming extensive mould patches (Grant *et al.*, 1989).

TABLE 3. Counts of fungi at two air-conditioned (AC) and one naturally ventilated (NV) locations in two buildings (after Austwick *et al.*, 1989)

	Count (CFU/m^3 air)					
	Building 1 (June)			Building 2 (November)		
Type of fungus	AC		NV	AC		NV
	(1)	(2)		(1)	(2)	
Alternaria sp.	-	-	4	-		6
Aspergillus fumigatus	45	-	10	-	-	8
A. versicolor	2	-	-	81	122	39
Aureobasidium pullulans	-	-	-	6	-	4
Botrytis cinerea	-	-	4	-	-	2
Cladosporium spp.	30	45	209	2	2	39
Phoma fimeti	-	8	12	-	-	-
Penicillium spp.	2	4	12	31	64	2
Yeasts	4	-	12	-	-	6
Unknown small	-	-	-	-	-	24
Unknown white	12	20	8	1	-	22
Basidiomycetes	2	4	2	-	-	-

It is obvious that there must be some link between the air spora and mould growth in a building, and that counts should be higher nearest to the site of growth (Table 5). The clearest demonstration that growth on walls, filters, etc., contributes to the spora is the appearance in that spora of species which are uncommon in air outside but grow in these damp locations inside, e.g. *Stachybotrys atra*. However, there may also be mould growth in wall cavities and other areas which are not readily found. That there is some indoor site of amplification can often be detected by quantitative and qualitative comparison of indoor and outdoor air samples.

TABLE 4. Fungal air spora in naturally ventilated and air-conditioned offices during summer in Edinburgh

	Composition of air spora (%)				
	Naturally ventilated building	Air-conditioned building			
		Office 1.06		Office 3.29	
Type of fungus	Monday	Monday	Friday	Monday	Friday
Alternaria alternata	5	-	3	9	2
Aspergillus versicolor	-	1	-	-	-
Cladosporium spp.	59	71	77	73	42
Epicoccum purpurascens	<1	-	-	-	-
Mucor spp.	1	1	-	-	-
Penicillium spp.	29	18	5	2	54
Non-sporing isolates	<1	9	6	16	2
Yeasts	3	-	9	-	-

With commoner species found in both indoor and outdoor air, elucidation of a relationship is complicated by the effect of activity in buildings on the spore burden. Normal household or work routines, constructional work and any other dust-raising activities temporarily boost the airborne spore burden (Hunter *et al.*, 1988). Ventilation also creates air currents which affect spore clouds, so that there are large fluctuations in numbers (Figure 1), even over very short periods (Verhoeff *et al.*, 1990a). Because of such temporal variation, and also spatial differences, the taking of a single short-duration or "grab" sample may result in a false impression of the air spora in a room or office. To assess exposure of occupants of a room to moulds and other micro-organisms, it is necessary to take air samples at several sites and under all conditions of usage.

TABLE 5. Numbers of propagules in the air spora of living room of British houses (after Hunter *et al.*, 1988)

	Viable count (CFU/m^3 air)			
Mould growth	Range	Median	IQR*	Modal class
Absent from house	<12-23070	236	118-436	<12-200
In other room(s) only	<12-48000	360	165-759	<12-200
In room sampled	424-21790	2673	1165-4944	1001-2000

* Interquartile range

Yeasts are found in most air samples taken in buildings, and may sometimes be present in large numbers. There is little published work on the identity of these organisms, but it is known that pink yeasts in the genera *Rhodotortula* or *Sporobolomyces* are a prominent part of the airborne yeast flora and can be isolated from areas of mould growth (Hunter *et al.*,1988). In Japanese homes, *Trichosporon cutaneum* is not uncommon (Yoshida *et al.*, 1989).

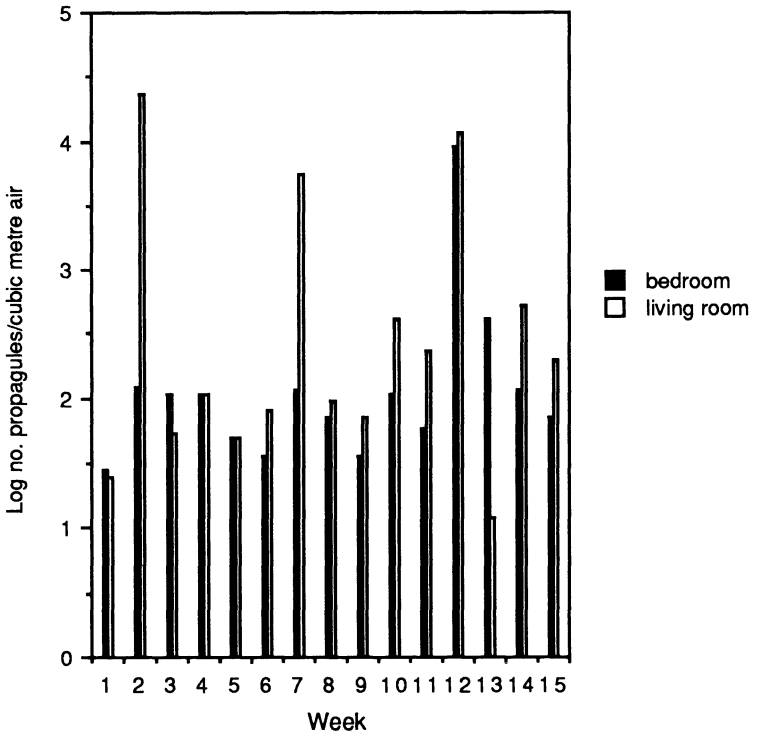

Figure 1. Numbers of fungal propagules in air samples taken weekly in a house during the winter (after Hunter *et al.*, 1988)

2.2. BACTERIA

It is not always so, but the numbers of bacteria in the air within domestic dwellings (Nevalainen *et al.*, 1988; Flannigan *et al.*, 1991) and in non-industrial workplaces (Table 6) may be higher than those of fungi. Nevalainen *et al.* (1988) recorded that in Finnish houses numbers of viable bacteria ranged from 60 to 12200/m^3 air, and Flannigan *et al.* (1991) reported counts of up to 22000 CFU/m^3 in Scottish homes. However, as with fungi in houses (Table 5) there is a skewed distribution, the majority of counts being relatively low.

TABLE 6. Numbers of viable airborne bacteria and fungi at sites within two buildings (after Austwick *et al.*, 1989)

		Mean CFU/m³ air			
		Bacteria		Fungi	
Site	n	37°	Max.*	25°	37°
Building 1 (June)					
Air-conditioned	2	200	200	97	22
Naturally ventilated	1	234	234	447	8
Building 2 (November)					
Air-conditioned	2	130	173	138	1
Naturally ventilated	1	190	613	352	23

* Maximum for samples incubated at 15 and 17°C

The characterisation of the airborne bacterial flora has received much less attention than fungi. However, a range of bacteria, including *Acinetobacter* sp., *Enterobacter* sp., *Pseudomonas aeruginosa* and *Staphylococcus aureus*, have been found in aerosols emitted by cool-mist humidifiers. Of course, *Legionella pneumophila* has also been isolated from humidifiers and air-conditioners. Austwick *et al.* (1989) isolated a broader range of bacteria from the air in office buildings (Table 7). The most abundant genera were *Staphylococcus, Micrococcus* and *Flavobacterium*. In a previous study of humidified indoor environments, Austwick *et al.* (1986) isolated *Alcaligenes, Bacillus, Pseudomonas* and members of the Micrococcaceae, including *Staph. epidermidis*. This last bacterium is associated with skin scales and is therefore usually present in abundance.

TABLE 7. Viable bacteria isolated isolated from indoor air in an investigation of sick buildings (after Austwick *et al.*, 1969)

Actinobacter calco var. *lwoffi*	*Ps. cepacia*
Aeromonas hydrophila	*Ps. fluorescens*
Flavobacterium sp.	*Ps. paucimobilis*
Micrococcus spp.	*Ps. vesicularis*
Moraxella sp.	*Staphylococcus aureus*
Pasteurella haemolytica	*Staph. epidermidis*
P. pneumotropica	*Streptococcus* spp.
Pseudomonas aeruginosa	C.D.C. Group VE

Actinomycetes were also isolated by Austwick *et al.*(1986), including various *Streptomyces* and thermophilic species. Although Nevalainen *et al.* (1988) found the

Actinomycetes comprised a small part of the airborne bacterial burden, it was later reported (Nevalainen *et al.*, 1990) that they were particularly associated with complaints of odour or mould growth in homes, schools, offices and day-care centres. Other bacteria may also be present in larger numbers in mould-affected homes (Flannigan *et al.*, 1990). Thermophilic Actinomycetes such as *Faenia rectivirgula* and *Thermoactinomyces candidus* or *Th. vulgaris* have not uncommonly been isolated from HVAC equipment (Kreiss and Hodgson, 1984).

3. The Indoor Air Spora and Health

Although the bacterial pathogen *Legionella pneumophila* has been isolated from humidifiers and air-conditioners most outbreaks of Legionellosis have been associated with cooling towers or water supplies. Pathogenic moulds are seldom found in abundance in indoor air, but pathogenic *Aspergillus* spp. may grow as saprotrophs in the soil of potted plants kept near to or on radiators in winter (Staib, 1984). Rhinitis and/or asthma and sometimes invasive aspergillosis can be caused in susceptible individuals by *A. fumigatus*, which is both allergenic and pathogenic. In addition to the pathogenic aspergilli listed by Staib, other opportunistic pathogens such as *Exophiala jeanselmei*, *Fusarium solani* and *Pseudallescheria boydii* may present an additional hazard to immunosuppressed patients or AIDS sufferers.

Although such pathogens are relatively uncommon in indoor air, there have been various reports linking airborne micro-organisms with a number of allergic conditions, particularly

(a) rhinitis, with nasal congestion, sneezing, lacrymation and conjunctivitis and other "hay fever" symptoms;

(b) asthma, with symptoms of wheeze, tightness of chest and shortness of breath;

(c) humidifier fever, with chills, muscle ache, malaise and fever, but no pronounced respiratory symptoms; and

(d) extrinsic allergic alveolitis (EAA), with acute symptoms including pneumonia-like bouts of fever, cough and tightness of chest, and chronic symptoms which include cough, shortness of breath and infiltration of lungs.

It has been noted in recent reviews of the role of indoor airborne micro-organisms in human health (Miller, 1990; Flannigan, 1991; Flannigan *et al.*, 1991) that the airborne fungi which have been shown to be allergenic, usually by skin-prick testing, include moulds which may be found in indoor air. *Alternaria*, *Aspergillus*, *Cladosporium*, *Fusarium*, *Geotrichum*, *Mucor*, *Penicillium*, *Rhizopus*, and *Stemphylium*/ *Ulocladium* are among these, and it has been indicated that exposure to at least some of these fungi can provoke rhinitis and asthma. In several recent studies, a strong association has been recorded between reported dampness and mould in the home and reported respiratory symptoms in children. In one study (Brunekreef *et al.*, 1989), the conclusions drawn were that (a) home dampness was a strong predictor of respiratory and other illness, and (b) the magnitude of the effect of moulds or dampness was comparable to passive smoking. In a Dutch study (Waegemaekers *et al.*, 1989), houses with two or more indicators of dampness showed higher average viable spore counts and a greater prevalence of respiratory symptoms among occupants. Su *et al.* (1990) found that parental reporting of rhinitis in children correlated with levels of *Cladosporium*, *Epicoccum* and yeast in indoor air during winter, and there was a significant association between *Aspergillus* and wheezing and/or physician-confirmed asthma. Recent large

studies of Canadian communities (Dales *et al.*, 1991a,b) revealed that increased respiratory symptoms in adults and children were associated with home dampness and mould reported by respondents. However, Strachan (1990) found earlier that, when reported respiratory symptoms were validated by objective testing, awareness of dampness among respondent parents could largely account for the observed link between mould and respiratory symptoms in their children. A follow-up mycological study found no significant differences in the airborne mycoflora between the homes of wheezy children and non-wheezy controls, except for higher, but nevertheless rather low, counts of unidentified non-sporing fungi categorised as Mycelia Sterilia. Evidence for the role of airborne mould spores in indoor air in wheeze/asthma is then contradictory, and Dales and his colleagues have concluded from their studies (Dales *et al.*, 1991a,b) that respiratory symptoms attributed to indoor moulds may be provoked by a non-allergic mechanism. Indications are that, in general, fungal allergens are less important than pollen, house dust mites and animal dander in Europe; in one investigation strong positive reactivity to fungi was observed in <4% of patients with suspected allergy (Beaumont *et al.*, 1985).

Fortunately, cases of EAA due to inhalation of micro-organisms in indoor air are relatively rare. However, a variety of different organisms may grow to a sufficient extent in humidifiers to be able to generate aerosols with high enough concentrations of allergenic spores or cells to provoke symptoms. *Bacillus subtilis*, *Flavobacterium* sp., *Pseudomonas aeruginosa* and the thermophilic Actinomycetes which cause farmer's lung, *Faenia rectivirgula* and *Thermoactinomyces vulgaris*, are among these. Unidentified species of *Cephalosporium*, *Mucor* and *Penicillium* from humidifiers or heating equipment have also been implicated. Other sites of growth reponsible for individual cases of EAA include walls, ceilings, floors, furnishings and heating systems, with unidentified species of *Cephalosporium*, *Cladosporium*, *Mucor* and *Penicillium*, and also *Aureobasidium pullulans*, *P. casei*, *P. chrysogenum*, and *P. cyclopium*, being involved (see Flannigan *et al.*, 1991). Although humidifier fever may appear to be the result of allergenic response and a variety of micro-organisms have been suggested as the causative agents, bacterial endotoxins may have a role to play. Extracted endotoxin or whole cells of a number of Gram-negative bacteria, including *Cytophaga*, *Flavobacterium* and *Pseudomonas*, can provoke symptoms like the acute stages of humidifier fever (Rylander, 1986)

4. Air Sampling

4.1. TYPES OF AIR SAMPLER

Since the wide range of micro-organisms in indoor air includes types with confirmed or apparent medical significance, how are we to investigate the possible role of the air spora in building-related diseases, including SBS? Clearly, if we are to discover whether there is any relationship between SBS and micro-organisms in buildings we must gather objective microbiological data which is as detailed and reliable as can be achieved. To do this we must be able firstly to identify precisely the bacteria, yeasts, and moulds and other filamentous fungi in the air and secondly to quantify these different types accurately. Two facts concerning a single mould genus which is a major component of indoor air, *Penicillium*, confirm the need for accurate identification. Firstly, the allergenic and toxigenic potential of *Penicillium* vary considerably between the many different species;

secondly, there may be marked differences in the relative concentrations of different *Penicillium* species indoors, with some species being less and others being more abundant outdoors (Fradkin *et al.*, 1987). Most investigators will at least acknowledge this, although in practice they may not get beyond identification to genus. However, when it comes to the means of quantification, there are marked differences of opinion between different groups of workers. Of course, new samplers and methods have been introduced over the years , but among a sizeable proportion of workers there has been a tendency to ignore these developments and to continue to use long practised methods without really examining their applicability to particular situations.

The sampling methods used most frequently permit micro-organisms to be cultured, but some methods do not. Samplers used to assess airborne populations by cultural methods are usually referred to (wrongly) as "viable" samplers, and those which do not are sometimes called "non-viable" samplers (Burge *et al.*, 1977). In "viable" samplers, the micro-organisms are collected on agar medium in Petri dishes or plastic strips. These are then incubated until colonies have developed from the inoculum and can be counted and identified (or subcultured onto other media for further examination). However, it has to be recognised that not all viable micro-organisms that are collected by a sampler will be able to grow on the isolation medium. The medium may not be suitable for particular types of micro-organism, or the organisms may have been subject to stress during collection and, although not dead, be unable to germinate and grow. The count that we arrive at using such a sampler is therefore strictly speaking a count of culturable micro-organisms. Nevertheless, most aerobiologists call it a "viable count". In addition to those micro-organisms which are not culturable, there is usually a large number which have truly lost their viability. A "non-viable" sampler is used to obtain a "total count", consisting of viable and non-viable micro-organisms but not distinguishing between them. As there is a range of different methods for microbiological analysis of air, it is appropriate to examine the main types of sampler and how they can be used in to investigate the indoor air spora.

4.2. SAMPLING METHODS FOR VIABLE MICRO-ORGANISMS

4.2.1. *Settle Plates.* The simplest method of assessing the range of culturable micro-organisms is to expose open Petri dishes containing appropriate media to the indoor air. This passive non-volumetric method of collection relies on the settling out of bacteria, yeasts and fungal spores and mycelial fragments by gravitation, but is strongly affected by atmospheric turbulence. Settle plates are generally regarded unfavourably, because large spores such as those of the mould *Alternaria* settle out more rapidly than smaller spores like those of *Aspergillus* or *Penicillium*. Effectively, a larger volume of air is sampled for large spores than for small, and for clumps of spores than for single spores. In a recent study (Verhoeff *et al.*, 1992), the number of species isolated from the air of houses over a period of 60 min by this method was significantly lower than by active sampling for 2 min with an Andersen N6 sampler. Nevertheless, there was a significant correlation between the number of colonies developing on the settle plates and the number of CFU/ m^3 air computed from the N6 isolation plates. It can be argued that, because of the considerable variation in the air spora (Hunter *et al.*, 1988) which occurs even over a few minutes (Verhoeff *et al.*, 1990a), a settle plate left to collect for an hour or more may give a better reflection of exposure to viable micro-organisms than a volumetric sampler operating for 1-2 min, or even as little as 20-30 sec.

4.2.2. *Slit-Type Impaction Samplers.* A type of volumetric sampler which has for many years been used routinely to investigate the airborne bacterial flora in hospitals is the slit-to-agar sampler originally developed by Bourdillon *et al.* (1941). Air is drawn through a slit set above the surface of a rotating agar plate on which propagules impact. In earlier versions of this type of sampler, a 9.0 cm isolation plate rotated at fixed speed, but more recent versions with higher flow rates use 10.0-15.0 cm plates and may have variable speed of rotation. One such sampler, produced by Casella, draws in air for 5 min at a rate of 770 litres/min through four slits onto a rotating 14 cm Petri dish. The collection efficiency of slit-to-agar samplers may be 95% or more for particles >1 μm in diameter, but the isolation plates are easily overloaded if the air which is being sampled is heavily contaminated with micro-organisms. As with other viable samplers, rapidly spreading bacteria such as *Bacillus* and fungi such as *Fusarium, Trichoderma* and members of the Mucorales are a particular problem, rapidly obscuring other micro-organisms growing in close proximity.

TABLE 8. Size distribution of particles trapped by the six-stage Andersen sampler

Stage	Diam. of hole (mm)	Range of particle size (μm)	Site of deposition
1	1.18	>7.0	Nose
2	0.91	4.7-7.0	Nasopharynx
3	0.71	3.3-4.7	Trachea/primary bronchi
4	0.53	2.1-3.3	Secondary bronchi
5	0.34	1.1-2.1	Terminal bronchioles
6	0.25	0.65-1.1	Alveoli

4.2.3. *Sieve-Type Impaction Samplers.* Instead of drawing air through a slit, in sieve samplers the air is drawn through a perforated plate. The best known and, certainly in US, the most widely used air sampler is a sieve sampler, the six-stage Andersen viable particle fractionating sampler (Andersen, 1958). In this cascade sampler, propagules impact on the agar in six Petri dishes, each below one of a series of six stacked sieve plates. The diameter of the 400 holes in the sieve plates decreases progressively from 1.18 mm in the top plate to 0.25 mm in the bottom plate (Table 8). Air is drawn through the stack by a pump operating at a flow rate of 28.3 litres/min. As the air passes through successively finer holes its speed increases more than 20-fold between the first and last stages. Consequently, there is a sorting out of particles according to their aerodynamic size. Particles >7 μm in diameter impact at the topmost stage and finer and finer particles impact at succeeding stages until only those which are 0.65-1.1 μm in diameter are collected on the agar below the sixth sieve plate. After incubation, the colonies on the isolation plates are counted and "positive hole" correction made to allow for multiple impaction below individual holes in the sieve plates. Because the range of spore or cell sizes for any given micro-organism is generally limited, it might be expected that the

colonies of that micro-organism would be found on the plates below only one or perhaps two sieve plates in the series. However, colonies of small-spored species are frequently found on earlier stages, indicating that a proportion of the inoculum consists of clumps of spores (or cells) or that some propagules are attached to larger particles, such as soil or plant fragments.

The sorting which occurs in the six-stage sampler gives some indication of where the different propagules would be deposited in the respiratory system (Table 8), but if there is no wish to "size" the propagules a single stage sieve sampler can be used. The Andersen N6 sampler (Jones *et al.*, 1985) is a modification of the six-stage sampler which employs only the sixth sieve plate but operates at the same flow rate. Although the N6 variant saves on both time (the exposure time can be as little as 20 sec) and culture media and can give counts which are comparable with those of its six-stage progenitor, it is very easily overloaded and cannot be used if the concentrations of airborne propagules are high.

There are two models of Pool Bioanalyse Italiana surface air system (SAS) single plate sampler, both operating at a flow rate of 180 litres/ min. The first has 220 holes in the sieve and uses a 5.0 cm Rodac plate containing only 12 ml agar medium; the second has 260 holes and a 9.0 cm Rodac plate containing 13.5 ml medium. From results of environmental sampling and laboratory tests with *Bacillus* spores and aerosols of known particle size Lach (1985) concluded that the sampling efficiency of both types of SAS sampler was nearly the same as that of a slit-to-agar sampler, but that the efficiency fell off for particles of a size <4 μm. However, Verhoeff *et al.* (1990 a,b) have reported that SAS sampler counts of moulds in houses were somewhat lower than corresponding Andersen N6 sampler counts, with the latter being comparable to slit-to-agar sampler counts (Table 9).

TABLE 9. Effect of sampler and collection medium on mean number of fungi isolated from samples taken in houses (after Verhoeff *et al.*, 1990a)

Medium	Sampler				GM per medium
	Slit	SAS	N6	RCS	
MEA	545	164	508	721	424
DG18	713	478	518	327	493
DRBC	455	147	361	193	260
GM/sampler	561	226	455	358	

Particles collected on the first two stages of the Andersen six-stage sampler are considered to be large enough to be "non-respirable", i.e. unlike the smaller particles impacting on stages 3-6 they would be trapped in the nasopharynx and fail to reach the lower respiratory tract (Table 8). However, although many industrial hygienists wish to have information on "respirable" and "non-respirable" propagules, they baulk at the time and expense incurred in using the six-stage sampler. To meet this need, a two-stage version of the Andersen sampler was developed, in which the sieve plates contain 200

tapered holes. The diameter of the holes in the first stage is 1.5 mm ("non-respirable" fraction) and in the second 0.4 mm ("respirable" fraction). However, Gillespie *et al.* (1981) concluded from environmental sampling that, compared with a six-stage sampler, the two-stage sampler characteristically underestimated the numbers of fungi and bacteria. It appeared that the two-stage sampler did not collect the smallest propagules, i.e. those which are collected on the last two stages of the six-stage sampler. Although the disparity was least when the air contained <1000 propagules/m^3, Gillespie *et al.* (1981) suggested that unless the numbers were of this order it would be preferable to use the six-stage sampler.

4.2.4. *Centrifugal impaction samplers.* The Reuter centrifugal sampler (RCS) is a lightweight hand-held sampler. The RCS has become popular because of its portability; it has a rechargeable powerpack, is relatively quiet in operation and is about the size of a large flashlight. On these grounds, Casewell *et al.* (1986) suggested that it would be of particular value in epidemiological investigations. Air is drawn into the instrument by an impeller fan. The resulting centrifugal acceleration causes airborne particles to impact at high velocity onto agar contained in a plastic strip which lines the sampling cylinder. As has been identified by Muilenberg (1989), it is difficult to determine the flow rate (and therefore the collection efficiency) of this sampler, because intake and exhaust air pass through the same opening.

Several groups of investigators (Nakhla and Cummings, 1981; Placencia *et al.*, 1982; Casewell *et al.*, 1984) found that the RCS yielded significantly higher counts than slit-to-agar samplers when used at various laboratory and hospital locations. However, Clark *et al.* (1981) and Macher and First (1983) reported that in controlled tests the effective sampling rate and collection efficiency changed with particle size. Over a size range likely to be found in indoor air (2.3-20 μm diameter) the effective sampling rate varied from 50 to 170 litres/min and fell rapidly for particles <5μm in diameter (Clark *et al.*, 1981). The mean sampling rate (100 litres/min) was 2.5 times the manufacturer's declared rate of 40 litres/min. Laflamme and Miller (1992) reported that their controlled laboratory experiments with fungal spores were in accord with earlier findings from controlled studies with bacteria and other particles of known size (Clark *et al.*, 1981; Macher and First, 1983). They indicated that their work showed that the RCS collects fungal spores of different sizes and shapes - from the approximately spherical spores of *Penicillium viridicatum* (3-4 μm) to the large beaked spores of *Alternaria alternata* (20-63 x 9-18 μm) - with approximately equal efficiency, and that RCS counts will be similar to the absolute value within the useful range of the device (<3000 CFU/m^3 air). Clark *et al.* (1981) concluded that the sampler might be useful if the level of accuracy of the RCS was acceptable, as it might be in many studies, but Macher and First (1983) considered that the RCS would not be the sampler of choice for quantitative estimates of mixed microbial aerosols such as will be encountered in indoor air. Macher and First conceded that it would be useful for gathering qualitative data and for extended monitoring programmes which employ the same sampler throughout. Although Binnie (1987) subsequently concluded that the efficiency of the RCS for collection of fungi was comparable to that of the Andersen sampler, Verhoeff *et al.* (1990 a,b) indicated that for collection of culturable moulds in the field the RCS sampler was inferior to both a slit-to-agar sampler and the Andersen N6 sampler (Tables 9 and 10). However, Laflamme and Miller (1992) have pointed out that in the studies of Verhoeff and his colleagues the counts arrived at were

proportional to the sampling time of the samplers tested. After examining the basis for calculation of counts in the RCS, Kaye (1988) identified that the sampling rate quoted by the manufacturer applies only to 4 μm particles. He concluded that overestimation of collection efficiency had led to earlier reports of higher counts being obtained than with slit-to-agar samplers.

TABLE 10. Effect of sampler and collection medium on number of species isolated from air samples taken in houses (after Verhoeff *et al.*, 1990a)

Medium	Sampler				Mean/ medium
	Slit	SAS	N6	RCS	
MEA	4.5	3.8	5.2	4.3	4.5
DG18	6.8	5.8	6.7	4.2	5.9
DRBC	4.8	4.7	4.2	4.3	4.5
Mean/sampler	5.4	4.8	5.3	4.3	

4.2.5. *Filtration Samplers.* The principle of filtration sampling is that air is drawn through a filter on which entrained micro-organisms are trapped. An example of such a method is the CAMNEA method described by Palmgren *et al.* (1986a). Here, a Nuclepore polycarbonate membrane (pore size 0.4 μm) contained within a Millipore disposable filter cassette is used for trapping the organisms, which are then washed off with peptone water containing Tween 80 to wet hydrophobic spores. Dilutions prepared from the washings can then be plated out on a range of agar media and counts of culturable bacteria and fungi made. Because of the risk of dehydration of trapped micro-organisms by the air flow during collection, Palmgren *et al.* (1986a) used a constant flow pump operating at 1 litre/min for several hours. A flow rate of 4 litres/min and a membrane with 0.8 μm pores have been used in other studies (Crook *et al.*, 1991). As with liquid impingers (4.2.6), the system is not readily overloaded.

Since relatively small rechargeable pumps can be used with these aerosol monitor cassettes and the pumps are relatively quiet, it is possible for the assembly to be clipped to a belt or harness and used to collect a personal sample over the duration of a normal working day. Alternatively, a series of such samplers can be used at different work stations within a building for similarly extended periods.

4.2.6. *Liquid impingers.* In the simplest, or single-stage, liquid impinger, air is drawn by vacuum pump through a glass tube with a capillary orifice immersed in liquid. The liquid usually contains a wetting agent, such as Tween 80, to increase the efficiency of trapping hydrophobic spores. Particles impinge within the liquid onto either the base of the glass container, as in the Ace Glass AGI (all-glass impinger) types, or a suspended glass platform, as in the Greenburg-Smith impinger. A more advanced, well-designed type is the May three-stage glass impinger (May, 1966). In the first two stages, particles are removed from the air stream by impingement on wetted sintered glass discs; in the

third stage, the particles leaving a smooth curved glass jet impinge on the liquid on the glass side wall of the collection vessel. The cutoff particle diameters estimated for a nominal flow rate of 55 litres air/min are 6.0, 3.3 and 0.7 μm for the three collection stages, which are considered to approximate to the nasopharyngeal, tracheobronchial and alveolar regions of the respiratory system.

Since the impinger collects micro-organisms into liquid, the extent of trauma caused by dehydration during collection is likely to be less than in other types of sampler. However, the high velocity in the capillary jets may cause injury. An obvious disadvantage of using this type of sampler is that a fresh (sterile) unit must be used for each sample - the sample is conveyed in the impinger to the laboratory for analysis. A further point to be considered is the additional handling involved, i.e. dilutions of the collection liquid are made and aliquots plated out onto agar in the laboratory. Set against this, however, is the fact that the numbers of fungi and bacteria, and groups within these major categories, can be arrived at by plating out aliquots on a range of different media and incubating the plates at a variety of temperatures.

Judged by counts of the bacterium *Escherichia coli* obtained in simulated wastewater spray dispersion experiments, it appears that there is good correlation between the May three-stage impinger and the Andersen two-stage impactor (4.2.3), with the impinger giving counts which are on average 80% of those derived from the impactor (Zimmerman *et al.*, 1987). The May impinger has the advantage over the Andersen impactor (or other impactors) of not being subject to overloading where particle concentrations are high.

4.2.7. *Cyclone Samplers.* Another type of sampler which can be used to collect airborne micro-organisms in liquid is the cyclone sampler (Errington and Powell, 1969). With this type of sampler, air is drawn tangentially into an inverted cone along with water from a fine jet. The stream of air spirals down toward the bottom and then passes up through the centre to the outlet at the top of the conical space. As a consequence of centrifugal acceleration, water droplets and airborne particles are propelled against the wall of the cone. Coalescing water droplets wash the particles into a collection vessel below the cone. Like the liquid impinger, the cyclone can be run for extended periods, and by using cones of different geometry successively it is possible to collect fractions of different particle size. The collected suspension of particles is analysed for culturable micro-organisms in the same way as the collection liquid from liquid impingers (4.2.6).

4.2.8. *Culture Media and Incubation.* Although a great deal of attention has been given to the development and assessment of samplers for viable micro-organisms in air, much less thought has been given by aerobiologists to the media on which the organisms are isolated. Not all investigators even incorporate antibiotics such as chloramphenicol (Austwick *et al.*, 1989) or penicillin and streptomycin (Hunter *et al.*, 1988) to prevent bacteria growing on plates used for the isolation of fungi, or cycloheximide (Austwick *et al.*, 1989) to prevent fungal growth on plates for bacteria. It is not just the presence or absence of antibiotics which influences what is isolated; nutrient composition, pH and a_w are also extremely important.

For primary isolation of bacteria, a general purpose medium with a pH around 7.0 is used, e.g. nutrient agar (Austwick *et al.*, 1989) or tryptone soya agar (TSA). Because of the carbohydrate in TSA, there is a greater chance of isolating nutritionally fastidious bacteria. However, set against this is the risk of overgrowth and masking of slower

growing species by rapidly growing types such as *Bacillus*. For isolation of some bacteria, such as *Legionella pneumophila*, highly selective media are necessary. The possibility of problems with overgrowth on rich media is generally greater with fungi. For example, the medium recommended by the American Conference of Governmental Industrial Hygienists (ACGIH, 1989) for primary isolation of fungi is a malt extract agar of pH 4.5-5.0. The ACGIH formulation for this medium is 20 g malt extract, 20 g dextrose, 1 g peptone and 20 g agar per litre. From calculations based on the quoted composition of dehydrated malt and peptone, this medium appears to contain approximately 34 g of easily utilised sugars (dextrose and maltose) per litre. This is even richer than the malt extract agar formulation used earlier by Burge *et al.* (1977), which contained 32 g malt extract and 1 g yeast extract per litre, i.e. approximately 22.5 g dextrose/maltose per litre. In our investigations (Hunter *et al.*, 1988; Strachan *et al.*, 1990) and those of Austwick *et al.* (1989), agar medium containing only 2% malt extract has been used. This contains only about 14 g dextrose/maltose per litre. Isolation plates therefore suffer less from rapidly growing moulds such as *Fusarium* and members of the Mucorales (*Mucor, Rhizopus* and *Absidia*), and are satisfactory for isolating other fungi. A medium which does restrict growth of most of these fungi, and others, is dichloran rose bengal chloramphenicol (DRBC) agar. However, in field trials Verhoeff *et al.* (1990a,b) found that DRBC gave counts lower than on malt extract agar (Table 9).

Although a wide range of fungi can be isolated on media like these, because of the high a_w slow growing xerophilic fungi are at a competitive disadvantage against more hydrophilic fungi and may not be detected. As has been mentioned earlier, it has recently been shown that some xerophilic fungi such as *Wallemia sebi* are allergenically important (Torii *et al.*, 1990) Members of the *Aspergillus glaucus* group have been noted in some studies, e.g. those of Miller *et al.* (1988) and Hunter *et al.* (1988), but other xerophiles such as *A. penicillioides* and *W. sebi* have seldom been noted. One reason for this is the failure of many investigators to appreciate the need to use low a_w media in addition to general purpose media. In our laboratory, we have been able to isolate *W. sebi* from housedust with increased frequency by incorporating 10% (w/v) sodium chloride in malt extract agar to reduce the a_w. Other workers have added 20% or more sucrose to achieve this (Miller *et al.*, 1988; Elixmann *et al.*, 1990). Verhoeff *et al.* (1990a) found that dichloran-glycerol agar (DG18) was suitable. In DG 18 agar, which is widely used in food analysis, 18% glycerol is included to reduce the a_w. Verhoeff and his colleagues (1990a) isolated a greater number of species and recorded higher counts on DG18 than on malt extract agar (Tables 9 and 10). However, in recent experiments in our laboratory we have found that, while DG18 is eminently suitable for isolation of xerophiles and many other fungi in indoor air, hydrophilic fungi such as *Stachybotrys* and *Trichoderma* are not isolated on this medium. Other hydrophilic fungi which can form a major portion of the air spora in British houses (Hunter *et al.*, 1988) and are unlikely to be isolated on low a_w media are *Sistotrema brinkmannii* and other Basidiomycetes. It is therefore clear that no thorough investigation of the fungi in indoor air can be made using a single medium.

The temperature at which isolation plates are incubated is extremely important. With relatively few notable exceptions, e.g. that of Austwick *et al.*(1989), has more than one temperature been used. There has been a tendency to incubate plates for isolation of bacteria at 37°C, largely because it is the temperature used to isolate human pathogens. However, it is possible that bacteria which grow at lower temperatures in the indoor environment could be of significance, e.g. as allergens. It is also the case that incubation

at lower temperatures slows the growth of rapidly spreading types, such as Bacillus, and therefore facilitates counting of bacteria which might otherwise have been overgrown. On the other hand, a temperature of 55°C is desirable for isolation of the allergenic thermophilic Actinomycetes, *Faenia rectivirgula* and *Thermactinomyces vulgaris*. Likewise, with fungi the tendency has been to incubate plates only at 25°C, or thereabouts. However, additional incubation at 37°C (Austwick *et al.*, 1989) is likely to increase the numbers of thermotolerant/thermophilic fungi isolated, including the allergenic and pathogenic mould *Aspergillus fumigatus*.

4.3. SAMPLING METHODS FOR TOTAL MICRO-ORGANISMS

4.3.1. *Rotating-Arm Impaction Samplers.* As implied by the name, these samplers collect airborne particles which impact on the collection surface of a rotating arm. Although the collection surfaces which are employed include metal bars covered by sticky tape and microslides with a 1mm adhesive-coated edge, perhaps the most frequently used sampler, the Rotorod sampler produced by Sampling Technologies Inc., employs suspended plastic "I"-section rods coated with silicon grease. The relatively wide collection surface (1.5 mm in width) of the rods, which swing out in use, means that the collection efficiency rapidly decreases for particles of <10-15 μm diameter. Although the Rotorod sampler may be reasonably efficient for collection of large-spored fungi such as *Alternaria alternata*, for the majority of fungi it is much less efficient. By counting the trapped spores under the microscope and calculating the volume of air to which the rotating collection surface was exposed the airborne concentration can be arrived at. However, particular care has to be taken in dealing with the plastic rods if satisfactory results are to be achieved (Muilenberg,1989).

4.3.2. *Slit-type Impaction Samplers.* In the 7-day recording volumetric spore sampler produced by Burkard Manufacturing Co. for indoor operation airborne particles impact on a gel-coated plastic tape on a drum which rotates below the sampling slit. After exposure, the tape is cut into sections, each corresponding to 24 h and attached to glass slides for counting of fungal spores under the microscope (or for storage). The collection efficiency for spores in the 3-15 μm range is much higher than in the Rotorod sampler. However, counting is demanding and time-consuming. Although large and/or dark-coloured spores are readily visible, e.g. *Alternaria, Cladosporium* and *Stachybotrys*, smaller and hyaline spores are often difficult to distinguish among dust particles, etc. In addition, it is seldom possible to distinguish between the small spherical or subspherical spores of different species of *Aspergillus* or *Penicillum* on the tape.

As well as the 7-day recording sampler, there is a rechargeable Burkard "personal" sampler which uses a conventional glass microscope slide. It is smaller and much more portable than the 7-day sampler, and the sampling time can be from 15 sec to 30 min.

4.3.3. *Other samplers.* Although adhesive-covered microscope slides can be used as passive gravitational samplers, sampling in this way has deficiencies similar to those mentioned for settle plates (4.2.1). A more successful method involves collection on a Nuclepore membrane filter as outlined for the CAMNEA method (4.2.6). An aliquot of the washings from the membrane is stained with acridine orange, filtered through a blackened membrane filter and examined under an epifluorescence microscope (Palmgren

et al., 1986). There is no reason why the collection fluid from a liquid impinger should not be examined by this direct epifluorescence filter technique (DEFT). Acridine orange staining is considered to impart an orange fluorescence to active (or viable) bacteria and a green fluorescence to inactive (or non-viable) bacteria. However, this is not a reliable distinction (Pettipher *et al.*, 1980) and in the present author's experience it can only be used to give a total count, i.e. orange- plus green-fluorescent micro-organisms. Counting is an arduous process, but it would seem possible to automate counting by using a microscope fitted with an image analyser and a computer-controlled mechanical stage.

4.4. CHOICE OF SAMPLER

Whichever of the available range of samplers are chosen for studies, they must meet the need for accurate qualitative and quantitative information. The qualitative information required is the identity of the various components of the air spora. Microscopical examination of the deposited spores on the collection surface of, for example, a Rotorod (4.3.1) or Burkard (4.3.2) sampler may enable some airborne fungi to be identified, but the use of a "viable" sampler offers the best means at present of identifying most micro-organisms, either directly from the isolation plates or after subculturing from these plates. Since airborne propagules range in size from the 1 or 2 μm diameter of some bacteria or Actinomycetes to the 20 μm or more of some moulds, the choice of sampler is important for qualitative and quantitative reasons. A sampler with a cutoff at a particle size of 4 μm would not be appropriate for either qualitative or quantitative investigation of a problem which could be caused by growth of thermophilic Actinomycetes in a HVAC system.

When published work is consulted for guidance in choosing a sampler, care has to be exercised in interpreting both field trials and carefully controlled laboratory investigations of sampler performance. As with any branch of biological science, valid comparison between one study and another can rarely be made because of differences in experimental conditions. In laboratory studies, different organisms and different microbial concentrations have been used; in field trials, location (and therefore types and numbers of micro-organisms), medium and incubation regime have been different; and in both laboratory and field studies, neither have the same ranges of samplers nor the same sampling times and volumes been used. There is little evidence of the type of inter-laboratory collaborative trials which are seen as an important part of methodological investigation in food microbiology. When it is considered that the concentration of propagules in the environment to be investigated may range from <100 in a house or office to $>10^9$ where mouldy agricultural products are being handled, the value of collaborative trials in enabling sound guidance to be drawn up is patent. Nevertheless, it will be appreciated that, for example, while the Andersen N6 (4.2.3) sampler might be recommended for investigation of low level contamination in a domestic or office environment, it will never be so for a heavily contaminated agricultural environment.

Nevalainen *et al.* (1992) have examined the collection characteristics of four impaction samplers, i.e. the Casella Mark II slit sampler (4.2.2), the Andersen six-stage (treating stage 1 and stage 6 as separate sampling devices) and SAS sieve-type samplers (4.2.3) and the Burkard personal sampler (4.3.2). They have suggested that the optimum density for counting micro-organisms impacting on collection surfaces of samplers is 1 propagule/cm^2 for agar plates (i.e. 64 colonies/9.0 cm plate) and 10^4 particles/cm^2 on the glass slide of the Burkard sampler (3 particles/200 μm microscope field at a magnification

of 1000x). It is calculated that to achieve this optimum from air containing 10^3 biological particles/m^3 the sampling time would be for the SAS sampler 8 sec; stage 6 of the Andersen sampler 2.6 min; stage 1 of the Andersen sampler 17.7 min; and the Burkard sampler 140 min. Nevalainen and her colleagues conclude that a short-period sampler collecting onto agar is therefore best employed either where propagule concentrations are very low and permit longer sampling times or when a series of shorter samples can be taken to reduce bias resulting from temporal fluctuation in numbers. They also note that, when the sampling time of the Burkard is reduced to the 5-10 min usually employed in the field because of overloading with dust particles, it may introduce sampling bias due to temporal fluctuation in numbers and also low surface density of particles on the collection slide.

As Nevalainen *et al.* (1992) have pointed out, in field trials the efficiency of the sampler is most often viewed only in terms of the counts obtained. It tends to be forgotten that both physical and biological factors are involved. Overall efficiency is compounded from the ability of the sampler to remove particles from the ambient air (inlet sampling efficiency); the ability to extract particles from the airstream and deposit them on the isolation medium (collection efficiency); and to carry out these functions without reducing the ability of the bioparticles to grow. To sampling bias caused by these sampler-related factors can be added (a) statistical bias in analysis resulting from selection of the wrong sampler for the circumstances or an inappropriate sampling period, and (b) further bias due to the use of unsuitable media or conditions of incubation. It is only when the individual contribution of each of these factors is known that a sampler be truly evaluated.

A further factor which should be taken into account is that non-viable spores (or cells) of allergenic and toxigenic micro-organisms are likely to contain as much allergen or toxin as their viable counterparts, and will produce the same medical effects. There is therefore a strong case to be made for assessing the total bioburden in the air, not just the fraction which can be readily cultured. This is graphically illustrated in a report by Kozak *et al.* (1979), who were unable to determine by means of an Andersen sampler the cause of recurrent asthma attacks in a child. It was only by using a Rotorod sampler that they were able to detect the distinctive spores of *Stachybotrys atra,* and to discover that growth of this organism in a damp carpet was the cause of the asthma. The failure to detect *S. atra* using the Andersen sampler was due to only about 1% of the spores being culturable.

Earlier work outdoors (Burge *et al.*, 1977) showed that at levels of *Cladosporium* above 500 spores/m^3 (as assessed using a Burkard recording sampler) the count on Andersen plates fell below 5% of the total count. Various other types were also recovered less frequently and less abundantly by the Andersen sampler than by the Burkard sampler, e.g. *Alternaria, Botrytis, Epicoccum* and *Torula*. More recently, Palmgren *et al.* (1986a,b) used the CAMNEA method to investigate a range of different work-related environments and reported that the viable (CFU) count ranged from as little as 1% to 100% of the corresponding total count. Not only were there considerable differences in the viable fraction between the various environments, but the fraction changed markedly within individual environments. Although a high correlation was observed between viable and total counts where the airborne flora was dominated by fungi, there was low correlation in the case of bacteria. The differences which can occur in the culturable fraction gathered by a Nuclepore filter, in terms of absolute numbers and relationship to the total count, can be seen in Table 11. As might be expected, the counts of culturable organisms obtained over a period of 4 h in this way can also be quite different from grab

samples taken with a six-stage Andersen sampler. Ström *et al.* (1990) found that the numbers of viable airborne organisms in both "sick" and "healthy" buildings were much lower than the total numbers. They were also significantly lower than the numbers of viable organisms in outdoor air.

TABLE 11. Counts of micro-organisms obtained using different sampling methods in a restaurant

	Count (CFU/m^3 air)						
	Andersen sampling			CAMNEA method			
				Plate count		DEFT method	
Area	Before open	Mid-day	Early evening	a.m.	p.m.	a.m.	p.m.
Pantry							
Moulds	212	141	129	3160	920	10200	7260
Bacteria	224	152	208	138	625	34910	5100
Kitchen							
Moulds	812	334	506	n.s.	n.s.	n.s.	n.s.
Bacteria	212	127	527	n.s.	n.s.	n.s.	n.s.
Dining							
Moulds	35	565	24	521	348	2010	12360
Bacteria	106	244	88	417	1180	43250	13580

n.s., not sampled

5. Conclusion

Since experimental evidence indicates that bacterial endotoxins produce symptoms of humidifier fever (Rylander, 1986), and since Dales *et al.* (1991b) have put forward the hypothesis that respiratory symptoms attributed to indoor moulds may be provoked by non-allergic rather than allergic mechanisms, there is a strong argument for giving more attention to the possible effects of inhalation of toxigenic fungi. As Sorensen (1989) and Miller (1990) have discussed, spores of toxigenic moulds can contain large concentrations of mycotoxins, which may affect respiratory well-being by inhibiting functions such as those of alveolar macrophages. One toxigenic species which calls for special attention is *Stachybotrys atra*, which grows on wallpaper and other cellulosic substrates in damp houses. There are toxigenic species of *Aspergillus* and *Penicillium* which are more frequently encountered in indoor air, but *S. atra* is particularly notable for the potency of macrocyclic trichothecene mycotoxins it produces. As well as being implicated in health

problems among occupants of a Chicago home (Croft *et al.*, 1986) and a Québec hospital (Mainville *et al.*, 1988), it caused severe irritation of the respiratory system in workers who removed heavily contaminated materials from the Chicago home. Detection of this fungus in the air spora of any building calls for investigation of the building to determine and eliminate the source of the spores, bearing in mind that if the sampling method depends on culture the count obtained is likely to be only a small fraction of the total burden in the air. As Palmgren *et al.* (1986a) pointed out when they found that the total counts obtained by the CAMNEA method consisted largely of micro-organisms which could be regarded as respirable (i.e. with an aerodynamical diameter <5 μm), both viable and total counts are necessary if possible respiratory risk is to be evaluated.

Finally, we must consider microbial volatiles. Although most fungal volatiles for which information is available appear to be of a relatively low order of toxicity (Sorenson, 1989), some can provoke acute respiratory responses in humans. Nevalainen *et al.* (1990) and Ström *et al.* (1990) have noted that in Scandinavian homes odours may be due to geosmin produced by Actinomycetes, but Ström *et al.* (1990) have also observed that some fungi which colonise damp building materials are additional geosmin producers, e.g. *Chaetomium*. However, Miller *et al.* (1988) reported that some of the commonest volatiles known to be produced by moulds also appeared to have other sources in the homes which they investigated. As there appears to be little evidence of significant qualitative or quantitative difference between sick buildings and unaffected buildings (Austwick *et al.*, 1989; Ström *et al.*, 1990), the need to investigate further both microbial toxins and volatiles must be added to the need for improved assessment of the air spora.

6. References

ACGIH (1989) Guidelines for the Assessment of Bioaerosols in the Indoor Environment, American Conference of Governmental Industrial Hygienists, Cincinnati.

Andersen, A.A. (1958) 'New sampler for the collection, sizing, and enumeration of viable airborne particles', J. Bacteriology 76, 471-484.

Austwick, P.K.C., Davies, P.S.,Cook, C.P. and Pickering , C.A.C. (1986) 'Comparative microbiological studies in humidifier fever', in C. Molina (ed.), Maladies des Climatiseurs et de Humidificateurs', INSERM, Paris, pp. 155-164.

Austwick, P.K.C., Little,S.A., Lawton, L., Pickering, C.A.C. and Harrison, J. (1989) 'Microbiology of sick buildings', in B. Flannigan (ed.), Airborne Deteriogens and Pathogens, The Biodeterioration Society, Kew, pp. 122-128.

Beaumont, F., Kauffman, H.F., Sluiter, H.J. and de Vries, K. (1985) 'Volumetric aerobiological survey of conidial fungi in the North-East Netherlands. II. Comparison of aerobiological data and skin tests with mould extracts in an asthmatic population', Allergy 40, 181-186.

Binnie, P.W.H. (1987) 'Airborne microflora in Florida homes', Proceedings, Fourth International Conference on Indoor Air and Climate, Berlin, Vol. 1, pp. 660-664.

Bourdillon, R.B., Lidwell, O.M. and Thomas, J.C. (1941) 'A slit sampler for collecting and counting airborne bacteria', J. Hygiene 41, 197-224.

Brunekreef, B., Dockery, D.W., Speizer, F.E., Ware, J.H., Spengler, J.D. and Ferris, B.G. (1989) 'Home dampness and respiratory morbidity in children', American Review of Respiratory Disease 140, 1363-1367.

Burge, H.P., Boise, J.R., Rutherford, J.A. and Solomon, W.R. (1977) 'Compar-

ative recoveries of airborne spores by viable and non-viable modes of volumetric collection', Mycopathologia 61, 27-33.

Casewell, M.W., Desai, N. and Lease, E.J. (1986) 'The use of the Reuter centrifugal air sampler for the estimation of bacterial air counts in different hospital locations', J. Hospital Infection 7, 250-260.

Casewell, M.W., Simmons, N.A., Fermie, P.G. and Thomas, C. (1984) 'Bacterial air counts obtained with a centifugal (RCS) sampler and a slit sampler - the influence of aerosols', J. Hospital Infection 5, 76-82.

Clark, S., Lach, V. and Lidwell, O.M. (1981) 'The performance of the Biotest RCS centrifugal air sampler', J. Hospital Infection 2, 181-186.

Croft, W.A., Jarvis, B.B. and Yatawara, C.S. (1986) 'Airborne outbreak of trichothecene toxicosis', Atmospheric Environment 20, 549-552.

Crook, B., Robertson, J.F., Travers Glass, S.A., Botheroyd, E.M., Lacey, J. and Topping, M.D. (1991) 'Airborne dust, ammonia, micro-organisms, and antigens in pig confinement houses and the respiratory health of exposed farm workers', American Industrial Hygiene Association J. 52, 271-279.

Dales, R.E., Burnett, R. and Zwanenburg, H. (1991a) 'Adverse health effects in adults exposed to home dampness and molds', American Review of Respiratory Disease 143, 505-509.

Dales, R.E., Zwanenburg, H., Burnett, R. and Franklin, C.A. (1991b). 'Respiratory health effects of home dampness and molds among Canadian children, American J. Epidemiology 134,196-203.

Elixmann, J.H., Schata, M. and Jorde,W. (1990) 'Fungi in filters of air-conditioning systems cause the building-related-illnesses', in D.S. Walkinshaw (ed.), Indoor Air '90, Vol. 1, CMHC, Ottawa, pp.193-196.

Errington, F.P. and Powell, E.O. (1969) 'A cyclone separator for sampling in the field' J. Hygiene, Cambridge 67, 387-399.

Flannigan, B. (1991) 'Deteriogenic micro-organisms in houses as a hazard to respiratory health', in H.W. Rossmoore (ed.), Biodeterioration and Biodegradation 8, Elsevier Applied Science, London, pp. 220-233.

Flannigan, B., McCabe, E.M. and McGarry, F. (1991) 'Allergenic and toxigenic micro-organisms in houses', J. Applied Bacteriology 70 (supplement), 61S-73S.

Flannigan, B. McCabe, E.M., McGarry, F. and Strachan, D.P. (1990) 'Wheeze in children: an investigation of the air spora in the home', in D.S. Walkinshaw (ed.), Indoor Air '90, Vol. 2, CMHC, Ottawa, pp. 27-32.

Fradkin, A., Tobin, R.S. Tarlo, S.M., Tucic-Porretta, M. and Malloch, M. (1987) 'Species identification of airborne molds and its significance for the detection of indoor pollution', J. Air Pollution Control Association 37, 51-53.

Gillespie, L., Clark, C.S., Bjornson, H.S., Samuels, S.J. and Holland, J.W. (1981) 'A comparison of two-stage and six-stage impactors for viable aerosols', American Industrial Hygiene Association J. 42, 858-864.

Grant, C., Hunter, C.A., Flannigan, B. and Bravery, A.F. (1989) 'The moisture requirements of moulds isolated from domestic dwellings', International Biodeterioration 25, 259-284.

Hunter, C.A.,Grant, C., Flannigan, B. and Bravery,A.F. (1988) 'Mould in buildings: the air spora of domestic dwellings', International Biodeterioration 24, 81-101.

Jones, W., Morring, K., Morey, P. and Sorenson, W. (1985) 'Evaluation of the Andersen viable impactor for single stage sampling', American Industrial Hygiene Association J. 46, 294-298.

Kaye, S. 1988. ' Efficiency of "Biotest RCS" as a sampler of airborne bacteria', J. Parenteral Science and Technology 42, 147-152.

Kozak, P.P.,Gallup, J., Cummins, L.H. and Gillman, S.A. (1979) 'Currently available methods for home mold surveys II. Examples of problem homes surveyed', Annals of Allergy 45, 167-176.

Lach, V. (1985) 'Performance of the surface air system air samplers' J. Hospital Infection 6, 102-107.

Laflamme, A.-M. and Miller, J.D. (1992) 'Collection of spores of various fungi by a Reuter centrifugal sampler', International Biodeterioration (in press).

Kreiss, K. and Hodgson, M.J. (1984) 'Building-associated epidemics', in P.J. Walsh, C.S. Dudney and E.D. Copenhaver (eds.), Indoor Air Quality, CRC Press, Boca Raton, pp. 87-106.

Leinster, P., Raw, G., Thomson, N., Leaman, A. and Whitehead, C. (1990) 'A modular longitudinal approach to the investigation of sick building syndrome', in D.S. Walkinshaw (ed.), Indoor Air '90, Vol. 1, CMHC, Ottawa, pp. 287-292.

Macher, J.M. and First, M.W. (1983) 'Reuter centrifugal air sampler: measurement of effective airflow rate and collection efficiency', Applied and Environmental Microbiology 45, 1960-1962.

Mainville, C., Auger, P.L., Smorgawiewicz, W., Neculcea, D., Neculcea, J. and Lévesque, M. (1988) 'Mycotoxines et syndrome d'extreme fatigue dans un hopital', in B. Petterson and T. Lindvall (eds.), Healthy Buildings '88, Swedish Council for Building Research, Stockholm, pp. 309-317.

Mathews, K.P., (1989) 'Inhalant insect-derived allergens', Immunology and Allergy Clinics of North America 9, 321-328.

May, K.R. (1966) ' Multistage liquid impinger', Bacteriological Reviews 30, 559-570.

Miller, J.D., (1990) 'Fungi as contaminants in indoor air', in D.S. Walkinshaw (ed.), Indoor Air '90, Vol. 5, CMHC, Ottawa, pp. 51-64.

Miller, J.D., Laflamme, A.M., Sobol, Y., Lafontaine, P. and Greenhalgh, R. (1988) 'Fungi and fungal products in some Canadian houses', International Biodeterioration 24, 103-120.

Muilenberg, M. M. (1989) 'Aeroallergen assessment by microscopy and culture', Immunology and Allergy Clinics of North America 9, 245-268.

Nakhla, L.S. and Cummings, R.F. (1981) 'A comparative evaluation of a new centrifugal air sampler (RCS) with a slit air sampler (SAS) in a hospital environment', J. Hospital Infection 2, 261-266.

Nevalainen, A., Jantunen, M.J., Rytkönen, A., Niininen, M., Reponen, T. and Kalioloski, P. (1988) 'The indoor air quality of Finnish homes with mold problems', in B. Petterson and T. Lindvall (eds.), Healthy Buildings '88, Swedish Council for Building Research, Stockholm, pp. 309-317.

Nevalainen, A., Kotimaa, M., Pasanen, A.L., Pellikka, M., Niininen, M., Reponen, T. and Kalliokoski, P. (1990) 'Mesophilic actinomycetes - the real indoor air problem?', in D.S. Walkinshaw (ed.), Indoor Air '90, Vol. 1, CMHC, Ottawa, pp. 203-206.

Nevalainen, A., Pastuszka, J., Liebhaber, F. and Willeke, K. (1992) 'Performance of bioaerosol samplers: collection characteristics and sampler design considerations', Atmosperic Environment (in press).

Palmgren, U., Ström, G.,Blomquist, G. and Malmberg, P. (1986a) 'Collection of airborne micro-organisms on Nuclepore filters, estimation and analysis - CAMNEA method', J. Applied Bacteriology 61, 401-406.

Palmgren, U., Ström, G., Malmberg, P. and Blomquist, G. (1986b) 'The Nuclepore filter method: a technique for enumeration of viable and nonviable airborne micro-organisms', American J. Industrial Medicine 10, 325-327.

Pettipher, G.L., Mansell, R., McKinnon, C.H. and Cousins, C.M. (1980) 'Rapid membrane filtration-epifluorescent microscopy technique for direct enumeration of bacteria in raw milk', Applied and Environmental Microbiology 39, 423-429.

Placencia, A.M., Peeler, J.T., Oxborrow, G.S. and Danielson, J.W. (1982) 'Comparison of bacterial recovery by Reuter centrifugal air sampler and slit-to-agar sampler', Applied and Environmental Microbiology 44, 512-513.

Rylander, R. (1986). 'The role of endotoxins in humidifier disease', in C. Molina (ed.), Maladies des Climatiseurs et des Humidificateurs, INSERM, Paris, pp. 179-192.

Schata, M., Elixmann, J.H. and Jorde, W. 'Evidence of heating systems in controlling house-dust mites and moulds in the indoor environment', in D.S. Walkinshaw (ed.), Indoor Air '90, Vol. 4, CMHC, Ottawa, pp. 577-581.`

Sorenson, W.G. (1989) 'Health impact of mycotoxins in the home and workplace: an overview', in C.E. O'Rear and G.C. Llewellyn (eds.), Biodeterioration Research 2, Plenum, New York, pp. 201-215.

Staib, F. (1984) 'Ecology and epidemiological aspects of aspergilli pathogenic for man and animals in Berlin (West)', Zentralblatt für Bakteriologie und Hygiene, Abteilung I, Originale A 257, 240-245.

Strachan, D.P. (1988) 'Damp housing and childhood asthma: validation of reporting of symptoms', British Medical Journal 297, 1223-1226.

Strachan, D.P., Flannigan, B., McCabe, E.M. and McGarry, F. (1990) 'Quantification of airborne moulds in the homes of children with and without wheeze', Thorax 45, 382-387.

Ström, G., Palmgren, U., Wessen, B., Hellström, B. and Kumlins, A. (1990) 'The sick building syndrome - an effect of microbial growth in building constructions?', in D.S. Walkinshaw (ed.), Indoor Air '90, Vol. 1, CMHC, Ottawa, pp.173-178.

Torii, S., Sakamoto, T. and Matsuda, Y. (1990) 'Significance of xerophilic fungi in indoor environment - allergenic and antigenic activities of the xerophilic fungi in asthmatic patients', IUMS Congress of Bacteriology and Mycology, Osaka, Japan, Abstracts, p.30.

Verhoeff, A.P., van Wijnen, J.H.,Boleij, J.S.M., Brunekreef, B., van Reenen-Hoekstra, E.S. and Samson, R.A. (1990a) 'Enumeration and identification of airborne viable mould propagules in houses', Allergy 45, 275-284.

Verhoeff, A.P., van Wijnen, J.H., Fischer, P., Brunekreef, B., Boleij, J.S.M., van Reenen- Hoekstra, E.S. and Samson,R.A. (1990b) 'Presence of viable mould propagules in indoor air of houses', Toxicology and Industrial Health 6, 133-145.

Verhoeff, A.P., van Wijnen, J.H., Brunekreef, B., Fischer, P., van Reenen-Hoekstra, E.S. and Samson, R.A. (1992) 'The presence of viable mould

propagules in indoor air in relation to home dampness and outdoor air', Allergy (in press).

Waegemaekers, M., van Wageningen, N., Brunekreef, B. and Boleij, J.S.M. (1989). 'Respiratory symptoms in damp houses', Allergy 44, 192-198.

Zimmerman, N.J., Reist, P.C. and Turner, A.G. (1987) 'Comparison of two biological aerosol sampling methods', Applied and Environmental Microbiology 53, 99-104.

Irritation of the upper airways. Mechanisms and structure-activity relationships

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ABSTRACT. Irritation from the eyes and nose, termed sensory irritation, is the effect mediated by the trigeminal nerves. The effect is quantified by psychophysical methods, by electrophysiological methods or from the reflexively induced effect. The first step in the generation of the irritation response occurs due to interaction between an airborne substance and a protein receptor in the nerve. The classical receptor theory and the tools known from medicinal chemistry can therefore be applied also to the sensory irritation processes. The "linear free energy models" and the "thermodynamic activity" concepts are discussed in depth. Both these methods, if combined with rational test strategies, offer the possibility, in a cost-efficient manner, to give estimates on effects of non-tested substances. The basic biological knowledge on sensory irritation is far behind the knowledge on the exposure concentrations in the indoor environment. This seriously limits the possibility of interpreting the chemical measurements.

1. Introduction

Irritation of eyes and nose due to exposure to airborne chemicals is termed sensory irritation (Alarie 1973a). Such sensations are typically described as irritation sensations, as cool, warm, itching, piquancy, pungency, stinging, tickling and they can increase to a painful and burning sensation with tearing and nasal secretion (Alarie 1973a, Doty et al. 1978, Nielsen 1991). The chemicals activate free nerve endings close to the surface of the nasal mucosa (Kane and Alarie 1977, Finger et al. 1990, Silver 1990). The nerves belong to the V cranial nerve, the trigeminal nerve (Alarie 1973a, Finger et al. 1990, Nielsen 1991, Silver 1990). The activation processes follow many of the characteristics of receptor mediated processes. Due to these similarities, which will be discussed below, the techniques from the classical receptor theory can also be applied for investigation of sensory irritation effects.

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2. Methods used for determination of sensory irritation

Three methods have been used for investigation of sensory irritation in humans and in animals. The methods are based on psychophysical, electrophysiological and reflexively induced effects, for details and further references, see Nielsen and Alarie (1992).

Psychophysical methods have been used most extensively in humans. The results are given either as a proportion of individuals responding at a given exposure level or by giving a magnitude of perceived intensity. Wood (1979 and 1981) developed a psychophysical bioassay for investigations in animals. An airborne irritant was introduced into the exposure chamber with a mouse. The mouse was able to terminate the delivery by poking its nose into a recess in the chamber wall with a photosensor and a light beam. Interrupting the light beam terminated the delivery of the irritant. The fraction of responding animals and the mean time to interrupt the exposure were determined as a function of the exposure concentration. In another animal model (Tepper et al. 1985) mice or rats were housed in individual cages, each fitted with a running wheel. The decrease in running activity was determined as a function of the exposure concentration.

Sensory irritation has been investigated by means of cerebrally evoked potentials. This electrophysiological technique offers an objective method for investigation of trigeminal effects in humans (Kobal and Hummel 1990). The technique is not used for that purpose in animal investigations. Surface potentiales can be obtained in the nasal mucosa of humans in relation to sensory irritation and therefore could be related to a trigeminal effect. This method has a counterpart in the extensively used animal model where electrical potentials are obtained from trigeminal nerve branches (Silver and Moulton 1982, Silver et al. 1986, Silver 1990).

Reflexively induced inhibition of respiration has been used as an indicator of the sensory irritating effect in humans (Cain 1990) and in animals (Alarie 1973a). The animal model has now become a standard test method adopted by ASTM (1984) and the model has been used extensively for the evaluation of effects of pure substances and many different types of products (Nielsen and Alarie 1992), including building materials (Hansen et al. 1991). The sensitivity of the ASTM (1984) method has been found to be equal to the sensitivity of the other animal models.

3. Receptor occupation

The interaction between the sensory irritant receptor and substances which can activate the receptor can be caused either by physical adsorption to the receptor or through a chemical reaction with the receptor. The activating substance is termed an agonist (A). The activation processes can generally be assumed to be reversible bimolecular reactions (Alarie 1973b, Nielsen 1991).

$$A + R \rightleftharpoons AR \qquad (1)$$

This reaction follows the law of mass action. The agonist concentration in the biophase (synonymous with the receptor phase and the receptor compartment), the concentration of the free receptors, the concentration of the occupied receptors and the total receptor concentration are termed [A], [R], [AR] and R_T, respectively. Using the law of mass action and that R_T = [R] + [AR] (Brink 1977, Kenakin 1987) results in:

$$[AR] = \frac{R_T \cdot [A]}{K_D + [A]} = \frac{R_T \cdot [A]}{1/K_A + [A]} \qquad (2)$$

where K_D is the dissociation constant and $K_A = 1/K_D$ is the affinity constant. In general, equation 2 forms the basis for direct radioligand binding studies. Binding studies can determine R_T and K_A but they cannot distinguish between full agonists, partial agonists and antagonists (Tallarida 1988) nor can the studies distinguish between active and inactive receptors (Tallarida 1988).

4. Receptor activation

Binding studies are lacking in relation to sensory irritation and information about affinities have been obtained indirectly from biological investigations (Alarie 1973b, Kane and Alarie 1978, Kristiansen et al. 1986, Kristiansen et al. 1988, Nielsen and Vinggaard 1988, Nielsen and Yamagiwa 1989). This being the case, further parameters have to be introduced to relate the biological response and receptor occupancy.

The first step after the occupancy is that the receptor-agonist complex is transformed into an active conformation, which thereby gives rise to a stimulus (S). The stimulus is proportional to the number of occupied receptors and the proportionality constant, e, is the intrinsic efficacy (Kenakin 1987 and 1989) which also reflects the intrinsic activity and the efficacy. The investigated biological response may be indicated for example by the electrical activity of a nerve, by a biochemical change of the level of an intracellular response or by another biological response. The relation between the response, E_A, and receptor occupancy can be written as (Brink 1977, Kenakin 1987 and Kenakin 1989):

$$E_A = F(S) = F(e \cdot [AR]) = F\left(\frac{e \cdot R_T \cdot [A]}{K_A + [A]}\right) \qquad (3)$$

Due to the fact that the relation between the stimulus and effect is unknown and in many cases

is a nonlinear function (Brink 1977, Kenakin 1987) equation 3 should ideally be handled by the pharmacological "null procedures" (Kenakin 1987 and 1989).

Only the simplest case of the receptor occupation theory has been applied within sensory irritation. In this case the relation between the stimulus and the response was assumed to be directly proportional (g):

$$E_A = g \cdot S = \frac{g \cdot e \cdot R_T \cdot [A]}{K_A + [A]} = \frac{E_{Amax} \cdot [A]}{K_A + [A]} \qquad (4)$$

The maximum response E_{Amax} is equal to $g \cdot e \cdot R_T$. As e is a substance dependent constant this is also the case for the maximum response. When equation 4 is used for the estimation of affinities and maximum responses it must, however, always be borne in mind that a nonlinear stimulus-effect relationship could influence the reliability of the estimates.

5. Influence of distribution to the biophase

In equation 2 and 4 the molar concentration [A] is measured in the biophase. However, only the concentration in the exposure air "[A]air" is known. At equilibrium the exposure concentration in the air is related to the concentration in the receptor compartment via the partition coefficient, $P_{R/A}$ = [A]/[A]air. When introduced in equation 4, this would result in:

$$E_A = \frac{E_{Amax} \cdot [A]air}{K_D/P_{R/A} + [A]air} = \frac{E_{Amax} \cdot [A]air}{\frac{1}{K_A \cdot P_{R/A}} + [A]air} \qquad (5)$$

The maximum response is the same in equation 4 and equation 5. Equation 5 is formally equivalent to equation 4 if defining the apparent dissociation constant, $K_{D,app} = K_D/P_{R/A}$, and the apparent affinity constant, $K_{A,app} = K_A \cdot P_{R/A}$. The results from many investigations (Alarie 1973b, Kane and Alarie 1978, Kristiansen et al. 1986, Kristiansen et al. 1988, Nielsen and Vinggaard 1988, Nielsen and Yamagiwa 1989) fitted the formal equivalent of equation 4. The formal constants also were able to give meaningful description of the interaction experiments. The interaction in mice between two chemically reactive substances, formaldehyde and acrolein, followed that of a competitive agonism (Kane and Alarie 1978). The same was the case for the interaction between the two nonreactive substances, cumene (isopropylbenzene) and *n*-propanol, as long as no desensitization occurred (Nielsen et al. 1988). Extrapolation to effects expected at occupational threshold concentrations and, also to the even lower indoor air levels, suggested an additive effect. In a recent investigation the interaction between formaldehyde and ammonia was investigated in humans. The sensory irritation (pungency) component was mainly found

to be additive (Cometto-Muñiz and Hernándes 1990). Thus, animal experiments and human data were at least to a fair extent in agreement, suggesting that equation 5, irrespective of the assumption made has utility.

6. Exposure-effect relationships for single substances

Two approaches exist for the determination of the sensory irritation effect of complex indoor air mixtures. One possibility is to establish some sort of empirical relation between exposures and effects. This has, for example, been done in the "Total Volatile Organic Compounds" (TVOC) concept established by Mølhave (1988). The TVOC concept was found valuable especially in relation to new building materials which emit high amounts of nonreactive substances mainly of the type of organic solvents. The concept has, for the mentioned substances, a certain theoretical foundation (Mølhave and Nielsen 1992).

Another possibility to obtain informations on the effects of complex air mixtures is to establish an exposure-effect realtionship for each substance, for example as that given in equation (5), and then establish an equation for the interaction of substances, for example like the one suggested by Nielsen et al. (1988). This approach is attractive. If the exposure-effect realtionships for the few hundred substances normally found in the indoor air (Mølhave and Nielsen 1992) could be established, then the necessary constants would be avaliable, and predictions on the effects of most of the complex mixtures in the indoor environment could be made.

If equation 5 is adequate for the description of the exposure-effect relationship the apparent dissociation constant or the apparent affinity constant, the maximum response and the expsoure concentration are all which is needed. As the exposure concentration [A]air is believed to be far below the apparent dissociation constant (Nielsen et al. 1988), equation 5 can be reduced to:

$$E_A = \frac{E_{Amax} \cdot [A]air}{K_D / P_{R/A}} = \frac{E_{Amax} \cdot [A]air}{K_{D,app}} \qquad (6)$$

This equation, where the ratio $E_{Amax}/K_{D,app}$ constitutes a proportionality constant, has been suggested for the description of the exposure-effect for concentrations up to the workplace TLV level (Nielsen et al. 1988). Even though the stimulus-response function is curvilinear the relation may well be linear in the lower end of the exposure range or at least sufficiently so and thus formally be equivalent to equation 6.

Equation 6 does not apply to very low exposure concentrations. For all sensory irritants, there is a concentration below which no effect is obtained. This is refered to as the threshold concentration. This has been shown by electrophysiological methods (Silver and Moulton 1982,

Silver et al. 1986) and recently in humans by a simple and very elegant sniffing technique developed by Cometto-Muñiz and Cain (1990 and 1991). The threshold may increase due to a prolonged exposure period (Kristiansen et al. 1986). In general, irritation thresholds constitute other important parameters in relation to the sensory irritation effect of single substances.

It is often claimed that sensory irritation is a persistent reaction occurring during the entire exposure period. This is often the case, but it must also be realized that the sensory irritation effect of some chemicals decreases (desensitization) during a prolonged exposure period (Alarie 1973a, Kristiansen et al. 1986 and 1988, Nielsen and Alarie 1982, Nielsen and Yamagiwa 1989). The stability of the sensory irritation response is an important factor in relation to the warning property of substances (Nielsen and Alarie 1982), but desensitization may also constitute an important factor in relation to classification of receptor sites.

7. Structure-activity relationship

Development of quantitative structure-activity relations (QSAR) for related groups of chemicals is attractive as the relations may give information about substances which have not yet been tested. The procedure may also reduce the use of experimental animals. When combined with a rational test strategy, where properly selected substances are used as benchmarks (Purcell et al. 1973), QSAR will allow generation of potency data in a fast and cost efficient manner.

Alarie (1973b) carried out the first modern QSAR for reactive chemicals capable of ewoking sensory irritation. The sensory irritation effects of derivatives of styrene, benzalmalononitrile, and cinnamalmalononitrile were investigated by means of equation 5 and the apparent affinity constant. The molecules investigated were nearly of the same size suggesting that the partition coefficient in equation 5 approximately is a constant. The apparent constants therefore are proportional to the true affinity constants. It was shown that the "potency can change by a factor of 600 or more depending on specific chemical groups" and "correlation between the biological and chemical reactivity data suggests that these compounds initiate the sensory irritation reaction by association with SH groups of the receptor molecule".

Recently, the "linear solvation energy relationships" have been applied to sensory irritation data from nonreactive chemicals (Abraham et al. 1990), which act by a different mechanism than the reactive chemicals selected by Alarie (1973b). This technique is promising as it allows deduction of the type of interaction between a non-reactive irritant and the receptor. The binding of a substance can be split into terms of dipolarity/polarisability, hydrogen-bond donor (acid) and hydrogen-bond acceptor (base). Except for the use of the boiling point (Muller and Greff 1984), an adjusted boiling point (Roberts 1986) and the saturated vapour pressure (Nielsen et al. 1990) other QSAR's used the methods of "linear free energy relationships" or the "thermodynamic activity" concept.

7.1 Linear free energy relationships

Equation 5 can be rearranged to:

$$[A]air = \frac{E_A}{E_{Amax} - E_A} \cdot \frac{1}{K_A \cdot P_{R/A}} \qquad (6)$$

Thus, if comparing substances at the same fraction of their maximum responses, [A]air is proportional (k) to the apparent dissociation constant. Applying the negative logarithm to both side of equation 6 results in:

$$\log \frac{1}{[A]air} = \log K_A + \log P_{R/A} - \log k \qquad (7)$$

Equation 7 shows that the right-hand part of the equation includes the sum of two free energy-realted terms, one for the interaction with the receptor:

$$\Delta G_B = -RT \cdot \ln K_A = -2.303 \cdot RT \cdot \log K_A \qquad (8)$$

and one for the partition process:

$$\Delta G_P = -RT \cdot \ln P_{R/A} = -2.303 \cdot RT \cdot \log P_{R/A} \qquad (9)$$

Free energy related models are commonly used in medicinal chemistry (Purcell et al. 1973, Franke 1984) and the procedures from this area therefore could be useful for handling sensory irritation data as well. Equation 7 contains only one measured value [A]air, whereas two unknown values, K_A and $P_{R/A}$, are found on the right-hand side. Within medicinal chemistry this problem is often overcome by applying the Collander equation (Franke 1984) as follows:

$$\log P_{II} = a \cdot \log P_I + b \qquad (10)$$

P_I is the partition coefficient in organic phase I-water and P_{II} that in the organic phase II-water system. The coefficients a and b are constants. Within medicinal chemistry P_{II} is taken to behave as in the distribution process for the receptor phase (biophase) and the water phase. P_I is termed a descriptor and very often the octanol-water partition coefficient ($P_{o/w}$) is used. Octanol approximates the properties of the biophase very closely (Franke 1984). Extensive tabulations of log $P_{o/w}$ exist, for example Hansch and Leo (1979).

Within sensory irritation $P_{o/w}$ has been used as a description for $P_{R/A}$ (Muller and Greff 1984, Nielsen and Vinggaard 1988) which is only allowed if dealing with homologous substances or otherwise very closely related substances (Nielsen and Vinggaard 1988, Nielsen and Yamagiwa 1989, Nielsen et al. 1990). The log $P_{R/A}$ in equation 7 deals with partition between a lipophilic receptor biophase (Nielsen and Alarie 1982, Nielsen and Vinggaard 1988, Nielsen and Yamagiwa 1989, Nielsen et al. 1990) and an air phase. As water has different properties from that of air it follows directly that only if the special case where collinearities exist, for example for homologous substances (Nielsen and Vinggaard 1988), can $P_{o/w}$ be a proper descriptor imitating the behaviour of $P_{R/A}$. Due to the theoretical relation of the distribution process ($P_{R/A}$) the octanol-gas partition coefficient ($P_{o/g}$) was selected as a descriptor for $P_{R/A}$, and $P_{o/g}$ was found clearly to mimic the properties of $P_{R/A}$ (Nielsen and Yamagiwa 1989, Nielsen et al. 1990). Introducing the "Collander equation" with $P_I = P_{o/g}$ in equation 7 gives:

$$\log \frac{1}{[A]air} = \log K_A + a \cdot \log P_{o/g} + b - \log k \qquad (11)$$

Equation 11 contain only one unknown variable, log K_A, as a and (b-log k) are constants and log $P_{o/g}$ is found from tables. Log $P_{o/g}$ can be found from the relation: log $P_{o/g}$ = log $P_{o/w}$ + log $P_{w/g}$, where $P_{w/g}$ is the water-gas partition coefficient. Tabulations of $P_{w/g}$ also exist, for example Hine and Mookerjee (1975).

The log K_A values can be obtained from regression analysis and the linear free energy-related model therefore clearly could be a valuable tool within sensory irritation. It can be pointed out that analysis of data via the above equations can be conducted for data from either animal or human studies, despite the fact that the evaluation of the potency of sensory irritation may be different in each type of studies.

7.2 Thermodynamic activity

The "thermodynamic activity" (a_{act}), introduced into toxicology by Ferguson (1939) and Brink and Posternak (1948), has been used extensively in work on sensory irritation (Nielsen and Alarie 1982, Nielsen et al. 1984, Nielsen and Bakbo 1985, Silver et al. 1986, Nielsen and Vinggaard 1988, Cometto-Muñiz and Cain 1990 and 1991). This term is defined as a_{act} = P/Po where P is the partial pressure of the substance in equilibrium with the receptor phase and Po is the vapour pressure of the pure substance. The main advantage of the (absolute) activity

concept is that the activity is the same in all phases which are in equilibrium. The activity, therefore, needs not be measured in the biophase, but can be in any phase which is in equilibrium with the biophase (Ferguson 1939). On the other hand, the problem arises, seen in equation 1 and 2, when seeking a mechanistic explanation, such as chemists are accustomed to devise in terms of concentration in mol/l.

The activity (Brink and Posternak 1948) can also be expressed by equation:

$$a_{act} = \gamma \cdot \frac{n_A}{n_A + n_B} \qquad (12)$$

where γ is the activity coefficient, n_A the mol fraction of A in the biophase and n_B (formally) the mol fraction of the biophase itself. If the biophase is water γ will vary tremendously, for example, the activity coefficient of metanol in water equal is to 1.5 but that of octanol as high as 12300 (Brink and Posternak 1948). Contrary to water, some organic solvents can behave more like ideal solvents where the activity coefficient is one. Octanol is such a solvent, for references see Nielsen et al. (1990). In this case:

$$a_{act} = \frac{n_A}{n_A + n_B} \qquad (13)$$

and, thus, the thermodynamic activity directly expresses the concentration in the organic phase. As mentioned above, the receptor biophase is lipophilic and octanol closely mimics the properties of the biophase. This suggest that the thermodynamic activity, at least as a first approximation, can be regarded as a measure of the concentration in the biophase. If the activity coefficient differs from one but is taken as a constant (not strictly the case, see Nielsen et al. 1990) it then follows from equation 12 that the activity is proportional to the concentration in the biophase. The confusion, which often arises when dealing with the activity concept, stems from the fact that the concept is of very limited value if dealing with aquous systems, but has a major advantage when dealing with "organic-solvent-like systems", including lipophilic biophases.

The thermodynamic activity concept can be combined with the classical receptor theory (equations 2 and 5) as previously shown (Kristiansen and Nielsen 1988, Nielsen and Vinggaard 1988). This connection is important because sensory irritation is a receptor mediated process (Alarie 1973a, and 1973b, Nielsen 1991).

The molar concentration ([A]air) is proportional to the partial pressure (P) of the gas. If P is measured in mmHg and the volume of one mol of a gas (liters) is termed Vm, the relation can be expressed as:

$$[A]air = \frac{P}{760 \cdot Vm} \qquad (14)$$

Vm is a constant which depends solely on pressure and temperature. Introduced into equation 5 and multiplying the numerator and the denominator with $1/P_o$ results in:

$$E_A = \frac{E_{Amax} \cdot P/P_o}{\frac{760 \cdot Vm}{K_A \cdot P_{R/A} \cdot P_o} + P/P_o} \qquad (15)$$

Equation 15 is formally equal to equation 5:

$$E_A = \frac{E_{Amax} \cdot a_{act}}{K_{D,act} + a_{act}} = \frac{E_{Amax} \cdot a_{act}}{1/K_{A,act} + a_{act}} \qquad (16)$$

where the thermodynamic dissociation constant ($K_{D,act}$) and the thermodynamic activity constant ($K_{A,act}$) is defined (Kristiansen and Nielsen 1988) as:

$$K_{D,act} = \frac{1}{K_{A,act}} = \frac{760 \cdot Vm}{K_A \cdot P_{R/A} \cdot P_o} \qquad (17)$$

Equation 16 can be rearranged to

$$a_{act} = \frac{E_A}{E_{Amax} - E_A} \cdot K_{D,act} \qquad (18)$$

Thus, if comparing substances at the same fraction of the maximum response, a_{act} is proportional to $K_{D,act}$ and $1/a_{act}$ is proportional to $K_{A,act}$.

Now, results about dissociation constants and affinity constants are in general obtained from the mol/l system, equations 2 and 5, which makes it necessary to see the thermodynamic

constants in relation to this system. The evaporation from the pure liquid is determined by the vapour pressure (Po) which can be regarded as an equilibrium constant dealing with the distribution process between air and the liquid itself. The process is related to the free energy ΔGevp. The vapour is brought into the air phase, which for for practical purposes is assumed to be an ideal gas state. The substance is then distributed from the air phase to the lipophilic biophase, a process related to the free energy $\Delta G_{R/A}$. If the interactions in the organic solvent itself and that in the biophase (due to the similarities of interaction properties) are the same, the two ΔG values are numerically identical but carry opposite signs. The product $P_{R/A} \cdot P_o$ in equation 17 will in this case be cancelled out. It therefore follows that K_D and $K_{D,act}$ as well as K_A and $K_{A,act}$ are proportional. In this case the P_o values can be used as a technique for normalization for differences in $P_{R/A}$ values. It must be emphasized that the above given outline only is a first approximation. A more thorough discussion is given in Nielsen et al. (1990).

The activity concept has, although serious limitations exist, been used extensively and it has been possible to distinguish between substances which are adsorbed physically to the receptor (low affinity) and those substances which additionally have reacted chemically (high affinity). Furthermore, the technique also allowed determination of differences in chemical reactivity (Nielsen et al. 1984, Nielsen and Bakbo 1985, Nielsen and Vinggaard 1988).

Note: The E_{Amax} value in the thermodynamic system, equations 15 and 16, is equal to the value in the mol/l system, equation (5).

7.3 Intrinsic efficacy and maximum response

The intrinsic efficacy and the maximum response are parameters which cannot be obtained from the above models. They must be obtained directly from investigations in animals or humans. Yet they are important in terms of acceptable exposure in industry or for indoor air quality. Within a homologous series of substances the maximum response may either be constant, as suggested from the approximately identical slopes of the log concentration-effect relationships of alkylbenzenes (Nielsen and Alarie 1982), or the maximum response may decrease with increasing molecular weight as has been shown for alcohols (Silver et al. 1986, Kristiansen et al. 1986 and 1988) and for amines (Nielsen and Vinggaard 1988, Nielsen and Yamagiwa 1989). Different maximum responses have also been found for styrene, benzalmalononitrile and cinnamalmalononitrile derivatives (Alarie 1973b) and for 29 substances which belonged to other types of chemicals (Silver 1990).

A decrease in maximum responses may also explain the results obtained in humans with homologous alcohols (Cometto-Muñiz and Cain 1990) and homologous acetic acid esters (Cometto-Muñiz and Cain 1991). The subjects were exposed to vapours, and the concentration was successively changed by the same dilution factor. Cometto-Muñiz and Cain (1991) found:

"Spontaneous comments and reactions from the anosmics suggest that when the pungency threshold is reached for the lower members of both homologous series, even one dilution step above it could be overwhelmingly pungent, whereas for the higher members the pungency at threshold is not so effective or clear, so the concentration could be increased by one, two or

even three dilution steps above the threshold and no such overwhelming effect is observed. This characteristic is typical of the highest members of both series".

Intrinsic efficacy and maximum response are parameters which only have been touched superficially in humans, except for one study. Doty and co-workers (1978) investigated the sensory irritation intensities of pure substances. Molecular descriptors and "linear learning machine pattern recognition analyses" enabled the prediction of the perceived trigeminal intensities. Thus it is important to obtain an estimate of both intrinsic efficacy as well as maximum response for single substances if modelling of the effects of complex mixtures is an objective, as with indoor air quality problems.

7.4 Conclusion

Sound physicochemical models developed as described above for chemical-receptor interactions in biological systems can be directly applied to predict the potency of airborne nonreactive chemicals as sensory irritants. Although many pitfalls exist we must take into account that limited data is available and prediction of potency from physicochemical models help to optimize a test strategy for the large number of chemicals identified in indoor air and suspected of causing sensory irritation. The use of physicochemical models would at least permit a first evaluation of the large number of chemicals identified in indoor air for which we have no potency data in either animals or humans. Also they would permit the prediction of the potency of mixtures, albeit neither intrinsic efficacy nor maximum response are obtainable from these models.

8. Acknowledgement

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9. References

Abraham, M.H., Whiting, G.S., Alarie, Y., Morris, J.J., Taylor, P.J., Doherty, R.M., Taft, R.W. and Nielsen, G.D. (1990) "Hydrogen bonding 12. A new QSAR for upper respiratory tract irritation by airborne chemicals in mice", Quant. Struct.-Act. Relat. 9, 6-10.

Alarie, Y. (1973a) "Sensory irritation by airborne chemicals", CRC Crit. Rev. Toxicol. 2, 299-363.

Alarie, Y. (1973b) "Sensory irritation of the upper airways by airborne chemicals", Toxicol. Appl. Pharmacol. 24, 279-297.

ASTM (1984) "Standard test method for estimating sensory irritancy of airborne chemicals",

designation: E 981-84, American Society for Testing and Materials, Philadelphia.

Brink, F.G. van den (1977) "General theory of drug-receptor interactions. Drug-receptor interaction models. Calculation of drug parameters", in J.M. van Rossum (ed.) Kinetics of Drug Action, Springer-Verlag, Berlin, pp. 169-254.

Brink, F. and Posternak, J.M. (1948) "Thermodynamic analysis of the relative effectiveness of narcotics", J. Cell. Comp. Physiol. 32, 211-233.

Cain, W.S. (1990) "Perceptual characteristics of nasal irritation", in B.G. Green, J.R. Mason and M.R. Kare (eds.), Chemical Senses, Vol.2, Irritation, Marcel Dekker, New York, pp. 43-60.

Cometto-Muñiz, J.E. and Cain, W.S. (1990) "Thresholds for odor and nasal pungency", Physiol. Behav. 48, 719-725.

Cometto-Muñiz, J.E. and Cain, W.S. (1991) "Nasal pungency, odor, and eye irritation thresholds for homologous acetates", Pharmacol. Biochem. Behav. 39, 983-989.

Cometto-Muñiz, J.E. and Hernández, S.M. (1990) "Odorous and pungent attributes of mixed and unmixed odorants", Percept. Psychophys. 47, 391-399.

Doty, R.L., Brugger, W.E., Jurs, P.C., Orndoff, M.A., Snyder, P.J. and Lowry, L.D. (1978) "Intranasal trigeminal stimulation from odorous volatiles: psychometric responses from anosmic and normal humans", Physiol. Behav. 20, 175-185.

Ferguson, J. (1939) "The use of the chemical potentials as indices of toxicity", Proc. Roy. Soc. London Ser.B, 127, 387-404.

Finger, T.E., Getchell, M.L., Getchell, T.V. and Kinnamon, J.C. (1990) "Affector and effector functions of peptidergic innervations of the nasal cavity", in B.G. Green, J.R. Mason and M.R. Kare (eds.). Chemical Senses, Vol.2, Irritation, Marcel Dekker, New York, pp. 1-20.

Franke, R. (1984) "Theoretical Drug Design Methods", Elsevier, Amsterdam.

Hansch, C. and Leo, A. (1979) Substituent Constants for Correlation Analysis in Chemistry and Biology, John Wiley, New York.

Hansen, L.F., Nielsen, G.D., Tøttrup, J., Abildgaard, A., Jensen, O.F.D., Hansen, M.K. and Nielsen, O. (1991) "Biological determination of emission of irritants from paint and lacquer", Indoor Air. 1(2), 95-110.

Hine, J. and Mookerjee, P.K. (1975) "The intrinsic hydrophilic character of organic compounds. Correlations in terms of structural constributions", J. Org. Chem. 40, 292-298.

Kane, L.E. and Alarie, Y. (1977) "Sensory irritation to formaldehyde and acrolein during single and repeated exposures in mice", Am. Ind. Hyg. Assoc. J. 38, 509-522.

Kane, L.E. and Alarie, Y. (1978) "Evaluation of sensory irritation from acrolein-formaldehyde mixtures", Am. Ind. Hyg. Assoc. J. 39, 270-274.

Kenakin, T.P. (1987) Pharmacologic Analysis of Drug-Receptor Interaction, Raven Press, New York.

Kenakin, T.P. (1989) "Challenges for receptor theory as a tool for drug and drug receptor classification", Trends Pharmacol. Sci. 10, 18-22.

Kobal, G. and Hummel, T. (1990) "Brain responses to chemical stimulation of the trigeminal nerve in man", in B.G. Green, J.R. Mason and M.R. Kare (eds.), Chemical Senses, Vol.2, Irritation, Marcel Dekker, New York, pp. 123-139.

Kristiansen, U., Hansen, L., Nielsen, G.D., and Holst, E. (1986) "Sensory irritation and pulmonary irritation of cumene and n-propanol: mechanisms of receptor activation and desensitization", Acta Pharmacol. Toxicol. 59, 60-72.

Kristiansen, U. and Nielsen, G.D. (1988) "Activation of the sensory irritant receptor by C7-C11 n-alkanes", Arch. Toxicol. 61, 419-425.

Kristiansen, U., Vinggaard, A.M. and Nielsen, G.D. (1988) "The effects of n-butanol vapour on respiratory rate and tidal volume", Arch. Toxicol. 61, 229-236.

Muller, J. and Greff, G. (1984) "Recherche de relations entre toxicite de molecules d'interet industriel et proprietes physico-chimiques: test d'irritation des voies aeriennes superieures applique a quatre familles chimiques", Food Chem. Toxicol. 22, 661-664.

Mølhave, L. (1988) Indoor Climate and Health. Air Quality and Indoor Climate, Institute of Environmental and Occupational Medicine, University of Aarhus. [Thesis in Danish].

Mølhave, L. and Nielsen, G.D. (1992) "Interpretation and limitations of the concept "Total Volatile Organic Compounds" (TVOC) as an indicator of human responses to exposures of volatile organic compounds (VOC) in indoor air", Indoor Air, submitted.

Nielsen, G.D. (1991) "Mechanisms of activation of the sensory irritant receptor by airborne chemicals", CRC Crit. Rev. Toxicol. 21, 183-208.

Nielsen, G.D. and Alarie, Y. (1982) "Sensory irritation, pulmonary irritation, and respiratory stimulation by airborne benzene and alkylbenzenes: prediction of safe industrial exposure levels and correlation with their thermodynamic properties", Toxicol. Appl. Pharmacol. 65, 459-477.

Nielsen, G.D. and Alarie, Y. (1992) "Animal assays for upper airway irritation: screening of materials and structure-activity relations", Ann. NY Acad. Sci., in press.

Nielsen, G.D. and Bakbo, J.C. (1985) "Sensory irritating effects of allyl halides and a role for hydrogen bonding as a likely feature at the receptor site", Acta Pharmacol. Toxicol, 57, 106-116.

Nielsen, G.D., Bakbo, J.C. and Holst, E. (1984) "Sensory irritation and pulmonary irritation by airborne allyl acetate, allyl alcohol, and allyl ether compared to acrolein", Acta Pharmacol. Toxicol. 54, 292-298.

Nielsen, G.D., Kristiansen, U., Hansen, L.F. and Alarie, Y. (1988) "Irritation of the upper airways from mixtures of cumene and n-propanol. Mechanisms and their consequences for setting industrial exposure limits", Arch. Toxicol. 62, 209-215.

Nielsen, G.D., Thomsen, E.S. and Alarie, Y. (1990) "Sensory irritant receptor compartment properties", Acta Pharm. Nord. 2, 31-44.

Nielsen, G.D. and Vinggaard, A.M. (1988) "Sensory irritation and pulmonary irritation of C3-C7 n-alkylamines: mechanisms of receptor activation", Pharmacol. Toxicol. 63, 293-304.

Nielsen, G.D. and Yamagiwa, M. (1989) "Structure-activity relationships of airway irritating aliphatic amines. Receptor activation mechanisms and predicted industrial exposure limits", Chem. Biol. Interact. 71, 223-244.

Purcell, W.P., Bass, G.E. and Clayton, J.M. (1973) "Strategy of Dry Design: A guide to Biological Activity", John-Wiley, New York.

Roberts, D.W. (1986) "QSAR for upper-respiratory tract irritation", Chem. Biol. Interact. 57, 325-345

Silver, W.L. (1990) "Physiological factors in nasal trigeminal chemoreception", in B.G. Green, J.R. Mason and M.R. Kare (eds.). Chemical Senses, Vol. 2, Irritation,Marcel Dekker, New York, pp. 21-41.

Silver, W.L., Mason, J.R., Adams, M.A. and Smeraski, C.A. (1986) "Nasal trigeminal chemoreception: responses to n-aliphatic alcohols", Brain Res. 376, 221-229.

Silver, W.L. and Moulton, D.G. (1982) "Chemosensitivity of rat nasal trigeminal receptors", Physiol. Behav. 28, 927-931.

Tallarida, R.J. (1988) "Pharmacologic methods for identification of receptors", Life Sciences, 43, 2169-2176.

Tepper, J.S., Weiss, B. and Wood, R.W. (1985) "Alterations in behavior produced by inhaled ozone and ammonia", Fund. Appl. Toxicol. 5, 1110-1118.

Wood, R.W. (1979) "Behavioral evaluation of sensory irritation evoked by ammonia", Toxicol. Appl. Pharmacol. 50, 157-162.

Wood, R.W. (1981) "Determinants of irritant termination behavior", Toxicol. Appl. Pharmacol. 61, 260-268.

ASSESSMENT METHODS AND CAUSES OF EYE IRRITATION IN HUMANS IN INDOOR ENVIRONMENT

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ABSTRACT. No model is well established for indoor air induced eye irritation - a consequence of the lack of good models for the common chemical sense in general and even more a consequence of the extreme lack of data. We have to use the understanding from models established in other situations or related to other organs. Existing models suggest that indoor air pollutants may decrease the stability of the tear film either by changing the surface lipid layer or by decreasing the amount of mucus in the water-phase of the film. This may then lead to increased dryness and subsequently damage the corneal and conjunctival epithelium. This may by itself or by increasing sensitivity of the nociceptors in the epithelium lead to increased sensory irritation. Furthermore, inflammatory responses may follow due to release of eg. neuropeptides from the nociceptors. Another mechanism suggested is that inflammatory responses leads to release of mediators triggering nociceptors (histamine release is an example). Reports (epidemiological and and experimental) support that dust and volatile organic substances (VOCs) may induce decreased tear film stability, increased epithelial damage, increased inflammatory responses as well as sensory irritation. Furthermore, there seem to be some association between objective parameters and subjective irritation for Polymorphonuclear neutrophils and tear film stability. This is remarkable results, achieved within the past 5 years. However, data is not sufficient to decide about the reliability of pathophysiological relations suggested in the models. The main future need is to gather more data on these methods and further development and refinement of measurement techniques.

1. Background

1.1. GENERAL ASPECTS

Several epidemiological studies e.g. the study by Skov et al (1) have demonstrated that sensory irritation (pain, itching, etc) of mucous membranes is a very prevalent symptom in the "sick buildings" together with the unspecific reactions reflecting general effects upon the central nervous system (fatigue, headache etc). High prevalence of different combinations of these symptoms in a building population constitutes together the "sick building syndrome". Sensory irritation of the mucous membranes in eyes and nose is probably some of the most important symptoms in the sick building syndrome, mainly because such reactions in general are believed

H. Knöppel and P. Wolkoff (eds.),
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to be indications of harmful effects, ie to be primary warnings to the organism.

Odors are not believed to be warnings only about harmful effects; but may more or less be positive or used for orientation dependant upon the situation and the individual exposed.

The sensory irritation of the eyes and the nose, and the odors are not independent of the subject expressing the symptoms; that is they are processed by the brain before we can assess them. Therefore they are normally termed subjective measures. This is a problem in assessment of irritation effects from the air pollution or other indoor factors, since the expression of the irritation symptoms may be biased by many factors e.g. interactions with other people and odors. The subjective measures has been suggested as an important problem in several studies dealing with psychogenic mass hysteria etc. (2, 3).

Because of the bias problems in indoor research there is increased demand for objective assessment of eye and nose irritation; that is mainly physiological parameters. Other reasons for measurement by objective methods is a the need of a better understanding of the pathophysiological events leading to adverse effects like tearing or itching of the eyes in indoor air and to understand the consequences of sensory irritation.

Since sensory eye irritation is very prevalent (15-20 %) and in many studies is the most increased symptom (up to 50-60 %) in 'sick buildings' it is reasonable to focus on this effect (4). In the past years several different objective and subjective methods have been used to assess eye irritation in both epidemiological and experimental studies. In this paper the results of these studies will be summarized and some suggestions about future needs will be given.

1.2. THE OUTER EYE ANATOMY AND PHYSIOLOGY

The eye surface (Fig. 1) differs in some characteristics from the other mucous membranes. Especially the corneal surface makes a difference in being nonvascularized and to consist of squamous epithelium cells. This means that the corneal cells has to exchange all nutrients, waste, and gases (CO_2 and O_2) by diffusion from the underlying cellular layers and chambers of the eye or from the ocular surface via the tear film.

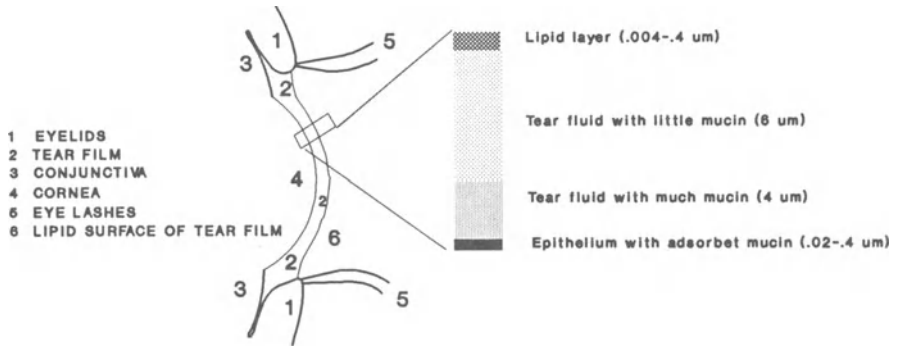


Figure 1. Eye surface schematically.

The conjunctival surface which covers the eyeball and the inside of the eyelids is more comparable to nasal lining although there is no cilia as in the nose and upper airways. Furthermore, cells are merely squamous and cuboidal dependant on conjunctival area (5). Conjunctiva is vascularized and has mucus producing goblet cells.

Trigeminal nerve-endings (nociceptors) converting the physico-chemical signal transmitted to the brain and expressed as irritation and pain are distributed in the epithelium, with the highest density in the corneal epithelium (4). The corneal epithelium is also more sensitive to tactile stimuly than conjunctiva (5).

Exterior depositions and off scaled cell material is removed from the surface by the combined action of the eyelid (blinking) and the tear fluids. The material and the mucus secreted by the goblet cells are collected in a mucus thread below the lower eyelid. This mucus thread is normally removed to the inner canthus of the eye and out on the skin by the blinking at a rate of 1.13 mm/min (5).

Important for the function and the protection of especially the cornea is an adequate and accurate production of tears from the tear glands, mucus form the goblet cells, and of the lipids from the meibomian glands located in the eyelid. These substances form in common during a blink the stratified tear film (fig 1). The mucus probably stabilises the film against the gravitational force while the lipid layer reduces evaporation. The film is renewed at each blink and may be stable from 1 second to more than a minutes. In normal cases this time is more than 10 seconds. Inadequate wetting of cornea and conjunctiva may cause keratoconjunctivitis sicca, a dry eye. This may bee caused by different types of diseases e.g. Sjögrens Syndrome. Such conditions makes the eye irritated and may be damaging to the function of cornea.

1.3. MECHANISM OF EYE IRRITATION

No model has been established for eye irritation as reported in indoor environments. Presently the best model may be the model established by Damgaard Nielsen (6). His model may be used for the basic neurological response in the trigeminal nerveendings but needs modifications in some aspects with relation to the eyes.

One important question is unresolved; is the feeling of irritation a direct sensory triggering of the nerves in the eyes eventually followed by a inflammatory response ie. a neurogenic inflammation; or is the response indirect ie. small inflammatory responses leading to nerves through chemical transmitters or is both processes running more or less simultaneously. There is studies supporting both hypotheses as discussed by Damgaard-Nielsen in his recent review of irritation by air pollution (6). For the eyes there seems to be some support for the last possibility. However, result are preliminary and differences may depend on differences in pollutants. So both pathways may actually be in action when subjects respond to indoor pollution.

A gross model for eye irritation (sensory and inflammatory) may include several different ways of action as indicated in figure 2. Several of the realtions and of the boxes could be more detailed than shown eg. the inflammatory response, the nociceptor response.

It should be recognized that the model is based on limited data. Some of the relations shown are adapted from other models for other organs or from models for eye diseases. Furthermore, other relations which seem to be based in actual studies may be independent responses to the same causative agent ie. they are only correlated. Such problems are discussed below.

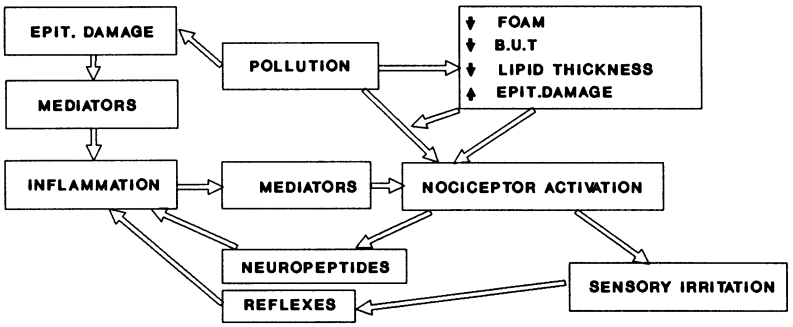


Figure 2. Suggested working model for eye irritation in the indoor environment.

2. Methods of objective assessment

Below is a short description of the methods used so far to assess eye irritation in the studies of indoor air pollution. Objective methods assessing neural activity have been developed; but is not useful in studies of the real life situation or studies attempting to simulate this. Trigeminal evoked potentials and mucus membrane potentials are such methods (21) and may be interesting in the future if they can be developed further. Main demands posed to the methods in indoor air studies are that they are as non-irritating and non-invasive as possible if used in real life sitautions.

2.1. INFLAMMATORY RESPONSES

Several possibilities exist to measure objectively the inflammatory response however only few have been used in indoor air pollution studies. Further development of micromethods may help analyzing directly on mediators etc. in the conjunctival fluids (tears) and development of videographic methods may help analyzing blood flow and vessel diameters etc.. However, here is presented two methods used in several studies.

2.1.1. *Eye-redness* can be assessed by photography (7,8). The eye (the bulbar conjunctiva) is photographed in a standardized manner while the subject is looking outward and slightly upward. By comparison of two pictures taken before and after exposure one can evaluate changes in eye redness in a randomized and double blind design, eliminating the risk of bias. This method makes it possible to evaluate even small differences between pre- and post exposure in experiments, or to follow inflammatory changes over time in epidemiological studies.

2.1.2. *Conjunctival cytology* has been performed using the quantitative pipette method (4,5). Using a small pipette tear fluid is sucked from the conjunctival sack and is washed out at a glass-slide using 10% formaldehyde for fixation. After staining, the cell content is analyzed and counted using microscopy. Differential counting identifying polymorphonuclear neutrophils, lymphocytes, eosinophils, and different kinds of epithelial cells. Experimentally, the baseline samples is compared with post-exposure samples. With more than 100 Polymorphonuclear

leucocytes, the patient suffer from conjunctivitis (5).

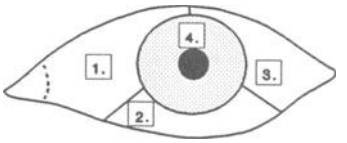
2.2. MEASUREMENTS ON SURFACE PHENOMENA OR PROTECTIVE FUNCTIONS

Several surface phenomena and protective functions can be studied. Relevant for indoor air may be blink rate and tear flow. Blink rate is very variable and seem to be responsive only to heavy exposure towards high concentrations of strong irritants eg. tobacco smoke and formaldehyde. Methods for tear flow measurements may be interesting as non-invasive methods is developed, however, nobody has used tear flow assessment yet.

2.2.1 *Tear film stability* measurements are performed using a slit-lamp (5,7,9). The stability is also named "break up time" (BUT). After installation of 10 μl 1% Na-fluorescein (some observers use 0.1%) in the lower conjunctival sack of the eye using a sterile glass-spatula, the subject is instructed to abstain from blinking by the will alone. The tear film stability is then measured as the time (seconds) from the last blink until the break-up of the pre-corneal tear film. The mean of three consecutive and acceptable measurements can be used (4) or a photographic method as described by Franck (10). The latter gives three levels of tear film stability (0 - 5, 5 - 10, and more than 10 seconds).

2.2.2 *Foam formation* in the outer canthus of the eye may be assessed just before the BUT measurement, and has been done in a few studies (11,12,13). Decreased foam formation may be caused by fatty substances or oils in the eye, but on the other hand increased foam formation may be caused by increased blink frequency due to irritation effects. It can either be quantified by a scale (e.g. 0, 1-6, 6-11, more than 11 bubbles), or dichotomized (foam or no foam).

2.2.3 *Lipid layer thickness* (LLT) on the tear film can be assessed semiquantitatively using a slitlamp microscope. This method is based on interference in reflected light from the inner and outer surface of this layer (22). A later method is more quantitative using reflectometry of specific wave lengths to assess LLT (23). Decreased LLT or instability in the fatty layer will leave the tear film open for evaporation and



1. Medial bulbar conjunctiva
2. Inferior bulbar conjunctiva
3. Lateral bulbar conjunctiva
4. Cornea

Figure 3. Counting areas for epithelial damage evaluations.

2.2.4 *Epithelium damage* (ED) can be measured as the number of dots in the intact epithelium using a vital stain either rose-bengal or lissamine green (14). Using slitlamp equipment the subject is seated and 10 μl of 1 % Lissamine Green B is instilled in the lower conjunctival sac.

After a blinking period adequate to eliminate surplus dye, the number of dots can be counted or estimated and thereafter categorized using the following four groups (0 - 10, 11-50, 51-100, more than 100 dots). This procedure is performed for the areas as shown in figure 3. In other studies only the nasal area score is used. Increased number of dots is a sign of increased corrosion (higher turn-over) of the conjunctival and corneal epithelium, and may be the first step in a change towards a replacement of cells with more keratinized cells. A dry eye (keratoconjunctivitis sicca) will bee intensely stained by the dye in the air exposed sections of cornea and conjunctiva.

3. Use of the objective methods in indoor air studies

The results of existing epidemiological and experimental studies are summarized below and discussed in relation to the model described in figure 2.

3.1 EPIDEMIOLOGICAL STUDIES

To the knowledge of the author only four indoor air studies have used the objective methods for measurement of effect on the eyes (10, 11, 16, 24).

The first two studies were conducted as a part of the Copenhagen Town Hall study (1). Franck (10, 11) describes measurements of effects on tear film stability, epithelium damage and on foam formation. In his second study he also investigate a normal population. The third study (16) was a part of the sick library study in Stockholm (17) and describes effects measured by all three measurements mentioned above. The fourth study which is prospective in design includes above measurements and measurement of inflammatory responses and just reported to the building administration in Denmark. The findings of the studies are summarized in table 1.

Franck (10) showed in his study an association between tear film stability, and lissamine stained dots in the eye and the period prevalence of sensory irritation. Kjærgaard (16) showed a similar association for the tear film stability and acute degree of sensory irritation (se table 1). Franck (10) established a correlation between an objective score and an irritation prevalence score. Thus the associations found in the Town Hall study was confirmed in the Swedish material with respect to acute sensory irritation. However, in the Swedish material it was demonstrated that there is no better 'explanation' of the sensory irritation using this combined score than using break up time alone as indicator. The Swedish material also demonstrated an effect of the use of eye make-up, which was as important an indicator for sensory irritation as was the objective measures. Franck found an similarly that make-up affected foam formation.

In the Swedish study, the absolute values from the objective measurements was compared with standard materials. These comparisons showed that there were in general a significantly higher level of sensory irritation, a higher number of lissamine green stained dots, and a lower mean of break up time in the library indicating that these factors may be related to indoor environment.

Two of the studies are cross-sectional, which makes it impossible to decide about cause-effect relationships between indoor air pollution, objective parameters and sensory responses. Therefore, there are several possibilities of relations as indicated in the model figure upper right corner (Fig. 2). One possibility is that the environment is the cause of the high frequency of abnormal values but so far the only documentation is for PMNs and epithelium damage as seen in the preliminary results from the prospective study showing relations to photocopying, VDU work and sedimentation rate of the dust (24). The few findings of significant relations between

exposures and effects in the epidemiological studies may be due to the missing or very sparse exposure assessment. Substances so as oils, n-decane or detergents have been suggested as cause of decreased tear film stability in some studies (4, 10, 11, 15, 18).

Table 1. Summary of results epidemiological studies.

Ref.	Number of subjects	Design	Measurements	Major findings
10*	169	Cross-sectional	BUT[a] ED[c]	BUT and ED associated with period prevalence of irritation
11*	169 112 ref.	Cross-sectional	FOAM	Different among referents and office workers. Associated with period prevalence of irritation.
16	53	Cross-sectional	BUT ED REDNESS FOAM	BUT and ED different from reference material BUT associated with acute sensation of irritation
24#	78 14 ref.	Prospective	BUT ED REDNESS FOAM PMNs[b]	PMN's increased with increased use of video display terminals, and perhaps with increased dust exposure (p=0.09). ED increased by increased dust exposure and perhaps by increased photocopying (p=0.06).

a. BUT = Break-up time (tear film stability).
b. PMNs = Polymorphonuclear Neutrophils.
c. ED = Epithelial damage.
* Reference 10 and 11 refers to the same subjects.
\# Preliminary results.

Abnormal objective values may be caused by others things than bad environment. Other possible causes are diseases of different kind known to cause dry eyes (Sjögreens syndrome, Steven Johnsons Syndrome, Rheumatoid arthritis). If this is combined with selective processes in the job choice it would influence the results in the direction seen in these studies. The well known primary and secondary healthy worker effect could be the reason for a selection of these people to the office environment, supposed to be without any pollution. Lifestyle may also be a parameter of interest eg. use of eye make-up has been shown to be associated to increased sensory irritation (16) and to decreased foam formation (11).

Changes in the objective parameters could be the reason for increased sensibility to irritants independent of their cause. This could be explained by longer time of contact (low tear fluid flow), easy penetration (damaged epithelium) to the sensory nerves in the tissues. But analyses in two experimental studies so far gives only very weak indications of that (4,15). However, eye irritation was itself weak in those studies. Furthermore, subjects characterized as suffering from Sick Building Syndrome did not have smaller average tear film stability (12), though they

reported more sensory irritation when exposed both to volatile organic compounds (4, 12) and to carbon dioxide (4).

The correlations found in the epidemiological studies may also be due to some other unidentified factors causing both effects at the same time.

Foam formation was decreased among office workers (11) and missing foam formation was associated with high prevalence of irritation but only among office workers. Again the study is cross-sectional and cause-effect relationships cannot be evaluated. However since foam formation is expected to be related to the stability of the lipid layer the findings on BUT may support the relation.

Cytology of the tear fluid has only been used once in relation to indoor air pollution (24). Beside from that it has been used in two studies with relevance for the occupational exposures. They were on changes on effects of the exposure to tobacco dust (15) and of exposure to man made mineral fibers (MMMF). In the tobacco dust study it was concluded that general exposure to active organic dust (tobacco dust) increased the number polymorphonuclear neutrophils even if the concentration was below 1 mg/m^3 (15). In that study we also found an increased eye redness among highly exposed tobacco workers. Similarly Stokholm and collegues showed increased PMNs by exposure to MMMF (25). These results are interesting especially if the sick building syndrome is caused by dust and dirt as suggested by Skov et al (1).

3.2 EXPERIMENTAL HUMAN EXPOSURE STUDIES

The methods described above have been used also in a series of experimental studies most of them performed at Institute of Environmental and Occupational Medicine, Aarhus University.

Until recently the only documentation that the break up time decreases because of indoor air pollution was from the study of Kjærgaard et al (7). In that study it was demonstrated that n-decane in a dose-related and even in small concentrations (below 10 ppm) could decrease tear film stability. But no increase in eye redness or in epithelium damage could be seen. Later studies (12) of the effects of 25 mg/m^3 of the 22 volatile organic compounds failed to show any effects of exposure on tear film stability. However, Johnson et al (13) have shown a reduction of BUT in 20 asthmatics exposed to emissions from 4 different building materials. LLT, Foam formation and the epithelium was not affected in Johnsons study.

A study on 30 subjects (19) by the author has shown decreased tear film stability by exposure to different mixtures of VOC's (12). In the same study it seems that the type of mixture is important in relation to the decreased values and at the same time these results indicate decreased values even at low exposure levels (2 mg/m^3).

On the other hand results of a small study (20) of combined effects of temperature and 10 mg/m^3 of the 22 VOCs could not reveal any effects on tear film stability. However, this study was on 10 subjects only, and the results were confounded by the that a subject used make-up during exposure.

Polymorphonuclear neutrophils has been counted in three experimental studies as pre- and post exposure samples. The n-decane study (7) showed a dose related change. The result was that there was no or less decreasing cell counts during the day for the exposed than for the unexposed. This result was caused by a diurnal change observed, indicating decreasing values during the day as the normal reaction (4). The other study (12) described above indicated the same reaction for the mixture of 22 volatile organic compounds. The last results are preliminary from the study of 10 subjects exposed to 10 mg/m^3. In that study no effects could be detected. In the studies with effects there were a small but significant positive correlation between changes

in polymorphonuclear neutrophils and changes in sensory irritation (4).

Table 2 Results summarized from experimental studies on organic indoor air pollutant effects on humans.

Ref.	Exposure and subjects		Measurements	Results
	Type. **Level.** Time	No of subjects, gender, age:span or average.		
7	n-decane. **0,10,35,100 ppm.** 6 h	32 ♀ 31 ♂ average 36	BUT[a] ED REDNESS PMNs[b]	BUT ↓ PMN ↑
12	22 VOCs[c]. **0, 25 mg/m³.** 2.5 h	20 ♀ 15 ♂ Average 41	BUT PMNs	PMN ↑
13	Gases from different materials. **0.6 - 1.9 mg/m³.** 6 h	13 ♀ 12 ♂ 19-53	BUT ED FOAM LLT	BUT ↓
19	VOCs, different mixtures. **0,2,5,15 mg/m³.** 1 h	16 ♀ 14 ♂ 19 - 60	BUT FOAM	BUT ↓ FOAM ↓ ?
26	VOCs and dust emitted during work with video display units. **0.03 - 0.13 mg/m³ dust** **0.04 - 0.18 mg/m³ VOCs.** 6 h	30 ♀ 24 - 45	BUT FOAM ED LLT	ED ↑
20	22 VOCs and temperatures. **0, 10 mg/m³** **18, 22, 26 °C.** 1 h	5 ♀ 5 ♂ 28 - 60	BUT PMNs	NS

a: BUT = Break up time.
b: PMN = polymorphonuclear neutrophils
c: VOC = Volatile organic compounds.
d: LLT = Lipid layer thickness

Lately another study on effects of emissions (dust and VOCs) from office machines is published (26). That study showed no effect on BUT, FOAM, and LLT but increased ED as well as significant irritation.

Summarizing the results of the experimental studies in table 2, it seems that cytology may be useful in assessment of eye irritation and that break up time may be decreased, due to some types

of exposures. Effects on foam formation and on epithelium needs to be repeated.

It seems that there is a small correlation between break up time and sensory responses only in a single study. However, only few studies have been analyzed for this association.

4. Discussion and needed research

There is a need for establishment of dose-effect relationships for cytologic effects, for break-up time, and foam formation to assess the thresholds for the effects of VOCs and of dust. But also investigation of the hypotheses that subjects with missing foam, with low BUT, and with high numbers of lissamine stained dots are more sensitive to air pollutants has to be investigated. Further, we need investigations on, whether subjects suffering from allergies like hayfever are more susceptible than the rest of the population. Another group of interest is subjects with dry mucous membranes because of diseases (eg Sjögreens syndrome).

However, a very important task of the experimental studies is to investigate new assays of eg. constituents of the tear fluid and their relation to indoor air pollution. A major task, maybe the most important, will be to get a better understanding of the pathophysiological events or mechanisms leading to the sensory eye irritation as seen in humans, or to understand the physiological events following the sensory irritation.

So far the only solution to the problems described is to perform more experimental epidemiological studies and certainly also to perform prospective cohort studies addressing cause-effect relationships.

A possibility is follow a cohort young office workers through several years with respect to exposure and objective parameters eg. tear film stability. This would make it possible to test the hypothesis, that the environment is the cause of decreased tear film stability, missing foam formation, increased epithelium damage etc. Also the hypothesis that the abnormal objective parameters leads to higher frequency of sensory irritation can be tested. However, this will be a very difficult study to do especially with respect to exposure assessment. No such studies are performed to the knowledge of the author.

Case-referent studies could answer some of the questions about eye problems but will probably be impossible to do since exposure assessment in retrospective studies is even more difficult when you are dealing with offices, which are characterized by the lack of any specific production related sources

One future demand will be development of more non-invasive methods for assessment of effects on eyes and of the other mucous membranes. A useful method may be analyses on small tear samples (three - five microliters) for markers of inflammatory mucous membrane effects (enzymes, leucotrienes, IgE etc) or markers of trigeminal nerve activity (e.g. Substance-P). Methods for sampling exists, and have been practiced successfully in USA in environmental studies on effects of outdoor air on school children of age 6-14 and their parents (not published). Stix to insert below the lower eyelid has been shown to work out reasonably good in the clinic If such standardized analysis kits can be developed they methods may be cheep enough to apply in epidemiological studies. This will be a major task for development of epidemiology on indoor air irritation of mucous membranes in the eyes.

5. Conclusions

I Break up time and related surface parameters, and polymorphonuclear neutrophils have been useful in assessment of eye irritation in indoor air studies. But results need confirmation.

II Conclusive longitudinal epidemiological studies are needed.

III Dose - response and effect relations needs to be established for existing objective tests.

IV Further development of methods for objective eye irritation assessment are needed.

V Research mentioned above is needed before an adequate pathophysiological model for the irritation of the low level exposure on eyes as seen in indoor air.

VI **First of all we simply need to gather more data using both the methods described and some of the new methods indicated.**

6. References

1 Skov P, Valbjørn O, DISG. 1987. The "sick" building syndrome in the office environment: the Danish town hall study. Environ Int 13 339-349.

2 Colligan MJ 1981. The psychological effects of indoor air pollution. Bull. N.Y. Acad. Med. 57, 1014-1026

3 Mølhave L. 1988. "Indoor Air and Health". Doctoral Thesis, Aarhus Universitets forlag, Århus, Denmark

4 Kjærgaard S. 1990. "Eye irritation and indoor air pollution". Ph.D Thesis (in Danish with English summary). Inst. for Miljø- og Arbejdsmedicin, Aarhus Universitet. Aarhus, Denmark.

5 Norn MS. 1983. The external eye. Methods of examination. Scriptor, Copenhagen.

6 Nielsen GD. 1991. Mechanisms of Activation of the Sensory Irritant Receptor by Airborne Chemicals. CRC Toxicology. 21, 183-208.

7 Kjærgaard S, Mølhave L, Pedersen OF. 1989. Human exposures to indoor air pollutants: n-decane. Environmental International 15,.

8 Kjærgaard S, Taudorff E, Mølhave L, Pedersen OF. 1990. Assessment of changes in eye redness. Int. Arch. Occup.Environ. Health, 62, 133-137

9 Norn MS. 1969. Desiccation of the pre-corneal film. I. Corneal Wetting-Time. Acta ophthalmol 47, 865-880.

10 Franck C. 1986. Eye symptoms and signs in buildings with indoor climate problems ("Office eye Syndrome"). Acta ophtalmol (Kbh.) 64 306-311.

11 Franck C , Skov P. 1989. Eye symptoms and signs in buildings with indoor climate problems ("Office eye Syndrome"). Acta ophtalmol (Kbh.) 67 61-68.

12 Kjærgaard S, Mølhave L, Pedersen OF. 1991. Human reactions to a mixture of indoor air volatile organic compounds. Atmos. Env. 25A 1417-1426.

13 Johnson CR, Albrechtsen O, Nielsen PA, Nielsen GD, Hansen LF, Wolkoff P, Frank C. 1990. Controlled Human Reactions to Building Materials in Climate Chambers - Part I Performance and Comfort. In Proceedings Indoor Air 90 The fifth International conference on Indoor air, quality and climate (Eds Walkinshaw et al), 1, 269-274, Toronto

14 Norn MS 1973. Lissamine green - Vital Staining of Cornea and Conjunctiva. Acta ophthalmol 51 483-491.

15 Kjærgaard S, Pedersen OF. 1989. Dust exposure, eye redness, eye cytology, and mucous membrane irritation in a tobacco industry. Int. Arch. Occup. Environ. Health, 61, 519-525.

16 Kjærgaard S. 1990. Eye changes in Stockholm University Library (In danish) Institute of Environmental and Occupational Health. Århus.

17 Berglund B, Johansson I, Lindvall T, Lundin L, Morath C. 1988. Air quality in a sick library. In Indoor and Ambient Air Quality (eds. Perry R, Kirk PW) Selber Ltd, London, 355-364.

18 Gluud BS, Boesen T, Norn M. 1981. Fedtvehiklets virkning på cornea og conjunctiva. Ugeskr Læger 143 2345-2347.

19 Mølhave L, Kjærgaard S, Pedersen OF, Jørgensen AH, Pedersen T. 1991. Total volatile organic compounds (TVOCs) as indicator of human responses to indoor air pollutants. (In danish with English Abstract). Ministry of Housing reports, Copenhagen.

20 Mølhave L, Zunyong L, Jørgensen AH, Pedersen OF, Kjærgaard SK. 1991. Effect of human comfort and health of combined exposures to varying air temperature and volatile organic compounds. Institute of Environmental and Occupational Health. Århus

21 Kobal G 1984 Pain related electrical potentials of the human respiratory nasal mucosa elicited by chemical stimuly. In pain measurements in Man - neurophysiological correlates of Pain (eds. Bromm B). Elsevier Science Publishers B.V.

22 Norn M. 1979 Semiquantitative interference study of fatty layer of precorneal film. Acta Ophthalmologica 57 766-774.

23 Olsen T. 1985 Reflectometry of the precornal film. Acta Ophthalmologica 63 432-438

24 Kjærgaard S 1992 Objektive eye changes in the indoor climate - a prospective study. The

Danish Building Agency. Copenhagen. Ministry of Housing reports, Copenhagen. (In Danish with an English summary).

25 Stokholm J, Norn M, Schneider T. 1982 Ophthalmological effects of man-made mineral fibers. Scand J work environ health 8 185-190.

26 Wolkoff P. 1991 Human reactions to the emissions of office machines in a climatic chamber. Arbejdsmiljøfondet, Copenhagen. (In Danish with an English summary).

INDOOR ENVIRONMENT AND THE SKIN.

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ABSTRACT. There is a lack of consensus about the clinical signs and prognosis of the sick building syndrome (SBS). Clinical reports are sparse and the inclusion of skin symptoms in the syndrome is a matter of controversy. Skin symptoms affecting both facial skin, scalp and trunc have been reported from buildings with indoor climate problems. During the last ten years there have been reports of facial skin symptoms associated with VDT work. Results from an interdisciplinary study of offices in northern Sweden are presented. Female gender, asthma/rhinitis, psychosocial factors, VDT and paper work were important non-building related risk factors for SBS-symptoms. VDT work especially raised the risk for self reported facial skin symptoms. Building factors of importance were, among others, outdoor air flow rate and water/mould problems. In VDT workers background electric fields and magnetic fields emitted by the VDT appeared as risk factors for skin symptoms. Skin symptoms in VDT workers preferrably affected facial skin while office workers with general and mucosal symptoms compatible with SBS had skin symptoms affecting larger areas of the body. The presented data support the inclusion of skin symptoms in the sick building syndrome.

1. Introduction

In 1982 a World Health Organization (WHO) expert group defined the "sick building syndrome" (SBS)(1). Their definition, based mainly on reports from the Scandinavian countries and the U.S., is still in widespread use and includes a list of general, mucosal and skin symptoms, i.e. "sensation of dry skin" and "erythema".

This definition however, is not an accepted clinical syndrome but rather a list of symptoms often perceived by persons working or residing in buildings with indoor climate problems. The lack of concensus regarding the concept SBS has led to a disparate use of this term. Skin symptoms are by some authors not included in the syndrome.

In a cross-sectional study from the U.K. skin symptoms were not reported (2). In the Danish Town Hall Study work-related skin symptoms were reported in very low prevalences and not included in risk assessments (3,4). In a Swedish cross-sectional study of SBS in the general population skin symptoms, both on hands and in facial skin, were reported (5).

H. Knöppel and P. Wolkoff (eds.),
Chemical, Microbiological, Health and Comfort Aspects of Indoor Air Quality – State of the Art in SBS, 129–140.

Clinical studies of SBS are sparse and it is sometimes stated that SBS is not a clinically significant problem. Skin reactions in patients referred to a dermatological clinic due to symptoms perceived in buildings with indoor climate problems have been reported. Facial erythema, rosacea, scaling of scalp, ears and face, urticaria and "itching folliculitis" were common work-related findings (6). Skin irritation and rashes on hands and face, associated with general, eye and airway symptoms, have been reported from intense handling of carbonless copy paper in small, badly ventilated rooms (7). A phenomenon named "low humidity occupational dermatoses" has been described appearing in work places in the U.K. were relative humidity was lowered to around 35% (8,9). The skin symptoms reported were pruritus and urticaria on covered areas and scaling dermatitis on the face, scalp and ears.

This summary of reported skin reactions related to indoor climate factors indicate that the suggested "primary SBS symptoms" in the skin, i.e. perceived dryness and erythema, in a number of predisposed individuals can evoke or aggravate a clinically observable disease. It also implies that the skin signs may be more diverse than previously recognized. Moreover, since these skin signs traditionally are considered to be of psychosomatic nature, the findings seen in clinical practice may reflect the impact from physical, chemical and psychosocial factors in a complicated interaction.

Further complicating the picture are reports, mainly from Norway and Sweden, of skin symptoms related to VDT work (10,11,12,13). The reported symptoms and signs have been compatible with the beforementioned facial skin symptoms reported from "sick buildings" suggesting a possible connection between "VDT related" and "indoor climate related" complaints (14). A cross-sectional study of office workers in Sweden confirmed an exposure-respons relationship between the prevalence of self reported skin symptoms and the amount of VDT work. Objective skin signs however, did not show this pattern (15). VDT work as a risk factor for skin disease is still controversal.

Due to an increasing number of patients with complaints from indoor environment factors an interdisciplinary study, the Office Illness Project in Northern Sweden, was started in 1988. It was commenced by a questionnaire screening study followed by two case-referent studies, one of SBS in office workers, the other of skin symptoms in VDT workers.

The aims of the project were
to estimate the prevalence of SBS symptoms and their distribution in different strata,
to assess personal, physical and psychosocial risk factors and
to study the impact from VDT use on skin symptoms.

2. Materials and methods

The structure of the project is shown in Figure 1.

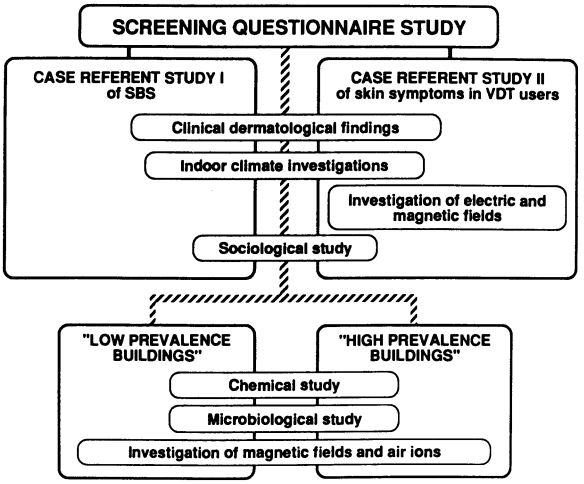

FIGURE 1. The structure of the Office Illness Project.

A questionnaire, tested and validated in a pilot study, was mailed to 6 000 office workers in the county of Västerbotten. It included questions about personal and demographic factors, work characteristics, perception of physical and psychosocial factors, symptoms, work factors such as paper and VDT use and building characteristics at work and at home.

The screening study was used as a base for a case–referent study of SBS (n=450) among non-VDT users and another case–referent study of skin symptoms in VDT workers (n=150) with equal numbers of cases and referents. SBS–cases were defined as persons perceiving general, mucosal and skin symptoms during the last three months. Cases in the VDT study were defined as persons with sensory symptoms (i.e. itching/stinging/tight or burning sensations in facial skin) and facial erythema and/or facial dry skin. The same skin symptoms were used for the definition of SBS.

From these symptoms a skin symptom index was constructed based on the frequency of perceptions (often=2, sometimes=1 and never=0). This index was grouped into three classes (0–2) of approximately equal size. "High skin index" thus means index class 2. Indices for the perception of psychosocial factors and paper exposure were also constructed. Psychosocial index sums up questions about stimulating work, work demands and influence on work conditions. Paper index sums up the frequency of work with carbonless copy paper, disposable carbon paper, printer paper and photo copies, each paper given the same weight from exposure point of view.

The case referent studies included both a clinical and a technical part. All employees were examined by a dermatologist. The technical part included investigations of the thermal climate and ventilation performance, inspection of the buildings regarding construction, materials, signs of water damage etc. In the VDT study an investigation of electric and magnetic fields as well as personal charge was added. All employees in the case–referent studies were subject to a separate sociological study of the psychosocial work load. Thirty buildings, half with low prevalences of SBS and half with high prevalences, were selected for separate studies of chemical and microbiological factors and investigations of electromagnetic fields and air ions.

3. Results

In this paper a sample of results from different parts of the project will be given.

3.1 THE QUESTIONNAIRE

In the screening study the return rate was 95%. After exclusion of persons not at work during the investigation period a total of 4 943 questionnaires were processed.
From the questionnaire risk factors for SBS symptoms, not associated with the building itself but rather with persons and activities within the building, could be assessed.

The age distribution was similar among males and females whereas smoking was more prevalent among females. Asthma/rhinitis occurred in 18–19% in both sexes. As for the position, women were mostly "lower" employees, men mostly "middle" or "higher". Two thirds of both females and males reported working with VDT. Paper work was more prevalent among women, especially work with carbonless and disposable carbon paper.

Complaints from physical climate factors were much more prevalent among females than males both in dwellings and in the offices. Dry and stuffy air were by far the most common complaints. Men more often reported interesting and stimulating work as well as greater opportunity to influence work conditions.

The symptoms recorded in the questionnaire were compatible with those included in the WHO definition of SBS, with some extra skin symptoms added (1).

Table 1 depicts prevalences of skin symptoms perceived every week during the last three months.

TABLE 1. Prevalence (%) of skin symptoms perceived every week by males and females.

Symptom	Males %	Females %
Dry facial skin	8.1	24.4
Flushed facial skin	4.6	8.5
Itching/stinging/tight or burning sensation in facial skin	3.0	8.1
Scaling/itching scalp or ears	8.6	9.9
Dry, itching red skin on hands	3.9	10.1

The prevalence of general symptoms ranged from 1.1% to 16.0% among males and 2.9% to 28.2% among females, fatigue being most prevalent. Mucosal symptoms were reported by 2.1% to 9.4% of males as compared to 3.3% to 15.9% of females, nose symptoms being most prevalent among males and eye symptoms among females. All symptoms but difficulties concentrating and scaling/itching scalp were significantly more prevalent among females. Eye, throat and nose symptoms, feeling heavy-headed and facial skin complaints were the symptoms most often attributed to indoor climate factors. One of four had sought medical care for one or several symptoms.

In the study population the prevalence of SBS-cases was 4% among men and 12% among women. SBS-cases and general symptoms were more prevalent in ages under forty, skin symptoms in ages 30 - 49 years. Smoking was not associated with any increase in symptom indices whereas asthma/rhinitis entailed increment of all symptom indices.

An exposure-respons relationship between all skin symptoms included in skin symptom index and the amount of VDT work was established. Table 2 depicts the crude odds ratios estimating the risk for having the highest skin symptom index class.

TABLE 2. Crude odds ratios for high skin symptom index at varying amounts of VDT work among males and females.

Symptom	VDT exposure	Odds ratio		95% C.I.	
		Males	Females	Males	Females
Skin symptom	0	1.0	1.0	–	–
	<1 h/day	1.25	1.22	(0.90–1.75)	(0.97–1.55)
	1–4 h/day	1.99	1.70	(1.53–2.6)	(1.39–2.1)
	>4 h/day	2.8	2.1	(2.1–3.7)	(1.62–2.7)

Besides index symptoms, the risk for itching and scaling of scalp/ears was elevated among males. Odds ratios standardized for age, asthma/rhinitis or paper work did not change this pattern. When stratifying for psychosocial index, a potential confounder, an additive effect of VDT work and psychosocial load was demonstrated (Figure 2).

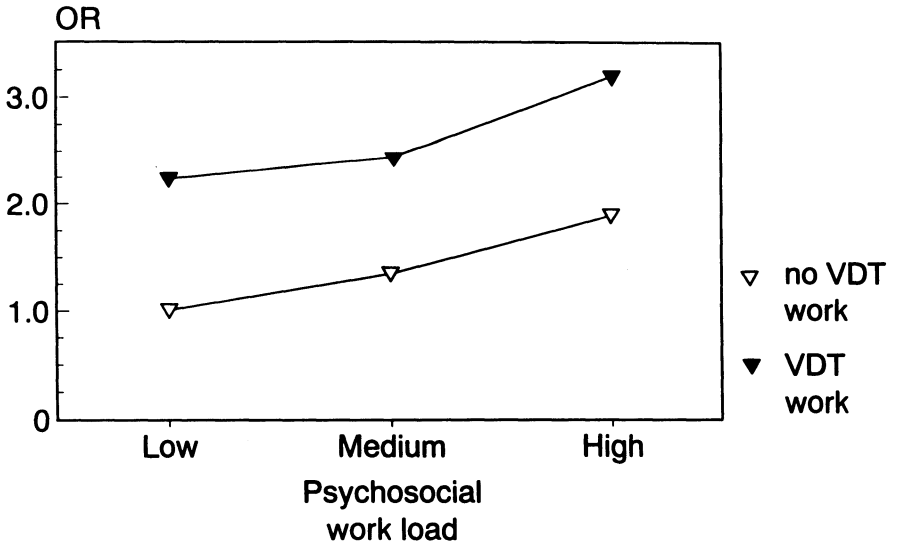

FIGURE 2. Odds ratios for high skin symptom index at varying amounts of VDT work and psychosocial load. Odds ratios standardized for gender.

Symptom risks in paper work are presented in a similar manner as for VDT work in Table 3.

TABLE 3. Crude odds ratios for high skin symptom index at varying amounts of paper work among males and females.

Symptom	Paper exposure index class	Odds ratio		95% C.I.	
		Males	Females	Males	Females
	0	1.0	1.0	–	–
	1	1.29	1.04	(0.99–1.68)	(0.83–1.31)
	2	1.74	1.45	(1.36–2.2)	(1.19–1.77)

Among both males and females the symptom risk pattern was much the same as for VDT work. A significantly increased risk for skin symptoms on the hands also appeared. Standardization for age, asthma/rhinitis or VDT work had no significant impact on the odds ratios.

Figure 3 illustrates the combined effects of gender, asthma/rhinitis ("atopy") and exposure to VDT and paper work on odds ratios for high skin symptom index. Males without asthma/rhinitis, with no VDT work and with low paper exposure constituted the reference group. All risk increments were significant. Female gender, in these analyses, stands for the sum of predisposing and personal as well as exposure factors unequally distributed among the sexes (16).

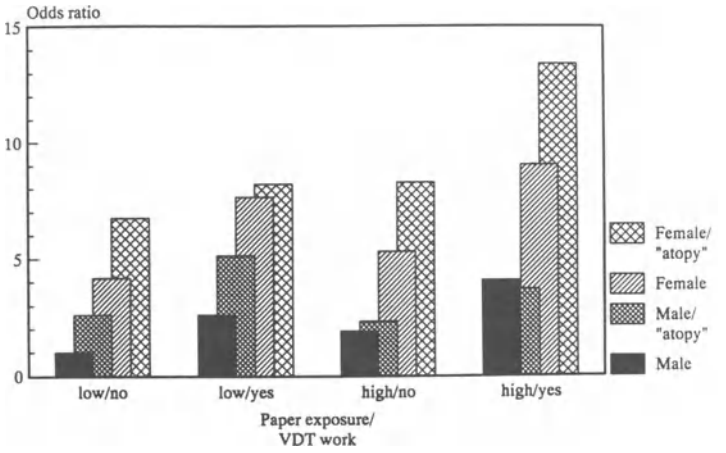

FIGURE 3. Odds ratios for high skin symptom index among males and females with and without asthma/rhinitis and with respect to paper and VDT work.

3.2 CASE-REFERENT STUDY I/BUILDING FACTORS

Skin symptoms are this far not assessed separately from SBS in this study. The results show that the precense of certain pollution sources as photocopiers and water/mould problems increased the risk for SBS. A high outdoor air flow rate and good cleaning reduced the risk (17).

3.3 CASE-REFERENT STUDY II/ELECTROMAGNETIC FIELDS, BUILDING FACTORS

This is the first study where the risk for skin symptoms is assessed with measured electric and magnetic fields. A number of environmental factors, e.g thermal climate, electrostatic fields, person charge etc, were measured. The electrical environment including background fields as well as fields emitted from the VDT were surveyed. Two factors significantly increased the risk for facial skin symptoms. Background electric (E) fields in the ELF (extremely low frequency, here around 50 Hz) range increased the relative risk (OR) to 3.0 and test for trend was significant (Figure 4).

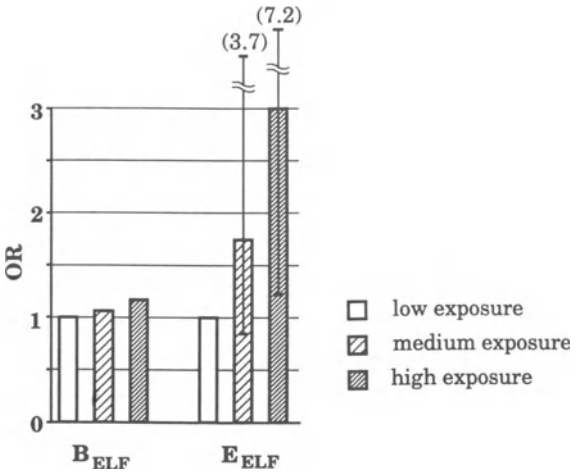

FIGURE 4. Odds ratio for skin symptoms among VDT workers with respect to measured background magnetic (B) and electric (E) fields in the ELF range.

The magnetic (B) field in the ELF range in front of the VDT showed the same pattern (Figure 5). The relative risk (OR) was increased to 2.7. Electomagnetic fields in the VLF (very low frequency) range did not increase the risk. The significance of these findings is not yet known (18). Background electric fields as a risk factor was supported by the finding that fluorescent tubes without metal screens (reducing the electric fields) also increased the risk for skin symptoms. A low cleaning frequency was a risk factor for symptoms also in this study (17).

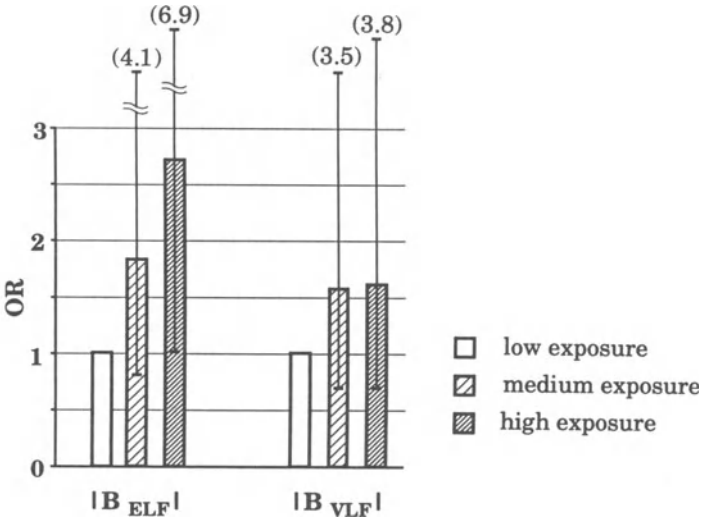

FIGURE 5. Odds ratio for skin symptoms among VDT workers with respect to measured magnetic (B) and electric (E) fields in the ELF range in front of the VDT.

3.4 SOCIOLOGICAL STUDY

The results from this independent part of the project showed that psychosocial and organizational factors are of importance for prevalence of symptoms, especially in the case-referent study of SBS. Unfavourable circumstances concerning work organization, work content, work satisfaction, social relations and information increased the risk for SBS-symptoms, including the beforementioned skin symptoms. The relation between these kinds of factors and symptoms were not as clear in the VDT study. Factors that seemed to increase the risk for skin symptoms were problems with social relations, lack of information and low work satisfaction. Because the VDT study was considerably smaller than the SBS study it's ability to identify risk factors was reduced (19).

3.5 CLINICAL STUDY

Because of the nature of the skin symptoms used in the definition of cases in both case-referent studies certain endogenic factors were expected to be more abundant among cases. Atopic and seborrhoeic dermatitis and light sensitivity was more common in both case groups, migraine only among VDT cases. These differences between cases and referents however, were not significant.
The most common clinical findings among SBS-cases were dry skin on face and trunc, erythema, seborroeic dermatitis and acne/facial folliculitis. Dry skin was significantly more prevalent among SBS-cases as compared to VDT-cases. The opposite was noted for rosacea/perioral dermatitis. Burning and prickling sensations were more frequent among VDT-cases while feeling of tight skin was more often reported by SBS-cases. Itch and smarting sensations was evenly distributed among

both groups. When asked to what extent the employees considered the symptoms to be work related some differences among the two case groups appeared. Rosacea/perioral dermatitis was more often aggravated by work according to VDT-cases while SBS-cases much more often considered work as a deteriorating factor for pruritus/urticaria and atopic dermatitis.

4. Discussion

This paper has summarized reported skin symptoms and signs attributed to indoor environment and findings from an interdisciplinary epidemiologic study.
These data support the inclusion of skin reactions in the Sick Building Syndrome. Furthermore they indicate that skin reactions from indoor environment factors can induce or aggravate skin disease.
It should be emphasized that most studies assessing risk factors for SBS are based on perceived symptoms reported in questionnaires. The clinical practice and the survey investigate partly separate sectors of the outcome of indoor climate problems.
Up to now it seems reasonable that earlier reported risk factors for general and mucosal symptoms, in most cases, are also pertinent for skin symptoms. There is of course a possibility that regional differences, e.g. climatic factors, may influence the prevalence of different symptoms and signs.
Differences in the outcome of questionnaire surveys may to some extent be due to different phrasing of questions. In our screening study the questions about skin symptoms were phrased according to descriptions used by patients referred to a dermatological clinic. The use of "work-related" symptoms, defined as symptoms improving over week-ends, may affect symptoms unequally. Skin symptoms are often more resistant than for example, general symptoms.
When discussing VDT work as a risk factor for SBS symptoms the presented results indicate that skin symptoms in SBS engage large ares of the body while VDT workers suffer from symptoms preferrably in facial skin.

5. References

1. WHO. (1983) 'Indoor Air Pollutants: Exposure and Health Effects', EURO Reports and Studies 78, World Health Organization, Copenhagen.

2. Burge, S., Hedge, A., Wilson, S., Bass, J.H., Robertson, A. (1987) 'Sick Building Syndrome: a study of 4373 office workers', Ann Occup Hyg 31, 493.

3. Skov, P., Valbjorn, O., Pedersen, B. V., the Danish Indoor Climate Study Group. (1989) 'Influence of personal characteristics, job-related factors and psychosocial factors on the Sick Building Syndrome', Scand J Work Environ Health 15, 286.

4. Skov, P., Valbjorn O., Pedersen, B.V., the Danish Indoor Climate Study Group. (1990) 'Influence of indoor climate on the Sick Building Syndrome in an office environment', Scand J Work Environ Health 16, 363.

5. Norbäck, D., Edling, C. (1991) 'Environmental, occupational and personal factors related to the prevalence of Sick Building Syndrome in the general population ', Br J Ind Med 48, 451.

6. Stenberg, B. (1989) 'Skin complaints in buildings with indoor climate problems', Environ Int 15, 81.

7. Calnan, C.D. (1979). 'Carbon and carbonless copy paper', Acta Derm Venereol Suppl. 85, 27.

8. Rycroft, R.J.G. Smith, W.D.L. (1980) 'Low humidity occupational dermatoses', Contact Dermatitis 6, 488.

9. White, I.R., Rycroft, R.J.G. (1982) 'Low humidity occupational dermatoses - an epidemic', Contact Dermatitis 8, 287.

10. Nielsen, A. (1982) 'Facial rash in visual display unit operators', Contact Dermatitis 8, 25.

11. Tjonn, H.H. (1984) 'Report of facial rashes among VDT operators in Norway' in B.G. Pearce (ed.), Health Hazards of VDT's? John Wiley & Sons, NY, p. 17.

12. Lidén, C., Wahlberg, J.E. (1985) 'Work with display terminals among office employees. V. Dermatologic factors', Scand J Work Environ Health 11, 489.

13. Stenberg, B. (1987) 'A rosacea-like skin rash in VDU operators', in B. Knave, P-G Widebäck (eds.), Work with display units 86. Elsevier/North Holland, Amsterdam, p. 160.

14. Wahlberg, J.E., Stenberg, B. (1991) 'Skin problems in the office environment', in T. Menné, H. I. Maibach, Exogenous dermatoses: Environmental dermatitis. CRC Press, Boca Raton p. 327.

15. Berg, M., Lidén S., Axelson, O. (1989) 'Facial skin complaints and work at visual display units; an epidemiologic study of employees', J Am Acad Dermatol 22, 621.

16. Stenberg, B., Hansson Mild, K., Lönnberg, G., Sandström, M., Wall, S. (1991) 'The Office Illness Project in Northern Sweden. A questionnaire study of perceived health and risk of symptoms related to personal factors and occupational and residential exposure factors'. National Institute of Occupational Health, Umeå, Sweden. Investigation Report 11 (in Swedish, summary in English).

17. Sundell, J., Lindvall, T., Stenberg, B., Wall, S. 'The Office Illness Project in Northern Sweden. Indoor climate, buildings and rooms. Part 2: SBS and skin symptoms in VDT workers', National Institute of Occupational Health, Umeå, Sweden. Investigation Report (in manuscript, in Swedish, summary in English).

18. Sandström, M., Hansson Mild, K., Lönnberg, G., Stenberg, B., Wall, S. (1991) 'The Office Illness Project in Northern Sweden. Electric and magnetic felds: a case-referent study among VDT workers', National Institute of Occupational Health, Umeå, Sweden. Investigation Report 12 (in Swedish, summary in English).

19. Eriksson, N., Höög, J. (1991) 'The Office Illness Project in Northern Sweden. The importance of psychosocial factors for prevalence of Sick Building Syndrome (SBS) and of skin symptoms among VDT workers', National Institute of Occupational Health, Umeå, Sweden. Investigation Report 13 (in Swedish, summary in English).

SENSORY EFFECTS FOR INDOOR AIR QUALITY CONTROL

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ABSTRACT. Indoor air should be viewed on the basis of positive criteria that surpass the mere avoidance of negative effects on occupants and buildings. The report aims at furnishing judgmental criteria for defining a good indoor air from the sensory effect point of view and at discussing requirements on methods of testing of sensory effects. Sensory experience is a foundation of all our knowledge of the physical environment. Sensory perceptions are real and possible to explicate, manipulate and measure. Common features of the sensory systems are multisensory perceptions, perceptual interactions and recognition of chemical and sensory patterns of the indoor air. It is strongly argued that sensory effects be used in indoor air quality control. Recently, clear criteria have been presented for the judgment of sensory effects and qualitative values based on sensory effects are now being used. Unwanted odorous compounds should not be present indoors in concentrations exceeding the 50th percentile for detection among the occupants and sensory irritants should never exceed the 10th percentile for detection. In the promotion of good indoor air quality priority should be given to the protection of the sensitive part of the occupant population.

1. Introduction

Already in the early seventies, UNESCO (1973) took the stand that increased attention should be paid not only to the environmental hazards now proven to affect adversely the physical health of humans but also to the quality of the environment as humans perceive it. In other words, the health criteria must include the pathogenic effects in a strictly medical sense as well as the negative and positive factors relevant to comfort and well-being. This is wholly in line with the definition of health taken by the World Health Organization (WHO): "A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (Yearbook of International Organizations, 1968-69). The WHO (1987, 1989a) has also pointed out the importance of sensory reactions as adverse effects in relation to several indoor air contaminants. However, in indoor air quality control we would like to formulate positive criteria that surpass the mere avoidance of negative effects on occupants and building. This positivistic view is not new to the nonindustrial indoor environment. For example, since long the thermal climate has been regulated from data on thermal comfort rather than on thermal discomfort (Hensel, 1982). It is evident that both approaches, problem prevention and problem therapy, have to be concomitantly effectuated for the promotion of a wholesome indoor environment.

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One reason for the awakened concern for the perceived qualities of the indoor air is that sensory effects expressed as complaints and reports of annoyance may be warning signals of illnesses to come on a long term basis (Lindvall & Radford, 1973), and thus, constitute possibilities for a preventive method of testing, at least theoretically (Baird, Berglund, Berglund & Lindvall, 1990). As a supplement to this development, environmental psychophysics has provided a theoretical framework as well as methods for measuring the perceived indoor air, including both the positive and negative aspects (Baird & Berglund, 1989; Craik & Zube, 1975).

However, the indoor air community has started to realize that the perceptual or comfort aspects are essential both for indoor air quality and healthy buildings. Several type of sensations are involved, which each may be viewed as a complex of sensations. The most prominent are thermal sensations (*e.g.*, thermal comfort), air quality sensations (*e.g.*, staleness or freshness), visual sensations (*e.g.*, lighting and visual outlooks), and auditory sensations (*e.g.*, sound and room acoustics). Other more complex psychological aspects of the indoor environment are also to some extent important for the perception of indoor air quality: perceived personal space (crowding), perceived physical space (closeness or openness), and aesthetic quality of building and room design. However, in the following presentation the focus will be on sensations related to indoor air quality.

2. Environmental versus Body Perceptions

In indoor air quality control it is important to realize that sensory criteria relate to different kinds of perceptions associated with the indoor air. Human sensory reactions or sensory effects are determined most easily and validly by self-reports of perceptions. Two main classes of perceptions can be identified: *Environmental Perceptions* and *Body Perceptions.* The first and obvious class, the environmental perceptions, includes perceptions attributed to the surrounding physical environments, for example, percepts of draft, odor, and "fresh air". Environmental perceptions can be adverse, as in the case of malodor, or nonadverse, as in the case of "fresh air". The second and less obvious class, the body perceptions, includes perceptions of events inside the body or on the body surface. The body perceptions, for example, perceived eye irritation, dry skin or congested airways, may or may not be attributed causatively to the surrounding indoor air. Also the body perceptions can be adverse, as for example perceived eye irritation, or nonadverse, as for example "feeling alert". It should be realized that it is much easier to establish psychophysical (or dose-response) relationships for environmental perceptions than for body perceptions. The latter are to a larger extent determined by unknown subject-related factors.

The recent interest in problem buildings has resulted in a concentration on either adverse perceptions of the indoor air as such or on adverse perceptions, or so-called symptoms, causatively attributed to indoor air by the occupants. However, the dream of anyone concerned with indoor air ought to be the promotion of positive internal perceptions. Thus, the ultimate goal in indoor air quality control is not just to eliminate the adverse perceptions but to create positive perceptions.

3. On the Philosophy of Sensory Experience

Sensory reactions play a decisive role for the person who intends to enter a space. These reactions are a synthesis and integration of the common complex air exposure. The perception of the air will decide whether the person will enter, stay in, or leave a room.

The decision may depend on an unfamiliar odor or peculiar irritation in the eyes. In the Sick Building Syndrome (SBS), self-reports on environmental or body perceptions are often considered as false reports, thus, implying that the respondents are malingerers. On the other hand, the self-reports may be true and refer to the set of symptoms defining the SBS. In indoor air quality control, sensory effects such as odor or mucosal irritation present specific problems: Although the odors may be malodorous or strongly perceived, they are naturally perceived and not necessarily harmful. The mucosal irritation referred to the upper airways may only be perceived without any independently observable physiological change. Several philosophers have thought about the meaning of perceptions and particularly discussed the relationship between the mental world and the physical world.

The existence of mental events of sensory experiences is usually admitted but the views of various schools of philosophy differ with regard to the relation between these events and the physical world. One extreme view is to consider mental events exclusively as epiphenomena or byproducts of physiological processes. Another extreme view is that of true parallelism which consider mental events to be noncausal but concomitant to physical events. The former view is well exposed by the philosopher Karl Popper and the brain physiologist John D. Eccles in their book *"The Self and Its Brain"* (Popper & Eccles, 1977) while a proponent for the latter view of parallelism is characteristic for the physicist Ernst Mach as revealed in his book *"The Analysis of the Sensations, in Man and Animals"* (Boring, 1929). The philosophical standpoint is as important for how we formulate and control for sensory criteria as is the legal issue for how we judge and intervene with nonfulfillment of, for example, building regulations.

From the simple fact that the experimental physics is forced to rely on sensory perception as its ultimate source of evidence, physicists like Albert Einstein and Niels Bohr came to hold the view that sensory experience is the foundation of all our knowledge of the physical world. Indeed, there are no known neural or physical-chemical events, that can truly explain sensory phenomena although they may well be necessary conditions for the sensory experience. Thus, the strain of events from the air exposure to the sensation is not simple (*e.g.*, Popper & Eccles, 1977)

Recent findings in neurophysiology prove, for example, that the causal road between the mental, neural and physical events is two-directed: the mere thought of moving a hand, for example, results in nervous activity in a designated area of the brain not only the actual movement of the hand. As expressed so well by the nerve physiologist Mountcastle (1975): *"Each of us believes himself to live directly within the world that surrounds him, to sense its objects and events precisely, to live in real and current time. I assert that these are perceptual illusions, for each of us confronts the world from a brain linked to what is "out there" by a few million fragile sensory nerve fibers. These are our only information channels, our lifelines to reality. These sensory nerve fibers are not high-fidelity recorders, for they accentuate certain stimulus features, neglect others. The central neuron is a story-teller with regard to the afferent nerve fibers; and is never completely trustworthy allowing distortions of quality and measure within a strained but isomorphic spatial relation between "outside" and "inside". Sensation is an abstraction, not a replication of the real world"*. I seems quite clear that this abstraction is uniquely available to the human individual in the form of images. Thus, the characterization of these images may only be made by self-reports.

If sensory perceptions are viewed as real and to some extent common to several individuals, then perceptual attributes are possible to explicate, manipulate, and measure. This view was held already by the psychophysicist Stanley S. Stevens in developing the direct methods of scaling (S.S. Stevens 1956, 1975; see also Torgerson, 1958, Baird & Noma, 1978). Together with the methods of category scaling, the direct scaling methods

(magnitude estimation, magnitude production, ratio scaling, equal-intensity matching, cross-modality matching) have been extensively applied in indoor air research (B. Berglund, 1990, 1991; B. Berglund & Lindvall, 1979, 1986; Cain, 1979). More recently, successful attempts have been made to calibrate magnitude scales of psychological attributes with the aid of a set of reference stimuli. The Master Scaling procedure has been developed by B. Berglund and associates (e.g., B. Berglund & Lindvall, 1979; B. Berglund, 1991; B. Berglund & Nordin, 1990) for applications in environmental psychology and the Method of Magnitude Matching by American researchers (J.C. Stevens, 1976; Marks, 1988) for clinical applications regarding sensory deficits.

4. Perception and Indoor Air Quality

Environmentally induced adverse perceptions could be accepted in certain industrial indoor environments. However, it is less natural that adverse perceptions should prevail in nonindustrial buildings. After all, the latter are meant for relaxation, and they are viewed as a safe refuge for children, for the elderly, and the sick. In other words, adverse perceptions resulting from indoor air may be accepted in occupational settings (where the "healthy person remains) but not in the nonindustrial settings (where the "sensitive" person spends most of his time). For example, people with allergies and other types of sensitivities (*e.g.*, asthma triggered by cold air; skin reactions caused by chemical airborne exposure) not only need a home as a refuge but also should be able to work in offices, schools, or in public buildings.

In attending to the sensory effects, the focus is on some unique aspects of the indoor air that may not be replaced by other effect measures. The aspects at focus are the low exposure levels, the immediate effects, the sensitive groups of individuals, and the interaction between exposure variables as well as between effect variables. In this connection, it may be noted that the sensory systems could be said to be tuned towards registering important environmental changes for the particular individual rather the registering and storing the absolute levels.

Since interaction and adaptation processes are characteristic of the sensory systems involved in the perception of odor and irritation, the time course of exposure as well as the other components of the air exposure influence the perception. For example, sensory adaptation is known to weaken the odor response over time at constant exposure, but, the exposure duration at concentrations close to the barely detectable level will enhance the perception (Ahlström, Berglund, Berglund & Lindvall, 1986; Berglund, Berglund & Lindvall, 1978; Corbit & Engen, 1971). Conversely to odors, sensory irritation is characterized by facilitation at constant exposure over time (Cain, See & Tosun, 1986). Since indoor contaminants often appear in complex gas mixtures that contain other low concentrations of odorous or irritating components, both the odor and irritation perception may potentially facilitate rather than adapt.

4.1. PERCEPTION AND SINGLE POLLUTANTS

Surprisingly little is known for olfaction, the common chemical senses, and the cutaneous senses which all seem to be critical for many of the symptoms in the SBS. This holds not only for the transduction and assessment of sensory signals, but even for the mechanisms behind the reception of the signals (Berglund & Lindvall, 1982, 1986, Marks, 1974; Cometto-Muñiz & Cain, 1991).

There are large differences in sensory sensitivity between individuals as demonstrated for vision, hearing and olfaction. Formaldehyde (Berglund, Berglund,

Högman, Johansson & Lindvall, 1985) at fairly high concentrations, about 0.8 mg/m³, is not perceived at all by some people while others show pronounced sensory reactions at concentrations that are less than 0.3 mg/m³. The absolute odor threshold for formaldehyde is as low as 0.06 mg/m³ (ED50) but with an extremely positively skewed distribution (Ahlström *et al.*, 1986) over individuals, ranging two powers of ten.

Most of our knowledge concerns pure substances and not complex gas mixtures. The sense of smell can handle a wide range of stimulus concentrations and in many instances it has been shown to detect odor substances at the part per billion (ppb) level. Several odors are significant mucosal irritants especially at high concentrations. All information on odor sensation must be viewed as a result of inputs from both the olfactory and irritant receptors. The absolute detection threshold for sensory stimuli varies widely with the chemical substance. In comparing anosmics with normals, the irritation threshold is usually found to be higher than the olfactory threshold (Cometto-Muñiz & Cain, 1990, 1991). Recognition thresholds are generally higher than detection thresholds. A number of biological variables influence the occupants' sensitivity to indoor air pollutants.

Compilations of odor thresholds for various chemical compounds are available in Fazzalari (1978), Gemert and Nettenbreijer (1977), and WHO (1989a, 1989b). The values presented in these publications should be interpreted with care because a number of methodological factors influence the reported threshold values. Unfortunately, the exposure control and method of threshold determination are usually poor (Berglund, Berglund & Lindvall, 1986a). Commonly, there are no data available that show the whole dose-response function for indoor pollutants. The reason for this is that most researchers have used the method of limits or only ascending series of concentrations in determining the absolute detection threshold. In order to display the whole psychometric function, it is necessary to use the method of constant stimuli which typically require an advanced dynamic olfactometer as well as long experimental sessions. For further information on the theory and methods of sensory detection, please consult Luce and Green (1974).

5. Perception of the Indoor Air Environment

Even low concentrations of sensory irritants in the indoor air of a building may be significant contributors to the overall sensory effect of the air (Ahlström *et al.*, 1986). Limit values are often based on effects registered for the target contaminant alone (*e.g.*, Lindvall, 1985) although in practice the limit values are applied for complex mixtures of the target together with other air pollutants (WHO, 1987, 1989a; B. Berglund, 1990).

Odors predominate among the indoor air pollutants at the concentrations they appear naturally in indoor air (Berglund, Berglund, Lindvall & Nicander-Bredberg, 1982). However, several of the contaminants are potential irritants but usually at higher concentrations than those found in indoor air (Anger, 1984; Lindvall, 1985). This is a puzzle in understanding the SBS which appear in buildings where approximately the same concentrations of practically the same indoor air pollutants are found as in healthy buildings (Berglund, Berglund & Lindvall, 1986b; B. Berglund, 1990). Because one single factor cannot be used to explain why a building's occupants get SBS, it seems evident that the hypothesis has to be changed. That is, several physical-chemical factors may be more potent in combination than singly. Theoretically, interaction models exist, and the practical consequences of their functional properties are quite complicated (*e.g.*, Haider, Kundi, Groll-Knapp & Koller, 1990). Very little empirical data, however, are available on interaction effects in general (*e.g.*, in occupational settings) or on interaction effects for specific environmental variables relevant for indoor air. A number of physical characteristics of the indoor environment may influence the effective stimulus causing

sensory effects, for example, the possible interaction between volatile chemicals and particulate matter.

5.1. PERCEPTUAL INTERACTION

For human sensory systems, two classes of interaction have been shown: "homogeneous" percept interaction and "heterogeneous" percept interaction. When a homogeneous percept is formed by simultaneous exposure to a mixture of two stimuli (*e.g.*, two component odors), these blend completely into a new percept that is perceived as an entity. In heterogeneous percepts of combined stimuli, the two single stimuli (*e.g.*, odor and radiant heat) do not blend but are perceived as separate percepts existing simultaneously, although they may differ from the perception of the single stimulus when presented alone.

For distinct odors, odor interaction (mixing odors only) is governed by a powerful attenuating process. The perceived odor strength of a mixture of two equally (subjectively) strong components is about 1.3 times the odor strength of the individual component. But, in cases where one component is much stronger than the other, the overall strength of the mixture will be almost the same as the strength of the strongest component alone. This type of odor interaction is congruent with a model of vector summation (Berglund, Berglund & Lindvall, 1976). It reflects an extremely strong attenuation of the human odor response to mixtures rather than a facilitation or synergism. Further, the empirical data show that when more and more odorous substances are mixed, the perceived odor strength of the mixture decreases to that of the single strongest component. Thus, odor problems may be expected when the air mix contains few types of odorous molecules or is dominated by a single strong odorant. One should note that an increase in the odor problem also would be expected when single odorous substances are removed from a complex mixture (B. Berglund, 1974).

A pertinent and simple question was asked by Ahlström *et al.* (1986) in the study of interaction effects from formaldehyde and sick building air: Can formaldehyde, at the low concentrations found indoors, enhance the odor strength of sick building air? They found that the odor strength of the indoor air samples approximately equals the odor strength of formaldehyde at concentrations between 0.10 and 0.17 mg/m^3. Furthermore, their results are congruent with the vector model of odor interaction which predicts that the odor interaction is largest for equal components (=point of subjective equality). They concluded that the odor of indoor air of a sick building most probably will add to the odor of formaldehyde only when formaldehyde is present at concentrations close to the sensory threshold. The effective odor threshold for formaldehyde is about 0.03 mg/m^3 according to Berglund, Högman, and Johansson (1988). That means that this concentration is not possible to separate from purified air in a controlled experiment.

Even if odors are important in indoor air quality, other sensory stimuli are also important for SBS (Berglund & Lindvall, 1986). Because SBS is dominated by sensory irritations, it can be suspected that open nerve endings in the skin are mediating some of the sensory information. Berglund, Högman & Olsson (1988) studied the influence of human-face radiant-heat exposure on the perception of odor and sensory irritation when persons were exposed simultaneously to indoor concentrations of formaldehyde (0.055-1.125 mg/m^3). The results show that face exposures of radiant heat above room background levels (background of exposure chamber = 42 mW/cm^2; a value subthreshold for warmth) may increase the odor of background charcoal-cleaned room air. The effect is quite clear at a radiant-heat face exposure of 135 mW/cm^2, an exposure level that is somewhat higher than can be expected in nonindustrial indoor environments. For radiant

heat levels that were suprathreshold for warmth and experimentally combined with formaldehyde gas exposure, the subjects reported higher odor strengths mainly at the low concentrations compared to the case when formaldehyde was presented alone. Half of the subjects reported that the odor quality of formaldehyde changed when they could perceive warmth on the face. Half of the subject reported that formaldehyde also caused sensory irritation at some concentration or another. Most of the latter reported nasal irritation and only a few reported throat, eye, or facial skin irritation. Although sensory interaction exists, no detailed mathematical model so far has been derived from the empirical data on heterogeneous percept interaction, in this case warmth-odor interaction.

So far, experimental research has shown that sensory interaction is possible for environmental factors at exposure levels relevant for the nonindustrial indoor air.

5.2. MULTISENSORY PERCEPTIONS

Many indoor climate problems express themselves as multisensory perceptions among which cutaneous and mucosal sensations are salient. Berglund and Lindvall (1986) points out that the sensations can result in symptoms the origins of which are impossible to identify, as in the aforementioned sensory interaction case for the influence of facial warmth on the odor of formaldehyde. Perceived air quality involves olfaction (odors), chemo-sensations (tickling, pain), thermo-sensations, and mechano-sensations (touch, pressure).

The symptoms of the SBS are multisensory in nature. This means that several sensory systems are involved in mediating the perceptions, which often blend into an entity or one unitary perception (an image). For example, perceived dryness of the indoor air is related to low humidity, thermal overload, and chemical pollution. A symptom such as eye irritation is related to chemical and particulate pollution, thermal load, draft, air humidity, and eye-straining lighting conditions. Thus, the cause of a symptom such as "eye irritation" may be difficult to identify.

6. Recognition of Chemical and Sensory Patterns

Air is usually perceived as an entity and humans cannot pinpoint the particular constituent odors in an air sample by the sense of smell alone. Results of pattern recognition analysis of indoor air samples (Berglund *et al.*, 1982; Baird, Berglund, Berglund, Nicander-Bredberg & Noma, 1987; Noma, Berglund, Berglund, Johansson & Baird, 1988) point out the joint impact of the large number of chemical and sensory components for the qualitative character of indoor air quality. It is probable that the chemical senses perform a pattern analysis on exposure to complex air pollution (Berglund & Lindvall, 1986; B. Berglund, 1990).

Since sensory systems are able to recognize patterns, it is possible that the concentration of numerous compounds is less important than the addition or subtraction of a few specific compounds to the gas mixture. Pattern recognition is particularly important in perception when the signal-to-noise concentration ratio for critical compounds is near to one. This is the predominant case for the volatile organic compounds which commonly appear at low concentrations in indoor air. Thus, the pattern of chemicals, rather than the concentration of a chemical, carries the information for perceived air quality or symptoms. For patterns, simple dose-response functions are not valid.

If sensory reactions and adverse perceptions are to be considered as guides for indoor air, knowledge of how these are mediated and of how the mechanisms function has

to improve. Instead of assuming that more concentration will give more effect, one now has to consider recognition phenomena. It is possible that human chemoreception with regard to complex patterns works similarly to visual pattern perception. If one imagines that the sick building and the healthy building can be represented by the face of an ape and a human, respectively, it is easy to see which face belongs to the ape and which one belongs to the human. If one further imagines that the different distinguishable parts of the faces are represented by a chemical so that the two noses are one chemical, the right ears another, the chins a third chemical, etc., it is quite evident that the two faces (buildings) can be distinguished although both of them contain the same parts (chemicals), all parts (chemicals) being present in both faces. This discrimination is believed to be performed as follows (Berglund & Lindvall, 1986). The individual has developed or learned specific class structure for encoding pattern information according to images, frames, or schemata. By selective search and selective attention, a data-reduction procedure is adopted by which a perceived critical pattern is matched to the stored pattern (the image). Presumably the specific class structure developed in the human sensory systems makes use of image comparisons. The memory images may be concrete or abstract.

7. Screening of Building Materials

Regardless of whether guidelines are needed in the form of building codes, standard business contracts or public health control strategies, the establishment of clear-cut criteria for what is meant by good indoor air quality is a must. By criteria is meant standards of judgment based on established rules and principles for testing. The explicated criteria have to be met by the indoor air of the building during its whole life, when used as intended, not only at the point in time when the building is commissioned and taken over by the owner. The very first step is to furnish the necessary judgmental criteria for defining what is good indoor air quality, followed by a second step of developing appropriate methods of testing (*i.e.*, to demonstrate compliance with established codes, contracts or public health standards). The control of indoor air quality may be most efficient when practiced preventively at the source. *Source Control* is primarily concerned with the materials or the combination of materials that constitutes or are introduced into buildings.

I am convinced that in the future, sensory analysis will provide important information in the screening of building materials. At least two approaches will be taken. In the tradition of toxicology, one type of screening according to sensory effects will involve the single chemical substances that are emitted from building materials. The other type of screening will be in accordance with the tradition of psychology and will involve the sensory effects generated by the complex gas emission from the building materials.

7.1. SCREENING BASED ON CHEMICAL SUBSTANCES

Sensory analysis is well fitted for screening among the huge number of air pollutants of potential health concern. Andersen, Seedorff and Skov (1982) suggest a strategy for reducing the indoor air exposure with regard to the major group of toxic indoor air pollutants in nonindustrial spaces. By a notification system, products are to be selected with a least impact on human health and comfort focusing on the reduction of three groups of substances: (a) carcinogenic substances, (b) eye/airway irritants, and (c) odorous chemicals. The first group of substances are few in number and cause severe diseases, the second are numerous and have great prospects for substitution, and the third should in general be avoided because they may produce nuisance.

Indoor air quality control according to health would particularly consider the carcinogenic and toxic substances as well as the irritants. On the other hand, the manufacturers of building materials have a great interest in reducing the odorous substances because the buyer, and later the building user, will disregard malodorous or strongly smelling products. It is evident that they will also disregard products emitting irritants at such levels that (sensory) irritation may be perceived in the eyes, the upper airways or the skin. This self-screening process according to perceptual preferences may very well be the dominating one in building renovations and for furnishing.

7.2. SCREENING BASED ON MATERIALS

In principle, the screening procedure of building material, may be performed at the same time as the chemical analysis of the emissions. A well-controlled climate chamber is necessary for the gassing-off of the materials. Samples may be taken from this chamber in a dynamic way and observers may be exposed for short periods of time. For example, facial exposures may be accomplished with hoods (*e.g.*, Berglund, Berglund & Lindvall, 1986a). The effects of such are exposures may be made in a similar way as when testing cosmetic products. The only difference is that for indoor air the interest is focused not only on skin the effects of direct contact but also air exposures.

Various scaling procedures are currently being developed by which both the psychometric function and the psychophysical functions for complex air mixtures may be determined both in under laboratory and field testing conditions. It is important to also test used building materials and not only rely on new products (Berglund, Johansson & Lindvall, 1989).

8. The Use of Sensory Effects in IAQ Control

The first priority in health promotion is to protect the sensitive individuals. The second is to protect the general population. Thus, also with regard to sensory effects it is essential to identify and characterize the sensitive groups or groups at risk, and to specify their specific needs. Methods for measuring sensory effects should reflect this demand. The indoor air control measures should involve both general measures directed to the whole population as well as individual measures to support the very sensitive persons.

As pointed out by WHO in their Air Quality Guidelines for Europe (WHO, 1987) many substances in the indoor environment may cause sensory effects at concentrations far below those at which toxic effects occur. As an example, odor annoyance may not be regarded as an adverse health effect by everyone but it is commonly viewed as adversely affecting the quality of life.

Since most indoor air pollutants are odorous (Berglund *et al.*, 1982), odor control would result also in a reduction of air pollutants in general. Provided no unethical manipulation of the sensory capabilities of the occupants is introduced (like olfactory fatigue), the efficiency of the odor control measures are easily checked. Furthermore, sensations are the integrated net response of the body to a large number of interacting components, and the effects appear at an early stage. Some pollutants lack sensory warnings and behave differently from the odorous ones, precluding the use of odor as an indicator effect. These substances must be controlled by other means.

Data available on odor and irritation potency may be used in different ways: (a) the effect of a compound or a mixture of compounds may be described quantitatively; (b) the

data may be used as signals or indicators for source control; or (c) the data may supply warning signals to protect against delayed effects.

8.1. CRITERIA FOR THE JUDGMENT OF SENSORY EFFECTS

In WHO's (1989a) document on environmental health criteria for the substance formaldehyde, the evaluation of human health risks is partly based on sensory criteria. The argument applied is that human exposure to formaldehyde should be minimized, not only for its probable carcinogenic effect, but also for its potential for irritant effect. WHO (1989a) recommends that in order to avoid strong sensory reactions in work-place environments where formaldehyde is being produced or used, peak concentrations above 1.0 mg/m^3 should not be allowed and mean concentrations should be kept below 0.3 mg/m^3. With regard to exposure outdoors and in the non-industrial indoor environment, formaldehyde concentration should not exceed 0.1 mg/m^3 in order to avoid odor and sensory irritation for the general population. In the case of specially sensitive groups that show hypersensitivity reactions without immunological signs, formaldehyde concentration should be kept to a minimum and should not exceed 0.01 mg/m^3.

Outspoken criteria for adverse sensory effects are given in a WHO document (WHO, 1989b). It is recommended for nonindustrial indoor environment that: (a) "Unwanted odorous compounds should not be present in concentrations exceeding the ED50 detection threshold. Similarly, sensory irritants should not be present in excess of their ED10 detection threshold." (b) "Increased emphasis should be given to research in humans on the sensory effects of organic compounds in low concentrations. This is especially true for detection and recognition data, which should be collected in such a way that the full dose-response curve can be determined, including the ED10 and ED50 values." [The ED50 stands for the 50th percentile Effect Dose].

As criteria for acceptability and annoyance, WHO (1987) in their Air Quality Guidelines for Europe 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 say, cannot be defined on the basis of concentration alone.

The established ASHRAE (1989) practice is that the air of a space can be considered acceptably free from 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. An observer should enter the space in the manner of a normal visitor and should render a judgment of acceptability within 15 sec. Each observer should make the evaluation independently of other observers and without influence of a panel leader. Users of this method are cautioned that the method is only a test for odors. Many harmful contaminants will not be detected by this test (*e.g.*, carbon monoxide and radon).

8.2. GUIDELINE VALUES BASED ON SENSORY EFFECTS

Many chemical compounds found in the indoor air may produce sensory reactions because they have odorous and/or irritant properties. The American Conference of Governmental Industrial Hygienists (ACGIH) has recommended and adopted threshold limit values (TLV) for about 600 chemicals relevant to occupational spaces (ACGIH, 1982, 1986). After reviewing the documentation of the TLVs, Anger (1984) abstracted the most relevant information basis for the ACGIH recommendations. In more than 400

TLVs, irritation effects (in eyes, respiratory tract, nose, skin, throat, and mucous membranes) were judged the most relevant for the ACGIH decision. A total of 167 chemicals have TLVs based, at least in part, on direct neurologic or behavioral effects.

It is striking that the occupational as well as the public health risk managers focus on the same critical organ systems. The difference in view seemingly is largely in the grading of the effects and the emphasis given to the different grades. Unfortunately, as for many other toxic compounds, there are little valid dose-response data that can be used to set valid exposure limits for air pollutants causing sensory effects in indoor environments (Lindvall, 1985).

ACGIH underlines that "The limits listed in this book are intended for use in the practice of industrial hygiene as guidelines or recommendations in the control of potential health hazards and for no other use" (ACGIH, 1986). Thus, the elimination of all effects, for example, unpleasant smells or mild mucosal and skin irritation is not attempted. On the other hand, ASHRAE (1989) points out that for contaminants where standards and guidelines have not been established, it has been customary to assume, as a first guide, that a concentration of 1/10 TLV would not produce complaints in a non-industrial indoor setting. However, the 1/10 TLV may not provide an environment satisfactory to individuals who are extremely sensitive. ASHRAE recommends that expert help should be sought in evaluating what concentration of such a chemical or combination of chemicals would be acceptable. ASHRAE (1989) presents lists of the United States, Canadian, and WHO standards and guidelines for acceptable concentrations of selected substances in the indoor and outdoor environment. The WHO (1987) has used as criteria for consideration of sensory effects, the sensory detection threshold (ED50) as well as the recognition threshold (ED50).

8.3. PRINCIPLES FOR THE TESTING OF SENSORY EFFECTS

The sensory effects should include in the testing single building materials (chipboard), combinations of such materials (plastic cover glued to board), indoor spaces of buildings, and ventilation systems. A screening procedure may be used for the building materials and their combinations. The sensory effects can be measured in the exposed populations or in a panel visiting a building. In intervention studies, the efficiency of different counter-measures may be determined in terms of sensory effects in appropriately designed longitudinal studies.

None of the recommended uses of sensory criteria requires any other method than perceptual measurement. It is only when a prognosis has to be made that the psychophysical relationships has to be known. For screening, selection or diagnosis of indoor environments or materials/systems, even simple classification according to acceptability or nonacceptability is sufficient.

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References

ACGIH. (1982). *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1982.* Cincinnati: American Conference of Governmental Industrial Hygienists.

ACGIH. (1986). *Threshold Limit Values and Biological Exposure Indices for 1986-1987.* Cincinnati: American Conference of Governmental Industrial Hygienists.

Ahlström, R., Berglund, B., Berglund, U., & Lindvall, T. (1986). Formaldehyde odor and its interaction with the air of a sick building. *Environment International* **12**, 289-295.

Andersen, I., Seedorff, L., & Skov, A. (1982). A strategy for reduction of toxic indoor emissions. *Environment International* **8**, 11-16.

Anger, W.K. (1984). Neurobehavioral testing of chemicals: Impact on recommended standards. *Neurobehavioral Toxicology and Teratology* **6**, 147-153.

ASHRAE. (1989). *ASHRAE Standard 62-1989: Ventilation for Acceptable Indoor Air Quality.* Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Baird, J.C. & Berglund, B. (1989). Thesis for environmental psychophysics. *Journal of Environmental Psychology* **9**, 345-356.

Baird, J.C., Berglund, B., Berglund, U., & Lindvall, T. (1990). Symptom patterns as an early warning signal of community health problems. *Environment International* **16**, 3-9.

Baird, J.C., Berglund, B., Berglund, U., Nicander-Bredberg, H., & Noma, E. (1987). Distinguishing between healthy and sick preschools by chemical classification. *Environment International* **13**, 167-174.

Baird, J.C., & Noma, E. (1978). *Fundamentals of Scaling and Psychophysics.* New York: Wiley-Interscience.

Berglund, B. (1974). Quantitative and qualitative analysis of industrial odors with human observers. *Annals of the New York Academy of Sciences* **237**, 25-51.

Berglund, B. (1990). The role of sensory reactions for guides of non-industrial indoor air quality. In D.M. Weekes & R.B. Gammage (Eds.), *The Practioner's Approach to Indoor Air Quality Investigations.* Akron, OH: American Industrial Hygiene Association, pp. 113-130.

Berglund, B. (1991). Quality assurance in environmental psychophysics. In S.J. Bolanowski & G.A. Gescheider (Eds.), *Ratio Scaling of Psychological Magnitudes–A Tribute to the Memory of S.S. Stevens.* Hillsdale, NJ: Lawrence Erlbaum Associates Inc., Ch. 11, pp. 140-162.

Berglund, B., Berglund, U., Högman, L., Johansson, I., & Lindvall T. (1985). Measurement of formadehyde odor indoors. In P.O. Fanger (Ed), *CLIMA 200. Vol 4: Indoor Climate.* Copenhagen: VVS Congres–VVS Messe, pp. 251-257.

Berglund, B., Berglund, U., & Lindvall, T. (1976). Psychological processing of odor mixtures. *Psychological Review* **83**, 432-441.

Berglund, B., Berglund, U., & Lindvall, T. (1978). Olfactory self- and cross-adaptation: Effects of time of adaptation on perceived odor intensity. *Sensory Processes* **2**, 191-197.

Berglund, B., Berglund, U., & Lindvall, T. (1986a). Theory and methods of olfactory evaluation. *Experientia* **42**, 280-287.

Berglund, B., Berglund, U., & Lindvall, T. (1986b). Assessment of discomfort and irritation from the indoor air. In: *IAQ'86. Managing Indoor Air for Health and Energy Concervation.* Atlanta, GA: American Society of Heating Regfrigerating and Air Conditioning Engineers, Inc., pp. 138-149.

Berglund, B., Berglund, U., Lindvall, T. & Nicander-Bredberg, H. (1982). Olfactory and chemical characterization of indoor air–Towards a psychophysical model for air quality. *Environment International* **8**, 327-332.

Berglund, B., Högman, L., & Johansson, I. (1988) Reliability of odor measurements near threshold. *Reports from the Department of Psychology, University of Stockholm*, No. 682.

Berglund, B., Högman, L., & Olsson, M.J. (1988). The combined effect of formaldehyde and ratiant heat on odor intensity and sensory irritation. In O. Manninen (Eds.), *Recent Advances in Researches on the Combined Effects of Environmental Factors*. Tampere, Finland: International Society of Complex Environmental Studies, pp. 567-579.

Berglund, B., Johansson, I., & Lindvall, T. (1989). Volatile organic compounds from used building materils in a simulated chamber study. *Environment International* **15**, 383-387.

Berglund, B., & Lindvall, T. (1979). Olfactory evaluation of indoor air quality. In P.O. Fanger & O. Valbjørn (Eds.), *Indoor Climate*. Copenhagen: Danish Building Research Institute, pp. 141-158.

Berglund, B., & Lindvall, T. (1982). Olfaction. In D.F. Proctor & I. Andersen (Eds.), *The Nose: Upper Airway Physiology and the Atmospheric Environment*. Amsterdam: Elsevier Biomedical Press, pp. 279-305.

Berglund, B., & Lindvall, T. (1986). Sensory reactions to "sick buildings". *Environment International* **12**, 147-159.

Berglund, B., & Nordin, S. (1990). Utilizing individual differences in loudness measurement. In F. Müller (Ed.), *Fechner Day '90*. Würzburg, FRG: Institut für Psychologie, Universität Würzburg, pp. 117-122.

Boring, E.G. (1929). *A History of Experimental Psychology*. New York: Appleton-Century-Crofts. (also 1957)

Cain, W.S. (1979). Ventilation and odor control: prospects for energy savings. *ASHRAE Transactions* **85** (1), 784-792.

Cain, W.S., See, L.C., &Tosun, T. (1986). Irritation and odor from formaldehyde: chamber studies. In: *IAQ 86. Managing Indoor Air for Health and Energy Conservation*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, pp. 126-137.

Cometto-Muñiz J.E., & Cain, W.S. (1990). Thresholds for odor and nasal pungency. *Physiology & Behavior* **48**, 719-725.

Cometto-Muñiz J.E., & Cain, W.S. (1991). Influence of airborne contaminants on olfaction and the common chemical sense. In T.V. Getchell, L.M. Bartoshuk, R.L. Doty & J.B. Snow Jr (Eds.), *Smell and Taste in Health and Disease*. New York: Raven Press, Ch. 49, pp. 765-785.

Craik, K.H. & Zube, E.H. (1975). *Issues in Perceived Environmental Quality Research*. Amherst, Mass.: Institute for Man and Environment.

Corbit, T.E., & Engen, T. (1971). Facilitation of olfactory detection. *Perception & Psychophysics* **10**, 433-436.

Fazzalari, F.A. (1978). *Compilation of Odor and Taste Threshold Values Data*. Philadelphia: American Society for Testing and Materials.

Gemert, L.J., van & Nettenbreijer, A.H. (1977). *Compilation of Odour Threshold Values in Air and Water*. Zeist, The Netherlands: Central Institute for Nutrition and Food Research, TNO (Report RID 3-79).

Haider, M., Kundi, M., Groll-Knapp, E. & Koller, M. (1990). Interactions between noise and air pollution. *Environment Internationl* **16**, 593-601.

Hensel, H. (1982). *Thermal Sensations and Thermoreceptors in Man.* Springfield, Ill.: Charles C. Thomas.

Lindvall, T. (1985). Exposure limits for office environments. *Annals of the American Conference of Industrial Hygienists* **12**, 99-108.

Lindvall, T., & Radford, E.P. (Eds.) (1973). Measurement of annoyance due to exposure to environmental factors. *Environmental Research* **6**, 1-36.

Luce, R.D., & Green, D.M. (1974). Detection, discrimination and recognition. In E.C. Carterette & M.P. Friedman (Eds.), *Handbook of Perception. Vol. II: Psychophysical Judgment and Measurement.* New York: Academic Press, pp. 299-342.

Marks. L.E. (1974). *Sensory Processes.* The New Psychophysics. New York: Academic Press.

Marks, L.E. (1988). Magnitude estimation and sensory scaling. *Perception & Psychophysics* **43**, 511-525.

Mountcastle, V.B. (1975). The view from within: Pathways to the study of perception. *Johns Hopkins Medical Journal* **136**, 109-131.

Noma, E. Berglund, B., Berglund, U., Johansson, I., Baird, J.C. (1988). Joint representation of physical locations and volatile organic compounds in indoor air from a healthy and a sick building. *Atmospheric Environment* **22**, 451-460.

Popper, K.R., & Eccles, J.C. (1977). *The Self and its Brain. An Argument for Interactionism.* Berlin: Springer Verlag.

Stevens, J.C. (1976). Equal-sensation functions generated by the method of magnitude estimation. *Journal of the Acoustical Society of America* **59**, 473-474.

Stevens, S.S. (1956). The direct estimation of sensory magnitudes–loudness. *American Journal of Psychology* **69**, 1-25.

Stevens, S. S. (1975). *Psychophysics. Introduction to its Perceptual, Neural and Social Prospects.* New York: Wiley-Interscience.

Torgerson, W.S. (1958). *Theory and Metods of Scaling.* New York: Wiley.

UNESCO (1973). *Programme on Man and the Biosphere (MAB): Expert Panel on Project 13: Perception of Environmental Quality.* Paris: UNESCO House, MAB Report Series No 9.

WHO. (1987). *Air Quality Guidelines for Europe.* Copenhagen: World Health Organization, European Series No. 23.

WHO (1989a). *Formaldehyde.* Geneva: World Health Organization, Environmental Health Criteria 89.

WHO. (1989b). *Indoor Air Quality: Organic Pollutants.* Copenhagen: World Health Organization, EURO Reports and Studies No. 111.

INDOOR AIR POLLUTION: IMMUNOLOGICAL INTERACTIONS

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ABSTRACT. Indoor air pollution is an objectionable consequence of our modern society. Urbanization, industrialization, energy conservation, microbial contamination, chemical or particulate emissions from heating, ventilating and air-conditioning systems, synthetic construction materials and interior furnishings, and employment demographics interact to degrade indoor air quality. Public health concern over indoor air quality issues, kindled by the discovery of numerous cases of air pollution-related illness, has stimulated notable research, regulatory and litigatory activities. Contemporaneous with the increased public concern over indoor air pollution, extraordinary discoveries have led to further definition and exploitation of the immune system. While a functional immune apparatus is essential to host defense and homeostasis, unfortunately, it is also exquisitely sensitive to toxic damage. Because of the significant exposure potential, interactions between indoor air pollutants and the immune system warrant careful examination.

1. Introduction

In a real sense, the human race is under siege. Infectious agents, natural and synthetic chemicals, and menacing physical agents assail us continuously. In spite of this relentless assault, man suffers only occasional episodes of clinical disease. "Boarders" are usually repelled by the tough barrier of the skin, overcome by the biochemical arsenal in sweat, saliva, and tears, rendered impotent by stomach acids or trapped in sticky mucous secretions common to the nose and throat before being flung unceremoniously into the environment by a cough or sneeze. Those agents clever enough to circumvent innate defenses are in for a nasty surprise as they will encounter nature's most elite legion, the immune system.

1.1 STRUCTURE AND FUNCTION OF THE IMMUNE SYSTEM

The immune system embodies a complex, well-distributed network of blood and lymphatic vessels through which courses an array of immunocompetent cells. These elements, together with lymphoid organs, collude to execute but one task: to discriminate between **self** and **non-self**. In a stepwise manner, the immune system: 1) concentrates foreign or "non-self" elements into a few lymphoid organs; 2)

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circulates the lymphocyte population (immunologically-specific components of the immune system) through these lymphoid organs so that "non-self" (antigen) is subjected to lymphocyte recognition and the extensive armory of antigen-specific lymphocytes; and 3) disseminates the products of the immune response (cells, cytokines and antibodies) to the blood and tissues. To prevent interminable confrontations, these immune responses are subject to up- and down-regulation via feedback circuits of cellular receptors and cytokines. The consequences of these immune responses may be acute or chronic, localized or systemic, reversible or irreversible, overt or covert. Research on the immune system in the last half of this century has borne prodigious fruit [1]. New descriptions of the immune system and its alliance with inflammatory, neural, endocrine and behavioral processes allow unique molecular insights into homeostasis [2-15]. For additional background information, reviews of basic immunology are available [16,17]. While much of the immune system remains unexplored, six key characteristics form the basis for an important paradigm.

1.1.1 *Specificity.* Specific resistance to infectious disease was known prior to even a fundamental understanding of the immune system. Due to the work of Landsteiner [18] and others, we now recognize that immune reactions can distinguish among even closely related molecules. Specificity is a hallmark of an immune response.

1.1.2 *Collaboration.* The attributes of cell-cell and cell-cytokine (humoral cell product) interactions in cell-mediated or antibody responses have been studied extensively [19,20]. The interaction of lymphocytes, cytokines and nonlymphoid cells is essential for an optimized and augmented immune response.

1.1.3 *Clonal Expansion.* The human body contains millions of immunocompetent cells, circulating or sessile, that are capable of participating in an immune response. However, only a few of these cells recognize any specific antigen. After recognizing a specific antigen, individual cells rapidly proceed into a blastogenic phase, cloning themselves. This expansion of antigen-specific cells permits an amplified and efficient immune response.

1.1.4 *Mobility.* Immunocompetent cells and their effector/regulator molecules must be mobile. The effectiveness of both innate and adaptive resistance mechanisms depends upon the circulatory system for dissemination throughout the body.
Cell mobility also accounts for local immune responses that generate systemic effects.

1.1.5 *Regulation.* A beneficial immune response must have a controlled onset, size, cellular/humoral participation and duration. Effective immune responses represent an equilibrium between up- and down-regulatory mechanisms.

1.1.6 *Memory.* Once antigen has evoked a specific immune response, certain elements of the immune apparatus are forever changed. Usually, future confrontations with the same antigen result in an amplified or "adaptive" response or positive memory. However, some secondary encounters with antigen can result in a diminished response or negative memory. Together, specificity and memory are often used to judge whether a response is immunologic or nonimmunologic.

1.2 IMMUNOCOMPETENCE

Immunocompetence is a term that implies a state of functional immunity that results in effective resistance to infectious agents or neoplastic cells. It depends upon both innate and acquired resistance. In healthy individuals, innate resistance operates continuously, depending upon physiologic status. However, innate resistance does not discriminate between self and nonself nor is it able to increase its intensity upon reexposure. In marked contrast, to innate resistance, acquired resistance mechanisms are usually "dormant" until roused by specific antigen. Acquired resistance mechanisms are mediated by antigen-specific lymphocytes and antibodies via idiotype/anti-idiotype networks. Acquired resistance mechanisms can alter significantly their magnitude and response time upon reexposure to "recall" antigen. Integration of both innate and acquired resistance is essential for maintaining a fundamental state of immunocompetence.

1.3 IMPORTANCE OF FUNCTIONAL IMMUNITY

The elegance of innate and immune mechanisms notwithstanding, the advent of calamitous infectious agents (experiments of nature) [21], and the continued urbanization of our environment (experiments of mankind) [1] challenge the dominion of even the most robust immune system. The inherent collusion and excess capacity within the immune system often rises to this challenge. However, recent evidence indicates that the frequency of immune anomalies and the severity of their sequelae are spiraling upward ominously [22-24]. Of these so-called experiments of mankind, indoor air pollution is associated inextricably with the immune system. Typical diseases related to indoor air pollution include asthma, hypersensitivity reactions, pneumonitides, pulmonary infections and dermatitides - all of which possess immunological components.

1.4 OTHER IMPORTANT BIOLOGICAL CONSIDERATIONS

In order to analyze immune interactions with indoor air pollutants, research approaches must confront the following issues:

1.4.1 *Route of Exposure.* Entrance of air pollutants into the body is usually through the respiratory tract. The anatomy and function of the human lung make it the internal organ most intimately in contact with the environment. In marked contrast to what we eat or drink, we have only limited ability to be selective about the materials we inhale. The respiratory tract is a key asset that requires protection. As with most of the body's interfaces with the external environment, the respiratory tract is armed with innate and immune defenses. While indoor air pollutants may interact directly with the pulmonary immune system, immune interactions are not limited to the respiratory tract. Dermal immune responses to indoor air pollutant are also observed [25]. In the context of indoor air pollution, exposure route is critical in any study of immune system function.

1.4.2 *Toxicological Considerations.* Among the many inherent difficulties in evaluating indoor air pollution and its potential toxicity, one obstacle towers above others. Most immunological and toxicological studies, including those concerned with air pollutants, have been limited to single chemical exposures. Real indoor air

exposures involve complex pollutant mixtures that result in a spectrum of possible interactions. Immune alterations may be due to simultaneous or serial exposure to multiple indoor air pollutants. This predicament is complicated further by fluctuations in the relative concentrations of pollutant species, differences in order and duration of exposure, and variations in constant or interrupted exposure patterns.

1.4.3 *Variations in Susceptibility.* There is a growing public concern for those who may be unusually susceptible to indoor air pollutants. Because most individuals, under most indoor environmental conditions, are not affected, an emphasis on susceptible occupants appears to be justified. However, this focus on the "tails of the bell-shaped curve" presents a challenge. While most statistical measures in medicine and biology measure central tendencies, few tests measure the extremes. Variable susceptibility to indoor air pollutants can be influenced by such factors as age, genetics, preexisting disease, gender, psychosocial milieu, and concurrent environmental exposures. Diet, work and exercise may also affect an individual's response to indoor air pollutants. It is imperative to note that susceptible populations seldom remain static; increased susceptibility is usually a dynamic trait.

1.4.4 *Interplay of Inflammatory and Immune Mechanisms.* In any response to nonself, both immune and nonimmune mechanisms may be activated and cause an inflammatory response. In many disease processes, more than one immune or nonimmune mechanism may operate sequentially, coincidentally, or both [26]. In acute or chronic inflammatory lesions, it is often difficult to distinguish lesions caused by immune or nonimmune mechanisms.

1.4.5 *Exposure vs. Disease.* Chronic exposure to indoor air pollutants is a fact of modern life. Complaints arising from exposure to multiple chemicals are common. Asthma, dermatitis, rhinitis, and reactive airway disease are common clinical problems associated with indoor environments. Allergy and hypersensitivity can be caused by numerous microbes and chemicals in occupational, residential or recreational settings. However, detecting an immune system response and differentiating this response from adverse effects and disease secondary to indoor air pollutant exposure requires careful evaluation of exposure circumstances, an accurate history and physical examination, and clinical immunologic laboratory testing [4]. Exposure to an indoor air pollutant followed by a normal immune response must not be equated with disease. In the process of determining disease, the clinical scientist must account for the difference between exposure to an indoor air pollutant resulting in a normal immune response (Table 1) and actual disease which may result from an altered immune status.

Table 1. Ontogeny of a "Normal" Immune Response

1) Confrontation between immune system and nonself (antigen).
2) Antigen-specific recognition by elements of the immune system.
3) Amplification of antigen-specific immune response.
4) Immunologic discrimination between self and nonself.
5) Regulation of the antigen-specific immune response.
6) Development of antigen-specific immunologic "memory".

2.0 Immune Interactions And Typical Health Effects

The impact of immunology upon our industrialized society and *vice versa* is indisputable. We owe much of our adaptive survival capacity to our functional immune systems. Frequent popular press reports of human exposure to various chemicals heightens public concern regarding the immune system as a **target organ** of toxicity. Thorough reviews of immunotoxicology are available [4,27,28] and we refer the reader to these references for further information about etiological agents, pathogenesis and pathology. Altered immune function resulting from exposure to environmental chemicals or biologics, including some found in indoor air, has been described [4]. It is important to note that while there is increasing public concern over indoor air pollution and its possible adverse effects, clinical diagnosis and management is not easy (Table 2).

Table 2. Clinical Obstacles Presented By Indoor Air Pollution

Nature of Pollutant	Exposure occurs to mixtures of chemicals; the agent(s) responsible for health effects may not be known to patient or physician.
Pattern of Exposure	Exposures often occur in random or unpredictable patterns. Exposure may occur at home, at work or in transportation environments.
Population Exposed	Exposure often involves large numbers of individuals, including susceptible populations not present in more rigorous environments.
Acute Effects	Acute exposures may result in a broad range of clinical features with time of onset depend upon pollutant mixture, route of exposure, duration of exposure, preexisting disease, age, lifestyle and other personal factors.
Chronic Effects	Clinical significance of chronic exposures to low level mixtures of volatile chemicals, gases and particulates found in indoor air is essentially unknown.

There are at least two rudimentary ways in which indoor air pollutants interact with the immune system: 1) Direct stimulation or suppression of immune mechanisms; and/or 2) Indirect or ancillary effects upon other organs systems triggered by mediators or nonspecific elements of the immune apparatus.

2.1. DIRECT EFFECTS

Indoor air pollutants can directly interact with the immune system resulting in a normal immune response, hypersensitivity or immunosuppression.

2.1.1 *Immunity.* Possibly the most overlooked category of immune interaction with indoor air pollutants is also the most ubiquitous: immunity to microorganisms. Obligate and opportunistic pathogens such as viruses, bacteria, fungi and rickettsia are known to be transmitted in indoor air [29-31]. The immune apparatus deploys its armory of specific and nonspecific mechanisms to contain and neutralize microbes and their associated toxins [4,32]. Control of extracellular pathogens is exerted through interactions of antibody, leukocytes and complement. Intracellular pathogens are vanquished by cellular cytotoxicity and humoral products such as interferon. Immune responses to microbes or their metabolites are desirable responses and are protective rather than detrimental. However, because the respiratory system is the portal of entry for airborne human pathogens and pollutants, injurious pathogen-pollutant synergies should be anticipated.

Infections associate with indoor environments became recognized with the identification of *Legionella pneumophila* as the etiologic agent of Legionnaire's disease [33]. *Legionella* spp. are ubiquitous, and can be isolated from soil or water. This disease is caused by aerosolization of *Legionella* bacteria from cooling towers, humidifiers, evaporative condensers and even shower heads. Various other febrile illnesses are associated with poor ventilation and recirculation of contaminated air [34,35].

2.1.2 *Allergy and Hypersensitivity.* In spite of the evidence that controlled hypersensitivity reactions can be advantageous (e.g., IgE responses to parasites), most manifestations of hypersensitivity are annoying. Hypersensitivity is the most prevalent form of immunotoxicity, and is the most readily recognized category of immune response to indoor air pollutants. Hypersensitivity can be depicted as an exaggerated immune response to organic or inorganic antigen, evidenced by a decreased threshold to the offending substance. The term **allergy**, betokens an altered reactivity to antigen as a result of previous exposure. Although allergy is a term that is misunderstood and misused, criteria exist to define this condition (Table 3).

Table 3. Criteria Defining Allergy

1) Initial exposure to antigen summons no response.
2) Only a small subpopulation of those exposed become sensitized.
3) The amount of antigen needed to induce allergy is below that needed to elicit an irritant effect.
4) Subsequent to sensitization, allergic reactions are elicited by amounts of antigen smaller than those required for sensitization.

It should be emphasized that allergic reactions are individualized; exposure circumstances that evoke an allergic response in one individual may have no consequence for others similarly exposed. The inclination to launch an allergic

response depends upon multiple factors, the most important of which are genetic. Data suggests that atopic individuals exhibit a defect in T-lymphocyte (suppressor) function [3,36]. Most of our understanding of allergy is derived from the study of reactions to "natural" antigens such as pollens, fungi, bacteria, insect antigens, and animal danders. However, the indoor air of commercial and residential buildings contains myriad natural and synthetic contaminants capable of eliciting allergic reactions in susceptible individuals [1,23,24,37-52]. Indoor air pollutants can also aggravate preexisting allergies. Synergism occurs between respiratory infections and asthma [53,54]. Furthermore, indoor air pollutants such as microbial/plant products, irritant gases, volatile organic chemicals (VOCs), or even odors often may function indirectly to exacerbate preexisting asthma [1,4,47,55-58]. Recent evidence indicates an even more ominous correlation between indoor air pollution and hypersensitivity; exposure to irritant gases such as SO_2 [59,60] and O_2 [61] can potentiate significantly the induction of allergy in animal models.

Hypersensitivity to indoor air pollutants may involve any of three mechanisms: 1) Immediate Hypersensitivity; 2) Delayed Hypersensitivity; and 3) Mixed Hypersensitivity (Table 4).

Table 4. Hypersensitivity Responses to Indoor Air Pollutants

Hypersensitivity Mechanism	**Typical Clinical Manifestation**	**Typical Pollutants**
Immediate	Asthma & Rhinitis	Acid Anhydrides Amines Acrylates Isocyanates Metallic Salts Microbes/Metabolites
Delayed	Allergic Contact Sensitivity	Amines Colophony Epoxies Insecticides Metallic Salts Plants
Mixed	Hypersensitivity Pneumonitis	Amines Anhydrides Animal Proteins Grain Dusts Microbes/Metabolites Wood Dusts

Immediate Hypersensitivity responses arise when multivalent antigen reacts with mast cells or basophils passively sensitized with cytophilic antibody, usually IgE. In the early phase, effector cells release a preformed arsenal of biologically active

substances including histamine, seratonin, and heparin. Early-phase mediator release causes smooth muscle contraction and arteriole dilatation. In the late phase, effector cells synthesize and release potent mediators such as leukotrienes and prostaglandins, which further exaggerate smooth muscle contraction and bronchoconstriction. Exposure to soluble high molecular weight antigens favors immediate hypersensitivity reactions. However, when combined with appropriate host proteins, even low molecular weight haptens can elicit immediate hypersensitivity responses. IgE-mediated allergic respiratory diseases such as asthma and rhinitis are the most common inhalant sensitivities in humans; these diseases are associated with indoor air pollutants [53,54,58,62,63].

Delayed Hypersensitivity responses are mediated by cellular immune mechanisms and are not thought to involve antibody directly. Delayed hypersensitivity is mediated by infiltration of lymphocytes (T-cells) and monocytes at the site of antigen deposition. As in all immune responses, initially only a few of these cells are antigen-specific. Subsequent cell-antigen confrontations cause the release of cytokines which induce and maintain an inflammatory response that "recruits" large numbers of other cell types into the area. Local tissue destruction is mediated by cytotoxic T-lymphocytes or cytokine-activated macrophages. As the number of antigen-specific cells increase, many leave the local reaction site and migrate to the general blood circulation. The delayed-hypersensitive status thus disseminates as a result of these effector T-cells to various other tissues, including the skin. Dermatitis caused by irritating or sensitizing chemical exposure is the most commonly seen occupational injury and may involve a variety of agents [4,25,64-68]. Furthermore, contact dermatitis caused by airborne contaminants has been observed in indoor occupational environments including offices. Reviews of agents causing airborne contact dermatitis are available [25,65]. While symptoms usually occur on skin exposed to the air, other locations can be involved due to volatile substances captured in clothing, or where dust may collect in major body folds.

Mixed Hypersensitivity reactions not involving the IgE-mast cell system can also be invoked by indoor air pollutant exposures. There is an increasing awareness that a wide variety of inhaled organic dusts may induce an interstitial lung disease, involving, in contrast to asthma, the interstitium as well as the middle and terminal air ways. The term hypersensitivity pneumonitis (HP=extrinsic allergic alveolitis) has been used to describe the syndrome, which varies depending on dust composition (particle size, solubility, antigenicity) intensity and frequency of exposure to the dust, and the immunologic response of the individual. The diverse etiologies of HP include exposure to contaminants found indoors [69-71]. The pathogenesis and pathology of HP involves both cell-mediated and antigen-antibody (immune complex) hypersensitivity mechanisms within the lung. While understanding of these disorders is incomplete, HP exhibits several typical features: 1) primary involvement of peripheral airways without systemic organ involvement; 2) lesions characterized by interstitial infiltrates of lymphocytes and monocytes that progress to granulomas; 3) activated alveolar macrophages and T-cells; 4) clinically-apparent disease often associated with precipitating antibody specific for etiologic agent(s). Typically, affected individuals describe multiple episodes of dyspnea, fever, cough and malaise [70], beginning four to six hours after exposure and lasting 12 to 24 hours. Intensity of these pulmonary granulomatous responses appears to be regulated by immunogenetic events that require further clarification. The

inflammatory process can organize into granulomas and progress further to fibrosis [69-72]. Progressive cases often require clinical intervention.

Humidifier fever (HF), a variant of HP, is often associated with microbial contamination of saunas and vaporizers [70,71,73-75]. While there are some differences between these two syndromes [58], diagnosis and treatment of HF is similar to that of HP.

Despite abundant examples of hypersensitivities caused by chemical exposure, knowledge of the induction phase of chemically-induced immediate-, delayed- or mixed hypersensitivities is not complete. Several mechanisms may be involved (Table 5).

Table 5. Potential Mechanisms in Chemically-Induced Hypersensitivity

1) Chemicals or chemical metabolites are antigenic.
2) Chemicals or chemical metabolites haptenize with autologous proteins to form "complete" antigens.
3) Autoantigens are released following chemically-induced tissue damage.
4) Shared antigenic determinants between the tissue and the host.

2.1.3 *Immunosuppression.* There is ample evidence that chemicals from diverse sources can diminish immune function [4]. Immunosuppression produces a wide range of clinical sequelae, ranging from profound and life threatening to academic curiosities [4,76-83]. Inhibition or destruction of innate and acquired immune resistance may result from exposure to pharmaceuticals, recreational drugs, pesticides or other environmental chemicals [4]. Defects can occur at any of several junctures during development and maturation of the immune apparatus or during the ontogeny of an immune response. Immune alterations can extend from stem cell defects to cytokine and cellular receptor deficiencies. Though indoor air often contains known immunosuppressants such as benzene and pesticides, the begged question is whether immunosuppression can be induced by exposure to these airborne chemicals at their typical concentrations indoors. Exposure to common indoor air pollutants such as O_3, NO_2, and SO_2 have been implicated in damaging lung defense mechanisms, resulting in increased susceptibility to respiratory infections [27,34,84-90]. Even low concentrations of these pollutants have been shown to provoke a range of pathology involving upper airways, the mucocilliary ladder, mucous secretion and alveolar macrophage function in animals [85,87-89]. Experiments involving human exposure to these gases corroborate animal studies; they identify similar defects in alveolar macrophage defense mechanisms [88,89].

Expanding beyond gross immunosuppressive phenomena, subtle forms of immunosuppression may affect immunocompetent cell capabilities such as Major Histocompatibility Complex (MHC) antigen expression or restriction [20,91], delays in the IgM-to-IgG antibody shift [83] and maturation/differentiation deficiencies [92]. The clinical significance of these subtle changes in the immune system is difficult to asses. Because the immune system is a multifaceted network that maintains a level of functional reserve, a toxic effect upon a particular immune cell or circuit may not necessarily lead to a detectable clinical manifestation. The clinically significant consequences of immunosuppression related to indoor air

pollution that have been identified relate to decreased resistance to infectious disease. Because many diseases can be transmitted in indoor environments, the potential synergy between indoor air pollutants and susceptibility to infectious agents should be investigated thoroughly. The growing number of immunocompromised persons in general, and in white collar work environments specifically, lends urgency to this issue.

2.2 INDIRECT EFFECTS

In addition to direct interactions with the immune system, exposure to indoor air pollutants may indirectly precipitate phenomena such as autoimmunity and pseudoallergic reactions.

2.2.1 *Autoimmunity.* The hostile environment in which we live challenges the immune system to respond to nonself without responding to self. The Major Histocompatibility (MHC) gene complex plays a central role in this furtive task. Paradoxically, response to nonself is MHC-restricted (requires recognition of self). Autoimmunity is the basis for both normal immune responses and immune regulation. Despite our incomplete understanding of how self-reactivity, or autoimmunity, is regulated, it is obvious that failure to control autoimmunity can result in tragic consequences [93-95]. Why an autoimmune response progresses to a disease state is baffling. Autoimmune disease appears to involve a multifactoral etiology including environmental triggers, polygenic disposition, and defects in immune regulation [96]. Autoimmune disease may be restricted to one organ or be non-organ specific, include autoreactive cells or antibodies, and be focused upon self antigens or self antigens modified by environmental agents. Indoor air pollutants such as pesticides [97], mercury [98] or mercury-containing preservatives [99] may induce autoimmunity via one or more mechanisms [4,100]. Although there are data demonstrating that autoimmune disease can be induced by environmental agents [95], there is no consensus as to whether autoimmune disease can result from exposure to these agents at concentrations found normally in indoor air.

2.2.2 *Pseudoallergic Phenomena.* There are two fundamental ways in which chemicals or other xenobiotics may interact with the immune system. First, they may be recognized as antigens and elicit a true immune response by interacting with immunologically-specific receptors on lymphocytes. Secondly, they may exert pharmacological effects by binding to nonspecific immune components, resulting in stimulation, suppression or qualitative alteration of the immune apparatus, irrespective of their antigenic specificity. In the latter, individuals exhibit features characteristic of allergy, yet in them it is impossible to establish the participation of any known immune mechanism. Indeed, certain drugs and chemicals may occasionally even mimic immune effector mechanisms. Genuine allergic reactions to pollutants, such as those found in indoor air, must be set apart from these pseudoallergic reactions that merely simulate chemically-induced allergic reactions, but lack pollutant-directed antigenic specificity. Divers chemicals and other xenobiotics possess the ability to bypass the regular IgE-mast cell triggering process and act directly to induce mast cell degranulation [3,36,101]. These curious reactions occur in only a small number of individuals and therefore may be under genetic control. Several mechanisms have been proposed to account for these phenomena: 1) direct cytolytic liberation of mast cell mediators [3,36]; 2) direct

non-cytotoxic, non-immune, chemically-induced degranulation [102]; and 3) induction of anaphylatoxic complement components. Formaldehyde, a common indoor air pollutant, has been implicated in pseudoallergic reactions [36,102]. Furthermore, certain pollutants may be capable of eliciting both allergic and pseudoallergic reactions, perhaps even in the same individual. The range of chemicals, found indoors or out, that may cause pseudoallergic reactions has not been determined.

3.0 Potential Psychoneuroimmune Interactions

Some adverse reactions to indoor air pollutants can be explained by pharmacologic, toxicologic and immunologic mechanisms. However, many of the vague and discordant symptoms ascribed to indoor air pollution exposure defy mechanistic explanation. As we further refine our paradigm of the immune apparatus *per se*, it becomes apparent that its role in homeostasis and host defense requires multilateral communication with both nervous and endocrine systems. Communication between these pivotal systems would seem reasonable, permitting synergistic responses to internal and external homeostatic demands. Immune responses spawn endocrine and central nervous system alterations [103]. Although investigation of this psycho-neuro-endocrine-immune "circuitry" is in its infancy, a burgeoning research literature has evolved [5,6,10,100,102-106]. From these studies, a fascinating multisystem paradigm is evolving. There is an expanding appreciation among immunologists that immunocompetent cells are acted upon by macromolecular mediators, cytokines and neuropeptides not unlike those studied by neurobiologists. Lymphoid organs are innervated and modulated by elements of the autonomic nervous system. Furthermore, empirical descriptions of behavioral conditioning of immune responses [5,104,106,107], effects of stressors on immune responsiveness to nonself and self [10,108], and immune response-associated changes in brain physiology [11], neurochemistry [109], and cytology [9] support existence of such a psychoneuroimmune network. Biomolecular research findings appear to corroborate these empirical descriptions. For example, interleukin-1 (IL-1), produced by macrophages, epithelial cells, glial cells, and astrocytes can serve as an immunoneurotransmitter, by modulating increases in glucocorticoid concentrations and stimulating catecholaminergic metabolism [10,103]. Glucocorticoids, catecholamines, neuropeptides, pituitary hormones and cytokines are communication molecules thought to link the immune, nervous and endocrine systems [10,110]. New insights from the basic sciences have provoked reassessment of certain diseases and/or their sequelae. Myasthenia gravis, measles, asthma, and rheumatoid arthritis appear to affect both immune and nervous systems, and may involve genetic predisposition [111]. Deficiencies in cortisol and corticotropin-releasing hormone have been identified in patients with Chronic Fatigue Syndrome (CFS), depression and other affective disorders [108]. Immunopathological mechanisms have also been proposed in the schizophrenic psychoses [14].

Indoor air pollutants may induce psychoneuroimmune perturbations that mimic specific immune responses and symptoms consistent with Sick Building Syndrome (SBS) [112-114] and Multiple Chemical Sensitivities (MCS) [115-118]. Peptide mediators of sensory nerves, such as substance P, released in tissues by noxious chemicals and biological agents, elicit rapid local and systemic responses similar to those of immediate hypersensitivity [119]. Stress and a variety of psychiatric

ailments, notably the affective disorders, have been associated with exposure to indoor air pollutants [120,121]. Basic and clinical investigations of indoor air pollution reveal that odor sensitivities and irritation phenomena are frequent adverse effects of exposure. Yet, ill-defined ailments such as SBS and MCS are not explained adequately by known immune or inflammatory mechanisms. It is tempting to invoke partially-defined immune-neuroendocrine or psychoneuroimmune mechanisms to explain the diverse symptoms associated with indoor air pollution. If the psychoneuroimmune network plays a functional role in the expression and modulation of hypersensitivity and inflammatory responses to indoor pollutants, evidence should be manifest in the respiratory tract.

3.1 NEUROIMMUNOMODULATION OF THE RESPIRATORY TRACT

Peptides are found throughout the respiratory tract, located in neurons, neuroendocrine cells, and inflammatory cells (Table 6).

Table 6. Typical Peptides Identified In The Respiratory Tract

Bronchoconstrictors	**Abbreviation**
Substance P	SP
Neurokinin A	NKA
Neurokinin B	NKB
Neuropeptide K	NPK
Calcitonin Gene Related Peptide	CGRP
Bronchodilators	**Abbreviation**
Vasoactive Intestinal Peptide	VIP
Peptide Histidine Methionine	PHM
Peptide Histidine Isoleucine	PHI

Neuroendocrine cells and inflammatory cells containing neuropeptides are distributed throughout the conducting airways. Upon release, these peptides may act as mediators, hormones or neurotransmitters. In the respiratory tract, several peptides act as neurotransmitters that regulate airway diameter, vascular permeability, and mucous secretion. Some of these peptides may also modulate the mediator release and chemotactic responses of inflammatory cells. If psychoneuroimmune networks interact with indoor air pollutants, the distribution and sundry physiologic effects of neuropeptides make them fitting candidates to participate in diseases associated with indoor air pollutants.

3.1.1 *Neuropeptides and Asthma.* Asthma is often associated with exposure to indoor air pollutants. Asthma is enigmatic; everyone who deals with it, "knows" what it is. Yet, its clinical definition and related concepts of pathogenesis/pathology have evolved markedly during the last decade [54]. Neural control of the airways is more complex and more integrated than recognized previously. In addition to cholinergic and adrenergic pathways, "nonadrenergic and noncholinergic" (NANC) pathways have also been identified. A review of the interrelationship of cholinergic, adrenergic and NANC pathways in the human lung is available [54]. Neurotransmitters for the NANC network are thought to be neuropeptides. Airway tone is regulated by cooperation between the cholinergic (parasympathetic), adrenergic (sympathetic) and NANC circuits. Cholinergic circuits are considered excitatory due to their function in maintaining bronchial smooth muscle tone and mediation of bronchospasm. Adrenergic are considered inhibitory because of their prominent airway relaxant effect via B-receptor stimulation. However, NANC circuitry is hypothesized to regulate both excitatory and inhibitory functions in human airways [54].

While still controversial, likely neurotransmitters in the inhibitory limb of NANC circuitry are VIP and PHM. In fact, VIP is the most robust endogenous large airway relaxant studied to date. PHM is a potent relaxant of human bronchi *in vitro* [54]. VIP is also known to modulate inflammatory cell function [122,123]. The inhibitory limb (nonadrenergic) of NANC counteracts the proasthmatic effects of the cholinergic and excitatory (noncholinergic) limb of NANC. Deficiencies in the nonadrenergic limb of NANC are thought to be associated with the development of bronchial hyperreactivity [99]. VIP has also been shown to have an inhibitory effect upon the immune system. VIP inhibits human natural killer (NK) cell activity, lymphocyte traffic, and lymphocyte proliferation [122-124].

Specific neuropeptides assumed to function in the excitatory limb of NANC circuitry include SP, NKA, NKB and CGRP. These neuropeptides are potent bronchoconstrictors released from nonmyelinated vagal afferent nerve fibers distributed throughout airway epithelium. In addition these neuropeptides can modulate the function of immune cells. SP causes the release of proinflammatory molecules and cytokines from macrophages, enhanced phagocytosis in macrophages and PMNs, release of mediators from mucosal mast cells, T-lymphocyte proliferation, and enhanced plasma cell antibody production [125,126]. SP has also been shown to provoke the infiltration of eosinophils through degranulation of mast cells [126]. Germane to the context of indoor air pollution, inhalation of antigen, irritant gases or mechanical irritants (respirable particulates) has been demonstrated to induce release of these bronchoconstricting neuropeptides [127,128]. Because vasodilatation, mucosal permeability, and bronchoconstriction are hallmarks of asthma, release of SP, NKA, NKB and CGRP is likely to contribute to asthma pathogenesis.

Neuropeptides are distributed throughout the respiratory tract, and influence vascular permeability and airway tone. In addition they modulate immune and inflammatory responses. Neuropeptide regulation of normal airway control and contribution to the pathogenesis of asthma is the subject of intense research; future developments are likely to have direct clinical relevance for the allergist/immunologist.

3.2 ODOR-DISTRESS AND PSYCHONEUROIMMUNE NETWORKS

A common feature of many indoor air quality complaints is perception of displeasing odors. Review of the physiologic and neurologic mechanisms of odor perception, and the psychophysiologic impact of smells, provides insight into the powerful influence the sense of smell has upon our daily lives [129-132]. Olfactory messages travel directly from receptors in the nasal passages to the limbic system of the brain. Certain odors can trigger the limbic system of the brain to stimulate the hypothalamus and pituitary gland to secrete hormones that control sex, appetite and even body temperature. It is important to remember that the limbic system is the major central system involved in adaptation, and in neuroendocrine and emotional responses to "stressful" stimuli [10]. Odors are always experienced in a specific context. In our field research, we have observed that odors are more annoying and/or stressful to people who work in clean environments, such as offices, than to those who work in dirty environments such as print shops. The smell of anything foreign, especially "chemical" provokes fear and alarm in certain individuals. Stress, regardless of its origin, results in a stimulation of adrenocortical secretion, ensuing increases in serum glucocorticoids and activation of the adrenergic nervous system, followed by release of catecholamines. This psychophysiologic interaction may well explain mysterious odor-related symptoms. A fascinating link has been established between odor-related "worry" (distress) and persistence of symptoms like those reported in SBS and MCS evaluations [133,134]. Further, it is proposed that odor-related worry may heighten symptom perception or recall [134,135].

Odors also have been reported to induce bronchospasm in asthmatics, [47,48,55,136] and odor-induced exacerbation of asthma is common [55]. Perfumes, colognes, environmental tobacco smoke, or unfamiliar odors have been implicated in this phenomenon. Odor-related bronchospastic responses may result from reactions occurring in the bronchial mucosa due to: 1) direct irritant effect; or 2) indirect psychoneuroimmune reactions resulting in neurotransmitter or chemical mediator release. Psychologic and somatic interactions are pivotal contributors to both allergy and pseudoallergy [13].

The indirect role of the psycho-neuro-endocrine-immune system network in responses to indoor air pollution, while not understood completely, may provide additional insight into baffling ailments such as MCS. The limited extent of this discussion does not allow for exhaustive examination of the potential involvement of the psychoneuroimmune network in responses to indoor air pollutants. Nevertheless, reviews on this topic are available elsewhere [5,11,13,102,105,110,137-139] Currently, the combined effects of indoor air pollution, stress and adaptation can neither be explained fully nor ignored.

4.0 Predictive And Diagnostic Methods

Scientifically established investigation procedures have led to the identification and clarification of immune parameters in normal, allergic and immunosuppressed conditions. Disciplined scientific investigations have resulted in understanding the immunologic components of allergic rhinitis, bronchial asthma, chemically-induced asthma, rheumatoid disease, hypersensitivity pneumonitis, and certain allergic dermatitides. Traditional immunologists/allergists emphasize the importance of the scientific method and comprehension of underlying mechanisms in approaching complex clinical problems. A thorough comparison and contrast of this reasoned approach with that of medical subcultures, such as *clinical ecology*

[115,117,140,141] is available elsewhere [118]. Methods for defining immune interactions with indoor air pollutants can be divided into two basic categories: 1) diagnostic testing and 2) predictive testing. A variety of sensitive and specific assay systems are applicable to investigation of immune responses to indoor air pollutants. Immune and inflammatory cells are easily isolated, their number and function measured. Antibodies and cytokines can be isolated and measured qualitatively and quantitatively.

4.1 DIAGNOSITC TESTING APPROACHES

Detecting immune system effects and substantiating immune alterations due to indoor air pollution requires careful analysis of the exposure milieu, a thorough medical history and physical examination, and immunological laboratory testing. Not all patients will present with pathognomonic signs or symptoms. In addition, clinical evaluation of immune responses to environmental agents can be expensive and lead to an unenlightening data set. Evaluation of the patient should begin with a complete history and physical examination, noting typical signs and symptoms of immune disorders such as hypersensitivity, immunosuppression and autoimmunity. The medical history and physical examination should guide selection of appropriate immunological tests. The World Health Organization's Immunology Section recommends eight basic immunologic screening tests be performed before other more expensive tests be performed (Table 7) [142].

Table 7. Clinical Immunology Screening Tests

General	CBC with Differential Cell Count Quantitative Protein Electrophoresis
Humoral Immunity	Immunoelectrophoresis IgG, IgM, IgA, IgE Quantitation Isoantibody Titers
Cellular Immunity	Delayed Type Hypersensitivity Skin Testing
Autoimmunity	Autoantibody Titers Complement (C3,C4) Analysis

Clinical approaches and assays available to diagnose hypersensitivity, immunosuppression, or autoimmune disorders have been reviewed [4,42,70,143,144]; selected examples are provided in Table 8.

Table 8. Typical Clinical Immunology Diagnostic Battery

Hypersensitivity	Skin Reactivity Eosinophil / Basophil Counts Mediator Release Assays Cytokine Release Assays

Table 8. Typical Clinical Immunology Diagnostic Battery (Cont't)

Hypersensitivity	IL-4 : IFN-gamma Ratios
Immunosuppression	Lymphocyte Mitogenic Responses Primary / Secondary Antibody Responses to Vaccines Cytokine Release Assays Lymphocyte Subset Enumeration
Autoimmunity	Antinuclear Antibody Titer Rheumatoid Factor Titer Immune Complex Quantitation Polyclonal Antibody Titers

The dynamics of the immune system and its relationship to other physiologic networks necessitates laboratory test results be viewed only as clinical "snapshots;" a fragmented view of the immune system at a single moment.

4.2 PREDICTIVE TESTING APPROACHES

Indoor air pollution causes increasing public concern. Regulatory agencies and consumer products manufacturers realize that careful selection of furnishings and products for indoor use is one tactic in an overall strategy to maintain acceptable indoor air quality. Prudent manufacturers of consumer products destined for indoor environments are taking responsibility for environmental impact data on their products, both during use and at end-of-life disposal. From the previous discussion, it should be apparent that no single assay can be used to evaluate all possible misfortunes that could be inflicted upon the immune system by indoor air pollutants. Predictive panels (tiered testing) for immune system alterations have been reviewed previously [4,145]. Representative assays useful in predicting hypersensitivity, immunosuppression or autoimmunity resulting from airborne pollutants are provided in Table 9.

Table 9. Predictive Testing of Immune Responses to Airborne Pollutants

Hypersensitivity	Pollutant-Specific IgE or IgG4 Eosinophil & Basophil Counts Mediator Release Assays Bronchoalveolar Lavage: - IL-4:IFN-gamma ratios - Cytology - Lymphocyte Reactivity
Immunosuppression	Host-Resistance Challenge Assays Tumor-Resistance Challenge Assays

Table 9. Predictive Testing of Immune Responses to Airborne Pollutants (Cont'd)

Immunosuppression	Primary / Secondary Antibody Responses to Vaccines Enumeration of Lymphocyte Subsets
Autoimmunity	Antinuclear Antibody Titers Rheumatoid Factor Titers Polyclonal Antibody Titers Immune Complex Quantitation Stress Protein Release Assays

Research that integrates qualitative and quantitative emissions analysis, inhalation toxicology, and human exposure and response data is integral to evaluation of immune interactions with indoor air pollutants. We have developed a three-chamber approach for estimating immune alterations due to airborne pollutant exposure.

4.2.1 *Analytical Chamber.* Chamber one is a Summa^{R} polished (passivated) stainless steel chamber used to determine the qualitative and quantitative emissions profile arising from materials or equipment. Standard Gas Chromatography/Mass Spectrometric techniques are used to measure emission rates, species ratios and emission half-life.

4.2.2 *Nose-Only Inhalation Chamber.* Our second chamber, a nose-only inhalation chamber, has been designed so that materials or equipment can be used as emission exposure sources. Such a design, coupled with multiple animal models with defined genetic backgrounds, provides a very realistic testing platform. Sensitive detectors and data gleaned from the analytical chamber enables real-time dose and exposure data logging. Sensitive and specific immunoassays (Tables 8 & 9) are used to determine the immune alterations resulting from controlled exposure to material and equipment emissions.

4.2.3 *Environmental Chamber.* Another is a large environmental chamber in which we can replicate a typical office setting, including floor and wall coverings, furniture, supplies and equipment. Environmental factors including temperature, relative humidity, air supply (ventilation rate), vibration, noise, lighting and ergonomics can be measured and controlled. During human occupancy, addition or removal of materials, equipment or supplies can be followed using both objective (analytical and biological measurements) and subjective (complaints and symptoms) evaluations. These data also enable the development of predictive, artificial intelligence-based models relevant to white collar office environments.

5.0 Epilogue

Four decades of basic research have provided exciting glimpses into the independent structure and function of immune, nervous and endocrine systems. In the future, integrative analyses of collaboration between these systems will reshape our

understanding of homeostasis and disease. Serendipitous experiments of mankind (e.g. indoor air pollution), though designed poorly, may provide a real-world framework from which unified and integrated models of the psycho-neuro-endocrine-immune alliance, and its circuitry, can be examined.

References

1. Salvaggio, J. (1990) 'The Impact of Allergy and Immunology on Our Expanding Industrial Environment', J. Aller. Clin. Immunol. 85, 689-699.
2. Gil, J. and Daniele, R. (1988) 'Morphology of the Lung's Immune System', in R. Daniele, (ed.), Immunology and Immunologic Disease of the Lung, Blackwell Scientific Publications, Boston, MA, pp. 321-333.
3. Stanworth, D. (1985) 'Current Concepts of Hypersensitivity', in J. Dean, M. Luster, A. Munson and H. Amos, (eds.), Immunotoxicology and Immunopharmacology, Raven Press, New York, NY, pp. 91-98.
4. Brooks, B. and Sullivan, J. (1992) 'Immunotoxicology', in J. Sullivan and G. Kreiger, (eds.), Hazardous Materials Toxicology: Clinical Principles of Environmental Health, Williams & Wilkins, Baltimore, MD, pp. 190-214.
5. Dunn, A. (1989) 'Psychoneuroimmunology for the Psychoneuroendocrinologist: a Review of Animal Studies of Nervous System-Immune System Interactions', Psychoneuroendocrinology 14, 251-274.
6. Casale, T. (1991) 'Neuropeptides And The Lung', J. Aller. Clin. Immunol. 88, 1-14.
7. Kroegel, C., Giembycz, M. and Barnes, P. (1990) 'Characterization of Eosinophil Cell Activation By Pepetides: Differential Effects of Substance P, Melittin, and FMET-Leu-Phe', J. Immunol. 145, 2581-2587.
8. Kroemer, G., Brezinschek, H., Faessler, R., Schauenstein, K. and Wick, G. (1988) 'Physiology and Pathology of an Immunoendocrine Feedback Loop', Immunol. Today 9, 163-166.
9. Hertz, L., McFarlin, D. and Waksman, B. (1990) 'Astrocytes: Auxiliary Cells for Immune Responses in the Central Nervous System?', Immunol. Today 11, 265-268.
10. Khansari, D., Murgo, A. and Faith, R. (1990) 'Effects of Stress on the Immune System', Immunol. Today 11, 170-1175.
11. Pert, C., Ruff, M., Weber, R. and Herkenham, M. (1985) 'Neuropeptides and Their Receptors: A Psychosomatic Network', J. Immunol. 135, 820s-826a.
12. Mason, D. (1991) 'Genetic Variation in the Stress Response: Susceptibility to Experimental Allergic Encephalomyelitis and Implications for Human Inflammatory Disease', Immunol. Today 12, 57-60.
13. Pearson, D. (1988) 'Psychologic and Somatic Interrelationships in Allergy and Pseudoallergy', J. Aller. Clin. Immunol. 81, 351-360.
14. Priboi, R. (1990) 'Conexitati Psihoneuroimunologice II', Rev. Med. Chir. Soc. Med. Nat. Isai 94, 313-317.
15. Dyck, D., Janz, L., Osachuk, T., Falk, J., Labinsky, J. and Greenberg, A. (1990) 'The Pavlovian Conditioning of IL-1-Induced Glucocorticoid Secretion', Brain Behav. Immun. 4, 93-104.
16. Sell, S. (1987) Immunology, Immunopathology and Immunity, Elsevier, New York, NY.
17. Rodgers, J. and Rich, R. (1991) 'Molecular Biology and Immunology: An Introduction', J. Aller. Clin. Immunol. 88, 535-549.

18. Chase, M. (1970) 'Specificity of Serological Reactions: Landsteiner Centennial', Ann. NY Acad. Sci. 169, 9-10.
19. Torok-Storb, B. (1988) 'Cellular Interactions', Blood 72, 373-385.
20. Katz, K. (1982) 'Genetic Control of Cell-Cell Interactions', Pharmacol. Rev. 34, 51-62.
21. Sell, S. (1987) 'Immune Deficiency Diseases', in Immunology, Immunopathology, and Immunity, Elsevier, New York, NY, pp. 617-652.
22. Pierson, W. and Sly, R. (1990) 'Epidemiology and Prevention of Asthma Mortality', J. Respir. Dis. June, s49-s56.
23. Jenkins, P., Mullins, J., Davies, B. and Williams, D. (1981) 'The Possible Role of Aeroallergens in the Epidemic of Asthma Deaths', Clin. Aller. 11, 611-620.
24. Miyamoto, T., Takafuji, S., Suzuki, S., Tadokoro, K. and Muranaka, M. (1988) 'Environmental Factors in the Development of Allergic Reactions', in R. Estabrook, E. Lindenlaub, F. Oesch and A. de Weck, (eds.), Toxicological and Immunological Aspects of Drug Metabolism and Environmental Chemicals, F.K. Schattauer Verlag, Stuttgart, Germany, pp. 553-568.
25. Dooms-Goossens, A. and Deleu, H. (1991) 'Airborne Contact Dermatitis: An Update', Contact Dermatitis 25, 211-217.
26. Sell, S. (1987) 'Interplay of Inflammatory and Immunopathological Mechanisms in Disease', in Immunology, Immunopathology and Immunity, Elsevier, New York, NY, pp. 545-549.
27. Graham, J. and Gardner, D. (1985) 'Immunotoxicity of Air Pollutants', in J. Dean, M. Luster, A. Munson and H. Amos, (eds.), Immunotoxicology and Immunopharmacology, Raven Press, New York, NY, pp. 367-380.
28. Ward, E., Murray, M. and Dean, J. (1985) 'Immunotoxicity of Nonhalogenated Polycyclic Aromatic Hydrocarbons', in J. Dean, M. Luster, A. Munson and H. Amos, (eds.), Immunotoxicology and Immunopharmacology, Raven Press, New York, NY, pp. 291-304.
29. Couch, R., Douglas, R., Lindgren, K., Gerone, P. and Knight, V. (1970) 'Airborne Transmission of Respiratory Infection with Coxsackie Virus A Type 21', Amer. J. Epidem. 91, 78-86.
30. Kawarabayashi, T. and Nakata, H. (1978) 'Pollution of Indoor Air: Airborne Bacteria', Hokkaido Igaki Zasshi 53, 67-77.
31. Feeley, J. (1985) 'Impact of Indoor Air Pathogens on Human Health', in R. Gammage and S. Kaye, (eds.), Indoor Air and Human Health, Lewis Publishers, Inc., Chelsea, MI, pp. 183-187.
32. Rook, G. (1983) 'Immunology of Infectious Disease', in E. Holborow and W. Reeves, (eds.), Immunology in Medicine: A Comprehensive Guide to Clinical Immunology, Grune and Stratton, New York, NY, pp. 159-178.
33. Davis, G. and Winn, W. (1987) 'Legionnaires's Disease: Respiratory Infections Cause by Legionella Bacteria', Clin. Chest Med. 8, 419-439.
34. Brundage, J., Scott, R., Lednar, W., Smith, D. and Miller, R. (1988) 'Building-Associated Risk of Febrile Acute Respiratory Diseases in Army Trainees', JAMA 259, 2108-2112.
35. Graham, N. (1990) 'The Epidemiology of Acute Respiratory Infections in Children and Adults: A Global Perspective, Epidemiol.Rev 12, 149-178.
36. Stanworth, D. (1983) 'Mechanisms of Hypersensitivity', in G. Gibson, R. Hubbard and D. Parke, (eds.), Immunotoxicology, Academic Press, New York, NY, pp. 71-86.

37. Gravesen, S., Larsen, L., Gyntelberg, F. and Skov, P. (1986) 'Demonstration of Microorganisms and Dust in Schools and Offices', Allergy 41, 520-525.
38. Burge, H. (1988) 'Environmental Allergy:Definitions, Causes, Control', in Engineering Solutions to Indoor Air Problems, ASHRAE, Atlanta, GA, pp. 3-9.
39. Lam, S. and Chan-Yeung, M. (1987) 'Occupational Asthma: Natural History, Evaluation and Management', Occup Med: State Art Rev 2, 373-381.
40. Burge, H. (1987) 'Approaches to the Control of Indoor Microbial Contamination', in Indoor Air Quality '87: Practical Control of Indoor Air Problems, American Society of Heating, Refrigerating and Air-Conditioning Engineers,Inc., Atlanta, GA, pp. 33-37.
41. Kaliner, M., Eggleston, P. and Mathews, K. (1987) 'Rhinitis and Asthma', JAMA 258, 2851-2873.
42. Bush, R. (1989) 'Aerobiology of Pollen and Fungal Allergens', J. Aller. Clin. Immunol. 84, 1120-1124.
43. Montanaro, A. (1989) 'House Dust, Animal Proteins, Pollutants, and Environmental Controls', J. Aller. Clin. Immunol. 84, 1125-1128.
44. Slavin, R. (1989) 'Allergic and Immunologic Disorders', J. Aller. Clin. Immunol. 84, 1059-1061.
45. Marks, J., Trautlein, J., Zwillich, C. and Demers, L. (1984) 'Contact Urticaria and Airway Obstruction From Carbonless Carbon Paper', JAMA 252, 1038-1040.
46. Kunkel, G., Rudolf, R. and Muckelmann, R. (1982) 'Indoor Air and Allergic Diseases', Schriftenr. Ver. Wasser. Boden. Lufthyg. 53, 75-89.
47. Brown, E. and Colombo, N. (1954) 'The Asthmogenic Effect of Odors, Smells and Fumes', Ann. Allergy 12, 14-24.
48. Herbert, M., Glick, R. and Black, H. (1967) 'Olfactory Precipitants of Bronchial Asthma', J. Psychosom. Res. 11, 195-202.
49. Tarlo, S. and Broder, I. (1989) 'Irritant-Induced Occupational Asthma', Chest 96, 297-300.
50. Malo, J., Gagnon, G. and Cartier, A. (1984) 'Occupational Asthma Due to Heated Freon', Thorax 39, 628-629.
51. Curran, T. (1980) 'Otolaryngologic Allergy: Its Diagnosis and Treatment', Laryngoscope 90, 992-996.
52. Kay, A. (1991) 'Asthma and Inflammation', J. Aller. Clin. Immunol. 87, 893-910.
53. Busse, W. (1990) 'Respiratory Infections: Their role in airway responsiveness and the pathogenesis of asthma', J. Aller. Clin. Immunol. 84, 671-683.
54. Busse, W. and Reed, C. (1988) 'Asthma: Definition and Pathogenesis', in E. Middleton, C. Reed, E. Ellis, N. Adkinson and J. Yunginger, (eds.), Allergy: Principles and Practice, C.V. Mosby, St. Louis, pp. 969-991.
55. Shim, C. and Williams, M. (1986) 'Effect of Odors on Asthma', Am J Med 80, 18-22.
56. Naus, A. (1985) 'The Occupational Meaning of Smell', J. Hyg. Epidemiol. Microbiol. Immunol. 29, 29-36.
57. Boushey, H. (1989) 'Ozone and Asthma', in M. Utell and R. Frank, (eds.), Susceptibility to Inhaled Pollutants, ASTM, Philadelphia, PA, pp. 214-217.
58. Brooks, B., Utter, G., DeBroy, J. and Schimke, R. (1991) 'Indoor Air Pollution: An Edifice Complex', J. Toxicol. Clin. Toxicol 29, 315-374.

59. Sheppard, D. (1988) 'Sulfur Dioxide and Asthma: A Double-Edged Sword?', J. Aller. Clin. Immunol. 62, 961-963.
60. Riedel, F., Kramer, M., Scheibenbogen, C. and Rieger, C. (1988) 'Effects of SO2 Exposure on Allergic Sensitization in the Guinea Pig', J. Aller. Clin. Immunol. 82, 527-534.
61. Osebold, J., Gershwin, L. and Zee, Y. (1980) 'Studies on the enhancement of allergic lung sensitization by inhalation of ozone and sulfuric acid aerosol', J. Environ. Pathol. Toxicol. Oncol. 3, 221-234.
62. Marsh, D. and Norman, P. (1988) 'Antigens That Cause Atopic Disease, in D. Talmage, M. Frank, K. Austen and H. Claman, (eds.), Immunologic Diseases, Little, Brown and Company, Boston, MA, pp. 981-1008.
63. Sullivan, J., Van Ert, M. and Krieger, G. (1992) 'Indoor Air Quality and Human Health', in J. Sullivan and G. Krieger, (eds.), Hazardous Materials Toxicology: Clinical Principles of Environmental Health, Williams & Wilkins, Baltimore, pp. 667-687.
64. Kreiss, K. and Hodgson, M. (1984) 'Building-Associated Epidemics', in P. Walsh, C. Dudney and E. Copenhaver, (eds.), Indoor Air Quality, CRC Press, Boca Raton, FL, pp. 88-106.
65. Lachapelle, J. (1987) 'The Concept of Industrial Airborne Irritant or Allergic Contact Dermatitis', in H. Maibach, (ed.), Occupational and Industrial Dermatology, Year Book Medical Publishers, Inc., Chicago, IL, pp. 179-189.
66. Beck, H., Bjerring, P. and Harving, H. (1989) 'Atopic Dermatitis and the Indoor Climate: The Effect from Preventive Measures', Acta Derm. Venerol. 69, 162-165.
67. Kaplan, A., Buckley, R. and Mathews, K. (1987) 'Allergic Skin Disorders', JAMA 258, 2900-2909.
68. Hausen, B., Shoji, A. and Jarchow, O. (1984) 'Orchid Allergy', Arch. Dermatol. 120, 1206-1208.
69. Salvaggio, J. (1987) 'Hypersensitivity Pneumonitis', J. Aller. Clin. Immunol. 79, 558-571.
70. Fink, J. (1988) 'Hypersensitivity Pneumonitis', in E. Middleton, C. Reed, E. Ellis, N. Adkinson and J. Yunginger, (eds.), Allergy: Principles and Practice, C.V. Mosby, St. Louis, pp. 1237-1252.
71. Fink, J. (1988) 'Hypersensitivity Pneumonitis', in R. Daniele, (ed.), Immunology and Immunologic Diseases of the Lung, Blackwell Scientific Publications, London, pp. 321-333.
72. Newman, L. (1992) 'Pulmonary Toxicology', in J. Sullivan and G. Krieger, (eds.), Hazardous Materials Toxicology: Clinical Principles of Environmental Health, Williams & Wilkins, Baltimore, MD, pp. 124-144.
73. Fink, J. and deShazo, R. (1987) 'Immunologic Aspects of Granulomatous and Interstitial Lung Diseases', JAMA 258, 2938-2944.
74. Finnegan, M., Pickering, C., Davies, P., Austwick, P. and Warhurst, D. (1987) 'Amoebae and Humidifier Fever', Clin. Aller. 17, 235-242.
75. Flaherty, D., Deck, F., Cooper, J., et al. (1984) 'Bacterial Endotoxin Isolated from a Water Spray Air Humidification System as a Putative Agent of Occupation-Related Lung Disease', Infect. Immun. 43, 206-212.
76. Pennington, J. (1988) 'Pulmonary Infections and Immune Defects in the Immunocompromised Host', in R. Daniele, (ed.), Immunology and Immunologic Disease of the Lung, Blackwell Scientific Publications, Boston, MA, pp. 581-600.

77. Rankin, J., Collman, R. and Daniele, R. (1988) 'Acquired Immune Deficiency Syndrome and the Lung', in R. Daniele, (ed.), Immunology and Immunologic Disease of the Lung, Blackwell Scientific Publications, Boston, MA, pp. 601-623.
78. Haseltine, W. and Wong-Staal, F. (1988) 'The Molecular Biology of the AIDS Virus', Sci. Amer. 259, 34-43.
79. Buckley, R. (1987) 'Immunodeficiency Diseases', JAMA 20, 2841-2850.
80. Purtillo, D., Linder, J. and Seemayer, T. (1988) 'Inherited and Acquired Immunodeficiency Disorders', in R. Colvin, A. Bhan and R. McCluskey, (eds.), Diagnostic Immunopathology, Raven Press, New York, NY, pp. 121-150.
81. Webster, A. (1983) 'Immunodeficiency Disease', in E. Holborow and W. Reeves, (eds.), Immunology in Medicine: A Comprehensive Guide to Clinical Immunology, Grune and Stratton, New York, NY, pp. 223-241.
82. Heise, E. (1982) 'Diseases Associated with Immunosuppression', Environ. Health Perspect. 43, 9-19.
83. Teale, J. and Abraham, K. (1987) 'The Regulation of Antibody Class Expression', Immunol. Today 8, 122-126.
84. Burge, H. (1990) 'Bioaerosols: Prevalence and Health Effects in the Indoor Environment', J. Aller. Clin. Immunol. 86, 687-701.
85. Gardner, D. (1984) 'Alterations in Macrophage Functions by Environmental Chemicals', Environ. Health Perspect. 55, 343-358.
86. Van Loveren, H., Rombout, P., Wagenaar, S., Walvoort, H. and Vos, J. (1988) 'Effects of Ozone on the Defense to a Respiratory Listeria monocytogenes Infection of the Rat: Suppression of Macrophage function and Cellular Immunity and Aggravation of Histopathology in Lung and Liver During Infection', Toxicol. Appl. Pharmacol. 94, 374-393.
87. Driscoll, K. and Schlesinger, R. (1988) 'Alveolar Macrophage-Stimulated Neutrophil and Monocyte Migration: Effects of In Vitro Ozone Exposure', Toxicol. Appl. Pharmacol. 93, 312-318.
88. Frampton, M., Smeglin, A., Roberts, N., Finkelstein, J., Morrow, P. and Utell, M. (1989) 'Nitrogen Dioxide Exposure In Vivo and Human Alveolar Macrophage Inactivation of Influenza Virus In Vitro', Euro Reports 48, 179-192.
89. Frampton, M. and Roberts, N. (1989) 'Respiratory Infection and Oxidants', in F. Utell and R. Frank, (eds.), Susceptibility to Inhaled Pollutants, American Society for Testing and Materials, Philadelphia,PA, pp. 182-191.
90. Amman, H., Berry, M., Childs, N. and Mage, D. (1986) 'Health Effects Associated with Indoor Air Pollutants', in Proceedings IAQ '86: Managing Indoor Air for Health and Energy Conservation, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA, pp. 53-70.
91. Simpson, E. (1988) 'Function of the MHC', Immunol. 1, 27-30.
92. Burchiel, S., Hadley, W., Barton, S., Fincher, R., Lauer, L. and Dean, J. (1988) 'Persistant Suppression of Humoral Immunity Produced by 7,12-Dimethylbenz(a)anthracene (DMBA) in B6C3F1 Mice: Correlation with Changes in Spleen Cell Surface Markers Detected by Flow Cytometry', Int. J. Immunopharmacol. 10, 369-376.
93. Cohen, I. (1988) 'The Self, the World, and Autoimmunity', Sci. Amer. 258, 52-60.

94. Condemi, J. (1987) 'The Autoimmune Diseases', JAMA 258, 2920-2929.
95. Kammuller, M., Bloksma, N. and Seinen, W. (1989) 'Autoimmunity and Toxicology: Immune Disregulation Induced by Drugs and Chemicals', Elsevier, Cambridge.
96. Cooke, A., Lydyard, P. and Roitt, I. (1983) 'Mechanisms of Autoimmunity: A Role for Cross-Reactive Idiotypes', Immunol. Today 4, 374-378.
97. Hamilton, H., Morgan, D. and Simmons, A. (1978) 'A Pesticide (dieldrin)-Induced Immunohemolytic Anemia', Environ. Res. 17, 155-164.
98. Nimmo, A., Werley, M., Martin, J. and Tansy, M. (1990) 'Particulate Inhalation During Removal of Amalgam Restorations', J. Prosthet. Dent. 63, 228-233.
99. Bigazzi, P. (1988) 'Autoimmunity Induced by Chemicals', J. Toxicol. Clin. Toxicol 26, 125-156.
100. Brooks, B., Aldrich, F., Utter, G., DeBroy, J. and Schimke, R. (1992) 'Immune Responses to Pollutant Mixtures From Indoor Sources', Ann. NY Acad. Sci. (In Press).
101. Sell, S. (1987) 'Atopic or Anaphylactic Reactions (Allergy)', in Immunology, Immunopathology and Immunity, Elsevier, New York, NY, pp. 439-470.
102. Goetzl, E., Chrenov, T., Rnold, F. and Payan, D. (1985) 'Neuropeptide Regulation of the Expression of Immediate Hypersensitivity', J. Immunol. 135, 802-805.
103. Besedovsky, H., del Ray, A. and Sorkin, E. (1985) 'Immune-Neuroendocrine Interactions', J. Immunol. 135, 750s-754s.
104. Risenberg, D. (1986) 'Can Mind Affect Body Defenses Against Disease? Nascent Specialty Offers a Host of Tantalizing Clues', JAMA 256, 313-314.
105. Heath, R. (1990) 'Psychoneuroimmunology: An Autoimmune Pathogenesis for Schizophrenia', Psychiatr. Med. 8, 95-110.
106. Smith, G., McKenzie, J., Marmer, D. and Steele, R. (1985) 'Psychologic Modulation of the Human Immune Response to Varicella Zoster', Arch. Intern. Med. 145, 2110-2112.
107. Mahaney, F. (1990) 'Psychoneuroimmunology: Can the Brain and Immune System Communicate?', J.Natl.Cancer Inst. 82, 738-739.
108. Gold, P., Goodwin, F. and Chrousos, G. (1988) 'Clinical and Biochemical Manifestations of Depression, N. Engl. J. Med. 319, 413-420.
109. Mozzanica, N., Finzi, A., Foppa, S., Vignati, G. and Villa, M. (1991) 'Association Between Circardian Rhythms of Endogenous Hypothalamic Opioid Peptides and of Natural Killer Cell Activity', Int. J. Immunopharmacol. 13, 317-321.
110. Blalock, E., Harbour-McMenamin, D. and Smith, E. (1985) 'Peptide Hormones Shared by The Neuorendocrine and Immunologic Systems', J. Immunol. 135, 858s-861s.
111. Barnes, D. (1986) 'Nervous and Immune System Disorders Linked in a Variety of Diseases', Science 232, 160-161.
112. Stolwijk, J. (1987) 'The "Sick" Building Syndrome, in Practical Control of Indoor Air Problems', ASHRAE, Atlanta,GA, pp. 14-20.
113. Molina, C., Pickering, C., Valbjorn, O. and DeBortoli, M. (1989) 'Sick Building Syndrome: A Practical Guide', Comission of European Communities,Directorate General for Science, Research and Development Joint Research Centre, Institute for the Environment, Luxembourg.

114. Sterling, E., Sterling, T. and McIntyre, D. (1983) 'New Health Hazards in Sealed Buildings', Am. Inst. Architects J 72, 64-67.
115. Terr, A. (1989) 'Clinical Ecology in the Workplace', J. Occup. Med. 31, 257-261.
116. Cullen, M. (1987) 'The Worker with Multiple Chemical Sensitivities: An Overview', State Art. Rev. Occup. Med. 2, 655-661.
117. Sullivan, J. and Brooks, B. (1992) 'Multiple Chemical Sensitivities', in J. Sullivan and G. Krieger, (eds.), Hazardous Materials Toxicology: Clinical Principles of Environmental Health, Williams & Wilkins, Baltimore,MD, pp. 215-219.
118. Selner, J. and Condemi, J. (1988) Unproven Diagnostic and Therapeutic Techniques for Allergy', in E. Middleton, C. Reed, E. Ellis, N. Adkinson and J. Yunginger, (eds.), Allergy: Principles and Practice, C.V. Mosby, St. Louis, MO, pp. 1571-1597.
119. Forman, J. and Jordan, C. (1983) 'Histamine Release and Vascular Changes Induced by Neuropeptides', Agents and Actions 13, 105-111.
120. Brodsky, C. (1987) 'Multiple Chemical Sensitivities and Other "Environmental Illness": A Psychiatrist's View', State Art. Rev. Occup. Med. 2, 695-704.
121. Schottenfeld, R. (1987) 'Workers with Multiple Chemical Sensitivities: A Psychiatric Approach to Diagnosis and Treatment', State Art. Rev. Occup. Med. 2, 739-774.
122. Moore, T. (1984) 'Modification of Lymphocyte Traffic by Vasoactive Neurotransmitter Substances', Immunol. 52, 511-518.
123. Stanisz, A., Scicchitano, R. and Bienenstock, J. (1988) 'The Role of Vasoactive Intestinal Peptide and Other Neuropeptides in the Regulation of the Immune Response In Vitro and In Vivo', Ann. NY Acad. Sci. 527, 478-482.
124. Stanisz, A., Befus, D. and Bienenstock, J. (1986) 'Differential Effects of Vasoactive Intestinal Peptide, Substance P and Somatostatin on Immunoglobulin Synthesis and Proliferation by Lymphocytes from Peyer's Patches, Mesenteric Lymph Nodes, and Spleen', J. Immunol. 136, 152-156.
125. Payan, D., Brewster, D. and Goetzl, E. (1983) 'Specific Stimulation of Human T-lymphocytes by Substance P', J. Immunol. 131, 1613-1615.
126. Matsuda, H., Kawakita, K., Kiso, Y., Nakano, T. and Kitamura, Y. (1989) 'Substance P Induces Granulocyte Infiltration Through Degranulation of Mast Cells', J. Immunol. 142, 927-931.
127. Saria, A., Martling, D., Yan, Z., Theodorsson-Norheim, E., Gamse, R. and Lundberg, J. (1988) 'Release of Multiple Tachykinins from Capsaicin-Sensitive Sensory Nerves in the Lung by Bradykinin, Histamine, Dimethylphenyl Piperazine, and Vagal Nerve Stimulation', Am. Rev. Respir. Dis. 137, 1330-1335.
128. Coleridge, J. and Coleridge, H. (1984) 'Afferent Vagal C Fiber Innervation of the Lung and Airways and its Functional Significance', Rev. Physiol. Biochem. Pharmacol. 99, 1-9.
129. Cain, W. (1987) 'Indoor Air as a Source of Annoyance', Dev. Tox. Environ. Sci. 15, 189-200.
130. Van Toller, S. and Dodd, G. (1988) Perfumery: The Psychology and Biology of Fragrance, Routledge, Chapman & Hall, London, England.
131. Gibbons, B. (1986) 'The Intimate Sense of Smell', National Geographic 170, 324-360.

132. Gilbert, A. and Wysocki, C. (1987) 'The National Geographic Smell Survey Results', National Geographic 172, 514-525.
133. Doty, R., Deems, D., Frye, R., Pelberg, R. and Shapiro, A. (1988) 'Olfactory Sensitivity, Nasal Resistance, and Autonomic Function in Patients with Multiple Chemical Sensitivities', Arch. Otolaryngol. Head Neck Surg. 114, 1422-1427.
134. Shusterman, D., Lipscomb, J., Neutra, R. and Satin, K. (1991) 'Symptom Prevalence and Odor-Worry Interaction near Hazardous Waste Sites', Environ. Health Perspect. 94, 25-30.
135. Finger, T., Getchell, M., Getchell, T. and Kinnamon, J. (1990) 'Affector and Effector Functions of Peptidergic Innervation of the Nasal Cavity', in B. Green, J. Mason and M. Kare, (eds.), Chemical Senses: Volume 2 - Irritation, Marcel Dekker, Inc., New York, NY, pp. 1-20.
136. Saluka, A. (1984) 'Sir John Floyer's A Treatise on Asthma', Thorax 39, 249-254.
137. Booth, R. (1990) 'The Psychoneuroimmune Network: Expanding our Understanding of Immunity and Disease', N.Z. Med. J. 103, 314-316.
138. Silver, W. (1991) 'The Common Chemical Sense, in T. Finger and W. Silber, (eds.), Neurobiology of Taste and Smell, Krieger Publishing Company, Malabar, FL, pp. 65-87.
139. Vollhardt, L. (1991) 'Psychoneuroimmunology: A Literature Review', Am. J. Orthopsychiatry 61, 35-47.
140. Terr, A. (1986) 'Environmental Illness: A Clinical Review of 50 Cases', Arch. Intern. Med. 146, 145-149.
141. American College of Physicians (1989) 'Clinical Ecology', Ann. Int. Med. 111, 168-178.
142. (1981) Report of an IUIS/WHO Working Group. 'Use and Abuse of Laboratory Tests in Clinical Immunology: Critical Considerations of Eight Widely Used Diagnostic Procedures', Clin. Exp. Immuol. 46:, 662-674.
143. Yunginger, J. (1988) 'Clinical Significance of IgE', in E. Middleton, C. Reed, E. Ellis, N. Adkinson and J. Yunginger, (eds.), Allergy: Principles and Practice, C.V. Mosby, St. Louis, MO, pp. 849-860.
144. Homburger, H. and Katzmann, J. (1988) 'Methods in Laboratory Immunology', in E. Middleton, C. Reed, E. Ellis, N. Adkinson and J. Yunginger, (eds.), Allergy: Principles and Practice, C.V. Mosby, St. Louis, MO, pp. 402-418.
145. Luster, M., Munson, A., Thomas, P., et al. (1988) 'Development of a Testing Battery to Assess Chemical-Induced Immunotoxicity: National Toxicology Program's Guidelines for Immunotoxicity Evaluation in Mice', Fundam. Appl. Toxicol. 10, 2-19.

INDOOR POLLUTION AND ALLERGIC SENSITIZATION

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ABSTRACT. Allergic sensitization and diseases are probably increasing in industrialized socities. The etiology is multifactorial, and depends on the interaction between the time and amount of allergen exposure, presence of non-specific adjuvant factors, including air pollution, in genetically susceptible individuals. Most of the potentially harmful environmental factors may be present in a sick building, caused by modern energy conservation measures and improper ventilation.

Methods are available for identification of high risk infants who are likely to develop allergies early in their life, and it is possible to delay the onset of allergic sensitization and allergic symptoms through combined effort of early prevention, allergen removal and reduction of various adjuvant factors.

The indoor environment probably plays a large role for the development of allergic sensitization and appearence of allergic disease in the sensitized individual.

Introduction

The prevalence of allergic diseases appears to be increasing in many parts of the world, especially in industrialized countries (1-5). As there has been no appreciable change in the human genotype over the past century, but there have been dramatic changes in human habits and life style, it is reasonable to assume that the increase is caused by environmental influences.

Allergens are present in almost every part of the world but the relative importance of the individual allergens vary, depending on climatic conditions. In subarctic regions, like the Nordic countries, house dust mites used to be absent, but there is now evidence for an increasing prevalence (6, 7). This may be due to modern technology used for building houses and energy conservation measures.

It has traditionally been assumed that air pollution is primarily an outdoor phenomenon. A number of studies have however shown that indoor concentrations of some pollutants may be far in excess of the outdoor concentrations.

In this review, various indoor pollutants which may influence the development of allergic sensitization and disease will be discussed.

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Development of sensitization

Sensitization, *i.e.* induction of IgE antibody formation, and subsequent allergic disease is an interaction between a predisposed individual, allergens and environmental adjuvant factors (Fig.1).

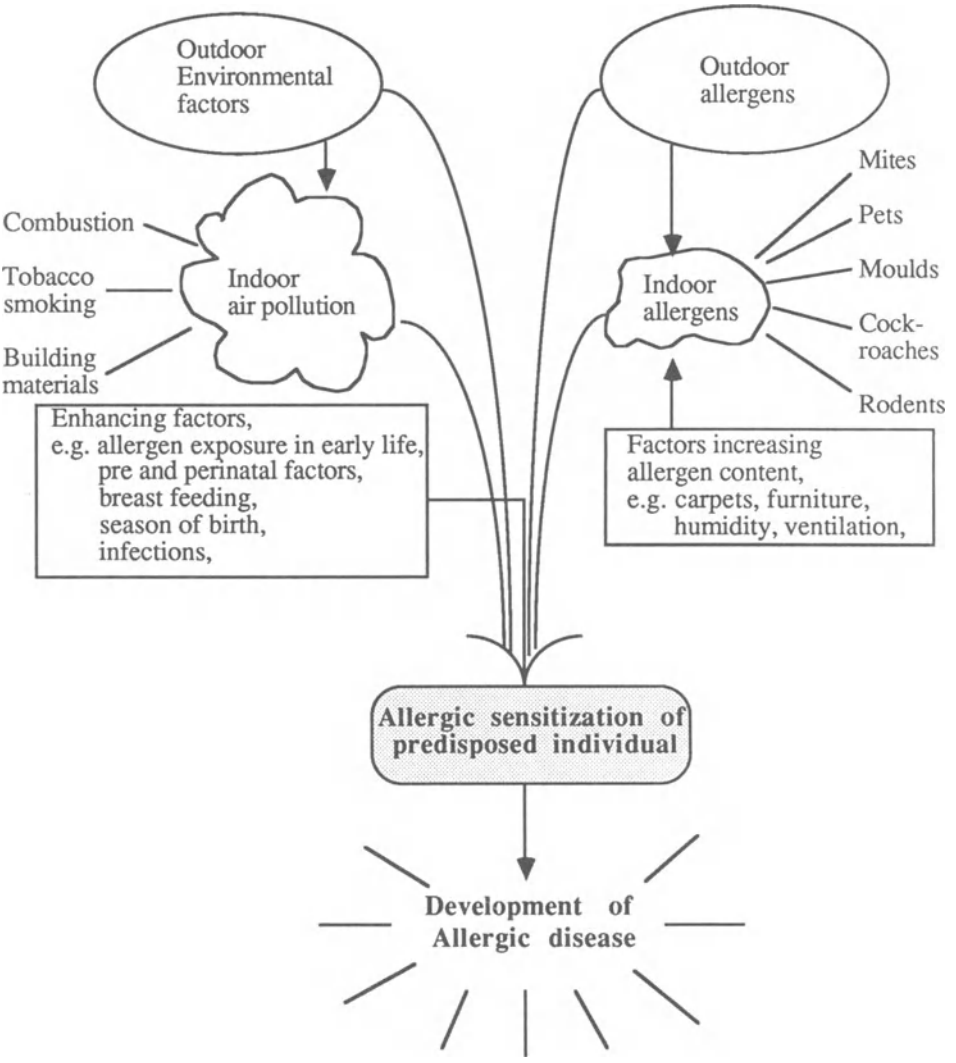

Fig. 1. Sensitization is the result of allergen exposure of a genetically predisposed individual. It is enhanced by various non-specific adjuvant factors in the environment.

Exposure to an antigen is necessary in order to induce IgE antibody formation in an individual with a genetically determined susceptibility. The IgE antibody formation is enhanced by various non-specific "adjuvant" factors, including exposure to various air pollutants (Table 1).

Table 1. Adjuvant factors enhancing sensitization and development of allergic disease.

Air pollution and sources:
Industries and traffic; solid particles, SO_2, NOx, heavy metals
Combustion by-products, including tobacco smoke; CO_2, CO, SO_2, NO_2, NO, arsenic, formaldehyde, volatile vapours
Building materials; radon, formaldehyde, asbestos
Decoration and paints; solvents, furnishings
Photochemical reactions; ozone, NO_2
Pesticides and consumer products; organic substances, aerosols

Respiratory tract infections

Ongoing allergic reaction (facilitates sensitization to new allergens)

Hyperreactivity (hyperresponsiveness), is a state of increased sensitivity of the respiratory tract to a wide range of stimuli, *e.g.* irritants, cold air, dry air, smoke and exercise. The level of hyperreactivity is partially genetically determined and it is enhanced by upper respiratory tract infections, exposure to allergens and pollutants and possibly other factors (8).

Mites, cat, dog, moulds and cockroaches are the most important major indoor allergens. In addition, outdoor allergens, e.g. ragweed, tree and grass pollen are also present indoors. Sensitization and appearance of allergic symptoms after exposure to an allergen are both influenced by the dose, amount and duration of allergen exposure, as well as the potency of the allergen. The age at which the individual is exposed, concomitant exposure to adjuvants and a variety of host factors are other important factors. An ongoing allergic reaction facilitates sensitization against new allergens. Thus, there is a more than three-fold increased risk for sensitization to furred pets, when a subject is already sensitized to aeroallergens (9)

A characteristic trait of IgE antibody formation in animal models is that extremely low doses of antigen are needed for sensitization (10,11). Similarly, only minute amounts of antigen are needed to induce an IgE response (12), or to trigger an allergic reaction (13) in humans. There is, however, a wide variation in sensitivity, as the difference between highly sensitive individuals and less sensitive persons is about one million times (14, 15).

The concentration of allergen which may sensitize an individual or elicit symptoms in a sensitive patient has not yet established for most allergens. A concentration of 2 μg of major mite allergen (*Der p1/Der f1*) per gram of fine dust has been suggested as a threshold level for mite sensitization (16). For the major cat (*Fel d1*) allergen, the risk level for sensitization has been suggested to be 8 μg/g fine dust (17). It has been estimated that for pollen allergens an annual dose of less than 1 μg can induce sensitization as well as symptoms in adults (13).

In sensitized individuals, the concentration of allergen needed to induce clinical symptoms varies. It has thus been estimated that a sensitive individual may react at an

exposure level between 8 and 80 ng of major cat allergen (18, 19), and to repeated exposure to only 10 ng of ragweed allergen per day one to two months, which is equivalent to a total exposure of 1 μg during the entire pollen season (13).

Individual variations in susceptibility

The relative risk for allergic disease and the tendency to develop allergic disease early in life are both strongly influenced by genetic factors and a family history of any allergic disease (20, 21).

There are a number of immunochemical and biochemical tests available for identification of subjects at high risk for developing allergy (reviewed in 22). They include family history, determination of total and specific IgE, skin prick tests, lymphocyte tests, amniotic fluid analysis, leucocyte phosphodiesterase levels, and other nonspecific findings like cell membrane lipids, blood eosinophil counts and infantile colics.

There seems to be a period in early life during which an infant is particularly susceptible to sensitization. A higher incidence of allergy to birch and grass pollen has thus been reported in Finnish school children born in the spring (23). A similar increase of grass allergy has been reported in British children born in the spring (24) and for the prevalence of ragweed allergy in Americans born in the late summer (25). This relationship between season of birth and development of allergy seems to be limited to children with a congenital propensity for allergy (26). Similarly, early contact with pets and animal epithelia (27, 28), house dust mites (29, 30) and early feeding with foreign proteins (31) appear to be associated with an increased risk for allergic disease. Birth during summer and fall is associated with an increased risk to develop asthma due to mites and other indoor allergens (24, 32, 33). A high concentration of allergens in the house of a newborn baby, particularly if there is a family history of allergy, may thus increase the prevalence of allergy several years later.

Variations in individual susceptibility to sensitization over time may also partly be explained by respiratory tract infection, as sensitization occurs more easily during an infection (34).

Two different studies of individuals belonging to the same ethnic group, but living under different conditions, clearly demonstrate that the incidence of allergic disease is higher in industrialized countries than in rural areas of developing countries (35, 36). This suggests that some exogenic factors are operating during early life.

Non-specific, adjuvant factors

Various environmental factors may enhance sensitization and also trigger an allergic reaction in a sensitized individual (Table 1, Fig.2).

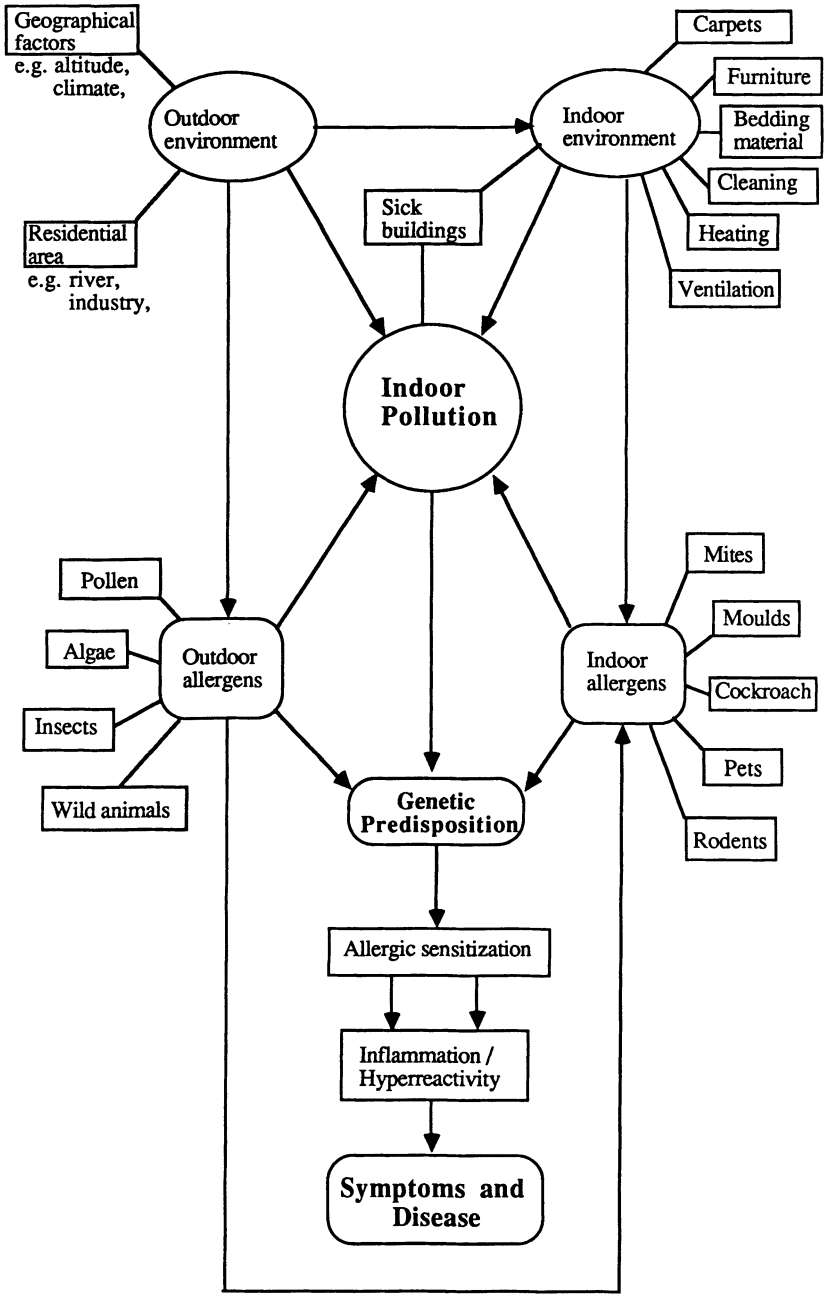

Fig. 2. Allergen sources, air pollution and adjuvant factors causing indoor pollution.

The most important air pollutant is tobacco smoke. It has been shown that light and moderate smokers more easily develop asthma after exposure to allergens, as compared to non-smokers who are similarly exposed to the allergens (37). Exposure to tobacco smoke in a house is also the most important known factor for the development of allergic sensitization in non-smokers, particularly children (38-41). The effects of tobacco smoke will be discussed more in detail below.

Numerous irritating compounds that may be present in the air may irritate the airways and induce allergic sensitization to simultaneously present allergens, as well as airway hyperreactivity. The irritating agents are derived from different sources, *e.g.* tobacco smoke, gas stoves, coal fires and building materials. Irritating compounds include ozone, SO_2, CO, CO_2 and nitrogen oxides (NO_x)(Table 1). It has been observed in experimental animals that exposure to ozone, SO_2, and NO_2 all may increase serum IgE levels (42).

Indoor allergens

A number of indoor allergens are listed in table 2.

Table 2. Indoor allergens.

Indoor sources:
- Acarids : Mites, Spiders
- Pets : Cats, Dogs, Guinea pigs
- Insects : Cockroaches, Crickets, Midgets
- Fungi : *Alternaria, Cladosporium, Penicillium*
- Rodents : Rat, Mice

Outdoor sources:
- Pollen, Ragweed, Tree, Grass
- Algae
- Insects
- Arachnids
- Animals : Horses, C,ows

Mites are ubiquitous in most parts of the world. Both *Der p1* and *Der f1* grow inside home under favourable conditions with regard to humidity and temperature. Storage mites (e.g. *Acaris siro, Euroglyphus mayani*) are found in farm houses (51, 52, 53). In several studies mites have been proved to be an important causative agent for allergic rhinitis, asthma and other respiratory allergic diseases (Table 4) (33, 48).

The major allergens derived from cat (*Fel d1*) and dog (*Can f1*) are commonly found in house dust samples. The concentrations are obviously higher in houses with pets but may also be present in homes and schools where no animals have been allowed for years (54, 55, 56).

Mould spores are ubiquitous indoors. Excessive growth may occur when humidity and dampness is increased. Presence of mould inside a home enhances mite growth, by providing nutrition for them (57). The fungal flora in homes may also be a cause for sensitization and allergic diseases as moulds are also allergenic by themselves (58-60).

Cockroaches have been established as an allergen and can cause significant inhalant allergy (61, 62) and direct cutaneous sensitivity (62, 63, 64), they are usually found in damp houses with a low hygienic standard. Less is known about the importance of other insects as allergens.

Green algae (65) and various pollens (32) may also induce sensitization indoors.

Various indoor conditions, *e.g.* indoor humidity and dampness, improper ventilation, low hygienic standard, pets at home, presence of carpets, upholstered furnitures, inefficient cleaning, life style (use of blanket, changes in food habits) may all potentiate allergen growth and increase mite allergen levels indoors (59-64), as well as enhance sensitization and facilitate the appearence of clinical symptoms (46, 65-67). When thus indoor humidity is high, mites thrive in carpets (68), furniture (69) and clothings (65). Similarly, indoor environmental factors affect mould growth (58, 60).

Particularly, during construction of buildings, an imbalance between heating and ventilation system in modern houses can create high indoor humidity which may increase the allergen content of the home (70). The allergen content of a house is also influenced by the localization of it. Houses located at a high altitude in a cold climate contain very little mite allergen (71, 72).

Indoor pollutants

Indoor air pollution originates from various sources (Table 3).

Table 3. Indoor adjuvant factors that may facilitate allergic sensitization and appearance of clinical symptoms upon exposure to an allergen.

Dampness
Temperature
Localization of house
Building materials e.g., bricks, woods, asbestos,
Construction pattern e.g., windows, ventilation system,
Indoor enclosures :
- Wall-to-wall carpets
- Upholstered furnitures
- Textile sofas
- Potted plants
- Aquarium

Several studies have shown that the levels of pollutants can be substantially higher indoors than those that can be detected outdoors (73, 74). Only few of the pollutants may however cause allergic sensitization, although they may irritate the human respiratory mucosa, thus enhancing sensitization to allergens. Emission from fuels (SO_2, NO_x), furniture and building materials (formaldehyde, asbestos, radon), tobacco smoke and volatile organic compounds (VOC) are among the most important indoor pollutants.

Tobacco smoke is the most significant source of indoor air pollution. The smoke contains most known major air pollutants. The concentrations vary widely, depending on efficiency of ventilation system and the amount and frequency of smoking. The level of CO in offices in which smoking is allowed, may be as high as 10 to 1000 ppm (75).

Indoor combustion of fuels such as gas cooking, kerosene heaters, coal heating, gasoline-powered equipment and overheated electrical appliances can be a source of variety of toxic products. Elevated levels of NO_x, CO_2 and CO have reported from homes with unvented appliances (reviewed in 76). The indoor CO concentration is usually about 5-50 ppm, but the levels may rise to as much as 100 ppm if an apartment or office is attached to an underground garage (reviewed in 76). In one study the emission of

formaldehyde was found to be higher from a radient type of kerosene heater, than from a gas oven and a gas burner (77).

Nitrogen oxides, including NO_2 have been associated with various symptoms of respiratory illness, e.g. cold, stuffy nose, runny nose, redness of eyes, sore throat, hoarseness of voice, ear ache and cough (79). Exposure to these compounds also enhances IgE antibody formation to simultaneously inhaled allergens, at least in rodents.

Indoor sources of SO_2 include sulfur emanating from the burning of coal and oil and radient kerosene space heaters (78). Sulfur dioxides have been shown to enhance IgE production in animals (42).

Several modern building materials emit many other compounds which may contribute to indoor air pollution. The importance of them in the sensitization process and in triggering clinical symptoms is not known.

Formaldehyde, which is a gaseous chemical used in a wide variety of building material, *e.g.* as chipboard, plyboard, insulation materials (foam), adhesives, textiles and paper coatings. It is also present in tobacco smoke. A preliminary upper level for continuous exposure to formaldehyde was proposed at 0.40 mg/m^3 (80). This standard was exclusively based on toxicity and did not take into account a possible role as an adjuvant for sensitization to allergens. The levels of formaldehyde may be much higher in newly built houses. In one study the mean level was 0.62 mg/m^3, and peak values up to 2.24 mg/m^3 were recorded (reviewed in 81).

Adverse effects from exposure to formaldehyde (Table 4) may results from inhalation, ingestion, or direct contact. An individual may become sensitized as a result of repeated exposure to formaldehyde. Higher frequency of asthma and dermatitis has been reported in the occupants of urea formaldehyde foam-insulated (UFFI) indoors (reviewed in 81).

Table 4. Health effects related to indoor pollution

Pollutant	Health effects
Allergens:	
Mites (a,d,e,f,i)	a. Asthma
Moulds (a,d,f)	b. Cough, bronchitis
Cat allergens (a,d,f)	c. Bronchoconstriction, wheezing
Dog allergens (a,d,f)	d. Hyperreactivity
Cockroaches (a,d,f)	e. Irritation of mucous membrane
Air Pollutants:	f. Sneezing, rhinitis, stuffy nose
CO_2 (c,j)	g. Conjunctival irritation
CO (j)	h. Sore throat
NO_2, NO (b,c,f,j)	i. Eczema, dermatitis, skin irritation
Passive tobacco smoke (b,f,g,h,l)	j. Headache, dizziness, drowsiness
SO_2 (b,c)	k. Anxiety
Formaldehyde (b,c,g,i,k)	l. Cancer
Radon (l)	
Ozone (a,d,e)	
Volatile Organic Compounds (d,e,i)	
Microorganisms (d)	
Solvents (e,g,i,j)	

Very little is known about radon exposure in allergic sensitization. It has been reported that indoor exposure to radon daughters may increase considerably in the presence of cigarette smoke, as radon particles tend to attach to the smoke particles (82).

Various volatile organic compounds (VOC) and solvents may be resposible for irritation of the respiratory tract. Solvents are used for painting and varnishing purposes, and are present in many other products, *e.g.* printing ink and dyes, cleaning fluids, glues, adhesives and synthetic rubber. Acetone, ammonia, benzene, toluene, chloride, phenol and alcohol are among the common contituents of solvents. The role of these compounds in allergic sensitization is not clear so far, but high levels can be found in the homes of allergic children (83).

Ozone, which originates predominantly from photochemical reactions, is found in indoor air at 0-10 ppb. Automobile traffic is considered to be the main source of nitrogen oxides and hydrocarbons which then reduce oxygen into ozone. Exposure to ozone is known to induce airway hyperresponsiveness both in normal and asthmatic subjects (84).

Quality of houses

Since the first recognition of "sick" buildings prior to 1960, there have many reports from several countries, paricularly during the last decade. This term included various symptoms induced by non-specific stimuli assumed to be caused by buildings related factors. Synonyms of the "sick" buildings syndrome (SBS) are 'building illness syndrome', 'building-related illness', 'ill buildings', 'building sickness', 'building associated illness', 'stuffy office syndrome' and 'tight building syndrome' (85-87).The development of sick building syndrome has been related to tight buildings with insufficient ventilation and high indoor temperature. The problems appear to be caused by an imbalance in thermal conditions and ventilation. In particular, partial recirculation of air and large areas covered with textiles and wall-to-wall carpets have been incriminated (68, 88).

Many symptoms and diseases have been related to sick buildings (Table 5) (89-91).

Table 5. Various symptoms that have been suggested to be Building-Related Illness (adapted from, 76, 89-91, 103)

- General symptoms:
  - Nausea, dizziness, headache
  - Mental fatigue, abnormal tiredness
  - Feeling of discomfort, annoyance and irritation
- Airway symptoms:
  - Dry mucous membranes
  - Irritation of mucous membranes and throat
  - Nasal congestion and running nose
  - Horseness of voice,wheezing
  - Airway hyperreactivity, bronchitis, asthma
  - Allergic alveolitis, hypersensitive pneumonitis
- Gastrointestinal symptoms:
  - Diarrhoea
- Symptoms related to skin and sensory organs:
  - Drynes of mucous membranes, abnormal taste,
  - Eye irritation
  - Irritation of ear and nose
  - Sensation of getting cold
  - Itching and erythema
  - Facial rash and rashes on the hands
- Infections:
  - Upper respiratory tract infections
  - Legionnaires' disease
  - Pontiac fever
  - Q fever
- Psychogenic symptoms:
  - Hyperventilation, mass hysteria

It should be noted however, that for many of the symptoms listed in table 5 the relation to sick buildings has not been confirmed in controlled studies. The symptoms associated with sick buildings are influenced by the number of occupants in the building (92, 93), office size (88), poor environmental control (94), and architecture of the work place (95). The clinical symptoms are most pronounced and most commonly encountered in newly constructed or newly remodelled buildings, and then usually decrease within 6 months.

As already discussed, the conditions in sick buildings can contribute to the accumulation of many indoor allergens, and act as adjuvants for the the development of allergies. A higher prevalence of SBS has been reported among individuals with a history of atopy, as compared to non-atopic persons (96).

Prevention of sensitization

Prevention of allergic sensitization and avoidance of allergic diseases can be performed in various ways, *e.g.* by elimination of allergens, by removal or modification of adjuvant factors and by education.

Prevention of environmental allergen in early life is the most important measure against development of allergy, as it has been shown that there is an association between exposure to allergens early in life and later development of allergic disease in infancy and adolescence (28,32,33).

Reduction of house dust allergens by regular vacuum cleaning of the house has been suggested for many years. Unfortunately, even meticulous cleaning with ordinary vacuum cleaners, can not significantly reduce the allergen content in the home. They may even increase the problem by increasing the quantity of airborne allergens (reviewed in 97).

Covering mattresses and pillows with zippered vinyl coverings, regular washing of bedding can significantly reduce symptoms and signs of asthma (98, 99).

Good hygienic standard indoors should also be maintained.

Cat allergen, which is mostly associated with smaller particles and are usually airborne, can be reduced significantly by using a HEPA (High Efficiency Particulate Air) filter in vacuum cleaner, together with a air cleaner (100), unfortunately this is an expensive measure.

Various chemical substances for house dust mite and cat allergen removal have been used in an effort to reduce house dust mite exposure. A solution containing 3% tannic acid has been proven to be satisfactory in this respect (101). Although the use of chemical substances appear to be a fairly efficient way of reducing mite and cat allergen, the long-term effects on human health are unknown, and they should therefore be used with caution.

A reduction of adjuvant factors can be achieved in several ways. Indoor humidity and dampness, can be reduced by establishing proper ventilation and by renovating houses, e.g., by replacing a leaking roof or an old plumbing. Removal of indoor enclosures, e.g., wall-to-wall carpets, furnitures, and textile sofas would reduce mite content in the house. Moulds can be reduced by removal of potted plants and aquirium as these are constant source of water vapour indoors and increase indoor humidity. Removal of open fire places could also be considered, as they increase indoor combustion products and also enhance mite growth (59).

More attention should be given for building properly ventilated, yet well-insulated dwellings, using building materials which do not emit imitating substances. Attention should be given to foundation and construction of the building, e.g. sealing of surfaces in direct contact with the soil, as this can reduce indoor growth of mites and moulds, and probably radon concentration (102).

The preventive measures associated with indoor air pollution are not well documented, as the information about health effects of specific air pollutants on humans is insufficient, and most efforts to control air pollution have focussed on outdoor air. Although many effective measures have been recommended, they are expensive. Further, reduction or elimination of only a single pollutant may not be sufficient, as the development of sensitization or disease may be a consequence of several simultaneously acting compounds.

Methods for early identification of individuals who are susceptible to develop symptoms should be developed and established. Pollutants which are related to tobacco and combustion by-products could be reduced by modification of human activities. Such measures represent the most effective and inexpensive way of controlling indoor air pollution. Radon, formaldehyde, and asbestos which are not related to activity patterns of

occupants may be controlled by removal of asbestos-containing material and selection of suitable building materials. Efficient ventilation remains however one of the most important preventive measures.

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References

1. Eaton, KK. (1982) 'The incidence of allergy-has it changed ?' Clin Allergy 12, 107-110.

2. Taylor, B., Wadsworth, J., Wadsworth, M., and Peckhman (1984) 'Changes in the reported prevalence of childhood eczema since the 1939-45 war'. Lancet 1, 1255-7.

3. Dowse, GK., Turner, KJ., Stewart GA., Alpers, MD. and Woolcock, AJ. (1985) 'The association between Dermatophagoides mites and the increasing prevalence of asthma in the village communities within the Papua New Guinea Highlands'. J Allergy Clin Immunol 75, 75-83.

4. Morrison Smith, J., Harding, LK. and Cumming, G. (1971) 'The changing prevalence of asthma in school children'. Clin Allergy 1, 57-61.

5. Åberg, N. (1989) 'Asthma and allergic rhinitis in Swedish conscript'. Clin Allergy 19, 59-63.

6. Haahtela, T., Lindholm, H., Björkstén, F., Koskenvuo, K. and Laitinen, LA. (1990) 'Prevalence of asthma in Finnish young men'. Br Med J 301, 266-268.

7. Wickman M, Nordvall SL, Pershagen G, Sundell J, Schwartz B. (1990) 'House dust mite sensitization in children and residential characteristics in a temperate region'. J Allergy Clin Immunol 88, 89-95.

8. Charpin, D., Kleisbauer, JP., Fondarai, J., Graland, B., Viala, A. and Govezo F. (1988) 'Respiratory symptoms and air pollution changes in children; the Gardanne Coal-Basin study'. Arch Envir Health 43, 22-27.

9. Popp, W., Rauscher, H., Sertl, K., Wanke, T. and Zwick, H. (1990) 'Risk factors for sensitization to furred pets'. Allergy 45, 75-79.

10. Jarret, EEE., Stewart D. Rat IgE production. (1974) 'I. Effect of dose of antigen on primary and secondary reaginic antibody responses'. Immunology 127, 365.

11. Ahlstedt, S., Björkstén, B.(1983) 'Specific antibody responses in rats and mice after daily immunization without adjuvant'. Int Arch Allergy Appl Immunol 71, 293-299.

12. Hattevig, G., Kjellman B., Johansson SGO., Björkstén B. (1984) 'Clinical symptoms and IgE responses in atopic and healthy children'. Clin Allergy 14, 551-559.

13. Marsh, DG. (1975) 'Allergens and genetics of allergy', in Sela M (ed.), The antigens, Academic press, New York, p. 271.

14. Dreborg, S., Basomba, A., Belin, L., Durham, S., Eriksson, NE., Frostad, AB., Grimmer, O., Halvorssen, R., Kay, AB., Malling, HJ., Nilsson, G., Sjögren, I., Week, B., Våla, IJ., Zetterström, O. and Holgersson, M. (1987) 'Biological equilibrium of allergenic preparations. Methodological aspects and reproducibility'. Clin Allergy 17, 537-50.

15. Dreborg S. (1990) 'Bronchial provocation test with biological standardized allergenic preparations', in Mellio G, Marone A, Norman PS. (eds.), Respiratory allergy, Clinical Immunology, C.W. Decker, Philadelphia, Montreal, pp.185-191.

16. Weck, Al de. and Todt, A., eds. (1988) 'Mite Allergy-Aworld wide problem', Mite Allergy workshop, Bad Kreuznach, September 1-2 (1987), The UCB Institute of Allergy, Avenue Louise 326, Brussels,pp.3-12.

17. Gelber, L., Pollart, S., Chapman, MD., Platts-Mills, TAE. and Wilmington. (1989) 'Serum IgE antibodies and allergen exposure as risk factors for acute asthma'. J Allergy Clin Immunol 83, 416.

18. Van Metre, TE., Marsh, DG., Adkinson, NF., Fish, JE., Kagey-Sobotka, A., Norman, PS., Radden, EB. and Rosenberg GL. (1986) 'Dose of cat (*Felis domesticus*) allergen 1 (*Fel dl*) that induces asthma'. J Allergy Clin Immunol 78, 62-75.

19. Ohman, JL., Findlay, SR. and Leiterman K. (1984) 'Immunotherapy in cat induced asthma: double-blind trial with evaluation of in vivo and in vitro responses'. J Allergy Clin Immunol, 74, 230.

20. Kjellman, N-I M. (1977) 'Atopic disease in seven-year-old children. Incidence in relation to family history'. Acta Paediatr Scand 65, 465-471.

21. Wittig, HJ., Mc Laughlin, ET., Leifer, KL. and Belloit JD. (1978) 'Risk factor for the development of allergic disease: analysis of 2,190 patient records'. Ann Allergy 41, 84-88.

22. Björkstén, B. (1989) 'New ideas on the prevention of allergy'. in Kay A.B (ed.). Allergy and asthma new trends and approaches to therapy. Blackwell Scientific Publications, pp.99-112.

23. Björkstén, B., Suoniemi, I. and Koski V. (1980) 'Neonatal birch-pollen contact and subsequent allergy to birch pollen'. Clin Allergy 10, 581.

24. Morrison-Smith, J. and Springett VH. (1979) 'Atopic disease and month of Birth'. Clin Allergy 9, 153-57.

25. Settipane, RJ. and Hagy, GW. (1979) 'Effect of atmospheric pollen on the newborn'. Rhode Island Med J 62, 477.

26. Croner, S. and Kjellman N-IM. (1986) 'Predictors of atopic disease: Cord blood IgE and month of birth'. Allergy 41, 68.

27. Souniemi, I., Björkstén, F. and Haahtela T. (1981) 'Dependence of Immediate hypersensitivity in the adolescent period on factors encountered in infancy'. Allergy 36, 263.

28. Rugtveit J. Environmental factors in the first months of life and possible relationship to later development of hypersensitivity. Allergy 45, 154-6, 1990.

29. Rowntree, S., Cogswell, JJ., Platts-Mills, TAE. and Mitchell, EB. (1985) 'Development of IgE and IgG antibodies to food an inhalant allergens in children at risk of allergic disease'. Arch Dis Child 60, 727.

30. Smith TF, Kelly LB, Heyman PW, Wilkins SR, Platts-Mills TAE. Natural exposure and serum antibodies to house dust mite of mite-allergic children with asthma in Atlanta. J Allergy Clin Immunol 76, 782-8, 1985.

31. Björkstén, B. and Kjellman, N-IM. (1987) 'Perinatal factors influencing the development of allergy'. Clin Rev Allergy 5, 339.

32. Warner, JA., Little, SA., Pollock, I., et al. (1990) 'The influence of exposure to house dust mite, cat, pollen and fungal allergens in the home on primary sensitization in asthma'. Pediatr Allergy Immunol 1, 79-86.

33. Sporic, R., Holgate, ST., Platts-Mills, TAE. and Cogswell JJ. (1990) 'Exposure to house dust mite allergen (Der p1) and the development of asthma in childhood'. N Engl J Med 323, 502-507.

34. Frick, OL., German, DF., et al. (1979) 'Development of allergy in children'. J Allergy clin Immunol 63, 228-241.

35. van Niekerk, CH., Wienberg, EG., Shore, SC., De V Heese, H. and van Schalkwyk, DJ. (1979) 'Prevalence of asthma: a comparative study of urban and rural Xhosa children'. Clin Allergy 9, 319-324.

36. Morrison-Smith, J. (1976) 'The prevalence of asthma and wheezing in children'. Br J Dis Chest 70, 73-77.

37. Zetterström, O., Osterman, K., Machado, L. and Johansson SGO. (1982) 'Another smoking hazard: raised serum IgE concentration and increased risk of occupational allergy'. Br Med J 70, 199-204.

38. Rantakallio, P. (1978) 'Relationship of maternal smoking to morbidity and mortality of the child up to the age of five'. Acta Paediatr Scand 67, 621-31.

39. Liard, R., Perdrizet, S. and Reiner P. (1982) 'Wheezy bronchitis in infants and patients 'smoking' habits'. Lancet i, 334-335.

40. Cogswell, J., Mitchell, E., and Alexender, J. (1987) 'Parental smoking, breast feeding, and respiratory infection in development of allergic diseases. Arch Dis Child 62, 338-344.

41. Halken, S., Høst, A., Husby, S., Hansen, L.G., Østerballe, O., and Nyboe, J. (1991) 'Recurrent wheezing in relation to environmental risk factors in infancy. Allergy 46, 507-514.

42. Gershwin, J., Osebold, JE., and Zee YC. (1985) 'Immunoglobin E-containing cells in mouse lung following allergen inhalation and ozone exposure'. Int Arch Allergy appl Immunol 65, 266-77.

43. Griffith, DA., Wilkin, DR., Southgate, BJ. and Lynch ,SM. (1976) 'A survey of mites in bulk grain stored on farms in England and Wales'. Ann Appl Biol 82, 180-184.

44. Terho, EO., Leskinen, L., Husman, K. and Karenlampi, L. (1982) 'Occurence of storage mites in Finnish farming environments'. Allergy 37, 15-19.

45. Leskinen, L. and Klen, T. (1987) 'Storage mites in the work environment of farmers'. Eur J Res Dis 71(suppl 152), 101-111.

46. Korsgaard, J. (1983) 'Mite asthma and residency: a case control study on the impact of exposure to house dust mites in dwellings'. Am Rev Respir Dis 128, 231.

47. Schou C, Hansen GN, Lintner T, Lowenstein H. Assay for the major dog allergen Can f1. I. Investigation of house dust samples and commercial dog extracts. J Allergy Clin Immunol. (submitted)

48. Dreborg, SKG., Munir, AKM., and Einarsson, R. (1991) 'The level of *Fel d1* in school dust is sufficiently high to induce symptoms in asthmatics. J Allergy Clin Immunol 87, 169.[abstract]

49. Munir, AKM., Andersson, R., Einarsson, R., Schou, C., and Dreborg, SKG. (1992) 'More dog allergen than mite and cat allergens in dust from Swedish schools even from American homes with a dog'. J Allergy Clin Immunol 89(1), in press. [abstract]

50. Spieksma, FTM. (1988) 'Mite Biology'. Clin Rev Allergy 8 (1), 31-49.

51. Nakayama, Y. (1966) 'Childhood bronchial asthma and airborne fungi'. Jpn J Med Mycol 7, 156-166.

52. O'Hollaren, MT., Yunginger, JW., Offord, KP., Somers, MJ., O'Connell, EJ., Ballard, DJ. and Sachs, MI. (1991) 'Exposure to an aeroallergen as a possible precipitating factor in respiratory arrest in young patients with asthma'. N Engl J Med 63, 359-63.

53. Ishii, A., Takaoka, M., Ichinoe, M., Kabasawa, Y. and Ouchi, T. (1979) 'Mite fauna and fungal flora in house dust from homes of asthmatic children'. Allergy 34, 379-387.

54. Kang, B. (1976) 'Study on cockroach antigen as probable causative agent in bronchial asthma'. J Allergy Clin Immunol 58, 357.

55. Zschunke, E. (1978) 'Contact urticaria, dermatitis, and asthma from cockroaches'. Contact Dermatitis 4(5), 313.

56. Kang, B. and Sulit, N. (1978) 'A comparative study of prevalence of skin hypersensitivity to cockroach and house dust antigens'. Ann Allergy 41, 333.

57. Monk, BE. and Pembroke, AC. (1987) 'Cockroach dermatitis: an occupational hazard'. Br Med J 294, 935.

58. Tiberg, E., Dreborg, S., Björkstén, B. (1992) 'Allergy to green algae *(Chlorella)* among children. J Allergy Clin Immunol, (in press).

59. Wahn, U., Lau, S., Ehnert, B., Rusche, A., Weber, A., Werthmann, I. and Schupp, K. (1990) 'House dust mites in German homes'. Allergologie 12, 255.

60. Turner, KJ., Stewart, GA., Woolcock, AJ., Green, W. and Alpers, MP. (1988) 'Relationship between mite densities and the prevalence of asthma: comparative studies in two populations in the Eastern Highlands of Papua New Guinea'. Clin Allergy 18, 331-340.

61. Gabriel, M., Cunnington, AM., Allan, WGL., Pickering, CAC. and Wraith, DG. (1982) 'Mite allergy in Hong Kong'. Clin Allergy 12, 157-171.

62. Korsgaard J. (1983) 'House-dust mite and absolute indoor humidity'. Allergy 38, 85.92.

63. Hart, BJ. and Whitehead, L. (1990) 'Ecology of house dust mites in Oxfordshire'. Clin Exp Allergy 20, 203-9.

64. Iversen, M. and Dahl, R. (1990) 'Allergy to storage mites in asthmatic patients and its relation to damp housing conditions'. Allergy 45, 81-85.

65. Tovey, ER., Chapman, MD., Wells, CW. and Platts-Mills, TAE. (1981) 'The distribution of dust mite allergen in the house of patients with asthma'. Am Rev Respir Dis 124, 630-5.

66. Iversen, M. and Dahl R. (1990) 'Allergy to storage mites in asthmatic patients and its relation to damp housing conditions'. Allergy 45, 81-85.

67. Wood RA, Eggleston PA, Lind P, Ingemann L, Schwartz B, Graveson S, Terry D, Wheeler B, Adkinson NF. (1988) Antigenic analysis of House Dust samples. Am Rev Respir Dis 137, 358-363.

68. Norbäck, D. and Torgen, M. (1989) 'A longitudinal study relating carpeting with sick building syndrome'. Environ Int 15, 129-35. .

69. Wood, RA., Chapman, MD., Adkinson, NF. and Eggleston, PA. (1989) 'The effect of cat removal on allergen content in house-dust samples'. J Allergy Clin Immunol 83, 730-4.

70. Leaderer, BP., Zagraniski, RT., Berwick, M., Stolwijk, Jan, AJ. and Qing-Shan, M. Residential exposure to NO2,SO2,and HCHO associated with unvented kerosene space heaters, gas appliances and sidestream tobacco smoke. In Indoor air, vol.4, Chemical characterization and personal exposure, Swedish council for building research, Stockholm, pp.151-156, 1984.

71. Vervloet, D., Penaud, A. and Razzouk, H. et al. (1982) 'Altitude and house dust mites'. J Allergy Clin Immunol 69, 290-96.

72. Spieksma, FTM., Zuidema, P. and Leupen, MJ. (1971) 'High altitude and house dust mites'. Brit Med J 1, 82-4.

73. Yocom, JE., et al. (1971) 'Indoor / outdoor air quality relationships'. J. Air Pollution Control Association, 21, 251-259.

74. Biersteker, K., et al. (1965) 'Indoor air pollution in Rotterdam homes'. Internation Journal of Air and water pollution 9, 343-350.

75. Repace, JL. and Lowrey, AH. (1980) 'Indoor air pollution, Tobacco smoke, and public health'. Science 208, 464.

76. Spengler, JD. and Sexton, K. (1983) 'Indoor air pollution: A public Health Perspective'. Science 221, 9-17.

77. Mattews, TG., Reed, TJ., Tromberg, BJ., Daffron, CR. and Hawthorne,AR. (1984) 'Formaldehyde emission from consumer and contruction products: Potential impact on indoor formaldehyde concentrations'. In Sensory and Hyperreactivity reactions to Sick Buildings.Swedish council for building research, Stockholm, Indoor Air, vol. 3, pp. 115-120.

78. Leaderer, BP. (1982) 'Air pollutant emissions from kerosene space heaters (Report)'. Science 218, 1113-1115.

79. Keller MD, Lanese RR, Mitchell RI, Cote RW. (1979) 'Respiratory illness in households using gas and electricity for cooking'. Environ Res 19, 495-503.

80. Andersen, I., Lundqvist, GR. and Molhave, L. (1974) 'Formaldehyd i indeluft i danske boliger'. Ugeskr Lager 136, 2133-39.

81. Andersen I. Formaldehyde in the indoor environment - health implications and the setting of standards. In Fanger PO, and Valbjorn O,(eds). Indoor climate effects on human comfort, performance and health. Copenhagen, Danish Building Research Institute, pp. 65-87, 1979.

82. Bergman, H., Edling, C. and Axelson, O. (1984) 'Indoor radon daughter concentrations and passive smoking'. in Berglund, B., Lindvall, T., and Sundell, J. (eds.), Indoor Air, vol. 2, Radon, Passive smoking, Particulates and Housing Epidemiology, Stockholm, Swedish Council for Building Research, D17, pp.79-84.

83. Sundell, J., Stridh, G., Wickman, M., and Nordvall, L. (1990) 'VOC and formaldehyde in the homes of allergic children'. Indoor Air 90, The Fifth International Conference on Indoor Air Quality and Climate, Toronto, Canada, pp. 53-56.

84. Selzer, J., Geffroy, B., Stulbarg, M., Holtzman, MJ., Nadel, JA. and Boushey, Jr HA. (1984) 'Association between airway inflammation and changes in bronchial reactivity induced by ozone exposure in human subjects'. Am Rev Respir dis 129, A262.

85. Akimenko, VV., Andersen, I., Lebowitz, MD. and Lindvall, T. (1986) 'The "Sick" Building syndrome', in Berglund, B., Berglund, U., Lindvall, T., Sundell, J. (eds.), Indoor Air, Vol. 6 (Evaluation and conclusions for health sciences and technology). Stockholm, Swedish Council for Building Research, (D13:1986) pp. 87-97.

86. Whorton, MD., Larson, SR., Gordon, NJ. and Morgan, RW. (1987) 'Investigation and work-up of tight building syndrome'. J Occup Med 29,142-7.

87. Rogers, SA. (1989) 'Diagnosing the tight building syndrome or diagnosing chemical hypersensitivity'. Environ Int 15, 75-79.

88. Skov, P. and Valbjörn, O., et al. (1990) 'Influence of indoor climate on the sick building syndrome in an office environment'. Scand J Work Environ Health 16, 363-71.

89. Indoor air pollutants: exposure and health effects. Report on a WHO meeting, Nördlingen, 8-11 June (1982), Copenhagen, WHO Regional Office for Europe, (EURO Reports and Studies, No. 78).

90. Indoor air quality research. Report on a WHO meeting, Stockholm, 27-31 August (1984), Copenhagen, WHO Regional Office for Europe, (EURO Reports and Studies, No. 103).

91. Norbäck, D., Michel, I. and Widström, J. (1990) 'Indoor air quality and personal factors related to the sick building syndrome'. Scand J Work Environ Health 16, 121-128.

92. Taylor, PR., Dell'Acqua, BJ., Baptiste, MS., Hwang, H-L. and Sovik, RA. (1984) 'Illness in an office building with limited fresh air access'. J Environ Health 47, 24-27.

93. Valbjörn, O. and Korsgård, N. (1984) 'Headache and mucous membrane irritation an epidemiological study'. (1984) In: Berglund, B., Lindvall, T. and Sundell, J (eds.), Indoor Air, Vol. 2, Radon, Passive smoking, Particulates and housing epidemiology. Stockholm: Swedish Council for Building Research, D17, pp. 249-254.

94. Hedge, A., Burg,e PS., Robertson, AS., Wilson, S. and Haris-Bas, J. (1989) 'Work-related illness in offices: a proposed model of the "Sick building syndrome', Environ Int 15, 143-158.

95. Hedge, A. (1984) 'Evidence of a relationship between office design and self reports of ill health among office workers in the United Kingdom'. J Archit Plan Res 1, 163-164.

96. Norbäck D, Edling C. Environmental, occupational and personal factors related to the prevalence of sick building syndrome in the general population. In Norbäck D, Environmental exposures and personal factors related to sick building syndrome, Uppsala University Medical Dissertation No. 280, Uppsala, 1990.

97. Pollart S, Chapman MD, Platts-Mills TAE. (1988) 'House dust mite and dust control'. Clin Rev Allergy 6 (1), 23-33.

98. Murray, AB. and Ferguson, AC. (1983) 'Dust-free bedrooms in the treatment of asthmatic children with house dust or house dust mite allergy: A controlled trial'. Pediatrics 71, 418-422.

99. Sarsfield, JK., Garland, G., Toy, R. and Norman, ALE. (1974) 'Mite-sensitive asthma of childhood. Trial of avoidance measures'. Arch Dis Childhood 49, 716-721.

100. Reisman, RE., Mauriello, PM., Davis, GB., Georgitis, JW. and DeMasi, JM. (1990) 'A double-blind study of the effectiveness of a high-efficiency particulate air (HEPA) filter in the treatment of patients with perennial allergic rhinitis and asthma'. J Allergy Clin Immunol 85, 1050-7.

101. Miller, JD., Miller, A., Kaminski, K., Gelber, L., Chapman, M. and Platts-Mills, TAE. (1990) 'Effects of Tannic acid spray on cat allergen levels in carpets'. J Allergy Clin immunol 85, 226.

102. Crameri, R., Furrer, D. and Burkart, W. (1988) 'Some Building Characteristics affecting the Indoor radon level of dwellings in the Swiss Alpine areas'. In Berglund, B., and Lindvall Thomas (eds). Planning, Physics and climate technology for healthier buildings, Healthy Buildings '88, vol. 2, pp. 135-141, Stockholm, Sweden.

103. Bardana EJ, Montanaro A, O'Hollaren MT. Building-Related illness. Clin Rev Allergy 6 (1), 61-89, 1988.

CHEMICAL HYPER-RESPONSIVENESS

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ABSTRACT. 'Environmental Hypersensitivity Syndrome' and Sick Building Syndrome are not syndromes. The label may deter seeking treatable diagnoses in those with multiple symptoms that believe exposures in their environment make them ill. In those suffering from IAQ problems, the label SBS may deter diagnosis of the building. Chemical hyper-responsiveness, to irritants and solvents, appears to occur at low dose levels, after a significant event exposure (substance identified), followed by generalized responses to other low level irritant exposures with symptoms decreasing overtime.

INTRODUCTION. Does "Environmental Hypersensitivity Syndrome" or sick building syndrome exist? Each classified as syndromes (meaning a cohesive array of symptoms and\or signs sharing a common demonstrable pathophysiology, the understanding of which may well be significantly deficient, and the aetiology of which remains unknown or only partially defined) are misnamed.

Who is Hypersensitive?

It is estimated that 10% of the general population is particularly responsive to the environment. These individuals can be termed hypersensitive (having a specific or general ability to react with characteristic symptoms to contact with allergens in amounts innocuous to normal individuals). The tendency to atopic diseases is inherited, with a positive family history in 80% of atopic individuals, as opposed to only 20% in the normal population. However, twin studies suggest that environmental factors, as causation, predominate despite the genetic susceptibility.

H. Knöppel and P. Wolkoff (eds.),
Chemical, Microbiological, Health and Comfort Aspects of Indoor Air Quality – State of the Art in SBS, 201–229.

Hypersensitivity reactions to indoor air exposures can be divided into the following classification:

IMMUNOLOGIC		
Type	Mechanism	Disease
I: Immediate	IgE: Mast cells and basophils	Atopic: Asthma, Rhinitis, Conjunctivitis, Anaphylaxis
Extrinsic Allergic Alveolitis		
TOXICOLOGICAL		
Type		Disease
Irritants		Bronchospasm, Rhinitis, Conjunctivitis, Skin Rashes
Solvents		Narcosis, Encephalopathy

Individuals, labelling themselves as "Environmental Hypersensitivity Syndrome" often believe that the indoor environment makes them ill.

What is Environmental Hypersensitivity Syndrome?

The public is aware and concerned about the potential effects of environmental pollutants on their health. Several reports have reviewed the literature on a syndrome known as Environmental Hypersensitivity, as well as, programs providing services, diagnosis and treatment, and have completed a preliminary study of a group of individuals with the diagnosis living in Nova Scotia (Thomson 1985 and Langley 1987).

Randolph and Rollins (1950) published case reports of patients with multiple symptoms that they attributed to food allergies. Randolph (1952) later stated that environmental chemicals were responsible for these ailments. This area is clouded by a number of disorders grouped under the names "20th Century Disease", "Yuppie Syndrome", "Post EBU Syndrome", "Post Viral Neurasthenia", "Chronic Candidiasis", "Environmental Hypersensitivity Syndrome", "Total Allergy Syndrome" and "Chronic Fatigue Syndrome". These have overlapping characteristics and symptoms, with no cohesiveness, whose aetiology is attributed to a variety of chemical exposures in food and air, and with no common pathophysiology. Treatments have a similar approach of avoidance and neutralizing techniques, along with rotation diets. Individual

suspectibility, sensitivity and treatment regimes are the rule. With no two cases alike, the techniques of epidemiological research are difficult.

Terr (1986) reviewed 50 patients, diagnosed with Environmental Hypersensitivity Syndrome and found "no consistent physical findings or laboratory abnormalities". This study had a small number of subjects, the majority involved in workers' compensation or litigation claims, no control group and a limited number of laboratory tests done on only some of the patients.

Terr's stated objective was to examine the following hypotheses:

1. "Environmentally induced illness as a disease entity with an identifiable set of clinical features,

2. A significant immunologic abnormality distinguishes the patients from normal persons,

3. Treatment by clinical ecology methods results in improvement in clinical and relevant laboratory test abnormalities."

The patients reviewed either had physical illness not related to the environment or were not ill, yet because of concern about possible ill effects from an exposure, they were given a diagnosis of environmental illness despite the absence of symptoms. A third group had extensive and involved histories with multiple symptoms, involving many body systems and no consistent pattern of symptoms or significant physical or laboratory abnormalities. There was no evidence for significant improvement (decrease in symptoms) in these patients under the treatment of a clinical ecologist.

A controlled study of 26 patients (Black et al 1990), corresponding with 46 gender and age matched community controls, screened the participants using the Diagnostic Interview Schedule. The screening results showed a larger percentage of the subjects with a recent or remote history of recognized psychiatric disorders. The study suffers from multiple subject selection techniques, as the screening tests were used primarily to determine psychiatric ailments only, the controls were solicited from another study (not randomly chosen), and the paediatric subjects were not assessed separately. There were significantly increased total number of DSM-III symptoms reported by the subjects, compared to the controls, and the number of DSM-III lifetime diagnoses in study subjects was also significantly greater among cases than controls. There was no physical diagnostic workup to rule out physical ailments that may have related to or accounted for the illness in the subjects and possibly in the controls.
The author concluded that those suffering from Environmental Hypersensitivity were mostly women, well educated, interested in their diagnosis, attended support groups, read the literature on Environmental Hypersensitivity and developed friendships with others who were suffering. Their lifestyle was organized around their

illness, they were dissatisfied with traditional medical practitioners, they felt they had been mistreated or misled by the medical community because they felt the physicians were ignorant or unsympathetic to the concepts of Environmental Hypersensitivity. Two-thirds of the subjects in the study were under the care of a clinical ecologist and three quarters reported that they were happy with the care.

The most common disturbances included mood disorders, anxiety, and somatoform disorders. The authors were surprised that more did not show somatization disorder, as the description for Environmental Hypersensitivity most closely resembles this disorder.

Stewart and Raskin (1985) reported on 18 patients they reviewed for physicians and lawyers through a psychiatric service. This selective group of patients were found to be suffering from somatoform disorder (7), psychosis or affective or anxiety disorder (10) and one with a personality disorder.

The two latter studies suffer from the bias that patients were referred for psychiatric evaluation. Patients involved in a legal process or referred to a particular speciality for evaluation cannot be considered representative of a group of patients.

Funded by the Government of Nova Scotia, Canada, the Committee on the Adverse Effects of the Environment on Health (1991) reviewed Province-wide physician referred individuals believed suffering from this ailment. All patients were given a complete history and physical by an Internist, a home visit by a social worker, and validated questionnaires on general health, activities of daily living, eating habits, occupational exposures, environmental exposures, and life stress. There is no widely agreed on definition for the disorder. The committee adopted the definition of the Thomson Committee (Thompson 1985):

- Symptoms must have been present for at least 3 months.
- Symptoms must involve the central nervous system and at least one other system,
- There must be no abnormal findings on physical or laboratory examination which would account for the symptoms.

Their report [(CAEEH) Committee on the Adverse Effects of the Environment on Health 1991] demonstrated some frequently occurring characteristics of those referred and some diagnostic trends.

Seventy-five per cent of the patients had a treatable diagnosis that could account for their illness. Only 31 individuals fit the above definition and are now involved in a case-control study. A very small number had non-immunologically based responses to indoor air pollutants (occupational).

Allergic rhinitis/sinusitis/conjunctivitis were common diagnoses in this group of patients. Many had not been assessed by a specialist in

Immunology. The limited access to adult immunological services within Nova Scotia has meant that at least some, in an effort to obtain relief and understanding, have sought care from a large variety of practitioners and have tried alternate therapies.

Many diagnoses were psychiatric syndromes. These psychiatric syndromes, especially in the areas of anxiety disorders and affective disorders, had the capacity to be either the primary cause of patient problems or secondary to pre-existing illness depending upon the case. The clinical course in any anxiety or affective disorder may be acute but often it is episodic and chronic. Thus these disorders account for a great degree of morbidity in this patient population over time. This renders extremely important the recognition in the early stages of these disorders target symptoms that are amenable to chemo-therapeutic intervention which suppress the symptoms and thus lessen morbidity.

Illness has had a profound impact on the lives of these patients referred for evaluation to the committee. Indeed, for these individuals, ill health has affected most aspects of their functions - occupational, financial, family, social and psychological.

It was found in a significant number of cases, that patients gave up their jobs or took a sickness leave because of their symptoms. This of course resulted in markedly reduced income for them and their families. The expenses for alternative therapies, reported by many patients, added up to thousands of dollars.

In addition to financial hardship, the patients' illness took its toll in another area - the family unit. While most patients were able to rely on at least some family members for material and emotional support, it was not without a cost. In a number of cases, the chronic nature of patients' problems greatly tested the patience and coping abilities of well members of the family. Arguments, communication problems and marital unrest sometimes occurred. Preoccupied with their health concerns, some patients were unavailable and/or unable to meet the emotional needs of other family members.

While most patients did live with or near family members, a great many experienced social isolation in varying degrees. This in most cases resulted from efforts to avoid coming in contact with cigarette smoke, perfume, automobile emissions, and a host of other environmental agents. As a number of patients were reluctant to stray far from their homes, or at least were careful to limit their exposure to suspected offending substances when they did, opportunities for social contact and interaction were somewhat limited. In a few cases, the patients' world had become quite small.

Generally, the eating habits of the majority of the group were atypical of both the actual and ideal eating habits of Canadians. Elimination of entire food groups was frequently noted. The reason stated was because of intolerance and allergy. Many subjects simply took inappropriate vitamin/mineral preparations to replace their perceived deficiencies. As a result, daily intakes usually included numerous

supplements, often in doses much higher that the RNI's, i.e. Vitamin C powder, Vitamin B complex, Vitamin A, Vitamin E, etc. Other substances of questionable therapeutic value were frequently noted, i.e., Psylluum Husk powder, oil of primrose, caprylic acid.

A majority of the subjects also appeared to have very selective eating habits. Many omitted major food groups, (i.e. meat, eggs, poultry, fish) but were able to consume foods high in fat, sugar, and preservatives (i.e. processed meats, potato chips, sweets, and other foods low in nutritional value). Some subjects omitted milk from their diet due to an "allergy" but were able to consume ice cream.

A review of current theories of food allergy and intolerance is explored in an article in the "New Scientist" (Gamlin 1989). Classical or true food allergies can be demonstrated to lead to the production of IgE antibodies to the offending molecule of antigen. Illness related to this response can include asthma, hay fever, eczema and anaphylactic shock.

Food intolerance, on the other hand, does not exhibit a classical immune response. The paper explores the current theories of gut inflammation, CIC (circulating immune complexes) deposition, lymphokines, exorphins and enzyme deficiencies. Each has some support in the literature, but there is no single well supported theory that can explain the large range of symptoms and clusters of symptoms occurring in patients claiming food intolerance. Similarly, the concept of fatigue and sleepiness caused by foods that one cannot tolerate is not explained. Equally difficult to explain is the craving of symptom producing foods by food intolerant patients. The presentation of the limited information supporting the theories, leads one to believe that with further research, some better understanding can be provided for these claims.

Pearson's (1985) article on the same topic takes a very different approach. He classifies adverse responses to food under the following: usual and unusual (intolerance of normally non-toxic substances). Under the unusual category he further breaks it down into organic and psychogenic. Under organic, he includes allergic (IgE and unproven non-IgE mediated), idiosyncratic (metabolic, pharmacologic and autonomic), and idiopathic. Under the psychogenic causes he includes distaste, phobias, pseudo-food allergy syndrome, and Munchausen's syndrome. He believes that the most common reason for failing to tolerate specific foods is psychological. In his review of the literature showing psychologically-induced allergomimetic changes, he decides that the positive responses to double-blind provocation tests used for food allergy may have occurred by chance.

There are many methodological concerns in determining food intolerance. Food allergy, on the other hand, is common in infancy and decreases in frequency with age. Provocation testing shows that clinically relevant food allergy is limited to a small number of foods. When they reviewed patients with pseudo-food allergy they found that they suffered from the same spectrum of psychiatric disorders as unselected new referrals

to a psychiatric out-patient department. Many of the sufferers believed they had the problem after reading a popular book on the subject and modifying their diet. This element of self-diagnosis implies that these individuals are highly suggestible. The author concludes that patients on these diets are at risk for developing dietary deficiencies. He states that "the application of objective investigations to food hypersensitivity has indicated that a number of different allergic and non-allergic reactions are important in several human diseases and also indicated a number of new directions for future research. In particular, since food hypersensitivity is a common cause of gastrointestinal disease in children, and since GI symptoms are frequent in organic food intolerance at all ages, the role of foods in adult human gut disorders should be reassessed".

Along with immunologic diagnoses, somatization disorder, panic attacks, dsythmia, chronic fatigue syndrome and fibromyalgia frequently figure as common diagnoses, in those referred to the committee with "Environmental Hypersensitivity Syndrome". Somatization was first systematically described by Briquet in 1959, who emphasized the importance of emotional suffering in its' aetiology.

Patients present with a long history of multiple, medically unexplained, somatic complaints that involve many organ systems. What is most important is the vague, dramatized and exaggerated manner in which the complaints are presented. Terms used to describe such patients on the psychiatric exam include:

- Dramatic
- Exhibitionistic
- Narcissistic
- Emotional
- Seductive
- Dependent
- Manipulative

Associated features of somatization disorder include:

- Anxiety
- Depression
- Suicidal thoughts and attempts
- Anti-social behaviour
- Occupational/interpersonal/marital difficulties
- Histrionicity and substance abuse disorders

Somatization disorder occurs mostly in women. Its prevalence is approximately 1-2% in the general female population. Symptoms usually begin in the teen years. In 90% of cases no other disease will develop that in retrospect will explain the initial symptoms. There is an increased incidence of the disorder itself in female relatives of

patients, while male relations have an increase incidence of anti-social personality disorder.

The differential diagnosis of somatization disorder includes:

- Various medical disorders, such as hyperparathyroidism
- Porphyria
- Multiple sclerosis and SLE
- Schizophrenia with multiple somatic delusions
- Major depression
- Panic disorder
- Conversion disorder
- Factitious disorder with physical symptoms

As of 1985 there existed no systematic studies of the treatment of somatization disorder. Such a patient deserves a meticulous psychiatric examination with the hope of detecting other syndromes for which psychotropic agents are beneficial. These agents are relatively useless in somatization disorder.

Psychotherapeutically, the treatment approach depends not upon the symptoms that may be present, but upon the personality structure in which these symptoms occur. Most of the more primitively organized personalities require a supportive psychotherapy. The primary care physician needs to be conservative about invasive procedures and medications. Under the best of circumstances, patients with somatization disorder tax the clinical skill and often the patience of the physicians caring for them.

Panic attacks, frequently a component of the illness in these individuals, occurs in 1.5% (may be as high as 3-4% to even 10%) of the general population, at some time in their life. Women are more commonly affected than men and the average age of onset is in the mid-twenties. It consists of recurrent episodes of sudden, unpredictable, intense fear accompanied by symptoms such as palpitations, chest pain, choking or a smothering sensation, dizziness, feelings of unreality, paraesthesia, hot and cold flashes, sweating, trembling, faintness and fear of dying or going crazy. Panic attacks, that do not completely meet those criteria, are two to three times more prevalent. As the symptoms frequently mimic other medical disorders, the patients use medical services frequently. The attacks may be accompanied by agoraphobia. To be classified as a panic disorder under the DSM-III-R, an attack must occur 3 times within a 3 week period, with at least 4 of the symptoms present during each attack. There is evidence that the disorder is familial (Crowe et al 1983) and possibly genetic (Torgerson 1983). A significant number of patients with panic attacks also have hyperventilation (Crowley and Roy-Byrne 1987).

A recent study of a random sample of 18,011 adults in the United States (Weissman et al 1989), showed that those with panic disorders, compared to other psychiatric disorders, had more suicidal ideation and suicide

attempts (odds ratio of 2.62) and vastly more than individuals with no psychiatric disorder (odds ratio of 17.99).

Dysthymia is a common form of affective disorder. It is a type of depression where the depression has been present most of the time for at least two years and interferes with functioning to some extent. A trigger may be present, such as some psychological, familial or social situation. The depressed mood is accompanied by at least two of the following:

- Poor appetite or overeating
- Insomnia or hypersomnia
- Low energy or fatigue
- Low self-esteem
- Poor concentration or difficulty making decisions
- Feelings of hopelessness

There is no evidence for a major depression, mania, hypomania, schizophrenia or delusional disorder.

Chronic Fatigue Syndrome is characterized by a new-onset fatigue lasting longer than six months with a decrease of at least 50% in activity. This diagnosis can only be made if there are no other medical or psychiatric conditions that could cause symptoms. The individuals show many symptoms that start with the fatigue or after the onset of the fatigue. These can include low-grade fever, sore throat, painful cervical or axillary adenopathy, generalized muscle weakness, myalgias, fatigue lasting 24 hours or longer after moderate exercise, headaches, migratory arthralgias, sleep disturbance, neuropsychological complaints, and acute onset. Signs may include a low grade fever, pharyngitis and cervical or axillary adenopathy twice documented by a physician each at least one month apart (Kroenke 1991). Two of three patients with chronic fatigue have co-existent psychiatric disorders (Kruesi et al 1989). Epstein Barr virus has been ruled out as the cause for chronic fatigue syndrome. However, many individuals show increased antibody titres to Epstein Barr virus, HHV6 (herpes virus), and adenovirus. There are no laboratory tests that can confirm or exclude the diagnosis of Chronic Fatigue Syndrome (Rozee 1989). The illness is not a new phenomenon and has had different names in the past. Now, with a set of diagnostic criteria, the prevalence of the problem can be determined. The illness waxes and wanes with periods of long spontaneous remission in about 20% of cases (Straus et al 1988). There have been no deaths attributed to this ailment, patients improve, not deteriorate over time. However, there is no specific treatment.

Fibromyalgia is a common musculoskeletal condition (prevalence of 6-15%) (Wolfe 1986) presenting with pain, stiffness and fatigue (Boulware et al 1990). The pain is prominent in the proximal muscle groups with defined trigger points. The stiffness does not decrease with activity. Fatigue is a major component and may be sufficient to impair work and recreation. Symptoms are enhanced by cold, overexertion, anxiety and

stress. Sleep disturbance occurs in 50% of the patients. This can result in non-restorative sleep and may be important in the pathogenesis of fibromyalgia. Stress is believed to play a causative role in fibromyalgia. There is a lack of objective findings on physical examination or laboratory tests. Tricyclic antidepressants have the capacity to reverse the consequences of non-restorative sleep in some patients.

Common to the records of many of the patients reviewed by the Committee (CAEEH 1991) is a theme of deep "disaffection" for "orthodox" medicine. Articulated or implied reasons included:

1. Inadequate access to relevant consultants, real or perceived,

2. Insufficient evaluation by physicians, real or perceived,

3. Excessive patient demands, excessively taxing of the time and/or patience of their physicians,

4. Dissatisfaction with "orthodox" medical diagnoses, particularly those with actual or implied psychiatric overtones,

5. Dissatisfaction with "orthodox" medical management, commonly of a "pharmacophobic" nature and particularly where perceived "psychotropic" drugs are concerned,

6. Global disaffection for many aspects of "modern technology" in "first world" society, encompassing, but by no means limited to, "orthodox" medicine, and,

7. Real if not always sufficiently acknowledged deficiencies in current "orthodox" medical knowledge.

Dissatisfaction with "orthodox" categories of diagnosis and management, as well as those which appear rooted in a discontent with modern technology, are of concern. Many patients ignored, dismissed or denied more plausible "orthodox" diagnoses and management strategies for their problems, even though the individuals were often highly literate and educated. Many implied, "Don't confuse me with the facts, my mind is made up!".

More of this group sought alternate therapies compared to the general population (where only 20% use alternate forms of medical care). Dissatisfaction because of the failure of a physician to "listen", to involve their patients in their care so that they feel they have some control, a poor "bedside manner", or disagreement with their patient's

self-diagnosis may have lead these individuals to seek alternative care. Within the present Canadian medical care system access to specialists and therapies is controlled by a general practitioner. By seeking care outside of traditional medicine, the patient is able to assume control for their own therapy and who can assess them.

The self-styled discipline termed Clinical Ecology, and now often referred to as "Environmental Medicine" masquerades as a fledgling specialty arising within "orthodox" medicine. It struggles for recognition in the face of "establishment" forces viewed as hostile, yet Clinical Ecology appears to be anti-analytical and may represent a refutation of the scientific basis of "orthodox" medicine.

Clinical Ecology care can result in imposed severe limitations upon the lifestyle and diet of the patient and family concerned. The label is frequently imposed by a family member (parent or sibling) on family members who see themselves as the victim of the disorder. The cost in terms of productivity and, in the case of children, social and educational development may be very high.

Despite the attempts on the part of "orthodox" medicine to focus valid criticism upon the theory and practices of Clinical Ecology it is consistently misrepresented by Clinical Ecology as hostility and professional "establishment" prejudice to the possibility of such entities as Environmental Hypersensitivity.

There is the failure, by the supporters of Clinical Ecology, to note the more credible and at least partially successful attempts on the part of "orthodox" medicine to define (CAEEH 1991):

1. Chronic Fatigue Syndrome,

2. Post-Viral Syndrome,

3. Relationship of Infection Diseases to Affective Disorders,

4. Relationship of Allergic Diseases to Affective Disorders,

5. Assays of T and B lymphocyte numbers and function in all of the above disorders,

6. Assays of cytokine production and function in all of the above disorders,

7. Assays of Natural Killer (NK) cell number and function in all of the above disorders,

8. Assays of "viral enhancement" by a variety of organic chemicals,

9. Increasing delineation of the mechanisms of both food and drug "intolerance" on non-immunological grounds,

10. The invalidation of "The Candida Hypothesis" and "Candida Syndrome/Chronic Candidiasis" as proposed by Clinical Ecology.

The failure of Clinical Ecologists to submit their theories and methods to validated means of analysis, or to formulate themselves in a manner capable of accreditation continues to bring them under criticism. It also leaves the average citizen, seeking their services, without the assurance of a minimal level of validated care, a procedure for discipline and a validated training program.

The Executive Committee of the American Academy of Allergy and Immunology (1986) reviewed Clinical Ecology. It was defined as an approach to medicine that attributes wide range of symptoms to exposure to numerous common substances in the environment. This adverse host response and multiple symptomology develop after prolonged environmental exposure.

It is now postulated, by Clinical Ecologists, that these chemical and food sensitivities are related to a malfunction of the immune system and it is called "immune system dysregulation". To establish the diagnosis, testing techniques include serial end point titration, subcutaneous and sublingual provocation and neutralization techniques in addition to RAST and paper radioimmunosorbent tests (Soc Clin Eco 1983-84). Fasting, except for water, and the introduction of new foods in a cyclic manner are also used. Multiple tests of the immune system may also be included. Tests for residual levels of chemicals in the blood may also be used (however, some of the chemicals do not remain in their absorbed form in the blood and there are no recognized normal values for these measures). Treatment requires major changes in the home environment and life-style. Diets can be restricted. Rotational diets are common. The patient is encouraged to develop a "safe" room at home and at work. Social lives are markedly restricted since most environments are "unsafe". As well as these restrictions, patients are often administered injected or sublingual solutions of "allergens". The are negligible (low) in dose and follow the provocation and neutralization technique.

The authors of the report concluded that "An objective evaluation of the diagnostic and therapeutic principles used to support the concept of clinical ecology indicates that it is an unproven and experimental methodology. It is time-consuming and places severe restrictions on the individual's life-style. Individuals who are being treated in this manner should be fully informed of its experimental nature.

Advocates of this dogma should provide adequate clinical immunologic studies supporting their concepts, which meet the usually accepted standards for scientific investigation".

The American College of Physicians (1989) review is extensive with particular emphasis on the published studies of Provocation-Neutralization Testing. The recommendations review the standards for a reliable and valid assessment of an experimental procedure. The authors conclude that the clinical ecology literature provides inadequate support for the beliefs and practices of clinical ecology. The methods of diagnosis and treatment are unproven.

A discussion in the Annals of Internal Medicine (Kahn and Letz, 1989) believe that examining the subculture related to the clinical ecology movement is more valuable than assessing its scientific foundation. As the current social environment has a strong environmental movement, with technology able to measure environmental contaminants at such a low level that meaningful interpretation is impossible, it is not surprising that many individuals are receptive to the notion that their health is adversely affected by their environment. The proponents of clinical ecology are highly effective at organizing, lobbying government, publicizing their concerns and cause, and obtaining special funding and tax breaks for their "disability" and desired home modifications. The constraints, placed on their lives by clinical ecology, at times causes invalidism, job loss and a severe financial burden to both individuals, their families and the health care system. Success with insurance companies and workers' compensation creates a further burden on society. This, along with the lack of efficacy for the diagnostic and treatment methods in clinical ecology, raised some "serious ethical problems".

The proponents of the concept of environmental hypersensitivity believes in the existence of a pathophysiological mechanism, whereby, the patient's "total load" of physical, chemical, environmental and emotional insults becomes overwhelming and results in the reduction of detoxifying enzymes in the body so that the patient is unable to detoxify even minute amounts of offending substances and thus becomes ill. The concept also invokes the idea of "biochemical individuality", which makes some patients more susceptible than others to this condition.

It is confusing to specialists in immunology and environmental medicine (based on the basic sciences of toxicology, epidemiology and community medicine) to understand how the alternative medicine practitioners can take information from the traditional medical literature and apply it to the diffuse diagnosis of environmental hypersensitivity. The term environmental implies that the individual was exposed through air, water (polluted) or soil (food contamination) as a result of industrial waste or an accidental spill. If the pollutant exposure is potentially harmful, in sufficient amount and over a long period of time, then the individual or group should absorb enough dose to get a response or illness. Our knowledge of the response to particular chemicals is determined through observation and examination of workers exposed on a daily basis to the product. This provides a dose level at which there is no effect (likely safe levels of exposure).

In the occupational setting, no effect levels, called Threshold Limit Values, are set to protect the well worker. A diagnosis of an occupational exposure, reviews the chemical exposures, their known symptoms and the potential dose that the worker may get based on exposure time, work practices, work environment, and if possible, actual levels. It appears that some individuals responding at very low levels may be responding to odour threshold rather than toxicological levels. Can such a response be called illness or is it discomfort?

Hypersensitivity implies a potentially immunologic basis for a response with very low doses being sufficient to elicit an immune response, e.g. asthma, hives etc. This is not to be confused with a response to irritants (acids, alkalies, solvents) where similar symptoms may occur, e.g. irritant rhinitis from ammonia cleansers, diaper dermatitis in infants.

Many of the practices of Clinical Ecology have some foundation in the doctrines of homeopathy, a discipline developed by Samuel Hahnemann and published in 1796 and 1810. There are three basic principles:

1. "Like Cures Like". Namely, disease is cured by agents capable of producing symptoms resembling those found in the disease under treatment.

2. The efficacy of medicinal substances can be maintained through serial dilutions to minute levels of the substance.

3. Disease should be recognized, not by one of the common names but as individual collections of symptoms, each of which differs from every other collection. These symptoms must be described with exactness in the patient's own words.

This leads to highly individualized treatments with different treatments for patients who would receive an identical treatment in orthodox medicine.

Efforts have been made to demonstrate the efficacy of the principles. To date, the only major areas of medicine where small doses of a substance provides a cure/protection is in the area of immunization. Efforts have also been made using desensitizing injections with low doses of the offending agent in those that suffer from hayfever. The results are quite variable.

A recent review of 107 clinical trials of homeopathic methods (Kleijnen et al 1991) found that only 14 trials scored high enough on design (patient characteristics described, sufficient sample size, randomized treatments, double blind, effect measurement sensible) and sufficient data to check the analysis. Of the published articles reviewed, more positive than negative results were reported. However, there are still

many unanswered questions. There is no defined method for the correct choice of the remedy and the potency to be used. There is no plausible mechanisms through which homeopathy would act. The authors conclude that at the moment the evidence of clinical trials is positive but not sufficient to make definitive conclusions. Poor methodology and potential unknown publication bias undermines the full support of homeopathic methods. Further evaluation is required using well designed and performed clinical trials.

As well as Clinical Ecology, these individuals use other alternative therapies. In a review of unconventional cancer remedies Danielson (1988) found the following common features among unproven treatments:

1. The promoters exploit fear and promise painless treatment with good results.

2. The treatments are described as "holistic, natural and nontoxic".

3. The theories upon which the treatments are based are often described with complex scientific jargon. However, no valid experimental evidence is provided to support these remedies.

4. The advocates of unproven treatments often claim to have made a miraculous recovery with their proof presented in anecdotal form and by testimonials.

5. Promoters frequently avoid valid studies that will subject their methods to rigorous scrutiny.

6. Profit is a major motivation for proponents of a specific treatment.

7. Characteristic philosophical stances, which usually have an adversarial relation with orthodox medicine, are taken by the proponents of unproven or disproved therapies. Such people attempt to promote distrust of traditional medicine by suggesting that the medical establishment is behind in its concepts and suppressing research results.

The authors felt that one reason for the use of alternative therapy is the attitude in society in which individual freedom and the devaluation of expertise is common.

The authors explored the reasons for the attraction to alternative therapies and found some common characteristics:

1. Those seeking alternative treatment early in their illness tend to be well educated. It is surmised that this is because these patients may be accustomed to being in control of their lives and may seek treatments to provide that apparent control.

2. Other well meaning people may exert pressure by providing the patient with literature on unproven treatments, by relating anecdotes of those who have been treated and suggesting that they have "nothing to lose". This usually comes at a time when the patient's coping skills are stretched to the limit.

3. The patients may be reacting to what they perceive as deficiencies in the traditional doctor-patient relationship. A negative opinion of the medical profession may cause patients to avoid conventional treatment.

4. Hewer (1983) found that practitioners of unproven methods spent more time with each patient and emphasized each patient's individuality and uniqueness. The patients felt the treatments were more "patient-oriented", with more explanation provided, and equal partnership and the opportunity for more input in the therapy. As well, the practitioners were more positive and enthusiastic about treatment results than conventional physicians.

5. Clinical Ecologists do not talk about cure and neither promise nor give hope of eliminating the problems. Similar to patients with chronic disease, the afflicted accept the inevitable and seem content with their condition, and with the reassurance that their symptoms are of a physical cause.

Taken from another point of view, Barsky (1988) explores the paradox in our society that despite the substantial improvements in health status, there has not been an accompanying improvement in the subjective feeling of healthiness and physical well-being. When people are surveyed they "report higher rates of disability, symptoms and general dissatisfaction with their health".

Traditional measurements of a population's health (infant mortality rate, mortality rates, life expectancy) all show improvements in the last 40 years. This has been coupled with an enhanced ability to detect, diagnose and treat human ailments. Advances in preventive medicine has encouraged many to modify their lifestyles. Within the United States, the proportion of Americans satisfied with their health and physical condition has decreased (61% to 55%) in a ten year period (1970-80) (Harris 1987). Large national surveys have shown the following trends:

1. Reporting of more frequent and longer-lasting episodes of serious, acute illness,

2. Increase in the number of men and women who report somatic symptoms that interfere with their feeling they can do all that they want to do,

3. Longer periods of disability per episode of illness, and

4. An increased proportion of people who report a permanent total disability.

There appears to be a decrease in our threshold and tolerance for mild disorders and isolated symptoms and an increase in viewing uncomfortable symptoms as pathological. This may be explained by the replacement of acute fatal disorders with chronic non-life threatening disorders, leading to a greater part of our lives spent in ill health. As well, health is a major area of concern as evidenced in happiness being equated with good health, the strenuous pursuit of a healthy lifestyle, continued emphasis on weight control and diet, the physical fitness boom, and the commercialization of health. This heightened awareness, although with substantial benefits, has increased body awareness and assessment of one's well being with a negative impact. Dissatisfaction amplifies discomfort and dysfunction leading to a poor appraisal of one's health. Individuals are less likely to tolerate what were once minor aches and pains.

With a heavy bombardment of advertising for products and opportunities that may enhance one's health, it is not surprising that many take a consumer approach to their health care. This has encouraged alternative therapies to provide and advertise their services. To effectively promote their services and products, many convince the public that something is seriously wrong, and that they can help correct it. This is further supported by the increased emphasis on health matters by the mass media. Targeted with all this gloom and doom, some of which is inaccurate but not refuted, cannot help but lead to anxiety and fear and a decline in one's feeling of well-being.

Given the above, one can conclude that the average person consults physicians more frequently, for less serious conditions that they ever did before. Therefore, the health care costs have risen. The advances

in medical care have increased the public's expectations of the medical profession to be able to explain and treat minor ailments and discomforts. All of this has serious implications on health care policy.

The diagnosis of Environmental Hypersensitivity is usually made by the patient, who having failed to find satisfactory resolution of his/her symptoms through the efforts of orthodox medicine, seeks an acceptable explanation for his/her illness. Environmental Hypersensitivity is a diagnosis of convenience, that is, it is based solely on symptoms without objective evidence of disease and is broad enough to encompass virtually any constellation of symptoms.

Illness, per se, is not sufficient for, or equivalent to, a medical diagnosis. Valid diagnoses can be classified as disease, syndrome, and/or a symptom/sign complex. Environmental Hypersensitivity Syndrome fails:

- to identify a consistent distinct symptomology,
- to identify any consistent physical signs of disease,
- to demonstrate any consistent or reliable 'in vitro' or 'in vivo' clinical or laboratory abnormalities, using modalities of investigations properly validated by contemporary standards,
- to define treatment strategies and/or programs of prevention which satisfy even minimal standards of contemporary clinical research,
- to stimulate, thus far, meaningful research.

This does not deny that the sufferers are ill nor that an entity such as Environmental Hypersensitivity Syndrome does not or could not exist. However, those suffering are not meaningfully diagnosed under the label Environmental Hypersensitivity Syndrome because the entity is not yet adequately defined.

Therefore, individuals presenting with symptoms from many body systems, that they may attribute to increased sensitivity to the environment, must be fully assessed for treatable causes and may present some not less readily treatable ailments such as somatization syndrome, dysthymia, fibromyalgia, chronic fatigue syndrome and panic attacks. The distrust of orthodox medicine may make them particularly difficult to treat and may result in extensive use of alternative therapies. The impact on the individual with the label of Environmental Hypersensitivity goes beyond the illness and its effect on the individual. It includes a natural history of economic and social events that affects the family and others close to the one that is ill.

The discipline of Clinical Ecology lacks scientific rigour and may in fact do more harm than good. As the pattern of symptoms is so diffuse and the course of the illness is unpredictable, calling this ailment a syndrome is incorrect and may interfere with attempts at more legitimate diagnosis.

What is Sick Building Syndrome?

The energy crisis in the 1970's encouraged building owners to search for ways to decrease heating costs. "Tight" buildings show a positive return on operating expenditures. This was coincident with office and home decor changing from natural material (wool, wood) to man-made fibres (pressed board and acrylic). Energy savings were offset by a decrease in the number of air changes per hour, leading to the air breathed by office workers containing higher levels and new pollutants than was common in the pre-energy crisis days. These included allergens and irritants. The increased humidity provided a microclimate for the growth of micro-organisms.

The term sick building syndrome was coined in the 1970's to denote a high prevalence of symptom complaints in building occupants strongly correlated with attendance time in the building. The term implies that diagnosis is extremely difficult because of the multifactorial aetiology and the nonspecific nature of the complaints. The symptoms greatly outnumber the signs - there are no laboratory abnormalities. Specific, readily diagnosable building-related illness, such as hypersensitivity pneumonitis and Legionnaire's disease can be ruled out. Here again, the term fails to meet the criteria for a syndrome or fully definable diagnosis. Unlike Environmental Hypersensitivity, indoor air quality complaints are investigated using epidemiological investigation in the affected groups. What is more likely is that, a label of sick building syndrome represents indoor air quality illness not fully diagnosed. Individuals or groups do not suffer from sick building syndrome. They are ill from pollutant(s) and inadequate ventilation, exposures and undiagnosed building.

To date, the most common exposures causing indoor air quality illness includes tobacco smoke, carbon monoxide, formaldehyde, other volatile organic compounds, biological pollutants, and carbon dioxide. These must be ruled out as "common problems are common". Respiratory symptoms include:

> rhinitis, stuffy nose, sore throat, cough, wheezing, aggravated asthma, and shortness of breath.
>
> Irritated eyes, headache, dizziness, fatigue and lethargy, nausea, vomiting, loss of appetite, difficulties concentrating, short term memory loss, personality change, rashes, and muscle aches can also occur.

There are clusters of symptoms occurring with these low level exposures:

- **tobacco smoke:** respiratory symptoms, conjunctival irritation, and headache,
- **carbon monoxide:** (product of incomplete combustion) headaches and fatigue,
- **carbon dioxide:** (inadequate ventilation) headaches, difficulty concentrating, short term memory loss,
- **formaldehyde:** (commonly from new furnishings and carpets) sore throat, irritated eyes, shortness of breath, wheezing, nausea, fatigue and lethargy,
- **other volatile organic compounds:** (photocopiers, paints and lacquers, perfumes, etc.) eye and upper respiratory irritation, rhinitis, nasal congestion, headache, nausea, vomiting and shortness of breath, and
- **biological pollutants:** illnesses diagnosed as hypersensitivity pneumonitis, Legionnaire's disease, humidifier fever, and allergic rhinitis.

IAQ (indoor air quality) investigations that only consider the people affected, without full investigation of the building pollutants and ventilation (all studied on the same days) is likely to yield a diagnosis of sick building syndrome. As human beings have only a limited range of symptom responses for a broad range of exposures, the ability to determine causality, focusing only on the biological indicator, is unlikely to yield productive results. Acids, alkalis and solvents are all irritating substances causing sore eyes and throat, itchy skin, rashes and sometimes shortness of breath. However, only by a careful history of the building and its activities, can the irritating substance be identified. It is careful history taking, in the preliminary epidemiological investigation, that can help to focus the industrial hygiene investigation that will confirm the pollutant source. The additional symptoms of headache, nausea, fatigue and difficulty concentrating may suggest a solvent exposure. Purely, irritative symptoms suggests an acid or a base.

Irritant exposures are a common cause of IAQ. It is important to distinguish antigens from irritants, although the mast cell response may be similar. Both reactions occur quickly after exposure, but the antigenic response would only occur on the second exposure. Irritants may cause histamine release directly or may activate one of the two initiating complement pathways without the intervention of antibody.

Irritant exposures are far more common than allergenic. Investigation for irritant exposures, acids, alkalis and solvents, is more profitable that searching for allergens when doing indoor air quality investigations.

In an investigation of a group of kitchen workers (Marchant et al 1990) exposed to sodium hydroxide through the short-circuiting of the dishwasher exhaust into the outdoor intake, the principle symptoms were eye irritation, rash, puritis, and shortness of breath. The workers were exposed to this substance for 2.5 years before the problem was diagnosed and corrected. The kitchen was thoroughly cleaned and most of the workers were able to return to work. Many were reacting to irritants in their home and were unable to visit shopping malls because of symptoms of itchy skin and shortness of breath.

After a relatively quiet summer, there was another outbreak in the already responsive population. This time, with investigation occurring immediately, the predominant symptoms were rash, itchy skin, sore eyes, hoarseness and sore throat. This suggested a different irritant that acted at a higher level in the respiratory system than the original one. Investigation demonstrated that the intake for the kitchen had been deliberately contaminated with sulphuric and nitric acid. This slight change in symptoms, provided the evidence to reinvestigate, to suggest the type of pollutant, but not to definitively identify the cause. Again the kitchen settled down for several months.

In the summer of 1991 a system to control humidity and temperature was added to the ventilation system. When the heating system was turned on, complaints of headache, rash, itchy skin and shortness of breath occurred. The rash was identical to the earlier rash caused by sodium hydroxide. On investigation, the new system had decreased the ventilation supply by one quarter and disrupted the relatively even distribution of supply within the kitchen, leaving some areas with one half the original supply. As well, the humidification system was hooked up to the boiler steam (not an uncommon practice) that contained descaling chemicals. The material and safety data sheets revealed that one of the products contained was sodium hydroxide along with other irritant chemicals. Wipe tests again confirmed the presence of very low concentrations of sodium hydroxide. The decreased ventilation was the cause of the headaches. This group of workers could not be termed hypersensitive, as the exposure is not allergenic. However, chemical hyper-responsiveness to low levels of irritants has occurred.

It appears that an initial insult with irritants, causing prolonged illness, may result in a quick response to low levels of other irritants. There is also some suggestion that the experience of the insult (and the long time until the pollutant source is determined), may be psychologically so difficult, that the ensuing anxiety heightens the responsiveness and awareness to other irritants in any environment. The response type may be normal (e.g. most people complain of sore eyes and nose on exposure to formaldehyde). Individuals at work with no expectation of exposure to pollutants, may not only suffer the health effects of low level exposures but may also believe they are

"victimized". Once "insulted" they may be more aware of low-level pollutants and, therefore, be more likely to recognize their symptoms.Other common irritants are, for example, solvents, either volatile aromatic and aliphatic organ compounds (e.g. styrene, toluene, xylene, trichloroethylene) which are potent narcotics when inhaled in high concentrations. Lower longer term exposures may lead to a toxic encephalopathy. Synergistic effects may occur with alcohol ingestion or exposure to more than one solvent.

A review of the literature shows that chronic disorders of the central nervous system are reported in association with exposure to solvents and other toxic agents and can be classified into three major types as adopted by the World Health Organization (Baker et al 1985). These are:

1. Chronic toxicity Type 1 consisting primarily of an increase in symptoms such as sleep disturbances, fatiguability, loss of interest in normal activities, psychomotor slowing and complaints of diminished mental efficiency such as difficulty in concentrating.

2. Mild chronic toxic encephalopathy is either an organic personality or mood disorder (Type 2A) followed by deficits in neurobehavioural function (Type 2B) usually accompanied, but not always, by Type 1 symptoms.

3. Severe chronic encephalopathy (Type 3) which appears to be similar to other forms of dementia.

Of the mild disorders, the most commonly documented deficit in neurobehavioural function is that of psychomotor performance (test of dexterity and auditory and visual reaction time). Intellectual decline occurs with measures of perceptual organization and visual constructive abilities. Verbal intelligence is seldom impaired. Consistent evaluations of personality with special reference to mode have been undertaken and disturbances have been reported.

In a study of 70 house painters (Arlein Soborg et al 1979), it was found that more than half suffered from memory impairment (forgetfulness), excessive fatigue, inability to concentrate, irritability, low frustration tolerance and headache. Symptoms displayed by fewer than half of the painters included dizziness, apathy, anxiety, depression, burst of perspiration and alcohol intolerance. This study did not have a control group. Mean exposure time was 27 years. Thirty nine of 50 of the subjects were characterized as intellectually impaired in various degrees, slight to moderate cognitive deterioration being predominant. Severe dementia, characterized by disorientation, marked personality disturbances and inability to pass the neuropsychological test battery were not seen. Difficulties in visuo-constructional praxis and verbal concept

formation were present in about half of the subjects. Disorders of vigilance and psychomotor slowing were seen in one third of the sample. Five patients showed neither intellectual impairment nor cerebral atrophy. It was found that the presence of acute intoxication symptoms with improvement over weekends and holidays often preceded the more chronic symptoms.

Another study of 52 painters (Hane et al 1977) which did use a control group, found that the painter group had significantly lower mean scores on psychological tests measuring intellectual capacity and psychomotor coordination than the reference group. The painter group also had significantly lower performances than expected on the memory test and the reaction time test. A health interview revealed that eczema and the experience of impaired memory were significantly more frequent among the painters than among the reference group. There was also an over-representation of diffuse chest pain, extreme fatigue and longer periods of sick leave among the painters. No correlation was found between the measures of exposures, i.e. occupational years and "painter years" and the effect. The painters that consulted the Clinic of Occupational Medicine showed symptoms of memory impairment, fatigue and personality changes of a depressive type.

A study of mental symptoms in lacquers (Struwe et al 1980) which used two control groups, showed that the exposed group scored higher than the control groups in the following areas:

> inner tension, hostile feelings, fatiguability, aches and pains, learning difficulties, short/long term memory failures, nausea, epigastric pain, headache, problems with precision movements.

The most statistically significant difference was observed for symptoms such as memory disturbances, headache and fatigue ($p < 0.001$).

The exposed subjects showed an increased verbal flow and signs of recent memory failures compared to both control groups. There were more signs of impaired long term memory, increased restlessness and muscular tension among the lacquerers. There was significant difference ($p < 0.001$) in symptoms related to decreased psychological capacity. Also statistically significant ($p < 0.05$) were emotional and cognitive changes and loss of manual dexterity. The overall mental ill health was rated higher in individuals with long exposure duration and lacquerers from the elderly age strata suffered from symptoms not acceptable in healthy men.

A study by Lindstrom (1980) looking at solvent exposed workers found slightly higher correlations for symptoms among car painters exposed to solvent mixtures and styrene-exposed workers.

There are numerous other studies confirming similar results. Linz et al (1986) stated that "one disturbing feature of organic solvent-related toxic encephalopathy is that symptoms and objective neurologic and psychologic deficits have developed with low airborne organic

solvent concentrations in both Sweden and Finland". Similarly, there does not appear to be a definite dose response relationship.

This encephalopathy is characterized by impaired verbal ability, disturbances of memory and mood, and impaired psychomotor function that may persist long after exposure has ceased. Poor, memory, depression, difficulty concentrating, lack of initiative, fatigue, irritation, sleep disturbances, decreased libido, dizziness, heart palpitations, tingling and alcohol intolerance are the predominant symptom complaints.

The acute neurotoxic effects of occupational exposure to organic solvents is well recognized. Level and type of exposures as well as personal characteristics, can increase or decrease the sensitivity to a given exposure. Most commonly, in an occupational setting, exposure includes a mixture of several substances that include a complex atmosphere containing various gaseous and particulate organic and inorganic substances.

With solvents and other substances with acute effects, the actual concentration has more influence on the health effects than the length of exposure time. A study on painters showed that exposure to mixtures of solvents 0.2 to 0.5 times the occupational exposure limits can provoke acute and possibly chronic symptoms. This suggests that there may be a synergistic effect with the solvents. Longterm exposure to solvents appears to lower tolerance for acute exposures.

One group exposed to 0.1-0.3 and 0.5 times the 1979 Danish occupational exposure limit showed an increased frequency of acute irritative and neurological symptoms. There was impaired perceptual speed, manual dexterity, and reaction time. There was also light signs of impairment of the peripheral nervous system.

Baelum (1991), exposing individuals to single and then combined mixtures of solvents well within the exposure guidelines, found that the irritative effects and, to a certain degree, the neurological symptoms seem to be more pronounced during an exposure to mixtures of solvent than expected from data on single substances.

The consumption of alcohol increases the level and duration of the internal dose of toluene. Baelum recommends that:

- workplaces should work to decrease the number of solvents used at one time,
- to decrease the number of solvents used at one time,
- to decrease the total exposure to solvents,
- to avoid alcohol intake, and,

- if eye, airway irritation, dizziness and feelings of intoxication occur, the levels of exposure in the workplace should be reviewed.

The American Conference of Governmental Industrial Hygienists has just given notice (December 1991) that the TLV for toluene will be decreased to 50 ppm.

Solvent attributed chronic diseases include peripheral neuropathy, cerebellar disease, chronic encephalopathy and dementia. The clinical features are frequently non-specific and evidence of solvent-related toxicity in most cases is circumstantial with no clear dose-response relationship.

Peripheral neuropathy most commonly occurs with n-hexane (jet fuel) and methyl n-butyl ketone. Cerebellar disease is frequently seen with toluene exposure. Chronic encephalopathy and dementia is seen in toluene abusers and mixed solvent workers. Arlien-Boborg et al (1982) demonstrated significantly decreased cerebral blood flow, compared to matched controls, in painters with clinical toxic encephalopathy with no brain atrophy on CT scan.

Juntunen et al (1980) reviewed workers exposed to mixed solvents (mean of 10 years exposure) and found that 64% had evidence of brain atrophy. There was no significant difference between those with low exposure and those with high exposure levels. The high level of brain atrophy in those exposed to mixed solvents has been confirmed by Anti-Poika (1986).

The literature to date has been unable to delineate what are safe levels of solvent exposure, why dose and effect levels differ so much, what mixtures of solvents produce the different clinical pictures, and can those who develop permanent neurological damage from what appears to be a small exposure be called hyper-responsive?

A recent investigation (Marchant et al 1991), of hospital workers complaining of extreme fatigue, difficulty concentrating, headache, nausea, short term memory loss, difficulty breathing, and eye irritation showed persistent environmental low levels of toluene, benzene, and xylene. This occurred from entrainment of the exhaust of an occupational therapy paint shop into the intake for an office area in the hospital. This poor exterior ventilation design, combined with inadequate air movement in the areas where the most affected worked, combined to cause significant illness (confirmed on psychometric testing) in a third of the exposed individuals. Although parking garage fumes could also be entrained, with the change in wind direction, the carbon monoxide levels on the day of testing were negligible. As well, the problems occurred all the time and not just related to peak activity in the parking garage. This suggests that ventilation problems, combined with low level mixed solvent exposure can lead to significant illness in particularly responsive individuals.

Conclusion

Environmental Hypersensitivity Syndrome is an invalid diagnosis whose label has been applied to individuals with multiple symptoms involving several organ systems that may have a recognized diagnosable and treatable condition. Those with the label may represent a segment of the patient population who distrust "orthodox" medicine, psychiatric diagnoses, modern technology and therapies. The label may represent those who desire increased control over their assessment and treatment than normally provided by orthodox physicians. Individuals with illness related to the environment may respond through classical immunological mechanisms to perfume and specific allergens or may have illness related to identifiable indoor air quality problems. It appears that using the label "Environmental Hypersensitivity Syndrome" (or any other similar terms) may be impeding full diagnostic assessment of some of these individuals and may confuse the assessment of the small number of patients who don't fit the traditional diagnostic categories.

Sick building syndrome, like environmental hypersensitivity, lacks validity as a diagnosis, and, therefore, should not be called a syndrome. What it really means is that the IAQ illness is not determined because the building in undiagnosed. Investigations should include assessment of the people epidemiologically, the ventilation system, common pollutants and less common ones as suggested by the material and safety data sheets, building activities, and symptom complex of those affected. This investigation should be done on the same days with a team of experts knowledgeable in IAQ problems related to ventilation, pollutants and their health effects. IAQ problems are usually related to both particular pollutants and ventilation problems. More effort is needed to diagnose building problems when there is an outbreak of IAQ problems.

Chemical hyper-responsiveness to irritants and solvents appears to:

- occur at much lower dose levels than reported in the literature (related to that chemical),
- occur after a significant (substance identified) event exposure frequently in an non-industrial workplace,
- may lead to generalized responses to other low level irritant exposures with symptoms decreasing with time.

The level of ill health may partly be attributed to the individual's feeling of being "victimized".

Anti-Poika, M (1986) 'Symptoms and signs in solvent exposed populations,' in V. Riihimaki and U. Ulfvarson (eds.), Safety and Health Aspects of Organic Solvents Alan R. Liss Publishers New York pp. 255-264

Arlien-Soborg, P. and Bruhn, P. and Glydensted, C. and Melgaard, B. (1979) 'Chronic Painter's Syndrome', Acta Neurol. Scandinav. 60, pp. 149-156

Arlien-Soborg, P.and Henrikson, L. and Gade, A. and Gyldested, C. and Paulson, OB. (1982) 'Cerebral blood flow in chronic toxic encephalopathy in house painters exposed to organic solvents'. Acta Neurological Scandinavica 66, pp. 34

Baelum J, (1991) Human Solvent Exposure, Pharm and Toxicol 68 Supp 1

Baker, E.L. and Smith, T.J. and Landrigan, P.J. (1985) 'The neurotoxicity of industrial solvents: a review of the literature', AM J of Industrial Medicine 8, pp. 207-217
Baker and Bus and Cranmer et al (1985) 'Workshop of Neurobehavioural Effects of Solvents: Consensus Summary', Neurotoxicology 6, pp. 99

Barsky, A. J. (1988) 'Special Article: The Paradox of Health', The New England JOM, Vol. 318, No. 7, pp. 414-418, February 18

Black, D.W.and Rathe, A. and Goldstein, R.B. (1991) "Environmental Illness: A Controlled Study of 26 Subjects with 20th Century Disease', JAMA, Vol. 261, No. 24, pp. 3166-3170 December 26,

Hayes, J.K. Chairman with Robert L. Brown, William Wood Jr., John G. Gatien, Carl Abbot, Rosemary Marchant, Don Wylie (1991) (CAEEH) 'Adverse Effects of the Environment on Health Committee, Province of Nova Scotia, Canada Summary Report on the Referrals to the Adverse Effects of the Environment on Health Committee'. Unpublished Draft

Cowley, D.S. and Roy-Byrne, P.P. (1987) 'Hyperventilation and Panic Disorder', The Amer JOM, Vol. 83, pp. 929-987. November

Crowe, R.R. and Noyes, R. Jr. and Pauls, D.L. and Slymen, D. (1983) 'A Family Study of Panic Disorder', Arch Gen Psychiatry 10, 106501069

Danielson, K. J. (1988) 'Unconventional Cancer Remedies', CMAJ, Vol. 138, pp. 1005-1011. June

Gamlin, L. 'Another Man's Poison'. (1989) New Scientist pp. 48-53, July

Hane, M. and Axelson, D. and Blume, J.and Hogstedt, C. and Sundell, L. and Ydreborg, B. (1977) 'Psychological Function Changes Among House Painters', Scan J Work Environ Health 3, pp. 91

Harris, I. (1987) Inside America, Vintage Books, New York

Hewer, W. (1983) 'The Relationship Between the Alternative Practitioner and His Patient: A Review Psychother Psychosom', 40, pp. 72-180

Juntunen, J. and Hernber, S. and Eistola, P. and Hupli, V. (1980) 'Exposure to Industrial Solvents and Brain Atrophy. A retrospective study of pneumoencephalographic findings among 37 patients with exposure to industrial solvents', European Neurology 19, pp. 366

Kahn, E. and Letz, G. (1989) 'Clinical Ecology: Environmental Medicine or Unsubstantiated Theory?', Annals of Internal Medicine, Vol. 111, No. 2, pp. 104-106

Kleijnen, J. and Knipschild, P.and ter Riet, G. (1991) 'Clinical Trials of Homeopathy'. BMJ 302, pp. 316-323

Kroenke, I.T. (1991) 'Chronic Fatigue Syndrome: Is It Real?' Post Graduate Medicine. Vol 89, No. 2, pp. 44-55
Kruesi, M.J. and Dale, J. and Straus, S.E. (1989) 'Psychiatric diagnoses in patients who have chronic fatigue syndrome', J Clin Psychiatry 50(2), pp. 53-56 [erratum, J Clin Psychiatry 1989, 50(4), 148]

Langley, G.R. (1987) 'Report on the Environmental Hypersensitivity Advisory Committee to the Minister of Health, Province of Nova Scotia

Lindstrom, K. (1980) 'Changes in psychological performances of solvent poisoned and solvent exposed workers', AM J of Industrial Med 1, pp. 69-84

Linz, D.H. and De Garmo, P.L. and Morton, W.E. and Weins, A.N. and Coul, B.M. and Maricle, R.A. (1986) 'Organic solvent-induced encephalopathy in industrial painters', J of Occ Med 128(2)

Marchant, R.E. and Yoshida, K. and Walkinshaw, D. and Ross, J.B. and Gallant, C.and Shires, D. (1990) 'Skin irritation and dyspnea in kitchen workers: sodium hydroxide proceedings of the fifth international conference on indoor air quality and climate', Toronto, Canada

Marchant, R.E. and Figley, D.A. and Saunders, G.A. and King, D. and Hayes, D. (1991) 'Fatigue and short term memory loss in a hospital', In preparation

Middleton, E. and Reed, C.E. and Ellis, E. F. and Adkinson,F. and Yunginger, J.W. (1988) Allergy Principles and Practice, CV Mosbe Company, St. Louis, Washington, D.C., Toronto

Pearson, D. J. (1985) 'Food allergy, hypersensitivity and intolerance', J of Royal College of Physicians of London, Vol. 19 No. 3, pp. 154-162

Position Paper (1983-1984) 'A new medical specialty designed to identify and treat environmental illness', Soc Clin Eco.

Position Statements (1986) 'American Academy of Allergy and Immunology: Clinical Ecology', J. Allergy Clin. Immunol. Vol. 78, No. 2, pp. 269-271.

Position Paper (1989) 'Clinical Ecology American College of Physicians Annals of Internal Medicine', 111(2), pp. 168-178

Randolph, T.G. and Rollins, J.P. (1950) 'Alergic reactions from the ingestion of intravenous injections of cane sugar (sucrose)', J Lab Clin Med 36, pp. 242-248

Randolph, T.G. (1952) 'Sensitivity to petroleum including its derivatives and antecedents, abstracted', J lab Clin Med 40, pp. 931-932

Reich, P. (1989) Letter, 'Panic attacks and the risk of suicide'. The New England JOM, Vol. 321 No. 18, pp. 1260-1261

Rozee, K. (eds.) (1989) 'Proceedings of a Workshop: Chronic Fatigue Syndrome', Diseases Weekly Report. Health and Welfare Canada. January 1991, Vol 17S1E

Stewart, D.E. and Raskin, J. (1985) 'Psychiatric Assessment of Patients with "20th-Century Disease"', Total Allergy Syndrome, Can Med Assoc. J. 133 pp. 1001-1006

Stollery, B.T. and Flindt, M. (1988) 'Memory sequelae of solvent intoxication', Scand J Work Environ Health 14, pp. 45-48

Straus, S. E. and Dale, J. K. and Tobi, M. and Lawley, T. and Preble, O. and Blaese, M. and Hallahan, C. and Henle, W. (1988) 'Acyclovir treatment of the chronic fatigue syndrome', The New England JOM Vol. 319 No. 26, pp. 1692-1698

Terr, A.I. (1986) 'Environmental Illness. A clinical review of 50 cases', Arch Intern Med Vol. 146, pp. 145-149

Terr, A.I. (1989) 'Position Paper: Clinical ecology. Annals of Internal Medicine', Vol. 111, No. 2, pp. 168-178
Thomson, G.M. (1985) 'Report on the ad hoc committee on environmental hypersensitivity disorders', Ministry of Health, Ontario

Torgerson, S. (1983) 'Genetic factors in anxiety disorders', Arch Gen Psychiatry 40, pp. 1085-1089

Weissman, M.M. and Klerman, G.L. and Markowitz, J.S. and Ouelette, R. (1989) 'Suicidal ideation and suicide attempts in panic disorders and attacks', New Eng J of Med 321, pp. 1209-1214

Wolfe, F. (1986) 'The clinical syndrome of fibrositis', Am J Med 81, pp. 7-14

SOME STUDIES OF HUMAN REACTIONS FROM THE EMISSIONS OF BUILDING MATERIALS AND OFFICE MACHINES

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ABSTRACT. Both building materials and office machines emit volatile organic compounds thus demanding for methods to evaluate the health aspects of their emission. Chamber studies with subjects differ from field studies in that measurements and reporting of symptoms can be carried out simultaneously. The exposure of voluntary subjects to selected building materials, and to a simulated office environment with selected office machines have been studied, respectively. A multidisciplinary approach has been used by combining air quality measurements with clinical investigations, the irritating potency of a mouse bioassay, and air quality evaluations on the decipol scale. This has given important information about the pollutants emitted, their relation to objective air quality measurements, and the tear film quality of the eye.

1. INTRODUCTION

Building related materials, consumer products, and human related activities like use of office machines are major sources of volatile organic compounds (VOC) to the indoor environment (Miksch et al. 1982; Mølhave 1982; Levin 1989; Wallace et al. 1987, 1989). The various contributions as continuous emission sources occur within weeks and months (Seifert and Ullrich 1987). However their emission rate will decline and give a low concentration level until a new renovation. Discontinuous emission sources like the use of household products for cleaning (Wallace et al 1989; Knöppel and Schauenburg 1989) will contribute within a time scale from minutes to hours or days. The sink effect of building materials will prolonge the emission period depending on climatic conditions and the surface characteristics (Berglund et al.,1989; Seifert et al. 1987) of which is reflected also in the fleecy and shelf factor (Nielsen 1987). However activities, the use of office machines, and office utensils contribute daily to the pollution of the office environment with VOC, particulates, ozone, formaldehyde, nitrogen oxides, and miscellanous compounds as shown in Table 1. Alternative pathways of exposure by skin contact of semi-VOC are also possible.

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Table 1. List of pollutants emitting from office machines and other office utensils.

Object	VOC	Parti-culates	Ozone	CH_2O	NO_x	Miscl.
Photocopying machines	+	+	+	+	+	toner powder fuser oils photoconduc-ting materials
Laser printers	+	+	+	+	+	
Jet printers	+					
Computers/VDT	(+)	(+)				fire retardants
Carbonless copy paper	+	+		(+)		colours developers biocides capsule materi-al
Carbon copy paper	+	+				
Copy paper after copying	+	+				
Paper		+				
Cleaning agents	+					Detergents

The adverse health effects of VOC in form of sensory reactions have recently been discussed in a WHO report (1989). The symptoms are irritation of eye, nose and throat, sensation of dry mucous membranes including dry skin; general symptoms like headache, mental fatigue, dizziness, nausea, difficulty of concentration, and odour. These symptoms are now recognized as the sick building syndrome (SBS). The consequence of indoor air quality problems as SBS can lead to disability in form of sensory reactions, discomfort, annoyance reactions, absenteeism, low worker productivity, and even chronic effects. WHO concluded *inter alia* that VOC may cause odours, mucosal and sensory irritation, and airway effects at levels encountered indoors.

WHO recommended *inter alia* that complaints about the indoor air quality should not exceed 20 percent. Complaints related to irritating (organic) pollutants and unwanted odours should not exceed 10 and 50 percent, respectively. It was further recommended that the emission of VOC from building materials and consumer products

should be determined and evaluated, and approaches to source control should be developed.

WHO has also recommended guidelines for the use of video display terminals (Knave et al. 1991).

The increased concern about SBS has prompted a public demand for more healthy building materials and products, i.e. materials with a low and harmless emission of pollutants. This has lead to a need not only for the development of new and safer materials but also of methods for measuring and evaluating the emission (ASTM 1990; CEC 1989, 1991; Gustafsson and Jonsson 1990; Levin 1989; Tucker 1991; Wolkoff 1990; Wolkoff et al. 1991A).

The introduction of modern office technology appeared in the mid-seventies as did the energy crisis demanding for low air exchange rates, and at the same time the enhanced use of synthetic building materials emitting VOC. This increased the overall number of VOC in the indoor environment. In this same period the first reports about SBS appeared (Kreiss 1989).

There are several methods to evaluate the chemistry and biology of building materials in the laboratory as shown in Table 2. The emission of VOC may be characterized qualitatively by headspace procedures using gas chromatography combined with mass spectrometry. The measurement of the emission in controlled climatic chambers provides emission factors for the volatiles, and emission profiles as function of time. This allows for a relative comparison of different materials and an estimation of the time required to reach a given emission rate (Clausen et al. 1991).

Table 2. Various methods for the evaluation of VOC emissions from building materials in the laboratory.

Method	Qual.	Quant.
Headspace screening of the emission, static or dynamic	+	(+)
Relative comparison of emission profiles	+	
Measurement of the emission factors and initial masses and ranking thereof from different materials	+	+
Sensory irritation tests		+
Various cell culture tests		+
Odour and air quality acceptability methods, sensoric evaluation		+
Human exposure studies		+
Determination of the sink effect		+

Conclusions based upon field studies with the aim of identifying causative agents to SBS may be biased because self-reported questionnaires and measurements have not been performed simultaneously. Secondly the measurements have been stationary, usually in the centre of an office, rather than in the breathing zone, and therefore not presentative, thus explaining the lack of correlation (Hodgson and Collopy 1989). The indoor pollutants are usually not homogeneously mixed so the concentration near a source or work station may be large (Rodes et al. 1991). Personal activities may further provide time dependent concentration profiles of pollutants. Concentration gradients of indoor specific VOC and their relation with SBS have been discussed by Noma et al. (1988). Chamber studies differ from field studies in that measurements, reporting of symptoms, evaluations of the air quality, and clinical investigations can be carried out simultaneously and under strictly controlled conditions, i.e. some climatic parameters are kept constant during the exposure period.

The aim of this paper is to briefly discuss the aspects with regard to the evaluation of the emission of VOC from building materials, and office machines, and their relation to indoor air quality. Further to briefly focus upon some of the major results of two recently finished studies on building materials (Johnsen et al. 1991; Wolkoff et al. 1991) and office machines (Wolkoff et al. 1992) with special emphasis on VOC and their interaction with other air quality parameters like decipol and the tear film quality.

2.1 STATUS of FIELD and CHAMBER STUDIES

There have been several reports about how to measure the emission of VOC from building materials, see above, as well as an overview of human exposure studies (Johansson 1990).

The first report ever about using a bioassay on an office related material was the measurement of the irritating potency of carbonless copy paper with the mouse bioassay (Wolkoff et al. 1988). This ASTM modified method (ASTM 1984) has later been applied to the evaluation of paints (Hansen et al. 1991). In another bioassay the exposure of rats to mixtures of indoor air pollutants including VOC and aerosol followed by subclinical tests have been studied by Glaser et al. (1989).

Mølhave and colleagues have studied the exposure of SBS sensitive humans for 2.75 hours to a mixture of 22 VOC (Mølhave et al. 1986; Kjærgaard et al 1991) in concentrations of 5 and 25 mg/m^3 in climatic chambers. Several symptoms were monitored and it was *inter alia* shown that both healthy and SBS sensitive humans suffer from mucous irritation more so in the latter group. In addition the exposure of decane in the concentration of up to 580 mg/m^3 has been studied by Kjærgaard et al. (1989). The exposure with the same mixture of 22 VOC has been repeated later by Otto et al. (1990) but with healthy humans. This study confirmed that both olfactory and trigeminal systems are activated by the VOC mixture. The study further showed that perceived irritation did not decay as opposed to the perception of odour.

The same mixture of 22 VOC has been used to expose healthy humans for 4 hours followed by nasal lavage (Koren et al. 1990). The study suggested that the exposure causes an inflammatory response most noticeable after 18 hours.

Ozone, formaldehyde, VOC, nitrogen oxides, and particulates are known pollutants emitted from office machines (Allen 1978; Selway et al. 1980; Bruun and Andersen 1986; Eggert et al. 1990; Olander 1990) and carbonless copy paper (Gockel et al. 1981; Norbäck et al. 1988; Wolkoff et al. 1988). The emission of VOC from office machines have not been described except from wet photocopying machines (Tsuchiya 1988, 1990; Walkinshaw et al. 1987). Emission data on particulates have similarly not been reported. The data available so far cannot be used to evaluate the possible role with regard to SBS and poor IAQ.

The Danish Town Hall Study showed that SBS was correlated with the use of office machines like photocopying machines, visual display terminal (VDT) work, and handling of carbonless copy paper (Skov, 1989, 1990).

Both VOC and particulates have now been identified in field studies to correlated with SBS. Norbäck et al. (1990A,B) found that both total VOC and particulates correlated significantly with SBS although measurements and reporting of symptoms were not performed at the same time. Hodgson et al. (1991) have similarly identified TVOC strongly correlated with SBS. Particulates as a causative agent were recently identified by Wallace et al. (1991).

Skin symptoms in relation *inter alia* to the use of carbonless copy paper and visual display terminals have recently been reviewed (Stenberg and Wahlberg, 1991; Knave 1991). An overview of the relevant literature about investigations of the office environment in relation to indoor air quality measurements and SBS is presented in Table 3.

In two cases symptoms have been reported related to the use of office machines, a laser printer by Skoner et al. (1990) and photocopy paper by Tencati and Novey (1983). SBS symptoms with regard to VDT use have recently been reviewed by Knave et al. (1991) and Wallberg and Stenberg (1991). Cases concerning the use of carbonless copy paper are listed in Table 3.

Fanger and colleagues (Fanger 1988A,B, 1989) have evaluated the perceived air quality on the decipol scale by a trained panel in office buildings. It was shown that the ventilation system, the inventory like the building materials contributed markedly to a worsening of the air quality.

Gunnarsen (1990) studied the adaption to indoor air pollutants like environmental tobacco smoke (ETS), human bioeffluents, and VOC emitted from building materials in a climatic chamber. A panel evaluated the air quality. They found that adaption to the perceived air quality was less for the building materials than for ETS and bioeffluents.

Table 3. Air quality parameters measured in the office environment.

Subject	Literature
Type of work, stress and health, gender, hierarchy, psycosocial factors	Burge et al. 1987; Lam et al. 1987; Kröling 1987; Espir et al. 1988; Robertson et al. 1989, 1990; Skov et al. 1989, 1990; Wallace et al. 1991
Age of building	Skov et al. 1989; Norbäck et al. 1989; Wolkoff 1990A
Building materials	Miksch et al. 1982; Mølhave, 1982; Levin, 1989
Carbonless copy paper	Marks et al. 1984; Morgan et al. 1986; Wolkoff et al. 1988; Norbäck 1988; Skov et al. 1989A; Buring and Hennekens 1991; Wahlberg and Stenberg 1991
ETS	Robertson et al. 1987
Eye irritation	Franck 1986, 1989
Floor surface, intervention	Norbäck et al. 1989
Laserprinters	Eggert et al. 1990; Olander 1990; Skoner et al. 1990
Light	Robertson et al. 1989
Macromolecular organic matter	Skov et al. 1989A
Noise, Vibration	Kröling 1987; Hodgson et al. 1987
Paper	Rycroft 1986; Tencati and Novey 1983
Particulates	Armstrong et al. 1989; Hodgson et al. 1989B: Quackenboss et al. 1989; Norbäck et al. 1990; Wallace et al. 1991
Perceived air quality	Fanger 1988A-C
Photocopying machines	Allen et al. 1978; Bruun and Andersen 1986; Selway et al. 1980
Photocopying machines (wet)	Tsuchiya 1988,1990; Walkinshaw et al. 1987
The fleece and shelf factor	Nielsen 1987
VDT	Rycroft 1986; Skov et al. 1989A; Rossignol et al. 1987; Wahlberg and Stenberg; 1991; Knave et al. 1991
Ventilation	Fanger 1988B,C; Turiel et al. 1983
VOC	Norbäck et al. 1990; Hodgson et al. 1991

2.2 EXTRACT OF STATUS

In conclusion several activities have been going on testing and measuring the emission of VOC from building materials. The present chamber studies on humans exposed all point to that VOC may be a causative agent of SBS and as substantiated by some recent field studies. Some field studies have also shown that building materials *inter alia* reduce the air quality. One chamber study have confirmed that building materials are important with regard to dimensionig the ventilation system. The advantage and power using a multidiscplinary approach by combining air quality measurements with clinical investigations under controlled conditions have so far not been applied in climatic chambers. In the following two recent studies, one about humans exposed to building materials (Johnsen et al. 1991; Wolkoff et al. 1991B) and the other study in which humans have been exposed to a simulated office environment (Wolkoff et al. 1992) will briefly be reported.

3.1 DESIGN OF CHAMBER STUDY WITH HUMANS EXPOSED TO BUILDING MATERIALS

Selected volunteers were exposed to four selected building materials in a climatic chamber for six hours. They were also exposed in an empty chamber with fresh air. The materials were the following: a) painted gypsum board covered with wallpaper and painted with a waterborne paint (age at exposure = 2 weeks); b) a rubber floor covering (age at exposure = 8 months); a nylon carpet (age at exposure = 8 months); and a particle board coated with an acid-curing paint (age at exposure = 1 month). VOC, TVOC, formaldehyde, and the decipol value were measured in the chambers. The irritating potency of the materials was measured in the laboratory. The eye irritation was measured pre and post the exposure period. It was expressed as the eye index reflecting the tear film quality which comprised of break-up time, foam formation at canthus, thickness of the precorneal lipid layer of the tear film, and epithelial damage. The VOC, TVOC and formaldehyde measurements will be discussed in terms of the air quality and the tear film quality.

3.2 DESIGN OF STUDY WITH HUMANS EXPOSED TO A SIMULATED OFFICE ENVIRONMENT

Thirty subjects were exposed for six hours during typical clerical work in a simulated office climatic chamber having three personal computers with colour video display units and connected to a selected laser printer, and one photocopying machine. They were also exposed in a climatic chamber without machines. The temperature was deliberately set to 24.0°C and 45% rh. During exposure air quality parameters were measured. Clinical investigations of the tear film quality as above were measured together with nasal cross-sectional area and volumina, and in addition to the analysis of leukocytes, albumine, and

histamine in the nasal lavage. Symptoms and evaluation of IAQ were self-reported on questionnaires during exposure.

4.1 SALIENT RESULTS OF STUDY OF HUMANS EXPOSED TO BUILDING MATERIALS

Table 4 presents some of the salient results of this study.

Table 4. Humans exposed to four building materials in a climatic chamber (Wolkoff et al. 1991B).

Material	TVOC[1] µg/m³	CH_2O µg/m³	Air quality Decipol	Tear film quality index
a. Painted gypsum board	1234	86	9.3	- 2
b. Rubber floor	1974	11	24.1	- 4
c. Nylon carpet	1313	26	20.8	- 3
d. Particle board	1110	>743[2]	16.4	- 1

1) TVOC = sum of individual calibrated VOC. 2) Minimum value because of breakthrough.

Many of the emitted VOC were strong odourants or irritants which should induce some action like substitution or removal of unwanted VOC during manufacturing.

Evaluation of the air quality showed a marked increase in the decipol evaluation for the rubber floor and the nylon carpet while less so for the particle board. The lowest value, same as for the empty chamber, was found for the gypsum board. The VOC emision measurements showed that several odorous VOC emitted from the rubber floor and the carpet responsible for their high decipol evaluation. Odourless and polar VOC emitted from the gypsum board and consistent with a low decipol evaluation. This is also reflected in the decipol/TVOC ratios which are inverted for the odourless gypsum board. The particle board emitted formaldehyde and as major VOC the odorous and polar butanol. The decipol evaluation did not react upon the high formaldehyde concentration in the particle board exposure. This indicates that the decipol evaluation is not particularly sensitive to an irritant like formaldehyde and a mixture of VOC.

The mouse bioassay only reacted upon the particle board by a significant decrease of the respiratory rate for several months compatible with its large formaldehyde emission.

The eye sign measurements showed that the tear film quality was lowest (worst) for the rubber floor and the carpet and best for the gypsum board and the particle board. The high formaldehyde concentration appeared not to be reflected in the tear film quality.

The tear film quality index is reflected in the perceived symptoms, i.e. the material giving lowest tear film quality also resulted in the experience of eye irritation. An analysis of the various VOC emitted from the building materials leads to the hypothesis that lipophilic VOC, like those emitted from the rubber floor and the nylon carpet, deteriorate the tear film possibly by a destabilizing effect of the multilipid layer of the tear fluid. Both the gypsum board and the particle board emit primarily hydrophilic VOC thus having less dissolving/destabilizing effect.

This study provides so far the lowest TVOC value (1-2 mg/m^3) that related to symptoms like eye irritation. Any threshold guideline for TVOC should be taken cautiously because the sampling capacity may vary with sorbent type (Rothweiler et al. 1992).

4.2 SALIENT RESULTS OF HUMANS EXPOSED TO A SIMULATED OFFICE ENVIRONMENT

Table 5 summarizes the major results of the air quality parameters measured.

Table 5. Humans exposed to a simulated office environment (Wolkoff et al. 1992).

Parameter[1,2]	Subjects + machines	Subjects alone
Temperature °C at exhaust - ceiling	25.7 ± 0.3	25.1 ± 0.2
Humidity % r.f. at exhaust - ceiling	49	56
Ozone µg/m^3	12 ± 7	< 2
Formaldehyde µg/m^3	95 ± 10	34 ± 3
Carbon dioxide ppm at exhaust - ceiling	3114 ± 204	3089 ± 386
TVOC µg/m^3	157 ± 106	230 ± 271
Total particulates µg/m^3	58 ± 43	28 ± 18
Respirable particulates µg/m^3	44 ± 26	31 ± 12
Perceived air quality decipol	9.3	7.2
Noise dBA	55-70	60-65

1) Mean values of all exposure days.
2) Values generally measured in the center of climatic chamber.

It shows that apart from a high temperature and high carbon dioxide concentration the levels of ozone, formaldehyde, TVOC, and particulates were low. Isolated they

would not give cause to alarm. The self-reported questionnaires, however, showed an increased experience of headache, mucous irritation of eyes, nose, and throat, and dry facial skin. In addition the subjects experienced the indoor climate worsened during the day in the office environment with regard to air quality, draft, and noise, but not the temperature. This was also compatible with a slightly higher decipol evaluation. Because the TVOC level was the same same in both climatic chambers it is believed that the decipol increase may be caused by an integrated exposure of ozone , formaldehyde and possibly particulates.

In addition epithelial damages on the conjunctiva was the only clinical parameter which turned out to be significantly greater in the office environment compared to the chamber without machines.

It is concluded that the observed effects can only be assigned to the presence, the use of the office machines, and their emission in the climatic chamber.

5. CONCLUSION

The combined results of the two studies may lead to the conclusions that the causes of eye irritation may be of chemical origin, physical origin, and user related or a combination thereof, as illustrated in Table 6. It may also be concluded that TVOC as a single air quality parameter should be used with caution.

Table 6. Possible causes of eye irritation

Effect	Exposure
Chemical	Integrated exposure of ozone, formaldehyde, VOC, or specific irritants
Physical	Exposure of particulates combined with their physio-chemical properties → destabilization of the tear film
User related	Reduced blink frequency at VDT work → decrease of break-up time of the tear film, and epithelial damage of conjunctiva

6. REFERENCES

Allen, R.J., R.A. Wadden, and E.D. Ross. (1978) 'Characterization of potential indoor sources of ozone'. *American Industrial Hygiene Association Journal* **39**, 466-471.

Armstrong, C.W., P.C. Sherertz, and G.C. Llewellyn. (1989) 'Sick Building Syndrome Traced to Excessive Total Suspended Particulates (TSP)'. The human equation: health and comfort, in: Proceedings IAQ 89, 3-7.

ASTM. (1984) 'Standard test method for estimating irritancy of airborne chemicals. American Society for testing and materials'. Designation E981-84, Philadelphia, pp 1-16.

ASTM. (1990) 'Standard guide for small-scale environment chamber determinations of organic emissions from indoor materials/products'. American Society for testing and materials. Designation D5116-90, Philadelphia.

Bruun Hansen, T., and B. Andersen. (1986) 'Ozone and Other Air Pollutants from Photocopying Machines'. *American Industrial Hygiene Association Journal* **47**, 659-665.

Burge, S., A. Hedge, S. Wilson, J.H. Bass, and A. Robertson. (1987) 'Sick Building Syndrome: A Study of 4373 Office Workers'. *Annales of occupational hygiene* **31**, 493-504.

Buring, J.E., and C.H. Hennekens. (1991) 'Carbonless Copy Paper: A Review of Published Epidemiologic Studies'. *Journal of Occupational Medicine* **33**, 486-495.

CEC European Concerted Action - COST 613. (1989) 'Report No. 2. Guideline for the Determination of Steady State Concentrations in Test Chambers'. Brussels-Luxembourg: Commision of the European Communities. EUR 12196 EN.

CEC European Concerted Action - COST 613. (1991) 'Report No. 8. Guideline for Characterization of Volatile Organic Compounds Emitted from Indoor Materials and Products Using Small Test Chambers'. Brussels-Luxembourg: Commision of the European Communities. EUR 13595 EN.

Clausen, P.A., P. Wolkoff, E. Holst, and P.A. Nielsen. (1991) 'Long Term Emission of Volatile Organic Compounds from Waterborne Paints. Methods of Comparison'. *Indoor Air*, **1**.

Espir, M.L.E., J. Thomason, J.N. Blau, and Z. Kurtz. (1988) 'Headaches in civil servants: effect on work and leisure'. *Brit. Med. J.* **45**, 336-340.

Fanger, P.O. (1988) 'Hidden Olfs in Sick Buildings'. ASHRAE November, 40-43.

Fanger, P.O. (1988) 'Introduction of the olf and decipol units to quantify air pollution perceived by humans indoors and outdoors'. *Energy and Buildings* **12**, 1-6.

Fanger, P.O., J. Lauridsen, P. Bluyssen, and G. Clausen. (1988) 'Air pollution sources in offices and assembly halls'. *Energy and Buildings* **12**, 7-19.

Franck, C. (1986) 'Eye Symptoms and Signs in Buildings with Indoor Climate Problems ('Office Eye Syndrome')'. *Acta Ophthalmologica* **64**, 306-311.

Franck, C., and P. Skov. (1989) 'Foam at Inner Eye Canthus in Office Workers, Compared with an Average Danish Population as Control Group'. *Acta Ophthalmologica* **67**, 61-68.

Glaser, U., D. Hochrainer, W. Klein, and F. Otto. (1989) 'An experimental animal study for risk assessment of indoor air pollutants'. *Environment International* **15**, 463-472.

Gockel, D.L., S.W. Horstman, and C.M. Scott. (1981) 'Formaldehyde emissions from carbonless copy paper forms'. *American Industrial Hygiene Association Journal* **42**, 474-476.

Gunnarsen, L. (1990) 'Adaption and ventilation requirements', in: Proceedings of Indoor Air '90, vol. 1, 599-604.

Gustafsson, H., and B. Jonsson. (1991) 'Review of Small Scale Devices for Measuring Chemical Emission from Materials'. Swedish National Testing and Research Institute, Borås, Sweden.

Hansen, L.F., G.D. Nielsen, J. Tøttrup, A. Abildgaard, O.F. Dahl Jensen, M. Kragh Hansen, and O. Nielsen. (1991) 'Biological Determination of Emission of Irritants from Paint and Lacquer'. *Indoor Air* **1**, 95-110.

Hodgson, M.J., and P. Collopy. (1989) 'Symptoms and the Micro-Environment in the Sick Building Syndrome: A Pilot Study'. The human equation: health and comfort, In: Proceedings IAQ '89: 8-16.

Hodgson, M.J., J. Frohliger, E. Permar, C. Tidwell, N.D. Traven, S.A. Olenchock, and M. Karpf. (1991) 'Symptoms and Microenvironmental Measures in Nonproblem Buildings'. *Journal of Occupational Medicine* **33**, 527-533.

Johansson, I. (1991) 'Flyktiga organiska ämnen i inomhusluft av betydelse för hälsa och komfort'. Institut for miljomedicin, Karolinska institut, Stockholm.

Johnsen, C.R., J.H. Heinig, K. Schmidt, O. Albrechtsen, P.A. Nielsen, P. Wolkoff, G.D. Nielsen, L.F. Hansen, and C. Franck. (1991) 'A study of human reactions to emissions from building materials in climate chambers. Part I: Clinical data, performance and comfort'. *Indoor Air* **1**.

Kjærgaard, S., L. Mølhave, and O.F. Pedersen. (1989) 'Human Reactions to Indoor Air Pollutants:n-Decane'. *Environment International* **15**, 473-482.

Kjærgaard, S.K., L. Mølhave, and O.F. Pedersen. (1991) 'Human reactions to a mixture of indoor air volatile organic compounds'. *Atmospheric Environment* **25A**, 1417-1426.

Knave, B., G. Westlander, and U. Bergquist. (1991) 'Datorn och hjälpmedel'. Arbete och Hälsa **19**.

Knöppel, H., and H. Schauenburg. (1989) 'Screening of Household Products for the Emission of Volatile Organic Compounds'. *Environment International* **15**, 413-418.

Koren, H.S., R.B. Devlin, D. House, S. Steingold, and D.E. Graham. (1990) 'The inflammatory response of the human upper airways to volatile organic compounds (VOC)'. In: Proceedings of *Indoor Air* '90 **1**, 325-330.

Kreiss, K. (1989) 'The Epidimiology of Building-Related Complaints and Illness'. *Occupational Medicine: State of the Art Reviews* **4**, 575-592.

Kröling, P. (1987) 'Untersuchungen sum ‚Building Illness'-Syndrom in klimatisierten Gebäuden'. *Gesundheits-Ingeniur-Bauphysik-Umwelttechnik* **108**, 121-130.

Lam, T.H., P.W.H. Lee, S.G. Ong, C.M. Wong, W.K. Chow, and J.W.L. Kleevens. (1987) 'Mental Health and Work Stress: A Comparison of Response Patterns in Executives and Clerical Workers in Hong Kong'. *Journal of Occupational Medicine* **29**, 892-987.

Levin, H. (1989) 'Building Materials and Indoor Air Quality'. *Occupational Medicine: State of the Art Reviews* **4**, 667-693.

Marks, J.G., J.J. Trautlein, and C.W. Zwilich. (1984) 'Contact urticaria and airway obstruction from carbonless copy paper'. *Journal of American Medical Association* **252**, 1038-1040.

Miksch, R.R., C.D. Hollowell, and H.E. Schmidt. (1982) 'Trace Organic Chemical Contaminents in Office Spaces'. *Environment International* **8**, 129-137.

Morgan, M.S., and J.E. Camp. (1986) 'Upper Respiratory Irritation from Controlled Exposure to Vapor from Carbonless Copy Paper'. *Journal of Occupational Medicine* **28**, 415-419.

Mølhave, L. (1982) 'Indoor Air Pollution Due to Organic gases and Vapours of Solvents in Building Materials'. *Environment International* **8**:117-127.

Mølhave, L., B. Bach, and O.F. Pedersen. (1986) Human reactions to low concentrations of volatile organic compounds'. *Environment International* **12**, 167-175.

Nielsen, P.A. (1987) 'Potential pollutants - their importance to the sick building syndrome - and their release mechanism', in: Proceedings of Indoor Air '87 vol. 2, 598-602.

Noma, E., B. Berglund, U. Berglund, I. Johansson, and J.C. Baird. (1988) 'Joint Representation of Physical Locations and Volatile Organic Compounds in Indoor Air from a Healthy and a Sick Building'. *Atmospheric Environment* **22**, 451-460.

Norbäck, D., I. Michel, and J. Widström. (1990) 'Indoor Air Quality and Personal factors related to the Sick Building Syndrome'. *Scandinavian Journal of Work,Environment & Health* **16**, 121-128.

Norbäck, D., G. Rand, I. Michel, and S. Amcoff. (1989) 'The Prevalence of Symptoms Associated with Sick Buildings and Polluted Industrial Environments as Compared to Unexposed Reference Groups Without Expressed Dissatisfaction'. *Environment International* **15**, 85-94.

Norbäck, D., M. Torgén, and C. Edling. (1990) 'Volatile organic compounds, respirable dust, and personal factors related to prevalence and incidence of sick building syndrome in primary schools'. *Brit. Med. J.* **47**, 733-741.

Norbäck, D., G. Wieslander, and C.-J. Gothe. (1988) 'A Search for Discomfort-Inducing factors in Carbonless Copy Paper'. *American Industrial Hygiene Association Journal* **49**, 117-120.

Olander, L. (1990) 'Laserskrivare och luftföroreningar En översikt'. Arbete och Hälsa **23**.

Otto, D.L., L. Mølhave, G. Rose, H.K. Hudnell, and D. House. (1990) 'Neurobehavioral and sensory irritant effects of controlled exposure to a complex mixture of volatile organic compounds'. *Neurotoxicology & Teratology* **12**.

Quackenboss, J.J., M.D. Lebowitz, and C.D. Crutchfield. (1989) 'Indoor-ourdoor relationships for particulate matter: exposure classifications and health effects'. *Environment International* **15**, 353-360.

Robertson, A.S., P.S. Burge, A. Hedge, J. Sims, F.S. Gill, M. Finnegan, C. Pickering, and G. Dalton. (1985) 'Comparison of health problems related to work and environmental measurements in two office buildings with different ventilation systems'. *Brit. Med. J.* **291**, 373-376.

Robertson, A.S., M. McInnes, D. Glass, G. Dalton, and P. Sherwood Burge. (1989) 'Building Sickness, Are Symptoms related to the Office Lighting'. *Annales of occupational hygiene* **33**, 47-59.

Rodes, C., R. Kamens, and R.W. Wiener. (1991) 'The Significance and Characteristics of the Personal Activity Cloud on Exposure Assessment Measurements for Indoor Contaminants'. *Indoor Air* **1**, 123-145.

Rothweiler, H., P. Wäger and C. Schlatter. (1991) 'Volatile organic compounds and some very volatile organic compounds in new and recently renovated buildings in Schwitzerland'. *Atmospheric Environment* (in press).

Rycroft, R.J.G. (1986) 'Occupational Dermatoses among Office Personnel. *Occupational Medicine: State of the Art Reviews* **1**, 323-328.

Seifert, B., W. Mailahn, C. Schultz, and D. Ullrich. (1989) 'Seasonal Variation of Concentrations of Volatile Organic Compounds in Selected German Homes'. *Environment International* **15**, 397-408.

Seifert, B., and D. Ullrich. (1987) 'Methodologies for Evaluating Sources of Volatile Organic Chemicals (VOC) in Homes'. *Atmospheric Environment* **21**, 395-404.

Selway, M.D., R.J. Allen, and R.A. Wadden. (1980) 'Ozone production from photocopying machines'. *American Industrial Hygiene Association Journal* **41**, 455-459.

Skoner, D.P., M.J. Hodgson, and W.J. Doyle. (1990) 'Laser-Printer Rhinitis. *New England Journal Medicine* **332**, 1323.

Skov, P., O. Valbjørn, B.V. Pedersen, and DISG. (1989) 'Influence of Personal Characteristics, Job-Related Factors and Psychosocial Factors on the Sick Building Syndrome'. *Scandinavian Journal of Work, Environment & Health* **15**, 286-297.

Skov, P., O. Valbjørn, B.V. Pedersen, and DISG. (1990) 'Influence of indoor air quality on the sick building syndrome in an office environment'. *Scandinavian Journal of Work,Environment & Health* **16**, 363-371.

Stenberg, B. (1989) 'Skin Complaints in Buildings with Indoor Climate Problems. *Environment International* **15**, 81-84.

Tencati, J.R., and H.S. Novey. (1983) 'Hypersensitivity Angiitis by Fumes from Heat-Activated Photocopy Paper'. *Annals of Internal Medicine* **98**, 320-322.

Tsuchiya, Y. (1988) 'Volatile Organic Compounds in Indoor Air. *Chemosphere* **17**, 79-82.

Tsuchiya, Y., and J.B. Stewart. (1990) 'Volatile organic compounds in the air of Canadian buildings with special reference to wet process photocopying machines', in: Proceedings of Indoor Air '90 vol. 2, 633-638.

Tucker, W.G. (1991) 'Emission of organic substances from indoor surface materials'. *Environment International* **17**, 357-363.

Turiel, I., C.D. Hollowell, R.R. Miksch, J.V. Rudy, R.A. Young, and M.J. Coye. (1983) 'The impact of reduced ventilation on indoor air quality in an office building'. *Atmospheric Environment* **17**, 51-64.

Wahlberg, J.E., and B. Stenberg. (1991) 'Skin problems in the office environment. In Exogenous Dermatoses: Environmental Dermatitis'. T. Menné, and H.I. Maibach, editors. CRC Press, Boca Raton. 327-338.

Walkinshaw, D.S., Y. Tsuchiya, and I. Hoffman. (1987) 'Exploratory field studies of total volatile organic compound concentrations in relation to sources and ventilation rates', in: Proceedings of IAQ 87, 139-149.

Wallace, L.A., C.J. Nelson, and G. Dunteman. (1991) 'Workplace Characteristics Associated with Health and Comfort Concerns in Three Office Buildings in Washington, DC', in: Proceedings of Healthy Buildings '91, ASHRAE, 56-60.

Wallace, L.A., E. Pellizari, B. Leaderer, H. Zelon, and L. Sheldon. (1987) 'Emissions of Volatile Organic Compounds from Building Materials and Consumer Products'. *Atmospheric Environment* **21**, 385-393.

Wallace, L.A., E.D. Pellizzari, T.D. Hartwell, V. Davis, L.C. Michael, and R.W. Whitmore. (1989) 'The Influence of Personal Activities on Exposure to Volatile Organic Compounds'. *Environmental Research* **50**, 37-55.

Wolkoff, P. (1990) 'Proposal of Methods for Developing Healthy building materials; Laboratory and Field Experiments'. *Environmental Technology* **11**, 327-338.

Wolkoff, P., L. Hansen, and G.D. Nielsen. (1989) 'Airway-irritating effect of carbonless copy paper examined by the sensory irritation test in mice'. *Environment International* **14**, 43-48.

Wolkoff, P., G.D. Nielsen, L.F. Hansen, O. Albrechtsen, C.R. Johnsen, J.H. Heinig, and C. Franck. (1991) 'Controlled Human Reactions to Building Materials in Climatic Chambers. Part II: VOC Measurements, Mouse Bioassay, and Decipol Evaluation in the 1-2 mg/m3 TVOC Range'. *Indoor Air*, **1**.

Wolkoff, P., P.A. Clausen, P.A. Nielsen, Gustafsson, H., B. Jonsson, and E. Rasmussen. (1991A) 'Field and Laboratory Emission Cell: FLEC', in: Proceedings of Healthy Buildings '91, ASHRAE, 160-165.

Wolkoff, P., C.R. Johnsen, C. Franck, P. Wilhardt, and O. Albrechtsen. (1992) 'A Study of Human Reactions to Office Machines in a Climatic Chamber'. Submitted.

World Health Organization (1989) 'Indoor Air Quality: Organic Pollutants'. EURO Reports and Studies No. 111, World Health Organization, Copenhagen.

HUMAN REACTIONS TO CONTROLLED EXPOSURES TO VOC's AND THE "TOTAL-VOC" CONCEPT

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ABSTRACT. This paper summarizes controlled experiments on the relation between low levels of indoor air pollution with volatile organic compounds (VOC) and human health and comfort. The dose response relation between VOC's and health and comfort effects is discussed. A biological model for human responses is suggested, based on three mechanisms: sensory perception of the environment, weak inflammatory reactions and environmental stress reactions. Further, the TVOC-indicator concept for exposure is discussed. A tentative guideline for VOC's in non-industrial indoor environments is suggested. The no-effect level seems to be about 0.2 mg/m^3. A multifactorial exposure range may exist between 0.2 to 3 mg/m^3. Above 3 mg/m^3 discomfort is expected.

1. Introduction

Volatile organic compounds (VOC's): VOC's are frequent air pollutants in non-industrial environments. A working group of the WHO categorized the entire range of organic indoor pollutants into four groups. The VOC category was defined by a boiling-point range with a lower limit between 50°C and 100°C and an upper limit between 240°C and 260°C, where the higher values refer to polar compounds (WHO 1989). Normally, 50 to 300 volatile organic compounds (VOC) are found in air samples from most non-industrial environments. Each compound seldomly exceeds a concentration of about 50 ug/m^3 (Mølhave 1986). The total concentration of all VOC-compounds (mg/m^3), is normally well below 1 mg/m^3.

Health has been defined by WHO as "A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO 1961). The toxic effects of volatile organic compounds may be defined as any significant change caused by VOCs on a person when compared to otherwise comparable, but unexposed persons. Such effects may be classified in effects common to most VOC's and effects specific for individual compounds.

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This paper is focused on the causality behind the more common effects of VOCs according to the definition above. These also happens to be the most frequent effects of low level VOC exposure. For simplicity, the effects of low level exposures to VOC's will be divided into a) Disturbances of body functions and b) Perception of the environment or of body conditions. Further, to avoid confusion, the term perceived indoor air quality (PIAQ) will be used for the subjectively perceived air quality in contrast to measured indoor air quality (MIAQ) which is the chemically or physically measured indoor air quality e.g. in the form of air temperature, air humidity, pollution concentrations etc. A distinction will be made between the occupants' adapted perception after exposure for one hour or more and the visitors immediate and adapted response upon entrance into the room. Generally, in this paper these two types of evaluations are referred to as subacute and acute responses. Also, the term "irritation" will be specified as either stimulation of sensory systems, inflammatory-like skin reactions, or a psychologic mood condition. If not specified generally sensory irritation is meant.

2. A Biological Model for Health Effects caused by VOC-Exposures at Low Levels

One of the Henle-Kock criteria (Mølhave 1991) for a causality between VOC's and health effects (e.g. complaints about reduced indoor climate) is that a reasonable biological model exists which can explain the known features of the suggested causality. In the following, such a model will be suggested with the aim of explaining as many as possible of the indications found in the literature and leaving a minimum of unexplained evidence of effects. The suggested model is still a postulate and should be challenged in future experiments and investigations.

From the literature it appears that the most frequent acute or subacute effects of VOC-exposure at low level fall in three main classes: a) perception of the environmental exposure caused by acute stimulations of senses, b) perception or observation of weak acute or subacute inflammatory-like reactions in the exposed tissues, and finally c) a number of effects which may be described as a group of subacute environmental stress reactions caused by the perceptions (Mølhave 1990).

Perceived air quality: Our present knowledge about the senses indicates that VOC's are sensed by either the odorous sense in top of the nasal cavity, the gustatory senses on the tongue or the chemical sense (Cain 1989). The three sensory systems: odor, taste and chemical sense respond to airborne chemicals, but to different qualities of the exposure. Stimulation of one, two or three of these sensory systems seem to result in a combined perception of something which may be called the perceived indoor air quality (PIAQ). This perceived air quality may even include additional nerve signals from other senses like vision (e.g. haze), or the thermal environment.

The chemical sense includes both the trigeminal nerve in facial skin and in mucosal membranes of eyes, nose and mouth and other similar non-myelinated nerves in other skin-areas (Cain 1989). These nerves have polymodale receptors. They, therefore, can respond to many different types of stimuli. The receptors are supposed to respond to environmental chemicals following a chemical reaction or a physical adsorption of the compounds to the receptor proteins.

Activation of the senses leads to two effects. First, a sensation of, for example, an irritation, a burning, smarting or stinging feeling and, secondly, protective reflexes. These may, for example,

be tearing, changed respiratory frequency, cough or sneezing. (Brink et al. 1948, Nielsen et al. 1985a, Nielsen et al. 1988).

Inflammation: In medicine inflammatory reactions are related to microbiologic, metabolic or immune system reactions and are generally considered to be a protective reaction to a potential cell damage. Inflammation is known both as acute and subacute reactions (Thaysen et al. 1980). Only the acute reversible reactions seem to be relevant to the low level VOC-exposures in non-industrial environments. Generally, the first sign of acute inflammation is indications of peripheral dilatation of vessels causing color and temperature changes of tissue. Subsequently granulocyte and other cell types are activated (Thaysen et al. 1980).

Most acute inflammatory reactions are supposed to be activated by chemical mediators released in the exposed tissues. More than ten different chemical classes of mediators have been identified (like Histamine and Kinines). These mediators are produced after an external exposure to irritants. Most of these mediators are themselves known to be sensory irritants and are supposed to stimulate sensors in the tissue and cause a secondary perception of the exposure (Thaysen et al. 1980).

If the exposure increases in intensity or duration beyond the point of comfort or safe, the body may react by initiating protective reflexes or mechanisms. These reflexes may be activated either by chemical mediators or through sensory perception and nervous signals. Examples are running eyes or nose, cough, changes in respiratory pattern, increased mucosal secretion, increased blood flow to exposed skin areas etc.

Environmental stress: The constant effort needed to identify the wanted and to override the unwanted sensory information as well as the efforts needed to maintain protective reflexes is a strain to humans and may by itself cause secondary effects. If such stress-situations are continued for an extended period of time stress-like complaints will be heard, of which headache seems to be the most important.

Symptoms of weak environmental stress are well known from both the indoor- and the outdoor environment. Many different physical or chemical exposures have been shown to cause these typical stress-symptoms which have been reviewed by Evans et al (Evans et al. 1989). Some typical symptoms are shown in table 1.

A biologic model, which explain the combined reactions of humans to multifactorial exposures in the indoor environment (MIAQ) including VOC's must reflect that environmental exposures or stressors are causing overlapping spectra of health effects. Also, the combined reversible effects of a MIAQ exposure which include a major VOC-component should be falling in the three classes described above. They are: perception, inflammatory-like- and stress-like reactions.

In the exposed tissue both primary and secondary acute processes occur. The primary processes are stimulation of sensory nerveendings or initiation of weak inflammatory tissue reactions. The secondary acute effects in the exposed tissue are perceptions of the tissue reactions, initiated reflexes due to the primary perception of exposures or changed sensitivity of the senses due to tissue changes. Subacute effects may also occur. They are environmental stress reactions or

Table 1. Some typical symptoms of environmental stress [a]).

Increase in stress hormone levels.
Blood pressure increase.
Fatigue.
Irritability and reduced tolerance.
Reduced productivity, errors.
Psychological symptoms.
Attempts to change stressors.
Feeling of helplessness, lack of control of stressors.
Changes in feeling of job satisfaction, or life quality.

Note: [a])Evans et al. 1989.

more severe skin reactions. The three types of effects expected to follow from low level exposure to VOC according to this model are summarized in table 2.

The intensity of each of the symptoms may be modified by additional factors such as age, smoking history, or gender. Further, the number of symptoms observed and their intensity may cause a feedback on the individual's behavior, thereby causing them, for example, to modify their environment, or to focus on certain symptoms and thus suppress others. Consequently, each subject may react differently to the mixed exposure and exhibit only a few of the symptoms from the spectrum of symptoms observed in the exposed population as a group.

According to this model, the type of effects associated with VOC exposures are unspecific and may be caused by environmental exposures other than chemicals. For example physical exposures, such as temperature or inert dust, may cause a similar spectrum of symptoms. Any discussion of a causality between VOC's and the type of symptoms appearing in table 2, therefore, must discuss not only the VOC exposure levels, but also the level of other contributing exposure factors.

The discussions in occupational hygiene normally focus on one health risk factor at a time and in such ranges of it, that the considered exposure factor can be assumed to be the only, or at least the primary cause of health effects. Such extreme exposures are typically not found in non-industrial buildings. In consequence, the dose-response relationship may be multifactorial and include a number of exposure factors (temperature, concentration of pollutants, etc.) in the etiology.

Under field conditions three exposure ranges are of interest. They are defined by the relative contribution of VOC exposure to the prevalence of effects or symptoms. Below a lower threshold (the no-effect level) no effects are expected to follow from the exposure to VOC's despite any other simultaneous occurring exposure. Above an upper threshold (the effect level), an effect of VOC's is expected even when all other exposure factors are controlled and acceptable.

Between the two thresholds a correlation may or may not occur between VOC's exposure and the prevalence of effects depend on the interactions from other exposure-factors or the composition of the exposure. This range is called the multifactorial exposure range. In this exposure range a consistent or monotonous dose-response relation may not exist and complaints may not necessarily disappear if one of the relevant exposure factors is removed from the environment.

3. The Concept of Total Volatile Organic Compounds (TVOC)

At present no proper unit has been established for a measure of the combined effects of the many different compounds in the atmosphere. Addition in mg/m^3 of masses of polluting molecules has been suggested and in relation to volatile organic compounds it is often called the TVOC-indicator (Mølhave 1986, 1990). This measure is easily obtained through the chemical analysis (e.g. using an integrating FID-detector). From a biological point of view, number as molecules per m^3 (the molar concentrations in PPM of PPB) may be more relevant. Mathematical functions based on combinations of other variables like type of radicals, vapor pressure or polarity of the compounds have also been suggested as indicators.

According to our present knowledge a simplified chemical and physical model, includes three steps which describe the absorption of airborne pollutants into the liquids of the mucosal membrane, and the subsequent binding to the receptor, which is followed by reactivation of the receptor. Such a model has previously been described in the literature (Nielsen et al. 1985 b, Nielsen et al. 1988, Kristiansen et al. 1988) and among other things assumes ideal gas conditions of the air phase and a lipophilic receptor compartment. In Mølhave et al. (1992) this model has been used to identify the short-cuts made in the derivation of the TVOC-indicator. It appears that the TVOC-indicator under specified assumptions may be an estimation of the lower level of response in the form of perceived unspecific stimulation of nerves in a population after exposure to VOC's. The response may be proportional to the sum of mass-concentrations (mg/m^3) of the compounds in the air if the following assumptions are made:

a) The response is caused by unspecific stimulation of lipophilic sensors which respond additively to a multicomponent exposure.

b) The exposure consists of compounds with equilibrium constants differing no more than the compounds can still be assumed to react equally strong with the unspecific sensors.

c) The molecular weights and the vapor-pressures of the compounds are assumed to be within limited ranges.

d) This will not apply for substances which react chemically with the receptor, e.g. formaldehyde or acrolein. Such reactions may cause an additional reaction to be added to the estimated lower limit for unspecific response.

e) The indicator can not be used to predict other types of effects for example effects on CNS, tissue changes or cancer.

The simplifications used in Mølhave et al. (1992) to develop the TVOC concept are based on experimental evidences. However, it must be emphasized that the TVOC concept has not yet been thoroughly tested in practice and therefore still is a postulate.

4. Some Controlled Experiments with Low Level VOC Exposure and Health Effects

4.1. CONTROLLED EXPERIMENTS WITH LOW LEVEL VOC EXPOSURE AND HEALTH EFFECTS

Investigations and experiments with controlled low levels of volatile organic compounds (VOC's) are for several reasons more difficult to interpret than traditional clinical investigations and experiments with toxic compounds (Mølhave 1991). At the present few acceptable objective measures exist for effects. These low level experiments often use unspecific subjective reactions as the only available measures of effects. This has a number of consequences for the experiments.

These limitations reduce their usefulness for conclusions about causality of most experiments at low exposure level and are summarized in (Mølhave 1991).

Experiments at higher exposure level e.g. experiments around or above occupational threshold limit values often focus on health effects much more severe for the affected few persons than the relatively harmless, but more frequently appearing comfort-reduction caused e.g. by mucous membrane irritation. Also, these high level exposure experiments may use only an adult and healthy population excluding more sensitive groups such as children or older persons. Further, the high level exposure experiments may include exposure times different from normal non-industrial occupancy.

Few occupational experiments, therefore, are relevant for extrapolation to the low range of concentrations found in the non-industrial indoor environments. Some experiments have been done in which humans have been exposed to low levels of VOC. Four controlled exposure experiments were established in the climate chamber at our institute to test if low exposure levels of VOC's may cause reduced well being or discomfort (Mølhave et al. 1986, Mølhave et al. 1991, Kjærgaard et al. 1989, Kjærgaard et al. 1990). A more recent experiment in the USA replicated the first of these Danish experiments (Otto et al. 1990). These experiments are summarized in table 2 and 3.

5. Discussion

5.1. DOES A CAUSALITY EXIST BETWEEN VOC EXPOSURE AND HEALTH FULFILLED

In order to be accepted, any proposed causality between VOC and health must fulfill criteria such as the Henle-Kock criteria (Mølhave 1991). It must be emphasized that although fulfillment of these criteria is a strong evidence for the proposed causality, then this may not be a sufficient or a final prof.

Table 2 and 3 summarizes the conclusions of the five controlled experiments dealing with low level VOC exposures. The table shows the positive or negative findings at different TVOC levels in relation to the main types of effects expected according to the suggested biological model (Mølhave 1990).

The experiments indicate that in controlled exposures, effects follow exposure to VOC's as required according to the Henle-Kock criteria, which requireres that Exposure to VOC's should be present more commonly in those showing the effect than in controls without the effect when all risk factors are held constant. Perceptive effects are observed at TVOC-concentrations higher than 3 mg/m^3. Other subjective effects follow exposures at higher exposures.

Few inflammatory reactions were reported although some of the irritative effects may be of inflammatory origin or may be caused by chemical mediators. Changed tearfilm stability and cell counts were seen at 25 mg/m^3. Subjects also reported changed temperature sensation in the exposed skin areas at 25 mg/m^3. These observations may indicate weak inflammatory reactions. 25 mg/m^3 seem to cause weak environmental stress symptoms like headache and drowsiness. Associated psychological effects like changed performance, confusion, and fatigue is also found at 25 mg/m^3. These effects are known from higher exposure levels, but have not been consistently found in low level exposure experiments. At present 25 mg/m^3 seem to be the lowest controlled exposure which has indicated such physiological effects.

These experimental findings show that measurable group responses are found in controlled exposure experiments as required in criterion. A measurable response following exposure to VOC's should regularly appear among occupants lacking this before exposure or should increase in magnitude if present before exposure. The responses follow a gradient from sensory effects (odor 3 mg/m^3) and indications of subacute inflammatory reactions (changed leukocytes in liquids, perceived skin temperature at 25 mg/m^3) and indications of subacute stress-reactions at 25 mg/m^3. The Henle-Kock criterion of progression of the effects, therefore, also seems fulfilled.

The total environmental exposure in most field investigations is multifactorial as other factors than VOC exposure may exceed their no-effect levels. Most of the effects reported in field investigations, therefore, may have more than one cause. Consequently, it is not surprising that effects of VOC exposures in field investigations seem to occur at lower exposure levels than in controlled experiments where other exposure factors than VOCs are supposed to be below their no-effect levels. Further, in the clinical experiments the exposure times were less than 3 hours which from field experience seem too short a period to cause severe subacute effects at low exposure levels. Much more research is needed to finally establish if subacute effects may occur after prolonged exposures.

In a review of field investigations, it was found that complaints seem to be present when the concentrations exceed 1.7 mg/m^3. Below 1.7 mg/m^3 complaints may occur if other types of simultaneous exposures are present (Mølhave 1986). The concentrations reported from field investigations are improperly documented and they may be biased. The published investigations do, however, indicate that the concentrations of volatile organic compounds are generally higher in problem houses than in the houses without problems (Mølhave 1986).

Table 2. Three classes of human responses to VOC's in normal indoor air. Primary reactions are observed at acute low-level exposures. Secondary effects are observed after prolonged or more intense exposures. Their intensity depend on the properties of the dominating compounds in the exposures and on the sensitivity of the subjects. The table further shows examples of effects found in controlled experiments with humans. (+ significant effect; - no effect seen; 0 no information; ( ) indication of effect/no effect)

A: Acutely perceived deteoriation of the quality of the environment.

	Type of mechanism	Examples of effect	Concentration (mg/m^3)					
			3	5	8	15	25	40
Primary	Recognition of exposures	Odor perception	+2	+1	0	0	+4 +5	+3
		Stinging itching etc.	0	(-1)	+2	0	+4 +5	+3
		Reduced air quality, Need more ventilation	0	0	+2	0	+1 +4 +5	+3
Secondary	Reflexes in eyes, nose and airways	0	0	0	0	0	0	0
	Changed mucosal secretion	Changed tearfilm stability	0	0	0	0	0	+3
		Changed cell counts in eye liquids	0	0	0	0	+4	+3
	Difficulties in breathing	0	0	0	0	0	0	0
	Activities to change the environment	Need more ventilation	0	0	+2	0	0	0

Continued:

Table 2 (continued)

B: Acute or subacute reactions in skin or mucous membranes similar to beginning inflammatory reactions.

	Type of mechanism	Examples of effect	Concentration (mg/m^3)					
			3	5	8	15	25	40
Primary	Dilation of peripheral vessels	0	0	0	0	0	0	0
	Stinging, itching or tingling feeling	Perceived irritation	0	(-1)	+2	0	+5	+3
Secondary	Pain	0	0	0	0	0	0	0
	Changed skin temperature	Perceived skin temperature	0	0	0	0	(+1)	0

C: Subacute and weak stress-like reactions ("Environment stress").

	Type of mechanism	Examples of effect	Concentration (mg/m^3)					
			3	5	8	15	25	40
Primary	Discomfort and complaints	Headache	0	0	0	-2	-1 -4 +5	0
		Drowsiness	0	0	0	0	+5	0
Secondary	Complications in body functions and physiological effects	Changed composition of eye and nose liquids	0	0	0	0	(+1)	0
		Changed odor threshold	0	0	0	0	(+1)	0
		Changed performance	0	0	0	0	(+1) (+4) -5	0
		Changed mood	0	0	0	0	(+1) +5	0
		Changed lung function	0	0	0	0	(+4)	0

Table 3. Summary of 5 exposure experiments.

Ref.	Exposure		Population		Measures of effects
	type	mg/m^3	type	number	
1	M22	0, 5, 25	Randomly selected but SBS-sensitive	64	Subjective sensory responses, indications of neurologic effects and changes in eye and nose liquids
2	M22	0, 1, 3, 8, 25	Randomly selected and healthy	25	Sensory symptoms headache and general well-being
3	N-decane	0, 40, 140, 400	Random healthy	63	Sensory symptoms Tear film stability Leukocytes in eye liquids
4	M22	0, 25	Healthy SBS subjects	21 14	Sensory Symptoms Lung function Leukocytes in eye liquids and nasal secretions Performance
5	M22	0, 25	Healthy males	76	Sensory symptoms Neurobehavioral tests

M22 = standard mixture of 22 indoor air pollutants

1 Mølhave et al. 1986
2 Mølhave et al. 1990a
3 Kjærgaard et al. 1989
4 Kjærgaard et al. 1990
5 Otto et al. 1990

A recent field investigation finds effect of VOC's at concentrations in the range from 0.05 to 1.38 mg/m^3 (Nordbäck 1990). The exposure range from 0.19 mg/m^3 to 0.66 mg/m^3 was estimated in the Danish Town Hall Study for the lower threshold of no-effects (Zweers et al. 1990). This range corresponds to the range of the lower limit of concentrations in buildings with complaints and is at present the best estimate of the lower exposure limit for no-effects of VOC's.

Reactions do not seem to be related to a hypersensitive group of subjects. The same reactions were found among normal healthy subjects in the Danish experiments (Mølhave et al. 1986, 1991, Kjærgaard et al. 1989, 1990) and in the American experiment (Otto et al. 1989). Subjects responding strongest did, however, seem to have special characteristics like stronger skin-response to irritating compounds (Kjærgaard et al. 1990) and among persons claiming often to suffer from Sick Building Syndrome, a significant, but only slightly stronger response was found (Kjærgaard et al. 1990). These SBS-subjects also showed indications of lung-functional changes (Kjærgaard et al. 1990). However, the five controlled experiments contain few or no consistent investigations of lung function, allergic or systemic effects.

No definitive conclusion can be made with respect to the influence of other co-factors. In those few investigations dealing with such factors both positive and negative indications were found. The information, however, indicates that future research with more sensitive experimental designs and analytical methods may show such effects.

The laboratory experiments indicate that the effects which are expected according to the biological model, can be experimentally reproduced and are acutely following the exposure. The two criteria that the effects should follow exposure to VOC's (possibly with a delay time) and experimental reproduction of the effects should produce higher incidence in animals or man appropriately exposed to VOC's than in those not so exposed, therefore, are also fulfilled. No field investigations have been reported of tests of the effects of elimination or modifications of VOC-exposure. Post exposure measurements during the controlled experiments, however, indicate that the effects are reversible and disappear shortly after exposure.

In conclusion no evidence is contradicting the proposed causality between the effects tentatively related to low level exposure to VOC. On the contrary does evidence from controlled exposure experiments support the causality. The controlled experiments are, however, yet too few to allow a final conclusion.

5.2. THE MODEL FOR HUMAN REACTIONS TO LOW LEVEL EXPOSURES TO VOC

Previously, in (Mølhave 1991) a set of four criteria was established, which an acceptable biological model for the causality of a proposed etiology must fulfill. The first criterion was that the model must explain the observed effects. The list of effects expected according to the model to follow from low level exposure to VOC's coincides very well with the effects observed in epidemiological field investigations and controlled experiments. It appears that sensory irritation, olfaction, irritation, and weak neurologic effects seem to be the dominating effects of low level VOC exposure. The first criterion for an acceptable model, therefore, seems to be fulfilled.

Table 4. Tentative dose-response relation for discomfort resulting from exposure to solvent like volatile organic compounds as air pollutants in non-industrial indoor environments

Total concentration[a] mg/m^3	Irritation and discomfort	Exposure range
<0.20	No irritation or discomfort	The comfort range
0.20-3.0	Irritation and discomfort possible if other exposures interact	The range of multifactorial exposures
3.0-25	Exposure effect and probable headache possible if other exposures interact	The range of discomfort
>25[b]	Additional neurotoxic effects other than headache may occur	The toxic exposure range

[a]Measured as TVOC according to Mølhave et al. (1992)
[b]This range is only partly discussed in this paper

The effects are all known from similar or higher exposure levels. The third criterion, therefore, is fulfilled. Any delay in effects caused by low level exposure has yet to be identified. Some indications of a sub-acute latency exist. According to the model, such a latency of the effects is explained by the subacute skin and stress reactions following prolonged exposures. Therefore, the fourth criterion also seems to be fulfilled.

The model does not include acceptable measures of a combined exposure to the many compounds simultaneously found indoors. Some indicator measures have been suggested. These indicator measures are all based on simplifications of which only some have been justified and fewer thoroughly investigated. At present, they cannot be used for risk assessment, mitigation etc. Further, co-variables e.g. in relation to non-chemical exposure and subject sensitivity have not been investigated in details, and few acceptable measures or indicators exist for possible co-variables related to the model. The criterion 2 dealing with acceptable measures or indicators of an exposure, therefore, is not yet fulfilled.

5.3 TENTATIVE GUIDELINES FOR VOC'S IN NON-INDUSTRIAL ENVIRONMENTS

The observations summarized here have major limitations. They do, however, indicate that VOC's may be important for the indoor air quality especially in the form of discomfort due to odors and irritative symptoms in eyes, nose, and throat, and headache. The list of effects may include other effects, for example, related to productivity and performance. Such effects have not yet been positively identified.

The tentative conclusion of the available epidemiological studies (Mølhave 1986, Mølhave 1990) and the exposure experiments are summarized in table 4. It indicates that no effects are expected as a result of exposure to VOC's below about 0.2 mg/m^3.

At concentrations higher than about 3 mg/m^3, complaints seem to occur in all investigated buildings with occupants having symptoms. In controlled exposure experiments, odors are significant at 3 mg/m^3.

At 5 mg/m^3 objective effects were indicated besides the subjective irritation. Exposures for 50 min. to 8 mg/m^3 lead to significant irritation of mucous membranes in eyes, nose, and throat.

In the reviewed literature few acceptable indications of exposure levels are given, which allow an estimate of the threshold for headache. Concentrations below 3 mg/m^3 in field investigations were found to show a significant difference in frequencies of headache between problem buildings and control buildings. On the other hand significant headache was found in only one of the exposure experiments and then at 25 mg/m^3.

The reason for the lower threshold in field investigations may be either the interaction of other exposures, or the effect of longer exposure durations. Therefore, based on the present information, the threshold for headache and other weak neurotoxic effects caused by exposure of less than a few hours' duration are expected to be between 3 and 25 mg/m^3.

These conclusions refer to the more prevalent of the effects caused by VOC exposure of norma subjects. Risk groups may exist, which respond stronger than the normal population. Such indications of lungfunction reactions were found in a pilot study on allergic persons exposed to 25 mg/m^3 VOC (Harving et al. 1989). Further, future investigations dealing with larger groups of persons may reveal special effects like allergy or carcinogenicity from low level exposures to VOC's. These special effects, however, have not been demonstrated to follow from exposure to the type of compounds and concentrations of VOC's found in indoor air.

6. References

Brink F, Posternak I (1948). "Thermodynamic Analyses of the Relative Effectiveness of Narcotics". J.Cell.Comp.Physiol. 32:211-233.

Cain, WS (1989) "Perceptual Characteristics of Nasal Irritation". Report/NIH grant NS 21644 from John B. Pierce Foundation Laboratory and Yale University, 290 Congress Avenue, New Haven, CT 06519. Presented at: Course on Sick Building Syndrome, October 1989, National Danish Institute on Occupational Health, Copenhagen, Denmark.

Cometto - Muniz JE, Cain WS (1984) "Temporal Integration of Pungency", Chemical Senses 8:315-327.

Evans GW, Carrere S, Johansson G (1989). "A Multivariate Perspective on Environmental Stress". Arch. of Complex Environmental Studies. 8(1):1-5.

Harving H, Dahl R, Mølhave L (1989). "Lung Function and Bronchial Reactivity in Asthmatics During Exposure to Volatile Organic Compounds". Am. Rev. Resp. Dis. 143:751-754.

Kjærgaard SK, Mølhave L, Pedersen OF (1989). "Human Reactions to Indoor Air Pollutants: n-Decane". Environment. International 15:473-482.

Kjærgaard SK, Mølhave L, Pedersen OF (1990). "Human Reactions to a Mixture of Indoor Air Volatile Organic Compounds". Atmospheric Environment 15:473-482.

Kristiansen U, Nielsen GD (1988). "Activation of Sensory Irritants Receptors by C7-C11 Alkanes". Arch.Toxical 61:419-425.

Mølhave L (1986). "Indoor Air Quality in relation to Sensory Irritation due to Volatile Organic Compounds"; Paper 2954, ASHRAE Transactions, 92(1).

Mølhave L (1990). Volatile Organic Compounds, Indoor Air Quality and Health. In (Edit) D. Walkinshaw "Indoor Air '90", Toronto, Canada, 5:15-23.

Mølhave L (1991). Design Considerations for Exposure Experiments at Exposure Levels below TLV. (Accepted for Eur. Psychol. J.).

Mølhave L, Bach B, Pedersen OF (1986). "Human Reactions to low Concentrations of Volatile Organic Compounds". Environment International 12:167-175.

Mølhave L, Grønkjær J, Larsen S (1991). "Subjective Reactions to Volatile Organic Compounds as Air Pollutants"; Report 1987 from Inst. Occup. & Environm. Med., University of Aarhus, Denmark. Atmospheric Environment. 25A:1283-1293.

Mølhave L, Nielsen GD (1992). "The TVOC Indicator of Human Response to Low Level Exposures to Volatile Organic Compounds (VOC)". Submitted for "Indoor Air" 1991.

Nielsen GD, Bakbo JC (1985a). "Sensory Irritating Effects of Allyl Halides and a Role for Hydrogen Bonding as a likely Feature at the Receptor Site. "Acta Pharmacol. et Toxicol. 57:106-116.

Nielsen GD, Bakbo JC (1985b). "Exposure Limits for Irritants". Annal. Am. Conf. Governm. Indust.Hyg. 12:119-133.

Nielsen GD, Vinggaard AM (1988). "Sensory Irritation and Pulmonary Irritation of C3-C7 n-Alkylamines; Mechanisms of Receptor Activation". Pharmacology and Toxicology. 63:293-304.

Nordbäck D (1990). "Environmental exposures and personal factors related to Sick Building Syndrome". Theses from Uppsala University, Acta Universitatis Upsaliensis. 280, P. 1-60, Uppsala, Sweden.

Otto DA, Mølhave L, Hudnell HK, Goldstein G, O'Neil J (1990). "Neurotoxic Effects of Controlled Exposure to a Complex Mixture of Volatile Organic Compounds". USEPA, HEARL, Research Triangle Park, NC 27711, USA. EPA/600/1-90/001;P1-98.

Thaysen JH, Christensen LK, Lorenzen I (1980). "Medicinsk Kompendium". 12: Vol 1. Copenhagen, Denmark.

World Health Organization (WHO) (1961). "Constitution of the World Health Organization: Basic Documents". 15th edition, Geneva, Schwitzerland.

World Health Organization (WHO) (1989). "Indoor Air Quality: Organic Pollutants"; Report on a WHO-meeting, Euro Reports and Studies 111, WHO Regional Office for Europe, Copenhagen, Denmark.

Zweers T, Skov P, Valbjørn O, Mølhave L, Danish Indoor Climate Study Group (DISG) (1990). "The Effect of Ventilation and Air Pollution on Perceived Indoor Air Quality in Five Town Halls". Energy and Buildings, 14:175-181.

QUESTIONNAIRES IN EXPOSURE AND EFFECT ASSESSMENT IN THE FIELD

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ABSTRACT. In indoor climate studies, a recurrent problem is to quantify discomfort and annoyance due to disturbing factors in the building. The typical approach is the questionnaire survey. One difficulty is to select attributes that adequately reflect people's conceptions of environmental factors. Discomfort, disturbance and annoyance have different meanings for different population groups. Furthermore, environmental variables are difficult to scale quantitatively as they are perceived. Since we design our buildings with regard to capacities and abilities of individuals to cope with them we are obliged to consider the opinions of people. As a consequence, a quantification of reactions has to rely on verbal reports or other kinds of "subjective judgments." The methods used must give quantitative information about psychological variables on a satisfactory level of measurement (interval or ratio scales) as a base for reliable conclusions about dose-response relationships. Scales of discomfort or annoyance from different populations will always give different units of measurement and such scales cannot be compared unless the scales are calibrated.

1. Introduction

Perceptual and comfort aspects are essential in building climate control. They involve a complex of thermal, air quality, visual, and auditory sensations. Thus, sensory reactions play a decisive role. These reactions are a synthesis and integration of complex environmental exposures. The measuring device is mainly the sensory systems. Evaluations may be based on measuring the excess incidence or prevalence rates of subjective observations, symptoms, and complaints, or of medically more or less well defined disorders.

The typical tool for assessing sensory effects in occupied buildings is the questionnaire survey from which dose-response relationships may be constructed. Two main classes of perceptions are at focus. The first and obvious class includes perceptions which the observer attributes to the surrounding physical environment (*Environmental Perceptions*). Examples are draft and odor. The second and less obvious class includes perceptions of events inside the body or taking place on the body surface (*Body Perceptions*). Examples are perceived eye irritation or dry skin. The observer may or may not be able to attribute the body perceptions causatively to the surrounding physical environment. Commonly, it is much easier to establish dose-response relationships for

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environmental perceptions than for body perceptions. The latter are to a larger extent determined by unknown observer-related factors.

In a survey of sensory effects usually a representative group of persons is presented questions on perceptions and symptoms with several well defined response categories. Two principal approaches are common: (a) a battery of questions constituting an attitude scale to obtain, for example, scores of annoyance and discomfort or (b) self-rating questions to obtain direct estimates of perceptions and symptoms. The results of the self-rating questions are treated in different ways depending on whether the aim is to measure the extensity of effect (e.g., prevalence) or the mean degree of the effect (e.g., symptom strength) in the population. When self-rating questions are chosen, certain general requirements should be satisfied. First, one should openly display the assumptions behind the method of effect assessment. Second, the allowances and constraints of the measurement method should be clarified before it is used for comparing dose-response relationships. Finally, a calibration procedure should be attempted in the measurement.

Surveys of sensory effects are mostly conducted in occupant populations who are chronically exposed to the indoor environment. This circumstance always limits the generalization of result for criteria work. The responses from exposed individuals may be biased due to the exposure itself, differences in attitudes, and other so-called extra expositional factors. Their response criteria may differ from the criteria of the non-exposed individuals. Similarly, the response criteria for populations exposed but to a varying degree may differ. To obtain comparability between differently exposed populations, the variation of the response criteria must be known and if necessary corrected for.

As said above, questionnaire techniques are often used for measuring both indoor air quality variables (Environmental Perceptions) and reported symptoms (Body Perceptions) among occupants in buildings. Usually, a pattern of indoor air perceptions and a pattern of symptoms are desired. A pattern can be different between indoor chemistry and odors: the presence or absence of a chemical substance has been shown to be uncorrelated with the presence or absence of perceived odor. A similar point can be made for the relationship between chemistry and symptom reports: the pattern of presence or absence of chemical substances may exert a joint effect on the health of the occupants. In addition, concentration may be irrelevant for both chemistry and symptom patterns. For instance, substances available in very weak concentrations may nonetheless produce strong odors and, conversely, substances available in strong concentrations may not be sensed at all. A single spike of chemical concentration may be a powerful stimulus for a sensory reaction whereas long-term health effects may result from the continued exposure to low concentrations of toxic substances in the indoor air.

It is clear that pattern representations should be examined together with the concentration for single substances. This means that recognition of patterns (e.g., between sick and healthy buildings) requires that we match patterns obtained in different buildings, decide on the similarity among patterns, and use similarity measures to decide upon the similarity of conditions within different buildings.

2. The Questionnaire

Writing questions for questionnaires is not simply an art; a scientific approach should be taken. Some guidelines have emerged from the collective research tradition, as for example presented by Sudman and Bradburn (1982) and Converse and Presser (1986). The basic core of questions is of course that they are formulated with the aid of language.

Thus, there is a need for simplicity, intelligibility, and clarity. It is imperative that common language should be used, questions should be short, and confusions should be avoided (Sheatsley, 1983).

If the respondent is faced with a task he cannot manage, the responses have low information value. It is believed that it is easier to answer questions bearing on one's own experience and behavior ("facts") than questions on opinions and attitudes ("evaluations"). The latter are assumed to be more open to the respondent's own definition than the former. Thus, it has been repeatedly pointed out by field researchers that it is the respondents who know the full definition of the question.

2.1. RECALL OF THE PAST

Valid descriptive data are obtained from questionnaires that focus on the current, the specific, and the real (Turner & Martin, 1984). Memory questions in general appear to be difficult for the respondent. Recalling an event or behavior can be especially difficult in several circumstances: (a) if the decision was made almost mindlessly in the first place, (b) if the event was so trivial that people have hardly given it a second thought since, (c) if questions refer to events that happened long ago, and (d) if recalls are required of many separate events. Even important events either fade with time or require specific cues to bring them into focus at the time of the survey. Preferably questions should refer to the respondents' perceptions "right now."

Five techniques have been recommended to improve the validity of reporting on past events (Converse & Presser, 1986). (1) *Bounded recall* addresses the over-report due to "forward telescoping" outside the requested time range. It may be controlled by establishing the baseline in an initial survey. (2) *Narrowing* the reference period for survey reporting is a good corrective means. In questions related to the Sick Building Sundrome (SBS), it is recommended that they refer to the conditions "right now." (3) *Averaging* or questions about typical conditions are better than the "single day" focussed questions. (4) *Landmark events* may be referred to instead of specific dates to anchor the timing of other events. The question could ask about a symptom "since Christmas", instead of "during the last month." (5) *Cueing* means that cues are provided to help memorizing. The purpose of cues is to simulate recall by presenting a variety of associations.

2.2. SIMPLICITY IS THE RULE, COMPLEXITY THE EXCEPTION

There are some cases when the simplicity rule of question design does not apply. For example, *Factorial Surveys* uses vignettes of "stories" in the study of judgment, decision making, or attribution processes. Factorial surveys have some attractive features. The respondents see the vignettes of concrete, detailed situations on which to make judgments rather than being asked for abstract generalizations. Even though the questions are hypothetical, vignettes reduce the need for respondents to be insightful and conscious of their own thought process. This vignette technique has been conducted with occupational groups as well as with the general public, for example, in studies of annoyance to community noise. According to Converse and Presser (1986) methodological work is not yet available on various important issues.

Ranking Scales have a long history in survey research. Alwin and Krosnick (1985) showed that rankings (rank order is given) do not show the same relationships to predictor variables as *Ratings* (category scale value is given) even though the same factors were investigated. *Magnitude Estimation Scales* are examples of a third, more complex, technique of responding. Magnitude scaling of annoyance and attitudes has been

"calibrated" through numerical estimation and physical line-length estimation of physical stimuli such as light and sound (Berglund, Berglund & Lindvall, 1975; Lodge, 1981). Although these more complex techniques have considerable interest and potential usefulness in survey research, there is much about them that we do not yet understand.

2.3. SOME OTHER IMPORTANT ISSUES

Standardized measurement is central to survey research. The idea of standardization is to define the measurement instrument in relation to a subpopulation for which it discriminates, for example, the normal population or children or asthmatics. The survey instrument may simply be a questionnaire or a questionnaire combined with psychological and physiological tests thus together constituting a test battery. The standardization of questionnaires is most successful if the respondents only are allowed to respond according to the same principles. Therefore questionnaires with closed questions are easiest to standardize for a subpopulation. A widespread criticism of closed questions is that they force people to choose among offered alternatives instead of responding in their own words. Because closed questions give the same response options, they are more specific than open questions, and therefore more apt to communicate the same frame of reference to all respondents.

The typical survey question incorporates assumptions not only about the nature of what is to be measured, but also about its very existence. The most basic finding from research on question wording is a double edged one: Even small changes in wording can shift the answers of many respondents, but it is frequently difficult to predict in advance whether or not a wording change will have such an effect.

Large-scale surveys are now common in SBS research. In designing a questionnaire, one should consult these earlier data for they are very likely to save time and effort. However, also borrowed questions need pre-testing because the meaning of questions can be affected by the context of neighboring questions in the questionnaire. The following should be considered in a pre-test: variation, meaning, task difficulty, respondent interest and attention, flow and naturalness of the questionnaire sections, the order of questions, "skip" patterns or internal drop outs of responses, timing, respondent interest and overall attention, and respondent well-being with the response task (Converse & Presser, 1986).

3. What is Being Measured?

In questionnaire and physical-chemical surveys of the indoor climate in buildings, it is imperative that the purpose or research problem of the survey will determine in which "measurement form" the results have to appear. There is a difference between (a) measuring a physical or psychological variable and (b) estimating the risk of an outcome; the social scientists usually focus on the former type of results while the health epidemiologists focus on risk estimation (probability of an event).

3.1. OUTCOME

In epidemiology the concept of outcome has a specific meaning. It refers to "all possible results that may stem from exposure to a causal factor, or from preventive or therapeutic interventions; all identified changes in health status arising as a consequence of the handling of a health problem" (Last, 1983). Miettinen (1985) has a more restricted definition: "The state or event whose occurrence the study is to address." The impression

of restriction stems from the feeling that occurrences can only be determined in two classes, presence or no presence. According to Last (1983) "occurrence" is used in epidemiology for the frequency of disease or other attribute or event in a population without distinguishing between types of frequency measure.

3.2. MEASUREMENT

The measurement concept refers to a system of measuring or of measures as such; the act of measuring is often performed by comparison with a standard. Thus, Last (1983) defines measurement as a "procedure of applying a standard scale to a variable or to a set of values."

Measurement scales may be characterized with regard to level of measurement, which will put restrictions on potential data analysis (e.g., Torgerson, 1958). The most common data are in the form of a *Nominal Scale* only (presence/no presence of an occurrence or a set of qualitatively different classes such as different types of symptoms). Sometimes the responses are assessed on *Ordinal* (rank order), *Interval* (distance is constant, relative to a zero-point), or *Ratio Scales* (ratios are constant, absolute zero-point). Physical-chemical measurements are usually interval or ratio scales in contrast to the questionnaire data with self reports that are commonly on nominal or ordinal scales. The causal relationships sought between SBS and the physical-chemical variables may only pertain to rank order causations. It seems that there is a great need for improving the level of measurement in questionnaire studies. This is particularly true for applications in intervention studies where it is desirable to draw more refined conclusions. For example, after a remedial action it is appropriate to conclude that the indoor concentrations of total volatile organic compounds (TVOCs) have been reduced to e.g., 50% (ratio), but it is usually only permissible to conclude that SBS related symptoms became less (rank order), not how much less.

The grading of scales may have different *Resolutions* for different types of measuring instruments, instrument here defined as the combination of a individual or group of individuals and a particular questionnaire. For perceptual measurements the resolution is related to the discrimination capability along the scale. For example, it is expected that older people have lost some of their discriminatory power for sensory stimulation and therefore the resolution of response scales obtained from old persons may be less than that for young persons.

3.3. CALIBRATION

The procedure for calibrating scales is tied to the level of measurement. Calibration of scales is performed in order to rectify the grading of quantitative measurements obtained. Ordinal scales are dubious to calibrate. Interval scales may be calibrated with regard to a distance between two scale values and ratio scales may be calibrated with regard to one scale value only, respectively. Calibration procedures are imperative in chemical and physical measurements but are relatively new to psychological scales in environmental questionnaires (Berglund, Berglund & Lindvall, 1975). In order to accomplish comparability between scales in behavioral science, the practice have been to standardize scales by transforming the empirical response distributions to a standard distribution of z scores (e.g., Lord & Novick, 1968) rather than to calibrate the scale as such.

3.4. PREVALENCE AND INCIDENCE

Traditionally, epidemiological studies have been concerned with occurrences measured as prevalence and incidence. The term *Prevalence* (or status distribution) is used for the "number of instances of a given disease or other condition in a given population at a designated time; sometimes used to mean Prevalence Rate. When used without qualification, the term usually refers to the situation at a specified point in time (point prevalence)" (Last, 1983). Thus annual prevalence would mean the total number of persons with the disease or attribute at any time during a year.

The *Incidence* (or change distribution) is often calculated. Incidence is not as clearly a population phenomenon as prevalence, because it refers to changes within individuals (prevalence has to do with differences among individuals). Miettinen (1985) suggests that incidence is defined only for populations of candidate individuals for the event, that is, individuals who could experience the event in principle (as matter of logic). To manifest incidence (of events) for a candidate population, the incidence of events must move over time. *Incidence Rate* is defined as the number of disease (or symptom) onsets in the population divided by the sum of the time periods of observation for all individuals in the population.

In this context it may be enlightening to reflect on the concept of *Risk* which is related to that of incidence proportion (Miettinen, 1985). Risk is the probability that a particular event will happen. Thus, the risk of an event is similar to its incidence in the sense that it has to do with its beginning. Moreover, risk refers to individuals (of a given kind), whereas incidence characterizes populations.

3.5. QUESTIONNAIRE DATA AND SYMPTOM MEASUREMENT

With regard to measurement, it is not quite clear what has been accomplished with commonly used SBS questionnaires. *Frequency* of persons reporting a specific symptom is often used as a graded effect measure of the symptom. Do such frequencies (or percentages) represent a quantification of symptoms in such a way that symptom frequencies may be added into some SBS index or score? Theoretically, a prerequisite for such a calculation is that all respondents both define each symptom identically and use identical criteria in reporting each symptom. The practical importance of not fulfilling these prerequisites is not clear but in the worst case situation the SBS scores are only rank order or cannot be compared at all on the same scale.

In social surveys, frequencies are considered to represent the *Extensity* of a symptom in a target population (often defined geographically) rather than the symptom intensity for groups of individuals. *Intensity* is defined as an attribute or dimension that may be quantified or measured, while extensity refers to the counting of occurrences reported by individuals. A questionnaire may also be used for assessing the *Perceived Severity* of symptoms.

4. Measurement of Annoyance/Discomfort

By definition, annoyance and discomfort are psychological phenomena. First, they involve mental processing. Second, annoyance and discomfort are believed to start with a perception. In a way the perception can be regarded as the effective dose on which the individual reacts by cognitive and emotional processing. Third, annoyance and discomfort are largely determined by the perceived characteristics of the environmental stimulus. For instance, perceived intensity is one of the most important determinants of degree of

annoyance. Fourth, annoyance and discomfort may arise indirectly, for example, from experience of perceived task interference. Fifth, annoyance and discomfort are also related to anger and frustration as well as to feelings of constraint in territoriality and control. Finally, they are largely modified by personal and contextual factors.

In epidemiological studies of self-reported annoyance or discomfort from environmental exposures, the investigator often assumes that one, and only one, relationship exists between reported and the actually experienced annoyance. However, identical expressions of annoyance may mean different things to different populations and groups.

5. Persons as Measuring Instruments

In indoor climate questionnaires, persons are used for measuring Body Perceptions (symptoms) as well as Environmental Perceptions (Berglund, 1990). A prerequisite for using persons as "measuring instruments" is that we know something about the nature of the sensory systems and humans as measuring instruments. For example, all persons are able to perceive the thermal sensations in a room but only some persons may be able to perceive eye irritation in that same room.

5.1. TIME FACTORS

Some psychological variables will be continuously *Varying over Time* for all or only some individuals while other variables will be *Present* or *Absent* or be *Discrete Events*. It should also be realized that the selected time period of the study will statistically provide some *Censoring*. If the study is made longer (controlled by researcher), then more people have a chance to react with a symptom (or not react any more), for example, after an intervention. The term *Induction Period* is the period of time from causal action (intervention) until disease (or SBS) appears or disappears. The term *Latent Period* defines the time interval between the actual disease (or SBS) occurrence and its detection. *Delayed Reactions* may be important to SBS symptoms like sensory irritation. Other important processes related to time of exposure are *Adaptation* and *Habituation* which both will reduce the effect. Occasionally, *Cross-Adaptation or Cross-Facilitation* may occur for successive exposures of different kinds.

Repeated measurements by questionnaires are troublesome becausee the respondents may memorize their earlier responses. The *Memory* effect may be controlled by arranging the same questions irregularly in several versions of the questionnaire.

5.2. PSYCHOLOGICAL ISSUES IN PERCEPTUAL MEASUREMENT

A number of psychological factors will have an influence on questionnaire data because they function as modifiers. Human *Stress* is considered to increase the adverse effect of pollutants. Given that stress can reduce host resistance to biological pathogens (e.g., Dubos, 1965), stress may also affect reactivity to environmental pollutants (e.g., Evans, 1982). Other psychological factors believed to be modifiers of adverse effects are individual evaluation of *Threat,* possibilities for cognitive *Coping* with the exposure situation, as well as possibilities for individual *Control* of the exposure situation. Such psychological factors will contribute to true measurement variance which should not be confused with error variance of measurement. For example, true differences in host sensitivity may show up as an increased measurement variance but not in error variance.

This is a fundamental problem in identifying sensitive groups and thus also in causal analysis.

5.2.1. *Expectancy.* A critical psychological variable in intervention studies is *Expectancy.* The famous Elton Mayo's Hawthorne studies (reviewed in Roethlisberger & Dickson, 1939) revealed that environmental change, whether in positive or negative physical direction, resulted in improved work productivity. One theory is that the *Attention* given the workers by the management was the true causal factor. It would be expected that any environmental change will improve the outcome for psychological reasons, at least from a short-term perspective (cf. Griffith & Raw, 1987). In building intervention studies, the knowledge of change accompanied with expectations will become strong intervening variables which have to be controlled.

6. Reliability, Validity and Quality Assurance

One problematic point is that the measurement power of SBS questionnaires seems not yet to have been discussed. Is it at all possible to quantify symptoms with a questionnaire? Is the instrument, the questionnaire, sensitive and specific enough for the measurement task? These questions relate to the reliability and validity of the questionnaire as well as the quality assurance of questionnaire field studies.

The *Reliability* of a measurement refers to how well it measures what it measures (repeatability). The reliability is usually expressed as a reliability coefficient which is the proportion of obtained variance that is due to true variance in variables being measured. A number of practical methods for determining reliability are used: (a) Test-retest method, i.e., the same measuring instrument is applied on two occasions to the same sample of individuals. (b) Parallel-forms method, that is, equivalent forms of a test are administered to the same group of subjects. (c) Split-half method, that is, the test may in some fashion be divided into two halves and two scores obtained from the same sample of subjects. (d) Internal-consistency methods, that is, the method requires a knowledge of certain test-item statistics, for example regarding dichotomous scoring.

The *Validity* of the measurement refers to how well it measures what it intends to measure. There are two kinds of validity. *Empirical Validity* is defined as the degree of association between the measurement and some other observable measurement, for example eye irritation reports from a questionnaire and clinically diagnosed eye irritation (Franck & Skov, 1991). Validity is often expressed as a linear prediction of observable quantities expressed as correlations. A second and perhaps more meaningful kind of validity is *Theoretical Validity.* In this case the validity coefficient is the correlation of an observed variable (symptom frequency) with some theoretical construct of interest (a specific definition of SBS among a variety of suggestions). The most common theoretical validity is named *Construct Validity.* The difficulty in establishing the construct validity of a questionnaire is that the criterion, the construct (the SBS), is not directly measurable (but the symptoms may be).

The principles of *Quality Assurance* have been discussed by the World Health Organization (WHO, 1983) with regard to public health and the scientific community. This concept refers to all the steps that should be taken by the researcher to ensure that the research findings are of good quality; quality assurance is accomplished by adequate self-evaluative and self-corrective strategies. Thus, quality assurance covers the utilization of scientifically and technically sound practices for the collection, transport and storage of samples, the laboratory analysis, as well as the recording, reporting, and interpretation of results. More specifically, for questionnaire studies, quality control has two components.

One is external quality control which is a system for objectively checking investigation performance by an external group. The other is internal quality control which is a set of procedures used by the staff or the investigating group for continuously assessing results as they are produced in order to decide whether they are of good enough quality to be released.

7. Questionnaires in Stepwise Investigations of Problem Buildings

As recommended by the World Health Organization (WHO, 1986) and by the European Concerted Action 613 (Molina et al., 1989), it is important to conduct investigations of problem buildings in a systematic stepwise way. The reasons behind the stepwise procedure is cost-effectiveness as well as the belief that simple and immediate actions are basic elements in the good management of buildings with SBS problems. Questionnaires are recommended for the first initial step as well as for the final step of such investigations. The first step includes a technical survey and the use of a simple questionnaire. This concerns symptoms and complaints about different factors and is distributed to selected samples (preferably random) of employees. If all intermediate investigation steps fail to give enough information for the solution of the problem the investigation might eventually in the final step include medical investigations, specific measurements of suspected components, and a detailed questionnaire. The latter should explore in detail the symptoms reported and should ask questions about the psychosocial conditions at work, the relationships of individuals to their colleagues and superiors, and the type of work they are performing.

With regard to the sensory effect in buildings we suggest the following guidelines for questionnaire studies: (a) Whenever possible adopt a direct scaling technique. Preferably this should be done using a master scale based on defined reference stimuli and an adequate calibration procedure. (b) When the survey of sensory effects are based on self-reported category ratings, one should always use theory and methods of scaling that permit a control of response criteria and the establishment of the mean degree of effect (e.g., symptom strength; e.g., Thursonian scaling). (c) Finally, the need for calibrating the scales of sensory effects is emphasized.

Furthermore, in diagnosing buildings with SBS problems the following may be recommended: (a) Symptoms and sensory variables may have to be collected over time (weeks) in a longitudinal approach simultaneously with the measurement of chemical-physical variables. (b) Symptoms should be assessed by use of a combination of descriptors and questions referring to a specific point in time, "right now." (c) Associations with physical-chemical variables should be traced by recording perceptual variables several times a day followed by calculations of time of the day differences. (d) Reports of environmental and body perceptions should preferably be collected by two independent groups of occupants.

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Literature

Alwin, D.F., and Krosnick, J. The measurement of value in surveys: A comparison of ratings and rankings. *Public Opinions Quarterly*, 1985, **49**, 535-552.

Baird, J.C., Berglund, B., Berglund, U., and Lindvall, T. Symptom patterns as an early warning signal of community health. *Environment International*, 1990, **16**, 3-9.

Baird, J.C., Berglund, B., and Jackson, W.T. (Eds.). *Indoor Air Quality for People and Plants*. Stockholm: Swedish Council for Building Research, D1:1991.

Berglund, B. The role of sensory reactions for guides of non-industrial indoor air quality. In D.M. Weekes & R.B. Gammage (Eds.), *The Practioner's Approach to Indoor Air Quality Investigations*. Akron, OH: American Industrial Hygiene Association, 1990, pp. 113-130.

Berglund, B. Quality assurance in environmental psychophysics. In S.J. Bolanowski & G.A. Gescheider (Eds.), *Ratio Scaling of Psychological Magnitudes–A Tribute to the Memory of S.S. Stevens*. Hillsdale, NJ: Lawrence Erlbaum Associates Inc., 1991, Ch. 11, pp. 140-162.

Berglund, B., Berglund, U., and Lindvall, T. Scaling of annoyance in epidemiological studies. In: *Proceedings from the CEC-WHO-EPA International Symposium on "Recent Advances in the Assessment of the Health Effect of Environmental Pollution"*. Luxembourg: Commision of the European Countries, 1975, vol. I, pp. 119-137.

Broucke, J. van den. Prospective or retrospective: What's in a name? *British Medical Journal*, 1991, 302, 249-250.

Converse, J.M., and Presser, S. *Survey Questions. Handcrafting the Standardized Questionnaire*. Beverly Hills, CA: Sage, 1986.

Cook, T.D., and Campbell, D.T. *Quasi-Experimentation. Design & Analysis Issues for Field Settings*. Boston: Houghton Mifflin Co., 1979.

Dooley, D. *Social Research Methods*. Englewood Cliffs: Prentice Hall, 1984.

Dubos, R. *Man Adapting*. New Haven, CN: Yale University Press, 1965.

Evans, G. (Ed.). *Environmental Stress*. London: Cambridge University Press, 1982.

Franck, C., and Skov, P. Evaluation of two different questionnaires used for diagnosing ocular manifestations in the sick building syndrome on the basis of an objective index. *Indoor Air*, 1991, **1**, 5-11.

Firebaugh, G. A rule for inferring individual-level relationships from aggregate data. *American Sociological Review*, 1978, **43**, 557-572.

Griffith, I.D., and Raw, G.J. Community and individual response to changes in traffic noise exposure. In H.S. Koelega (Ed.), *Environmental Annoyance: Characterization, Measurement and Control*. Amsterdam: Elsevier, 1987, pp. 333-341.

Kalton, G. *Introduction to Survey Sampling*. London: Sage, 1983.

Kish, L. *Statistical Design for Research*. New York: Wiley, 1987.

Kleinbaum, D.G., Kupper, L.L., and Morgenstern, H. *Epidemiology–Principles and Quantitative Methods*. Belmont: Lifetime Learning Publications, 1982.

Last, J.M. (Ed.) *A Dictionary of Epidemiology*. Oxford: Oxford University Press, 1983.

Lee, E., Forthofer, R.N., and Lorimor, R.J. *Analyzing Complex Survey Data*. London: Sage, 1989.

Lodge, M. *Magnitude Scaling: Quantitative Measurement of Opinions*. Beverly Hills, CA: Sage, 1981.

Lord, F.M., and Novick, M.R. *Statistical Theories of Mental Test Scores*. Reading, MA: Addison-Wesley Publishing, 1968.

McGrath, J.E. Complexities, cautions and concepts in research on mass psychogenic illness. In M.J. Colligan, J.W. Pennebaker & L.R. Murphy (Eds.), *Mass Psychogenic Illness: A Social Psychological Analysis*. Hillsdale, NJ: Erlbaum, 1982, pp. 57-85.

Miettinen, O.S. *Theoretical Epidemiology. Principles of Occurrence Research in Medicine*. New York: Wiley, 1985.

Molina, C., Pickering, A. Valbjørn, O., and de Bortoli, M. *Sick Building Syndrome. A Practical Guide* (COST Project 613, Report No. 4). Luxenbourg: Office for Publications of the European Communities, 1989.

Piantadose, S., Byar, D.P., and Green, S.B. The ecological fallacy. *American Journal of Epidemiology*, 1988, **127**, 893-904.

Robinson, W.S. Ecological correlations and the behavior of individuals. *American Sociological Review*, 1950, **15**, 351-357.

Roethlisberger, F.S., and Dickson, W.J. *Management and the Worker*. Cambridge, MA: Harvard University Press, 1939.

Rothman, K.J. *Modern Epidemiology*. Boston: Little, Brown and Co., 1986.

Rothman, K.J. (Ed.). *Causal Inference*. Chestnut Hill, MA: Epidemiology Resources Inc.: 1988.

Sheatsley, P.B. Questionnaire construction and item writing. In P.H. Rossi, J.D. Wright & A.B. Anderson (Eds.), *Handbook of Survey Research*. New York: Academic Press, 1983.

Skov, P., Valbjørn, O., Pedersen, B., and DISG (Danish Indoor Climate Study Group). Influence of personal characteristics, job-related factors and psychosocial factors on the sick building syndrome. *Scandinavian Journal of Work Environment & Health*, 1989, **15**, 286-295.

Sudman, S., and Bradburn, N.M. *Asking Questions: A Practical Guide to Questionnaire Design*. San Francisco, CA: Jossey-Bass, 1982.

Torgerson, W.S. *Theory and Methods of Scaling*. New York: Wiley, 1958.

Turkey, J.W. *Exploratory Data Analysis*. Reading, Mass.: Addison-Wesley Publishing Company, 1977.

Turner, C.F., and Martin, E. (Eds.). *Surveying Subjective Phenomena*. New York: Russell Sage, 1984 (2 volumes).

WHO. *The Principles of Quality Assurance*. Copenhagen: World Health Organisation, Regional Office for Europe, EURO Reports and Studies No. 94, 1983.

WHO. *Indoor Air Quality Research*. Copenhangen: World Health Organization, Regional Office for Europe, EURO Reports and Studies No. 103, 1986.

THE EFFECTS OF MICROBIOLOGICAL POLLUTION IN BUILDINGS - RESULTS OF BUILDING INVESTIGATIONS

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ABSTRACT. The microbiological pollution of buildings may occur as a result of contamination of incoming air, of the airconditioning system itself, of water containing structures within the building, of the building materials themselves and may arise from the occupants either by person to person contact or circulated via the ventilation system. The types of disease produced in man by microbiological pollution include infectious disease, allergic disease and toxic reactions. This article will consider each of these disease groups and their relationship to buildings.

1. Introduction

The microbiological pollution of buildings may occur as a result of contamination of incoming air, of the airconditioning system itself, of water containing structures within the building (examples - humidifiers, jacuzzi's, sauna's and water features in swimming pools), of the building materials themselves and may arise from the occupants either by person to person contact or circulated via the ventilation system. In the majority of instances where microbiological pollution occurs within buildings only a minority of occupants are affected. The types of disease produced in man include infectious disease, allergic disease and toxic reactions. This article will consider each of these disease groups and their relationship to buildings.

2. Infectious Diseases

2.1 VIRAL INFECTIONS

It is common to hear individuals in mechanically ventilated buildings complain of the frequency that they experience upper respiratory tract infections. This occurs presumably by person to person contact in large open plan offices.

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There is, in addition, evidence that viruses may be circulated by the ventilation system itself. A study (1) of the spread of measles in an elementary school, where the source case infected two children in their own classroom and twenty-six children in thirteen other classrooms, suggested that the mode of spread was via the school's ventilation system. A more recent investigation (2) of acute febrile respiratory disease amongst army recruits in the USA again implicated the ventilation system in the spread of disease. The army trainees were located in either recently constructed, well-insulated, mechanically ventilated barracks or in older-style naturally ventilated barracks. The living accomodation was similar in both types of barrack with platoon-sized open bays for up to 55 trainees. The rates of hospital admissions with acute respiratory disease were significantly greater amongst trainees accomodated in the modern barracks compared to those living in the old style barracks (adjusted relative risk estimate, 1.51; 95% confidence interval, 1.46 to 1.56). Subsequently the risk of acute respiratory disease amongst trainees in modern barracks was significantly reduced by immunoprophylaxis (adenovirus vaccine). This study suggests that ventilation systems may have a more important role in the transmission of viral infections than is at present recognised.

2.2 BACTERIAL INFECTIONS

The circulation of bacteria within a contained space - a U.S. naval vessel - via the ventilation system was described in 1965 (3). A single sailor amongst a crew of 350 individuals was noted to have converted his tuberculin skin test from negative to positive. His chest x-ray was normal and he was not given anti-tuberculous chemotherapy. He developed respiratory symptoms ten months later which were not investigated for a further six months when he was diagnosed as having sputum smear positive pulmonary tuberculosis. The remainder of the crew were studied and 140 members were found to have converted their tuberculin skin test. The distribution of affected crew members around the vessel and their minimal or absent contact with the source case implicated the ventilation system in the spread of the disease.

Subsequently the bacteria, Legionella pneumophila, has been widely implicated in causing epidemics of both Legionnaires' Disease and Pontiac Fever. The spread of the infection occuring either by infected water droplets in the incoming air or by contamination of internal fittings for example shower heads or jacuzzi's. This building related infection was first described in 1976 (4), following an epidemic of pneumonia amongst a group of American Legion conventioneers. The pneumonia occured not only amongst the

conventioneers but also in those walking in the street alongside the hotel (Broad Street pneumonia). The source of the Legionella bacteria was not identified at the time but in the light of subsequent knowledge it is likely to have arisen from the hotel's airconditioning system. Two years later, in 1978 (5), the airborne spread of this bacterium via a ventilation system was clearly demonstrated in a hospital outbreak in America. A flash flood affecting the basement of the hospital closed down the cooling towers supplying the ventilation system and an auxiliary cooling tower, unserviced for 2 years, automatically came into operation. This cooling tower was downwind and in close proximity to two of the air intakes of the airconditioning system. The tower was operational for 30 days and the first cases of Legionnaires' disease presented 3 days after this cooling tower commenced functioning. Patients, visitors and staff occupying rooms supplied by air from these air intakes were more likely to develop the disease than those receiving air from air intakes located elsewhere in the building. The importance of the location of cooling towers in relationship to the air intakes of ventilation systems has been amply demonstrated. 13 cases of Legionnaires' disease occured in a hotel complex (6), in this instance infected air from a nearby cooling tower being drawn down a chimney supplying a meeting room in th hotel. A further study described 68 cases amongst hospital patients in a new district hospital (7) where the cooling tower was located above the air intake to the airconditioning system.

The passive ingress of infected droplets into domestic dwellings may also occur (8). An epidemic of 33 cases of Legionnaires' disease occuring in a city suburb, the patients living around a factory with an infected cooling tower. Cases occured downwind of this cooling tower up to a distance of 1700 metres and they included individuals confined to their homes by cardiac disease who appeared to have been infected through sitting by an open window. A further study in the same city (9) examined the places of residence of community acquired, non-travel, non-outbreak cases of Legionnaires' disease. They demonstrated a non-linear dose-response, with a relative risk fo more than 3.0 in those living within 0.5km of a cooling tower to 1.19 in those living 0.5 - 0.75km from one.

Water storage systems within buildings have also been implicated as sources of this bacterium causing disease, not only in a hospital situation with immunosuppressed patients (10) but also in hotels with apparently healthy people (11).

The most dramatic outbreak of disease due to airborne L. pneumophila within a building occured in 1968 (12). This occured in the health department in Pontiac, U.S.A., when 95% of employees developed a benign, self-limiting, febrile

illness, subsequently to be named Pontiac fever. At the time of this investigation an unidentified bacteria was isolated from the airconditioning system which some years later was identified as L. pneumophila. As is seen so frequently in outbreaks related to Legionella - design, structural and maintenance faults were identified in this building.

2.3 FUNGAL INFECTIONS

Fungal infections in man related to buildings have in almost all instances involved hospital buildings and usually immunocompromised patients. The fungal species most frequently implicated is Aspergillus either contaminating incoming air to the ventilation unit or the ducts of the ventilation unit itself. Over a 6-month period in a North Carolina hospital (13), while construction work was being carried out in the vicinity of the ventilation air intake, there was a 6-fold increase in sputum isolation of Aspergillus flavus. Investigation of the ventilation unit revealed Aspergillus growing on the external louvres and defective filters within the unit.

The most serious fungal infections are most likely to occur in immunocompromised patients. This has been well described in a renal transplant unit (14), where over a 5-month period three renal transplant patients developed infections with A. fumigatus. Investigation of the ventilation system identified that a protective screen on an exhaust duct (one of three ducts supplying the unit) had corroded and fallen off, allowing contamination of the ducting itself with pigeon droppings from which Aspergillus species were cultured. The fan supplying this duct was malfunctioning leading to reversed airflow down the contaminated duct and the dissemination of Aspergillus into the transplant unit.

3. Allergic Diseases

Allergic diseases associated with the microbiological contamination of buildings fall into three categories: bronchial asthma, extrinsic allergic alveolitis (hypersensitivity pneumonitis) and humidifier fever.

3.1 BRONCHIAL ASTHMA

Bronchial asthma caused by microbiological contamination of buildings is rare and is usually associated with poorly maintained humidification systems. The first account (15) involved the exacerbation of asthma in children in a house using a coolmist vaporiser. The unit had become contaminated with the fungus, Rhodotorula, when operated there was a rapid

increase in airborne spores associated with clincial deterioration in the children's asthma. The same study examined a number of similar units in different households - all were found to have heavy growths of organisms. The first description of occupational asthma related to a building (16) was in a clerical worker working in an airconditioned building with a contaminated cold water spray humidifier. The humidification system was shut down and the worker's asthma improved. It was presumed that the antigen was microbial in origin. A second case of building related asthma was also described in this paper. In this instance the building was new and the humidifiers were obviously not contaminated. The specific cause was not established and may have been due to factors other than the humidifiers.

Humidifiers within buildings as a cause of building related asthma was confirmed by Burge et al. (17). 15 workers with work-related respiratory symptoms were described. Four clinical patterns of asthma were described: worst asthma on the first day of the working week; equivalent daily deteriorations; progressive deterioration over the week and worst midweek. The subset of asthmatics with progressive deterioration over the week were found to have a high atopic status and the majority had positive skin prick tests to an extract removed from the humidifier. Two cold water spray humidifiers were implicated, both heavily contaminated by a large variety of micro-organisms. Microbiological studies of water from humidifiers usually reveal a wide variety of fungi and bacteria making the identification of a single aetiological agent difficult.

3.2 EXTRINSIC ALLERGIC ALVEOLITIS

Extrinsic allergic alveolitis was first associated with an airconditioning system in 1970 (18). Four of the twenty-seven office workers developed symptoms of allergic alveolitis, investigations incriminated a thermophilic actinomycete contaminating the building's central airconditioning system. The diagnosis was confirmed by a combination of bronchial provocation and immunological testing and a lung biopsy. There have been several further reports of allergic alveolitis in the office (19) and the home (20, 21, 22, 23, 24), all associated with various types of ventilation systems. Thermotolerant organisms have been implicated in nearly every instance. The potential scale of the problem is well demonstrated in an epidemiological study of 93 suspect homes in the U.S.A. Positive cultures for thermophilic actinomycetes were found in 74% of the suspect homes. In the U.K., this type of problem is rare, two cases (26) have been reported due to a contaminated coldwater spray humidifier. In this report the humidifier was operating at 15°C, bronchial provocation studies were negative to

thermophilic organisms but positive to a crude extract from the humidifier. The specific cause of the alveolitis was not identified.

Water based structures within buildings may also become contaminated with organisms and induce an allergic alveolitis. Some examples include a sauna - Pullularia (27), a hottub room - Cladosporium Cladospioroides (28), faulty central heating - Penecillium species (29), from "water features" in an indoor swimming pool - endotoxin (30), tap water (31) and a vacuum ring pump (32).

3.3 HUMIDIFIER FEVER

Humidifier fever was first described in 1959 (33) in a group of workers in a carpentry shop. Twelve out of seventeen workers developed a febrile illness with cough and breathlessness, occuring 8-12 hours after starting work and resolving over 24 hours. These symptoms only occured on the first day of the working week with no recurrence of symptoms until after a period away from work such as a weekend or holiday. Mould growth within contaminated humidifiers was considered to be the cause. There were no further reports until 1969 (34) when an outbreak of similar symptoms was described in a group of printers in a workshop with contaminated spinning disc humidifiers. A similar symptom complex was described with an influenzal type illness characterised by headache, myalgia, lethargy, fever and shortness of breath occuring on the first day back at work after a break, usually resolving over 24 hours and not recurring despite continued exposure to their polluted environment until after a further period away from work.

Subsequently a number of outbreaks of humidifier fever have been described (35, 36, 37, 38, 39, 40). Apart from the symptom periodicity, the clinical and physiological findings are similar to an allergic alveolitis but the chest radiograph remains normal. This difference between two essentially similar conditions may reflect exposure to a soluble antigen in humidifier fever and to a particulate antigen in allergic alveolitis. It is interesting that in a number of outbreaks of respiratory diseases (30, 31, 32) described as examples of an allergic alveolitis, where exposure has been to water droplets and thermophilic organisms have not been identified, the chest radiographs have been normal.

The specific cause(s) of humidifier fever is/are not known. However since inhalation challenge tests with water from the contaminated source reproduces the disease in affected workers (32) the antigen is contained in the water. There are several postulated causes including protozoa (41),

Bacillus subtilis (36) and endotoxin (37). These postulated causes have been based on serological testing and cirumstantial evidence only. In a study of the sera of 119 workers (42) from four different work sites with contaminated humidifiers of whom 25 had humidifier fever and 6 occupational asthma no correlation was found between the presence of antibodies to the amoebae, Acanthamoeba polyphaga and Naegleria gruberi and disease.

Pickering et al. (35) in the course of an investigation of an outbreak of humidifier fever in a group of printers carried out inhalation challenge tests with extracts of organisms to which the subjects had demonstrable precipitating antibodies. They were unable to produce any systemic symptoms or pulmonary function changes on challenge testing with these extracts. The available evidence suggests that serological testing is not a reliable method of determining the cause of this disease. In a study of a large group of workers (43) exposed to heavily and moderately contaminated humidifiers the two major factors influencing the development of precipitating antibodies were the duration of exposure and the smoking status of the worker. A strong inverse relationship between current smoking and the detection of precipitants was shown. This effect of smoking appeared to be lost within 3 years of smoking cessation. No relationship between the detection of antibodies and the presence of antibodies was shown.

Unlike cases of allergic alveolitis subjects with humidifier fever appear to make a full recovery when they cease exposure to the source of contamination.

In general outbreaks occur when there is heavy microbial contamination of the water source and poor maintenance and design are usually implicated.

4. Toxic Reactions

This is a more poorly understood type of response to microbial contamination of indoor air. Microorganisms produce secondary metabolites, these include mycotoxins and a large number of different types of volatile organic compounds (VOC).

Mycotoxins have a low volatility and they are likely to be inhaled absorbed on dust particles or in spores or mycelia. Little is known of their possible role in producing symptoms within buildings. Croft et al. (44) describe the heavy infestation of a Chicago suburban house by Stachybotrys atra. The family of five had, over a period of 5 years, experienced a variety of complaints including recurrent colds

and flu, sore throats, diarrhoea, headaches, fatigue, dermatitis, focal alopecia and general malaise.

After removal of contaminated duct work and ceiling materials the family's symptoms resolved. Some of these symptoms are similar to those which may be experienced in sick building syndrome. Nexo et al (45) describe building related symptoms in a group of 5 of 12 office workers. The symptoms they were experiencing included extreme fatigue and eye and upper respiratory tract irritation. The carpet in their workplace was found to be heavily contaminated with microorganisms. The organisms isolatd included massive growths of Aspergillus spp., Penecillium spp., Aureobasidium pullulans, Rhodotorula rubra and yeasts. Peak flow records in 2 subjects demonstrated a work-related decrease in peak flow recordings in one. Both subjects' peak flow recordings improved after cleaning of the carpet had been instituted and all work-related symptoms resolved.

In a recent study, Harrison et al (46) have examined the relationship between the specific symptoms of sick building syndrome and exposure to bacteria, fungi and airborne particulates in both naturally ventilated and airconditioned buildings. They found a significant inverse relationship between the prevalence of symptoms and environmental exposures to bacteria, fungi and particulates. The highest exposures to these various factors being in the naturally ventilated buildings and associated with the lowest levels of symptoms. However within each building group there was a significant positive relationship between measured levels of viable airborne fungi and blocked nose, dry throat, dry skin and symptom frequency. One possible explanation for these apparently contradictory findings would be the production of fungal metabolites from within the airconditioning unit itself which would not necessarily be reflected by measured airborne levels of fungi in the office space.

There is clearly a requirement for further research into this complex problem.

5. References

1. Riley, E.C., Murphy, G., Riley, R.L., (1978). 'Airborne spread of measles in a suburban elementary school', Am. J. Epidemiol, 107,421-432.

2. Brundage, J.F., Scott, R. McN., Lednar, W.M., et al., (1988). 'Building-associated risk of febrile acute respiratory diseases in army trainees', J.A.M.A., 259, 2108-2112.

3. Honk, V.N., Kent, D.C., Baker, J.H., Sorenson, K., (1968). 'The epidemiology of tuberculosis infection in a closed environment', Arch. Environ. Health, 16,26-35.

4. Fraser, D.W., Tsai, T.R., Orenstein, W., et al., (1977). 'Legionnaires' disease. Description of an epidemic pneumonia'. N.Engl. J. Med., 297,1189-1197.

5. Dondero, T.J., Rendtorff, R.C., Mallinson, G.F., et al., (1980). 'An outbreak of Legionnaire's Disease associated with a contaminated airconditioning cooling tower', N.Engl. J. Med., 302,365-370.

6. Band, J.D., LaVenture, M.,Davis, J.P., et al., (1981). 'Epidemic Legionnaires' Disease. Airborne transmission down a chimney', J.A.M.A., 245, 2404-2407.

7. Badenoch, J., (1985). 'First report of the committee of inquiry into the outbreak of Legionnaires' disease in Stafford in April 1985'. Her Majesty's Stationery Office, London.

8. 'Report of an ad-hoc committee. (1986) Outbreak of legionellosis in a community', Lancet, ii, 380-383.

9. Bhopal, R.S., Fallon, R.J., Buist, E.C., Black, R.J., Urquhart, J.D., (1991). 'Proximity of the home to a cooling tower and the risk of non-outbreak legionnaires' disease', Brit. Med. J., 302, 378-383.

10. Tobin, J.O'H., Dunnill, M.S., French,M. et al.(1980). 'Legionnaires' disease in a transplant unit: isolation of the causative agent from shower baths', Lancet, ii, 118-121.

11. Tobin, J.O'H., Bartlett, C.L.R., Waitkins, S.A., et al., (1981). 'Legionnaires' disease: further evidence to implicate water storage and distribution systems as sources', Brit. Med. J., 282, 573.

12. Glick, T.H., Gregg, M.B., Berman,B., et al., (1978). 'Pontiac fever. An epidemic of unknown etiology in a health department: 1. Clinical and epidemiological aspects'. Am. J. Epidemiol., 107, 149-160.

13. Sarubbi, F.A., Kopf, H.B., Wilson, M.B., et al.(1982). 'Increased recovery of Aspergillus flavus from respiratory specimens during hospital construction', Am. Rev. Respir. Dis., 125(1), 33-38.

14. Kyriakides, G.K., Zinneman, H.H., Hall, W.H., (1976). 'Immunological monitoring and aspergillosis in renal transplant patients', Am. J. Surg., 131, 246-252.

15. Solomon, W.R., (1970). 'Fungus aerosols arising from cold mist vaporizers', J. Allergy Clin. Immunol., 54,222-228.

16. Finnegan, M.J., Pickering, C.A.C., (1984). 'Work related asthma and humidifier fever in airconditioned buildings', in B. Berglund, T. Lindvall and J. Sundell (eds.), Proceedings of the 3rd International Conference on Indoor Air Quality and Climate, vol. 1: Recent Advances in Health Sciences and Technology. Swedish Council for Building Research, Stockholm, pp. 257-262.

17. Burge, P.S., Finnegan, M.J., Horsfield, N., et al., (1985). 'Occupational asthma in a factory with a contaminated humidifier', Thorax, 40, 248-254.

18. Banaszak, E.F., Thiede, W.H., Fink, J.N., (1970). 'Hypersensitivity pneumonitis due to contamination of an airconditioner'. N.Engl. J. Med., 283(6), 271-276.

19. Arnow, P.M., Fink, J.N., Schleuter, D.P. (1978). 'Early detection of hypersensitivity in office workers', Am. J. Med., 64, 236-241.

20. Sweet, L.C., Anderson, J.A., Callies, Q.C., Coates, E.O., (1971). 'Hypersensitivity pneumonitis related to a home furnace humidifier', J. Allergy Clin. Immunol., 48, 171-178.

21. Fink, J.N., Banaszak, E.F., Thiede, W.H., Barboriak, J.J., (1971). 'Interstitial pneumonitis due to hypersensitivity to an organism contaminating a heating system', Ann. Int. Med.,74,80-83.

22. Tourville, D.R., Weiss, W.I., Wertlake, P.T., Loudemann, G.M., (1972). 'Hypersensitivity pneumonitis due to contamination of home humidifier', J. Allergy Clin. Immunol., 49, 245-251.

23. Hodges, G.R., Fink, J.N., Schlueter, D.P., (1974). 'Hypersensitivity pneumonitis caused by a contaminated cool-mist vaporizer', Ann. Int. Med., 80, 501-504.

24. Marinkovich, V.A., Hill, A., (1975). 'Hypersensitivity alveolitis', J.A.M.A., 231, 944-947.

25. Banaszak, E.F., Barboriak, J., Fink, J.N., et al., (1974). 'Epidemiologic studies relating thermophilic fungi and hypersensitivity lung syndromes', Am. Rev. Respir. Dis., 110, 585-591.

26. Robertson, A.S., Burge, P.S., Weiland, A., (1985). 'Extrinsic allergic alveolitis due to antigen from a humidifier at 15°C', Thorax, 40(3), 229(abstr).

27. Metzger, W.J., Patterson, R., Fink, J., Semerdjian, R., Roberts, M., (1976). 'Sauna-takers Disease. Hypersensitivity pneumonitis due to contaminated water in a home sauna', J.A.M.A., 236, 2209-2211.

28. Jacobs, R.L., Thorner, R.E., Holcomb, J.R. et al., (1986). 'Hypersensitivity pneumonitis caused by Cladosporium in an enclosed hot-tub area', Ann. Int. Med., 105, 204-206.

29. Fergusson, R.J., Milne, L.J.R., Crompton, G.K. (1984). 'Penecillium allergic alveolitis: faulty installation of central heating', Thorax, 39, 294-298.

30. Rose, C.S., Newman, L.S., Martyny, J.W. et al., (1991). 'Outbreak of hypersensitivity pneumonitis in an indoor swimming pool: clinical, physiological, radiographic, pathologic, lavage and environmental findings', Am. Rev. Respir. Dis., 143, A315.

31. Muittari, A., Kuusisto, P., Virtanen, P. et al., (1980). 'An epidemic of extrinsic allergic alveolitis caused by tap water', Clin. Allergy, 10, 77-90.

32. Friend, J.A.R., Gaddie, J., Palmer, K.N.V., Pickering, C.A.C., Pepys, J., (1977). 'Extrinsic allergic alveolitis and contaminated cooling-water in a factory machine', Lancet, i, 297-300.

33. Pestalozzi, C., (1959). 'Febrile Gruppenerkrankungen in einer Modellschreinerei durch Inhalation von mit Schimmelpilzen Kontaminiertem Befeuchterwasser ('Befeuchterfieber')', Schweiz. Med. Wochenschr., 89(27), 710-713.

34. 'Her Majesty's Chief Inspector of Factories Annual Report for 1969'. H.M.S.O.: 1969:72-74.

35. Pickering, C.A.C., Moore, W.K.S., Lacy, J., et al., (1976). 'Investigation of a respiratory disease associated with an airconditioning system', Clin. Allergy, 6, 109-118.

36. Parrott, W.F., Blyth, W., (1980). 'Another causal factor in the production of humidifier fever', J. Soc. Occup. Med., 30, 63-68.

37. Rylander, R., Haglind, P., Lundholm, M., Mattsby, I., Stenqvist, K., (1978). 'Humidifier fever and endotoxin exposure', Clin. Allergy,8,511-516.

38. NewmanTaylor, A., Pickering, C.A.C., Turner-Warwick, M. (1978). 'Respiratory allergy to a factory humidifier contaminant presenting as pyrexia of undetermined origin', Brit. Med. J., 11,94-95.

39. Campbell, I.A., Cockcroft, A.E., Edwards, J.H., Jones, M., (1979). 'Humidifier fever in an operating theatre', Brit. Med. J., 2, 1036-1037.

40. Anderson, K., Watt, A.D., Sinclair, D. et al., (1989). 'Climate, intermittent humidification, and humidifier fever', Brit. J. Ind. Med., 46, 671-674.

41. Edwards, J.H., Griffiths, A.J., Mullins, J., (1976). 'Protozoa as sources of antigen in humidifier fever', Nature, 264, 438-439.

42. Finnegan, M.J., Pickering, C.A.C., Davies, P.S., Austwick, P.K.S., Warhurst,D.C., (1987). 'Amoebae and humidifier'. Clin. Allergy, 17, 235-242.

43. Finnegan, M.J., Pickering, C.A.C., Davies,P.S., Austwick, P.K.C., (1985). 'Factors affecting the development of precipitating antibodies in workers exposed to contaminated humidifiers', Clin. Allergy, 15, 281-292.

44. Croft, W.A., Jarvis, B.B., Yatawara, C.S. (1986). 'Airborne outbreak of trichothecene toxicosis', Atmospheric Envir., 20, 549-552.

45. Nexo, E., Skov, P.G., Gravesen, S., (1983). 'Extreme fatigue and malaise - a syndrome caused by badly cleaned wall-to-wall carpets?' Ecology of Disease, 2, 415-418.

46. Harrison, J., Pickering, C.A.C., Faragher, E.B. et al. (in press). 'An investigation of the relationship between microbial and particulate indoor air pollution and the sick building syndrome', Respiratory Medicine.

BUILDING EPIDEMIOLOGY - APPROACHES AND RESULTS (EUROPEAN EXPERIENCE)

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ABSTRACT. There have been three systematic studies in Europe, using randomly selected buildings and relating multiple office building characteristics to the symptoms of sick building syndrome. The studies have varied in design and to a certain extent in conclusions. All have shown an excess of symptoms in sealed, airconditioned buildings when compared to naturally ventilated buildings.

1. Description of Studies

There have been three systematic studies (1,2,3,4) in Europe, using randomly selected buildings and relating multiple office building characteristics to the symptoms of sick building syndrome. The studies have varied in design and to a certain extent in conclusions. All have shown an excess of symptoms in sealed, airconditioned buildings when compared to naturally ventilated buildings.

In the first study (1), nine buildings were studied. Seven of the buildings were studied in the absence of any known problem, for the remaining two buildings the study had been requested by the management as a response to complaints from the staff. The building types included three naturally ventilated, one mechanically ventilated and five air conditioned buildings. Of the airconditioned buildings, three had air recirculation and two used a single pass system with no recirculation of air. A doctor administered questionnaire was used to either random samples or the whole office population. Compliance in completing the questionnaire varied between 75.4% to 93.6% of the target populations. A total of 1385 office workers were interviewed.

The second study(2,3) was larger and included fortytwo office buildings and fortyseven ventilation types. The buildings fell into the following ventilation categories: 11 naturally ventilated buildings, 7 mechanically ventilated buildings, 6 buildings with local induction units, 10

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buildings with centrally ducted, water-based heating and cooling and 13 buildings with centrally ducted all-air systems. Of these buildings, 34 had no known problems and the remaining 13 buildings were known to have a problem. The ages of the buildings ranged from 1.5 to 57 years old (mean 16.9 years). A self-administered questionnaire was completed by random samples of the study populations, the total population studied was 4373 office workers. An overall response rate of 92% was achieved.

The third study(3) was conducted in 14 town hall buildings and 13 independent buildings affiliated to the town halls. The town halls were of two basic ventilation categories either naturally or mechanically ventilated. Six buildings were naturally ventilated and eight buildings were mechanically ventilated. Of the these eight buildings, five had outside air intake and three had air exhaust only. Two of the air intake buildings had air recirculation and two had humidifiers of which only one was functioning. The buildings were not selected on the basis of having a known problem. The study population was 4369 employees who completed a self administered questionnaire. Compliance in completing the questionnaire varied in the town hall buildings between 61% and 93% and in the independent buildings between 57% and 100%.

2. Design of Questionnaires for the Detection of Symptoms

The questionnaires used in the three studies inquired into similar, but not identical, symptoms (see table 1). In addition, in studies 1 & 2, a question designed to identify the presence of humidifier fever was asked.

In studies 1 & 2, a workrelated symptom was recorded as present if it was a symptom that had been experienced on more than two occasions over the previous twelve months and had improved on days away from work or on holiday. The criteria for the presence of a workrelated symptom in study 3 were considerably tighter. A workrelated symptom was only recorded if it was present on a daily or weekly basis and improved on days off/during weekends or vacations. These more restricted requirements for the presence of workrelated symptoms are reflected in the lower prevalence of symptoms described in this study(table 2). The two symptoms included in table 2 are those for which there is comparable information from each study. Every symptom measured in the Town Hall study has a lower prevalence than those measured in the other two studies. Using the same questionnaire in studies 1 and 2, the self administration of the questionnaire increased the prevalence of all workrelated symptoms.

Table 1. Questionnaire Symptoms

Study 1	Study 2	Study 3
Blocked/itchy runny nose.	Runny nose.	Blocked/runny nose.
Stuffy nose.	Stuffy nose.	Nasal irritation.
Itching/watering irritation eyes.	Itching eyes. Dry eyes.	Eye irritation.
Dry throat.	Dry throat.	Sore throat. Throat irritation.
Lethargy.	Lethargy.	Malaise. Irritability. Lack of concn. Fatigue.
Headache.	Headache.	Headache.
Dry skin.		Dry skin.
Rash.		Rash
Shortness of breath.	Difficulty in breathing.	
Chest tightness.	Chest tightness.	

Table 2. Symptom prevalences (%)

Symptom	Study 1	Study 2	Study 3
Headache	31.7	43	17.9
Eye irritation	14.9	46	11.5

3. Results and Discussion

3.1 THE INFLUENCE OF VENTILATION CATEGORY

The influence of ventilation category on the prevalence of workrelated symptoms and on building sickness score is clearly demonstrated in studies 1 and 2. Natural and mechanical ventilation having the lowest levels of symptoms and sealed airconditioned buildings the highest levels of symptoms. Study 2 had the greatest variety of ventilation systems. The highest number of symptoms was seen in buildings with local induction units, followed by those with centrally supplied induction units. The all air variable and constant air volume systems forming an intermediate group between buildings with induction units and the best buildings with natural and mechanical ventilation. There was considerable

variability in the prevalence of symptoms within each ventilation group.

The overall prevalence of workrelated symptoms in study 2 was as follows: lethargy(57%), blocked nose(47%), dry throat(46%), headache(43%), eye irritation(46%), difficulty in breathing(9%) and chest tightness(9%). At least one workrelated symptom being reported by 80% of the workers. In this study each building was given a building symptom index being the average number of workrelated symptoms present in the workers sampled. The questionnaire in this study containing a total of 10 symptoms.

The mean building symptom index (BSI) varied from 1.53 to 5.25. Although naturally ventilated were in general the best buildings, the range of building index within each ventilation group was considerable (table 3).

Table 3. Building sickness index by ventilation group

Ventilation Group	BSI range
Natural	1.53 - 3.57
Mechanical	1.25 - 3.76
All air systems	2.12 - 5.25
Local induction unit	3.05 - 4.76
Central induction unit	2.69 - 4.92

3.2 THE INFLUENCE OF OTHER FACTORS

Study 2 also examined other organisational and individual factors which might influence the presence of symptoms. A comparison of public and private sector buildings showed that workers in the public sector in general experienced more symptoms. In one building shared between the public and private sectors the level of symptoms between workers in the two sectors was similar, suggesting the buildings or their maintenance rather than the organisation was responsible.

The influence of personal characteristics such as gender and job category on the prevalence of symptoms (2) were also examined. Managers and professionals experience fewer symptoms than secretarial and clerical staff. This may be explained by the better accomodation usually provided to more senior members of staff, with smaller offices and more control over their environment. Females consistently had more symptoms than men. This was accounted for when they compared building symptom indices since the proportion of male to

females and senior to junior employees varied from building to building. An adjusted figure for the average number of workrelated symptoms for occupants of the building was developed to make each worker equivalent to a male manager.

The buildings with the lowest building sickness index were found to have a significantly higher proportion of staff in both cellular offices or offices with two to four staff in them. The authors suggested that open plan offices have higher sickness rates as a result of a combination of the type of work carried out in them and the loss of control of such factors as ventilation, temperature and lighting.

The proportion of people who considered their jobs to be very stressful was around 20% and did not vary significantly between sick and healthy buildings. Multiple regression analyses found that those with most symptoms had slightly higher stress ratings.

In study 2 the healthiest buildings tended to be privately owned, to have natural or mechanical ventilation, with nontinted glazing, openable windows and the majority of staff in 1-2 person offices. The least healthy buildings were publicly owned, with induction or all air systems and humidity control, sealed windows with tinted glazing and large open plan offices.

The town hall study examined the influence of both personal characteristics, job-related factors, psychosocial factors (5) and the indoor climate (6) on the sick building syndrome. The symptoms of sick building syndrome were analysed as two groups, work-related mucosal irritation and work-related general symptoms, as well as single symptoms. The questionnaire included questions on type of work, past and current diseases, symptoms, subjective assessment of indoor climate, family and housing conditions, exercise habits and consumption of tobacco, alcohol and various beverages. Multivariate logistic regression analyses were performed examining the relationships between these factors and the presence of work-related symptoms.

Women had a substantially higher symptom prevalence than men. Hayfever and migraine were significantly associated with work-related symptoms. Life-style factors were weakly associated with symptoms. There was a modest increased frequency of work- related general symptoms amongst smokers. Coffee drinkers had a lower frequency and contact lens wearers a higher frequency of work-related mucosal irritation. The number of workhours per week had an effect on work-related general symptoms and the number hours in one's office per day had an effect on work-related mucosal irritation. The type of work performed also significantly influenced symptoms. Handling carbonless paper weekly or daily, photocopying more than 25 sheets weekly, and working on a visual display terminal had a significant effect on work-related mucosal irritation.

Of the various psychosocial factors assessed only dissatisfaction with one's superior and the feeling that the quantity of work inhibits one's job satisfaction had a significant effect on work-related mucosal irritation. None of these factors although significantly associated with various work-related symptoms explained the different prevalences of work-related symptoms between buildings.

This study group then went on to examine the effects of the indoor climate on sick building syndrome(6). Indoor climate measurements included temperature and humidity, carbon dioxide, static electricity, formaldehyde, airborne dust and fibres, dust on the floor, fibres on surfaces, microorganisms, volatile organic compounds, lighting, noise and a cleaning factor. They also introduced two new terms, fleece factor and shelf factor. The fleece factor is the area of fabric such as carpets, curtains and soft furnishings divided by the room volume. The shelf factor is the length of open shelves and cupboards divided by the room volume. The prevalence of work-related symptoms was found to be associated with the concentration of macromolecular organic floor dust, the floor covering, the number of workplaces in the office, the age of the building, ventilation type and the fleece and shelf factors. There was a decreasing prevalence of work-related symptoms with an increasing concentration of airborne dust. This apparent paradox has been observed by other workers(7). It may be that the organic component of the dust is the most important factor. A validated method of measuring this factor in air has yet to be developed.

Results of some more recent studies. There have been a number of more recent European building studies using different methods of building selection which have reexamined the findings of the early studies of sick building syndrome. A large study (8) of 61 buildings has been conducted in Holland. The ventilation types were natural ventilation in 19 buildings and different varieties of airconditioning in 42 buildings. Humidification was present in 25 buildings (13 with steam humidification and 12 with water spray humidification). A self administered questionnaire was used in the study. The total study population was 10,500 workers with a response rate of 74%. The results again demonstrated an excess of symptoms in air conditioned compared to naturally ventilated buildings and an excess of symptoms amongst females compared to males. In this study the prevalence of symptoms was not influenced by the presence or absence of humidification, and they did not demonstrate a shelf or fleece factor and did not find an effect from cigarette smoking, age, ability to open windows or the number of occupants in an office. The strongest risk factor for the presence of symptoms was dissatisfaction with the procedures for complaint handling within a building. Other risk factors identified included the absence of local temperature controls and the use of visual display units.

A further preliminary report of a study from Sweden(9,10) of 6000 office workers has been published. A self-administered questionnaire was used and the response rate was 95%. The number of buildings studied was 192, with at least 10 workers per building. The ventilation types included natural ventilation 3%, mechanical exhaust 3%, the remainder having some form of air conditioning. The analysis of their data is only preliminary. The study again shows symptoms to be more common amongst females. Atopy was found to be a significant risk factor and the use of visual display units. A case-referent component (10) of this study examining fresh air supply rate, humidity, temperature, shelf and fleece factors demonstrated no difference between sick and healthy offices.

4. Conclusion

The studies described allow one to conclude that workers in air conditioned buildings have in general more symptoms than workers in naturally ventilated buildings. Females are more commonly affected than males. The presence of humidification systems is associated with higher levels of symptoms. Some studies have provided conflicting results in terms of risk factors. This may be related to building selection and/or study design. There is a need for a common European questionnaire to be used to investigate buildings, in order that results from different centres may be compared.

5. References

1. Finnegan, M.J., Pickering, C.A.C., Burge, P.S., (1984). 'The Sick Building Syndrome', Brit. Med. J., 289, 1573-1575.

2. Hedge, A., Wilson, S., (1987). 'The office environment survey. A study of building sickness', Pub. Building Use Studies Ltd.

3. Burge, P., Hedge, A., Wilson, S., Harris Bass, J., Robertson, A., (1987). 'Sick Building Syndrome: a study of 4373 office workers', Ann. Occup. Hyg., 31, 493-504.

4. Skov, P., Valbjorn, O., Danish Indoor Climate Study Group (DICSG), (1987). 'The 'sick' building syndrome in the office environment: The Danish Town Hall study', Environ. Int., 13, 339-349.

5. Skov, P., Valbjorn, O., Pedersen, B.O., DICSG., (1989). 'Influence of personal characteristics, job-related factors, and psychosocial factors on the sick building', Scand. J. Work. Environ. Health, 15, 286-295.

6. Skov, P., Valbjorn, O., Pedersen, B.V., (1990). 'Influence of indoor climate on the sick building syndrome in an office environment', Scand. J. Work. Environ. Health, 16, 363-371.

7. Harrison, J., Pickering, C.A.C., Faragher, E.B. et al., (in press). 'An investigation of the relationship between microbial and particulate indoor air pollution and the sick building syndrome', Respir. Med.

8. Preller, L., Zweers, T., Boleij, J.S.M., Brunekreef, B., (1990). 'Gezondheidsklachten en klachten over het binnenklimaat in kantoorgebouwen', Directoraat-generaal van de Arbeid, S 83.

9. Stenberg, B., Mild, K.H., Sandstrom, M., Lonnberg, G., Wall, S., Sundell, J., and Zingmark, P.A., (1990). 'The office illness project in Northern Sweden. Part 1: A prevalence study of sick building syndrome (SBS) related to demographic data, work characteristics and building factors', in Indoor Air '90, Precedings of the 5th International Conference on Indoor Air Quality and Climate, Toronto, Vol. 4, pp. 627-632.

10. Sundell, J., Lonnberg, G., Wall, S., Stenberg, B., Zingmark, P.A., (1990). 'The office illness project in Northern Sweden. Part 3: A case-referent study of SBS in relation to building characteristics and ventilation', in Indoor Air '90, Precedings of the 5th International Conference on Indoor Air Quality and Climate, Toronto, Vol. 4, pp. 633-638.

BUILDING EPIDEMIOLOGY AND INVESTIGATIONS - APPROACHES AND RESULTS (U.S. EXPERIENCE)

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ABSTRACT. Most epidemiology studies and investigations of Sick Building Syndrome in the United States are conducted in complaint buildings in contrast to Europe where researchers have conducted several important studies in "non-complaint" buildings. Many investigations have been conducted by indoor air experts in relation to litigation, though few of these have been published in the open literature. There is a sizeable body of literature on U.S. investigations of "problem buildings" including two major recent studies of federal government facilities in Washington, D.C. Additionally, the National Institute for Occupational Health and Safety (NIOSH) has published individual reports and several summaries of more than 500 investigations it has conducted into complaint buildings. A lack of standardized protocols, measurement methods, and standards or guidelines for interpretation of results impedes comparison of study results and more rapid improvement in understanding the causes of "problem buildings" and effective action to prevent the problems from occurring. The federal government is now embarking on a program to address these lacks, although funding is rather small to meet the need.

Introduction

While European researchers have conducted many building epidemiology and survey studies in "non-complaint" buildings, relatively few such studies have been conducted in the United States. Most U.S. investigations and studies have involved "complaint" buildings (also variously called "problem buildings," "sick buildings," among other names). Many investigations, some of them quite extensive, have been conducted by indoor air experts in relation to litigation, though few of these have been published in the open literature. In many instances, the law suits are settled before being tried in court, and a condition of the settlement often is that the case not be discussed by the experts who have conducted the investigations.

On the other hand, there is a very large body of literature on U.S. investigations of "problem buildings." These include two major recent studies of federal government facilities in Washington, D.C., the headquarters of the Environmental Protection Agency and an office building of the Library of Congress. Additionally, the National Institute for Occupational Health and Safety (NIOSH) has published individual reports and several overall summaries of 535 investigations it has conducted into complaint buildings.

There are two distinct approaches to understanding the effects of indoor air quality on occupant health and comfort. One is to intensively study one or more "problem buildings," buildings where abundant occupant complaints and reported health effects suggest that there are environmental factors that may be responsible. Here, it is assumed, it should be reasonably easy to find abonormalities in the environment, at least when compared with non-problem buildings.

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are environmental factors that may be responsible. Here, it is assumed, it should be reasonably easy to find abonormalities in the environment, at least when compared with non-problem buildings.

Investigators called in to resolve problems usually do not study a similar population in a non-complaint building as an experimental "control." Epidemiologists prefer to study a control building in order to develop a baseline for the frequency of occupant complaints and health effects reports.

The second basic approach is to investigate a large number of occupants in many buildings, usually buildings not known to have an excessive or unusually high rate of complaints. Here researchers try to find the potential causal environmental factors by identifying the environmental conditions associated with elevated complaint rates where they do occur.

There is a very large body of literature on problem building investigations. Therefore, this review is necessarily selective and incomplete.

SFSSB San Francisco Social Services Building (SFSSB)

The investigation of this building was the first published comprehensive problem building investigation in the United States (Turiel et al, 1983). The office building was subject to occupant complaints from the time it was first occupied. A more recent study by Mendell et al (1991) indicates that the building remains a "problem building" more than a decade.

A union questionnaire showed a high rate of complaints. An epidemiologic study was conducted by Molly Coye, then of NIOSH, comparing complaint rate prevalence to that of an older building with workers from the same agency. The symptom prevalence was clearly elevated at SFSSB as shown in Table 1. The results are not unlike those from many other studies.

Table 1. Comparison of health-related complaints at SFSS and control buildings.

Symptom Or Complaint	%Positive Responses At SFSS Building	%Positive Responses At Control Building	"p Value"
Eye irritation/itching	54.9	36.1	0.0493
Frequent irritation of nose or throat	52.5	23.5	0.0024
Increased shortness of breath	18.9	3.0	0.0405
Chest tightness	20.6	3.0	0.0268
Eye inflammation/ infection	19.5	3.4	0.0586
Skin dryness	35.1	22.4	0.0625

Scientists from Lawrence Berkeley Laboratory conducted extensive environmental measurements and found levels well within established industrial exposure limits. Their measurements were made nearly nine months after the outbreak of complaints, and the exposure levels used for

evaluating the results of their monitoring efforts were not established to protect the non-industrial worker. Considerably more sophisticated monitoring methods are now available, and industrial or outdoor air quality standards are no longer considered appropriate for interpretation of indoor air quality monitoring. But more relevant guidance for interpretation of results is still needed. And less obtrusive, less costly monitoring devices are still needed as well.

Carpet Shampoo

Kreiss et al (1982) investigated reported respiratory irritation among most employees in an office building. Symptom prevalence in cases (individuals whose symptoms abated when they left the building) was as high as 10 times the rate reported by other employees. Symptoms persisted for many weeks and even as long as three months, and did not abate until carpets were wet extracted. Three shampoo products implicated in the office building and two similar outbreaks contained sodium dodecyl sulfate, a respiratory irritant in mice. Symptom prevalence was high -- 80 to 100% of the exposed individuals. The authors found unpublished evidence that soap dust exposure may be associated with abnormal pulmonary function in exposed workers.

National Institute for Occupational Health and Safety (NIOSH)

Melius et al (1984) and later Seitz (1990) have reported on investigations by the Hazard Evaluations and Technical Assistance Branch of the National Institute for Occupational Safety and Health (NIOSH). Since 1971, NIOSH conducted more than 500 investigations presumed related to indoor air quality in various business and government office environments. In addition, it investigated schools and health care facilities. These investigations were initiated after reported complaints and illnesses among occupants.

NIOSH investigators have been presenting the results from their investigations at conferences and in publications since 1984. The presentation has been updated periodically to include more recent results. It usually includes the numbers and types of buildings investigated by year and building type and the "problem type" by number and percent.

Table 2 is from the most recent published version of the data by Teresa Seitz of NIOSH's Cincinnati office. Seitz originally presented the paper at the Indoor Air Quality International Symposium at the American Industrial Hygiene Association's 50th Annual Meeting in St. Louis, May 23, 1989. Nearly everyone who attends an indoor air quality course, seminar, or conference in the United States has seen these data at least once.

Table 2. NIOSH Indoor Air Quality Investigations by Problem Type (Seitz, 1990)

Problem Type	Number Completed*	%
Contamination (inside)	80	15
Contamination (outside)	53	10
Contamination (building fabric)	21	4
Contamination (microbial)	27	5
Inadequate ventilation	280	53
Unkown	68	13
TOTAL	529	100

* Investigations completed through 1988.

WHAT DO THE NIOSH NUMBERS MEAN?

NIOSH officials acknowledge privately and publicly that the numbers in their table do not necessarily define the causes of the problems they investigate. Often NIOSH investigators (like many others) recommend improved ventilation when they are unable to define the etiology of the occupants' complaints. This, the investigators admit, does not necessarily mean that they have demonstrated the presence of a ventilation problem. Indeed, pollutant sources may have caused or contributed to the problem.

Although NIOSH data have been interpreted to mean that ventilation problems caused 53% of the cases they investigated. But in most cases NIOSH investigators made no systematic effort to prove that poor ventilation caused the problems, and identifying the causes is not necessarily the focus of their efforts. Like most investigators of problem buildings, NIOSH teams attempt to alleviate complaints. The NIOSH teams did not follow a standardized protocl, nor did they conduct any routine follow-up to verify that their recommendations worked or were implemented.

Wallingford (1991) says that NIOSH investigators generally have used ASHRAE standards as a basis for comparison. According to Wallingford, of those cases attributed to "inadequate ventilation," roughly half did not meet ASHRAE Standard 62-1981 for outside air supply rates; about one-quarter did not meet ASHRAE Standard 55-1981 criteria for thermal control and relative humdity. And about a quarter involved other ventilation problems such as poor space air distribution, inadequate filtration, or other ventilation problems observed by the investigators and deemed inadequate according to their professional judgment.

Improving ventilation usually costs less and is more productive than conducting the kind of study necessary to demonstrate the causal relationships between contaminants and occupant responses. Furthermore, in most problem buildings, both owners and occupants are more interested in reducing the effects than in finding the causes. Since it is possible to improve ventilation in nearly every building, whether it has an air quality problem or not, it is almost *de riguer* to recommend improved ventilation. And for nearly every type of indoor air pollutant, increasing ventilation rates and improving ventilation system performance are likely to reduce indoor airborne concentrations. This, in turn, will mitigate the causes of increased many complaints.

Indoor Air Diagnostics

Woods (1987) conducted numerous investigations while he directed an interdisciplinary investigatory team at Honeywell's Indoor Air Diagnostic Program. Woods, a mechanical engineer as well as a physiologist, indicates that there are usually multiple problems that *could* be causing the occupant symptoms. The results of of his work are presented in Table 3. The numbers (given in percent) add up to more than 100 because he includes each type of identified problem that his team defines as potentially contributing to the complaints. Woods says there is usually more than one thing wrong with a problem building.

Woods says that of all the buildings he investigated, about two-thirds contained SBS and one-third contained Building-related illness (BRI). Like many other authorities, Woods classifies SBS and BRI as distinct types of of building problems. Woods says that you can find SBS without BRI but that you are unlikely to find BRI without SBS. He has never seen BRI without SBS. "If BRI is found, you must identify the source and absolutely must mitigate it. A good example of that is Legionnaire's Disease."

Table 3. Types of Predominant Environmental Stressors (Woods, 1987)

Type of environmental stressor	Prevalence in problem buildings (percent)
Chemical and particulate contaminants	75
(With odor discomfort)	70
Thermal discomfort	55
Microbiological contaminants	45
Nonthermal humidity problems (With eye irritation and mold growth from low and high relative humidities respectively)	30

Table 4. Frequencies of Occurrence of Physical Causes of Problem Buildings

PROBLEM CATEGORY	PHYSICAL CAUSE	FREQUENCY (%)
Design		
	System problems	
	Inadequate outdoor air	75
	Inadequate supply air distribution to occupied spaces	65
	Inadequate return/exhaust air	75
	Equipment problems	
	Inadequate filtration of supply air	65
	Inadequate drain lines and drain pans	60
	Contaminated ductwork or duct linings	45
	Malfunctioning humidifiers	20
	Inadequate access panels to equipment	60
Operations		
	Inappropriate control strategies	90
	Inadequate maintenance	75
	Thermal and contaminant load changes	60

Woods' investigation method focuses on the ventilation system, so it may exagerrate the contribution of ventilation by describing its many defects. The ventilation bias reinforces the notion Molhave that diagnosis of problem buildings usually reflect the disciplinary bias of the lead investigator. Woods' data support the notion that ventilation problems often exist in problems buildings, but the data do not attempt to demonstrate the nature of the contaminant sources.

Army Barracks Febrile Acute Respiratory Disease Study

One of the most valuable epidemiological studies in the United States is that of Brundage et al (1988) involving comparison of respiratory disease rates among army trainees housed in old and in modern army barracks. The study shows a significantly higher risk of febrile acute respiratory disease (ARD) among trainees housed in the modern barracks. The overall trainee hospital admission adjusted relative risk ratio for the modern barracks was 50% higher than for old barracks.

Old Barracks. The old barracks were single- to three-story structures generally constructed during the 1940s or 1950s of various designs and construction materials. Ventilation was routinely provided by opening windows and running ceiling exhaust fans. Typical heating and air conditioning systems (if present) recirculated more than 50% of previously conditioned air and used approximately 40% outdoor make-up air. Generally, old barracks were divided into open bays housing 20 to 55 trainees per bay.

New Barracks. The new barracks were three-story concrete structures constructed in the late 1970s or 1980s, were nearly identical, and were designed, built and operated to be energy efficient. Mechanical HVAC systems typically recirculated approximately 95% of conditioned air with total circulated air supply of 17 L/s per person [36 ft^3 per minute per person (cfm/p)] -- about three air changes per hour. Although not so stated in the published report, those figures calculate to slightly less than 1 L/s per person (1.8 cfm/p). Dampers for outside air intake were closed except when outside temperatures were within 2.8 °C (5 °F) of inside temperatures. New barracks were divided into platoon-sized open bays housing up to 55 trainees. Although windows were present on two sides of each bay, they were not generally opened in accordance with energy conservation guidelines.

RESULTS

The study reported results in terms of ARD rate (hospital admissions for febrile ARD) per 100 trainee-weeks. Overall there were 14,731 admissions during 2,633,916 trainee-weeks, or 0.56 admissions per 100 trainee-weeks. Table 5 shows the results. The overall admission rate per trainee-week in modern barracks was 0.67 (8,028/1,189,433) compared with an admission rate of 0.46 (6,073/1,444,483) in old barracks. The overall rate difference was 0.21 admissions per 100 trainee-weeks with and adjusted relative risk estimate of 1.51 (95% confidence interval, 1.46 to 1.56).

After an initial increase during the second week, the incidence of febrile acute respiratory disease (ARD) stabilized overall during the seven week progress of training in the old barracks while it increased steadily through the fifth of the seven weeks in the modern barracks. It was higher in the modern barracks in each week, and substantially higher during periods when adenovirus vaccines were administered only seasonally rather than year-round. The administration of adenovirus vaccine appears more effective in limiting the incidence of febrile ARD in old barracks than in modern ones.

CONCLUSIONS

The study's authors concluded that "...the increased risk attributable to residence in modern barracks was epidemiologically important, statistically significant, and consistent among the [various training] centers." They also concluded that several of the study's findings "...suggest modern barracks increased ARD risk by facilitating the transmission of respiratory pathogens among immunologically susceptible trainees. Relative risks were consistently and most significantly increased during the period when adenovirus immunizations were not administered."

Table 5. Admission Rate Ratios and Estimated Excess Admissions for Acute Respiratory Disease.

YEAR	MODERN BARRACKS	OLD BARRACKS	RATE RATIO (95% confidence interval)	NO. OF EXCESS ADMISSIONS
		POST JACKSON		
1982	151/34 360	134/40 148	1.32 (1.05-1.66)	41
1983	1998/136 565	1354/184 737	2.00 (1.87-2.14)	1028
1984	416/120 623	651/171 186	0.91 (0.80-1.03)	-33
1985	439/103 063	609/146 541	1.02 (0.91-1.16)	-5
1986	351/56 683	564/104 444	1.15 (1.00-1.31)	48
Subtotal	3355/451 294	3312/647 056	1.45 (1.39-1.52)	1078
		POST SILL		
1982	79/11 048	75/14 428	1.38 (1.01-1.88)	21
1983	674/51 902	489/63 760	1.69 (1.15-1.90)	279
1984	404/52 077	426/58 195	1.06 (0.93-1.21)	-1
1985	245/48 115	205/62 246	1.55 (1.29-1.86)	86
1986	45/14 014	85/29 299	1.03 (0.72-1.48)	-5
Subtotal	1447/178 156	1280/227 928	1.45 (1.34-1.56)	379
		POST McCLELLAN		
1982	110/15 109	79/14 543	1.34 (1.01-1.79)	31
1983	562/62 526	300/53 818	1.61 (1.40-1.85)	213
1984	687/62 338	564/65 596	1.28 (1.15-1.43)	192
1985	216/41 485	162/59 595	1.92 (1.57-2.34)	91
1986	52/10 289	159/36 058	1.15 (0.84-1.57)	14
Subtotal	1627/191 747	1264/229 610	1.54 (1.43-1.66)	542
		POST BENNING		
1982	225/24 348	113/20 990	1.72 (1.37-2.14)	90
1983	705/97 187	279/96 099	2.50 (2.19-2.86)	415
1984	238/102 341	144/95 938	1.55 (1.26-1.90)	84
1985	236/95 537	197/77 400	0.97 (0.80-1.17)	4
1986	195/48 823	114/49 462	1.73 (1.38-2.18)	72
Subtotal	1599/368 236	847/339 889	1.74 (1.61-1.89)	664
		ALL POSTS		
1982	565/84 865	401/90 109	1.46 (1.28-1.65)	183
1983	3939/348 180	2422/398 414	1.94 (1.85-2.04)	1935
1984	1745/337 379	1785/390 915	1.13 (1.06-1.21)	242
1985	1136/288 200	1173/345 782	1.22 (1.12-1.32)	175
1986	643/130 809	922/219 263	1.24 (1.12-1.38)	128
Subtotal	8028/1 189 433	6703/1 444 483	1.51 (1.46-1.56)	2663

Evidence for the higher risk of efficient transmission of pathogens in modern barracks comes from the data acquired during an epidemic in 1983. "Rates increased as training progressed in modern, but not in old, barracks. Contrasts in patterns of progression, supported by virus isolation findings, suggest that pathogenic microorganisms ... were efficiently transmitted, and cycles of infection and clinical disease were propagated primarily among trainees in modern barracks." Rate differences between old and modern barracks were neglible during low overall ARD incidence, after year-round adenovirus immunizations were commenced, and during the early weeks of training. Thus, it does not appear that factors intrinsic to modern buildings were responsible for ARD excesses; and "...reporting or ascertainment biases were not likely explanations for observed differences." The authors did qualify their conclusions by stating that "...potentially significant confounding factors, [such as crowding factors,] precludes a definitive judgment regarding causality."

IMPORTANCE OF THE STUDY

The study is fairly unique among building epidemiologic investigations. Most such studies have been conducted in office or school environments where environmental exposures and other factors outside the study building(s) and population variability can weaken the strength of the findings. Even those done in residential environments have been limited in scope or subject to confounding variation in population or exposure outside the study environments.

The military training population and environmental exposures make them ideal study subjects for several reasons. No geographic or demographic factors are used to assign trainees to training centers or barracks types; all trainees receive identical immunizations; there is minimal contact between members of different barracks-defined groups; activities outside the barracks are rigidly standardized; and all groups at a given training center are exposed to the same outdoor environmental conditions. The training environment is extremely uniform by regulation and intent.

Outbreaks of several important diseases are believed likely or certain to be transmitted by the aerosol route. These include rhinovirus infections, a significant cause of the common cold, rubella, measles, influenza, legionellosis, tuberculosis, and other viral and bacterial diseases. Outbreaks of these diseases "...have been documented among office workers, hospital patients and staff, outpatients, nursing home residents, hotel guests, prison inmates, elementary and secondary school students, and college students. The greatest potential threat is presented during influenza epidemics...[when] it is estimated that 10,000 or more excess deaths occurred in each of 19 different [epidemics] in the United States between 1957 and 1986." The impact is greatest in terms of morbidity and mortality among elderly but also for previously healthy children, adolescents, and young adults. Therefore, during influenze epidemics, indoor airborne-transmitted infections may contribute to thousands of disabling illnesses, and billions of dollars of financial, social, and health costs in a broad segment of the population over an extended period of time." So, if the characteristics of modern buildings of other types impart risks of similar magnitude to those imparted by modern barracks, then modifiable building design characteristics may be significant contributors to morbidity and mortality risk on a nationwide basis.

Investigation of EPA Headquarters Buildings, Washington, D.C.

The environment at the EPA Washington, D.C. headquarters facility at Waterside Mall has received considerable publicity ever since numerous employees complained of health problems following the installation of new carpeting in late 1987 and early 1988. Actually, health and comfort complaints have been reported there for many years. In fact, complaints about the build-

ing environment were reported on a National Public Radio broadcast as long ago as 1981 (Zwerdling National Public Radio). When employees publicly protested the building environment in the spring of 1988 the building received national press coverage as a result.

BACKGROUND OF THE STUDY

In March of 1990 EPA conducted a study of its Waterside Mall facility and two other Washington area buildings it occupies. The investigators used a questionnaire survey of building occupants and extensive environmental measurements. The study was one of the most comprehensive building environment studies conducted in the United States to date. EPA conducted the study with the assistance of the National Institute for Occupational Safety and Health (NIOSH), Yale University, and private consultants. The manpower and financial resources expended on it were considerable.

Until recently most of the reported results of the study have been disappointing in light of the investigators' and occupants' expectations and the expense and effort expended. As of this writing, EPA has not yet released the complete results but is expected to release the remainder of the four-volume series of reports in the Winter of 1992. Earlier volumes reported the results of the questionnaire survey and the environmental measurements. Selected study methods, results, and data analyses have been reported by the investigators (Wallace, 1991; Nelson, 1991). "IAQ '91 - Healthy Buildings."

METHODOLOGY

An important element of the Wallace's analysis was the use of principal component analysis as a statistical method. If building-associated illness is truly a result of multifactorial causes, then effective analysis of investigation results requires methods capable of managing multivariate data. Such data can provide information about the relationships between the variables and about the subjects in the study.

According to S.S. Cohen in his book, *Practical Statistics*, variables can be clustered or searched for combinations of them that as a single measurement account for a large proportion of the total variability in the sample. The linear [??] combination that corresponds to the largest amount of variability is called the "first principal component." After removing the effect of the first principal component, the factor accounting for the most remainging variability is called the "second principal component," and so forth. There are as many principal components as there are variables, but the first few usually explain a significant portion of the total variance and the rest are ignored.

The principal component analysis tries to combine the variables in the data set into a smaller set of "derived measurements" that describe the most salient features of the sample. Each component assembles correlated variables and provides a single value to express their information content.

The Statistical Analyses. The investigators analyzed separately 25 personal and psychological factors and 29 workplace factors included in the questionnaire. They also factored in new carpet and ventilation. They examined the effect of "coarse-grained" location (by building or major building sector) and "fine-grained" location (by 66 air handling unit/floor locations) in the three buildings. They ran numerous statistical analyses on each of 22 health, comfort, and odor factors. The 32 health symptoms clustered into 12 factors, "largely by single body systems such as eye, nose, throat, chest, central nervous system, etc."

They ran all of their regression analyses separately for men and women. In all, then, they ran 68 separate regressions within each set of three linear regressions and one set of logistic regressions. Each regression contained between 20 and 120 personal and workplace characteristics, so

thousands of asssociations were investigated. Since this approach increases the likelihood of "false positives," they considered effects significant only if there was no more than one chance in 100 ($p \leq 0.01$) that the association was due to chance.

RESULTS OF THE STUDY

The authors noted an important finding of their study was that headache is the single most common cause of absenteeism and lost work time. They also noted that glare appeared associated with headaches, and other ergonomic factors were associated with neck and shoulder pain. They suggested that improvement of the ergonomic design of work stations could be an effective means to improve productivity.

QUESTIONNAIRE RESULTS

Wallace reported his analysis of the questionnaire responses. About 5,000 EPA employees received the questionnaire, 3,955 (81%) returned it. The results were organized in terms of either comfort and odor factors or in terms of health factors. Wallace concluded that "...the workplace variable affecting the largest number of health symptoms and comfort/odor concerns was dust. Perceptions of hot, stuffy air and the odor of paint and carpet cleaning and other chemicals were also associated with a number of health symptoms." Glare, noise, and nearby water leaks were also associated with comfort and odor. Seven variables were associated with at least three comfort and odor factors. These are shown in Table 6.

Table 6. Variables Associated[a] with at Least 3 of the 10 Comfort and Odor Factors.

WORKPLACE CHARACTERISTICS	
Dust:	All four comfort concerns and all six odor factors.
Glare:	Hot air; Dry air; Odors of paint; Cosmetics; Dampness.
Noise:	Hot air; Dry air; Cold air Odors of paint and cosmetics.
Use fan:	Hot air; Humid air; Cold air (negative); Odors of cosmetics.
Water leaks:	Odors of dampness; Cosmetics; Tobacco smoke.
PERSONAL CHARACTERISTICS	
Sensitivity to chemical fumes:	Humid air; Odors of paint; Photocopying; New carpet; Tobacco smoke.
Conflicting demands:	Dry air; Cold air; odors of cosmetics; Photocopying; Dampness; Tobacco smoke.

[a] Significant ($p<0.01$) in at least two (of four) linear and logistic regressions.

The eleven variables associated with at least four of the 12 health factors are shown in Table 7.

Table 7. Variables Associated[a] with at Least 4 of the 12 Health Factors.

WORKPLACE CHARACTERISTICS	
Dust:	Headache; Nasal, chest, eye, throat symptoms; Fatigue; Chills and fever; Difficulty concentrating[b]; Dizziness; Dry skin; Contact lens problems.
Glare:	Headache; Eye Symptoms; Fatigue; Difficulty concentrating; Pain[c].
PERSONAL CHARACTERISTICS	
Sensitivity to chemical fumes:	Headache; Nasal, chest, eye, throat symptoms; Fatigue; Pain; Chills and fever; Difficulty concentrating; Dizziness.
Mold allergies:	Headache; Nasal, eye, throat symptoms; Fatigue; Pain; Dry skin.
No college:	Headache; Chest symptoms; Fatigue; Chills and fever; Dizziness.
PSYCHOSOCIAL CHARACTERISTICS	
Workload:	Headache; Eye symptoms; Pain; Difficulty concentrating; Dizziness.
Conflicting demands:	Nasal, chest symptoms; Chills and fever; Pain; Difficulty concentrating; Dizziness.
COMFORT AND ODOR CHARACTERISTICS	
Hot stuffy air:	Headache; Nasal eye, chest symptoms; Fatigue; Difficulty concentrating; Dizziness.
Dry air:	Headache; Nasal, eye, throat symptoms; Dry skin.
Odor of paint, chemicals:	Headache; Nasal, chest, throat symptoms; Fatigue; Chills; Difficulty concentrating; Dizziness.
Odor of cosmetics:	Eye symptoms; Chills and fever; Pain; Difficulty concentrating.

[a] Significant ($p < 0.01$) in at least two (of eight) linear and logistic regressions.
[b] Includes difficulty concentrating, difficulty remembering, depression, tension.
[c] Includes aching muscles, back pain, shoulder/neck pain, had/wrist pain.l
[d] Significant at $p < 0.01$ in at least two (of four) linear and logistic regressions.

The results did not implicate individual air-handling units. This is not surprising since the number of air handlers serving EPA's portion of Waterside Mall is believed upwards of 50; some sources have said that there are more than 100 serving the entire building complex. Areas with new carpet did have higher incidences of reported throat problems. This is also not surprising, since so much has been made of the problems occurring after new carpet installations at the Waterside Mall facility.

SIGNIFICANCE OF THE STUDY

According to Wallace, "[t]his is the first large-scale building study to employ an objective measure (PCA) [principal component analysis] to assess the way in which health symptoms cluster together." Wallace writes that authors of "[p]revious studies have subjectively grouped symptoms into clusters, which sometimes contain symptoms belonging to different factors as identified by the more objective PCA. The effect of lumping different factors would likely be to make it more difficult to detect associations."

Another important aspect of the study was that it attempted a census rather than a sample of the all the occupants of all three buildings studied. The 81% coverage achieved allowed analysis of the effects of spatial variation including the effects of ventilation and carpet installation. According to Wallace, "These analyses have not been possible in most preceding studies because they typically have involved only a sample of employees from multiple buildings. The Danish [Town Hall] study was also a census, but measurements were made in only one room per building."

Finally, reported health complaints and and indoor air quality problems at the EPA facility at Waterside Mall in Washington, DC, have been the subject of so much attention during the past four years, it is valuable to have the results of a fairly comprehensive study. We think that the most surprising study result is that the complaint rates at Waterside Mall were not terribly different from those at the other two facilities in the area.

DISCUSSION OF FINDINGS

Dust. Dust was the strongest contributor to reported effects. These included a wide variety of health, comfort, and odor concerns. The cause is not known, but it could be physical irritation, allergens, or endotoxins. This finding is similar to one from the Danish Town Hall Study (DTHS) where dust was the most highly correlated variable to self-reported health symptoms. Another study, conducted in Sweden by Norback and Torgen, found reduced health symptoms in an office environment following intensive cleaning of carpet and wet dusting. Hedge (1991) reported that increasing recirculation and filtration employing HEPA filters and charcoal) reduced occupant symptoms on two floors compared with occupants of two untreated floors.

Dust also contributed most strongly to comfort and odor factors. Since dust particles may be generated by processes that create odors such as tobacco smoking, printing, or painting, the relatioship between odors and particles may have physical causes, according to the authors. The main odor factor with health associations was composed of the odors of paints, carpet cleaning, pesticides, and other chemicals such as glues and cleansers. Most of these odors are associated with maintenance activities in the building.

Health Symptoms Cluster. The 32 health symptoms clustered into 12 factors, "largely by single body systems such as eye, nose, throat, chest, central nervous system, etc." The authors thought this finding should be useful in designing questionnaires for future studies. This is an important issue not only in questionnaire design but also in analysis of the results. Other investigators have found that the way symptoms or complaints are clustered can affect the results of the studies. A notable example is the Northern Sweden Office Environment Study. Jan Sundell reported some of the results of that study at the ASHRAE conference.

Building Maintenance. In the conclusion, the authors wrote: "The importance of dust, mold allergies, the odor of paints and other chemicals, and nearby water leaks in affecting multiple health symptoms and comfort/odor factors points to building maintenance or renovation as a possible factor in the complaints at the three buildings. Therefore, it is recommended that attention

be given to ways of improving building maintenance, particularly to reduce dust, clutter, and conditions conducive to growth of mold.... The design of new buildings should allow for adequate building maintenance and should reduce the likelihood of dust buildup. This could include decisions on the optimum extent of carpeting and fabric-covered partitions vs. other, more easily cleaned surfaces; the use of walk-off mats to reduce track-in dust and dirt; and techniques to alolow for easy replacement of water-soaked carpet or clenaing and disinfecting water-stained surfaces."

Air cleaning and filtration. The authors note that many office tasks are associated with dust production. Therefore, they recommend consideration of "supplemental air cleaning and filtration." They note that this would require additional ventilation which might also reduce complaints associated with hot, stuffy air. Some means to achieve reduced dust levels include more frequent, more effective housekeeping, more efficient filters in HVAC systems, increased air circulation, or the use of local fans and filtration systems. We note that there are many vendors available to provide all of these, but it is essential to obtain competent professional assessment of equipment and evaluation of the options.

Library of Congress

NIOSH and EPA investigators involved in the EPA Headquarters studied have conducted a parallel study on an office building at the Library of Congress. The results have not provided significant insights into the causes of the problems that have been present there for many years. Some observers believe that although the investigation was costly and extensive, the investigation did not address the problems in an effective manner. Either things were measured in an unusueful way, or the wrong things were measured.

California Healthy Buildings Pilot Study

Mark Mendell and colleagues at the California Department of Health Services and Lawrence Berkeley Laboratory have initiated a multi-building investigation intended to elucidate the differences between mechanically ventilated and naturally ventilated buildings. The work reported to date is from a pilot study involving ten buildings. Further work is contemplated for a much larger building population.

EPA Large Building Study

The U.S. Environmental Protection Agency (EPA) has initiated a process that will lead to funding of portions or all of several field studies of large buildings. The basic purpose of the study is to gather normative data and distributions of important environmental factors and occupant responses in a wide range of U.S. office buildings. No field work has commenced as yet, but the program promises to provide a needed injection of funding for building investigations in the United States.

Conclusion

It is difficult to identify the causes of health and comfort complaints due to the multitude of factors that separately or in concert affect building occupants. These factors include the building environment and the psychosocial environment. The building environment factors are physical, chemical, biological; the psychosocial environmental factors are personal, interpersonal, and institutional. Most factors are difficult to measure, vary over time, vary from space to space within buildings, and vary regarding their effect on different individuals. To date, U.S. researchers and investigators have had limited success in determining the causes of comfort and health complaints in many problem buildings. New efforts undertaken in California and at the EPA are likely to provide more opportunities for productive investigations and studies in the early 1990s.

References and Bibliography

Alexander, R.W., and Fedoruk, J. 1976. "Epidemic psychogenic illness in a telephone operators' building." J Occ Med, Vol. 28 No. 1, pp. 42-45.

Baker, D. R., Social and organizational factors in office building-associated illness, In

Brundage, J.F., Scott, R.N., Lednar, W.M., Smith, D.W., and Miller, R.N., 1988, Building-associated risk of febrile acute respiratory diseases in army trainees. Journal of American Medical Association, Vol. 259, pp. 2108-2112.

Colligan, M.J. 1981. "The psychological effects of indoor air pollution." Bull. N.Y. Acad. Med., Vol. 57, pp. 1014-1025.

Cone, J., and Hodgson, M., Preface, In Cone, J., and Hodgson, M., (Eds.) Problem Buildings: Building Associated Illness and the Sick Building Syndrome. Philadelphia: Hanely & Belfus, Inc., pp. x-xii.

Cone, J., and Hodgson, M., (Eds.) Problem Buildings: Building Associated Illness and the Sick Building Syndrome. Philadelphia: Hanely & Belfus, Inc.

EPA, 1989, *Indoor Air Quality and Work Environment Survey, Volume I: Employee Survey* . Washington, DC: U. S. Environmental Protection Agency.

EPA, 1991, *Indoor Air Quality and Work Environment Survey, Volume IV: Multivariate Analysis*. Washington, DC: U. S. Environmental Protection Agency.

Hedge, Alan, M. G. Martin, J. F. McCarthy. 1991. "Breathing zone filtration effect on indoor air quality and sick building syndrome complaints." In, *Healthy Buildings*, Proceedings of IAQ '91 - Healthy Buildings, September 4-8, 1991. Atlanta: American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc. pp. 351-357.

HESIS. 1987. "Investigation and work up of tight building syndrome. The state of the work place" Vol. 1, No. 2. An internal bulletin from HESIS, the Hazard Evaluation System and Information Service, Calfifornia Department of Health Services, Berkeley., p. 12.

Hodgson, M.J. 1988. "Health risks of indoor pollutants." Engineering Solutions to Indoor Air Problems; IAQ '88. April 11-13. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., pp. 284-293.

Hodgson, M.J., and Kreiss, K. 1986. "Building associated diseases." In Proceedings of the ASHRAE Conference IAQ'86; Managing Indoor Air for Health and Energy Conservation. April 20-23. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., pp. 1-15.

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. In B. Seifert, H. Edson, M. Fischer, H. Ruden, and J. Wegner, (Eds.) Indoor Air '87; Proceedings of the 4th International Conference on Indoor Air Quality and Climate, Vol. 2. West Berlin, 17-21 August. Berlin: Institute for Water, Soil and Air Hygiene, pp. 449-453.

Hodgson, M.J., and Collopy, M.E., 1989, Symptoms and the micro-environment in the sich building syndrome: a pilot study, In ASHRAE, The Human Equation: Health and Comfort, Proceedings of IAQ '89. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., pp. 8-16.

Hollowell, C.D., and Miksch, R.R. 1981. "Sources and concentrations of organic compounds in indoor environments." *Bull. N.Y. Acad. Med.*, Vol. 57, pp. 962-977.

Kreiss, K. (1982). Respiratory irritation due to carpet shampoo: two outbreaks." *Environment International* 8:337-341.

Kreiss, K. and Hodgson, M. 1984. "Building-associated epidemics." In Walsh, P.J., Dudney, C.S. and Copenhaver, E. D. (Eds), Indoor Air Quality, pp. 87-106.. Boca Raton, FL: CRC Press.

Levin, H., and Phillips, T.J. 1989a. "Pre-occupancy meaurements in California state office buildings." Design and Protocol for Monitoring Indoor Air Quality, ASTM STP 1002. Nagda, N.L. and Harper, J.P.(Eds.) Philadelphia: ASTM. pp. 99-110.

Marans, R.W., Generative evaluations using quantitative methods: a case study, In Preiser, W.F.E. (ed.), Building Evaluation, New York; Plenum Press.

Mendell, M., and Smith, A.H. 1990, Consistent pattern of elevated symptoms in air-conditioned office buildings: a re-analysis of epidemiologic studies, American Journal of Public Health, Vol. 80, No. 10, (October), pp. 1193-1199.

Mendell, Mark, and William Fisk (1991). "The California Healthy Buildings Pilot Study." Presented at ASHRAE Annual Meeting, June 23-26, 1991.

Molhave, Lars (1987). "The sick buildings -- a subpopulation among the problem buildings?" In B. Seifert, H. Edson, M. Fischer, H. Ruden, and J. Wegner, (Eds.) Indoor Air '87; Proceedings of the 4th International Conference on Indoor Air Quality and Climate, Vol. 2. West Berlin, 17-21 August. Berlin: Institute for Water, Soil and Air Hygiene, pp. 469-473.

Morey, P. R. 1988. "Microorganisms in buildings and HVAC systems: a summary of 21 environmental studies." Engineering Solutions to Indoor Air Problems; IAQ '88. Atlanta, April 11-13. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., pp. 10-24.

National Academy of Sciences, 1981. *Indoor Pollutants*. Washington, D.C.: National Academy of Sciences.

National Academy of Sciences. 1985. Building diagnostics: a conceptual framework. Washington, DC: National Academy Press.

Nelson, C.J. (1991). EPA's Indoor Air Quality and Work Environment Survey: Relationships of Employees' Self-Reported Health Symptoms with Direct Indoor Air Quality Measurements." *IAQ '91 - Healthy Buildings."* Proceedings of IAQ '91 - Healthy Buildings, September 4-8, 1991. Atlanta: American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc. pp. 22-32.

NIOSH. 1987. Guidance for indoor air quality investigations. Cincinnati: National Institute for Occupational Safety and Health.

Turiel, I.; Hollowell, C.D.; Miksch, R.R.; Rudy, J.V.; Young, R.A.; and Coye, M.J. 1983. "The effects of reduced ventilation on indoor air qulaity in an office building." Atmospheric Environment, Vol. 17, No. 1, pp. 51-64.

Wallace, Lance A., C.J. Nelson, and G. Dunteman (1991). " Workplace Characteristics Associated with Health and Comfort Concerns in Three Office Buildings in Washington, DC." In, *IAQ '91 - Healthy Buildings*, Proceedings of IAQ '91 - Healthy Buildings, September 4-8, 1991. Atlanta: American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc. pp. 56-60.

Wallingford, Ken (1991). Personal communication.

Woods, J.E. 1987. Testimony presented before the Subcommittee on Environmental Protection of the Committee on Environment and Public Works, United States Senate. November 20.

Zwerdling, Daniel (1981). National Public Radio broadcast.

REGULATING INDOOR AIR

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ABSTRACT. The possibilities to reduce indoor air pollution comprise source control, dilution and the setting of limit values for indoor air pollutants. While emission standards, voluntary agreements, and even bans are elements of the first option, the dilution approach includes ventilation standards and air cleaning devices. In contrast to the situation for outdoor air and the air at work places, setting air quality standards does not seem to be the appropriate way to reduce indoor air pollution. Rather, the use of guideline values for indoor air pollutants is recommended. Guideline values may be set two at a time, one defining a level of hazard for immediate action, the other a target concentration for the future. The example of tetrachloroethene is chosen to illustrate the applicability of the concept in practice.

1. INTRODUCTION

To reduce air pollution, many countries have regulations which limit emissions of air pollutants into outdoor air. These regulations include ambient air quality standards valid for both the short term and the long term. Generally, such standards are the result of a compromise between scientific knowledge and political will.

Like outdoor air, the air quality of industrial workplaces is subject to regulations. Limit values have been set by the various bodies responsible for the protection of the working population. Averages over one shift of several hours and short-term exposure limits have been defined.

As to the nonindustrial indoor environment, potential exposure to air pollutants has also been subject to certain regulations for many years. In many countries, building codes contain proscriptions which have an influence on the design of indoor spaces. In addition, research related to human comfort has been carried out with the aim of defining

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the acceptable indoor climate (cf. Pettenkofer 1858; Fanger 1970; McIntyre 1980). National and international bodies have issued recommendations (e.g., ASHRAE 1981; ISO 1984). However, the presence of chemical and microbiological pollutants in the air of private spaces, schools, offices, transportation systems, etc. has only become a matter of greater concern since the mid-1970s and has only been the subject of regulations to a very limited extent.

The major difficulty that one faces in dealing with indoor air regulation is that this topic is not under the responsibility of one single department or ministry and that no special law comprehensively addressing the subject exists in any country.

In the absence of clearly defined responsibilities, regulations are not easily established. As a result, private litigation becomes important in protecting individuals against damage such as that caused by environmental impact (Ricci et al. 1989). But not only is such private litigation costly, it also lays the interpretation of scientific findings into the hands of nonscientists, namely judges. Even if a judge calls on experts for assistance, a court can never assemble and evaluate the full body of scientific knowledge, especially if questions are to be answered for which there is no agreement among scientists.

Therefore, to create a system of legal guaranty is one of the most important rationales for establishing regulations, especially in the environmental field. However, regulations should not be too tight in the case of the indoor environment. Rather, the avenue indicated by O'Riordan (1989) should be followed: "Anticipatory environmental policy should seek to establish the right mix of regulations and incentives to coordinate planning, fiscal and economical instruments with regulatory measures...".

This article discusses the different regulatory options that are available to guarantee satisfactory indoor air quality. In the course of the text, "to regulate" is used in the more general sense of "to adjust by rule, method or established mode" which goes beyond the more restricted meaning of "to bring under the control of law or constituted authority".

2. THE POSSIBILITIES TO REDUCE INDOOR AIR POLLUTION

The fundamental equation which governs indoor air pollution is the following:

$$dc_i/dt = Q/V + n \cdot c_a - A \cdot c_i - n \cdot c_i \qquad (1)$$

with c_i = concentration of compound i in indoor air ($mg \cdot m^{-3}$)
Q = emission rate ($mg \cdot h^{-1}$)
V = volume of the indoor space (m^3)
n = ventilation rate (h^{-1})
c_a = concentration of compound i in outdoor air ($mg \cdot m^{-3}$)
A = decay factor (h^{-1})

This equation applies to static conditions. More complex equations are needed to describe dynamic situations (cf. Wadden and Scheff 1983 or other textbooks). Eq. 1 shows that the concentration of a pollutant in indoor air is expressed by a source part and a sink part. The source part takes into consideration the emission of a compound into the air, while the sink part comprehends removal processes.

For various reasons the most trivial way of reducing indoor air pollution, namely obtaining zero emission by avoiding the source completely, is only possible in a limited number of cases. Generally, following Eq. 1 there are two choices to reduce indoor air pollution: one is to prevent the generation of pollutants (e.g., by controlling the source), while the other is to remove the pollutants (e.g. by ventilating or using an air cleaning device). Both source control and removal processes are valid approaches to reduce indoor air pollution. However, they do not indicate the level to which this reduction should be conducted. This level must be defined by setting appropriate limit values.

2.1. The source control approach

According to Eq. 1 the rate at which a pollutant is emitted from a product determines the final concentration of this pollutant in indoor air. Thus, setting an emission standard is one means of source control, others include voluntary agreements not to produce and/or use a product or imposing a prohibitive ban on a product.

2.1.1. Emission Standards. One possibility to develop an emission standard is to start from a tolerable indoor concentration level, e.g., a guideline value (see section 2.3.2). With a number of assumptions regarding the average conditions under which the product is used in practice (temperature, relative humidity, air exchange rate, loading factor, etc.), the desired emission factor of a compound can be calculated.

Such a procedure is more easily described than achieved in practice for a number of reasons. For example, one difficulty is that more than one product may emit the compound under consideration. Assuming that the apportionment, though difficult, is possible for continuously emitting surface materials, a simple equation can be used to approximate the emission factor E_i ($mg \cdot m^{-2} \cdot h^{-1}$) for compound i in such material:

$$E_i = (c_i \cdot n)/L \qquad (2)$$

with c_i = concentration of compound i in the air ($mg \cdot m^{-3}$)
n = air exchange rate (h^{-1})
L = loading factor ($m^2 \cdot m^{-3}$)

More complex equations are used to take into account the influence of parameters such as the variation of the emission factor with time, the effects of removal processes other than ventilation, the temperature, or the relative humidity. An important example for the influence of the last two parameters is formaldehyde, for which special equations have been established describing this influence (e.g., Andersen et al.

1975). Generally, emission factors are obtained from test chamber measurements under well-defined conditions. Recent guidelines published in Europe (COST 613 1989) and in the USA (ASTM 1989) demonstrate that these conditions have to be described precisely and maintained very carefully during the experiment to obtain comparable data. Many difficulties still need to be solved in the testing of emission factors, especially if intermittent rather than continuous sources are being considered.

However, despite all the difficulties, source control is a very, if not the most, appropriate way of reducing indoor air pollution. As a first practical step towards this goal, the Council of the European Communities has issued a Council Directive on construction products (European Communities 1989). The Directive, among other requirements, states that

> "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."

The Directive does not specify details but leaves the implementation of these requirements to the European standards organizations which have to establish harmonized standards for products. Much work remains to be done to make such standards available. They are urgently needed in view of the Single European Market to come into force in 1993.

2.1.2. Voluntary Agreements. Fortunately enough, concentration levels of most air pollutants are below what may cause immediate adverse health effects. On the other hand, the available knowledge of potential adverse health effects of chronic exposure of humans to contaminants at low concentration levels is inadequate, especially if mixtures are being considered. Thus, the scientific proof of a need to lower the actually encountered exposure levels may be difficult and action only possible on the basis of "prevention is better than cure". In such situations, a reduction of indoor air pollution can only be based on a consensus reached by all parties of the society.

To achieve such a consensus, the dissemination of information beyond scientific circles is urgently needed. The difficulties which scientists and governmental institutions are facing in communicating environmental risks to the public are well recognized (Covello et al.

1987; Covello 1989; Renn 1989) and faulty behaviour of industrial and perhaps also governmental representatives may have contributed to creating some of these difficulties in the past. As has been pointed out recently by Fülgraff (1989), "scientists tend to neglect that they may be experts for risk assessment, but not at all experts for acceptability, adequacy, reasonability, justifiability, etc."

If it comes to voluntary agreements, special incentives may induce a kind of self-regulation of the market. Although the system is far from being perfect, positive experience has been made in the Federal Republic of Germany with an environmental label, the so-called "Blue Angel". Under certain conditions, this label can be assigned to products representing a lower burden to the environment than others.

Ranking is in fact an excellent way of driving market forces. However, a sound evaluation system is needed to establish the ranking order. In the case of many consumer products, (governmental) test institutes use such systems which permit to evaluate the technical performance of the product. However, most of these systems do not sufficiently take into account a potential negative environmental impact of a product. What is generally not part of the final evaluation at all is the existence or the danger of any adverse health effect due to the emission of air pollutants.

The difficulties encountered in establishing a ranking system for health-related material and product evaluation cannot be underestimated. However, a first step towards developing such system has been made recently (Seifert 1991) in that important criteria to be used to develop a ranking index were defined. The index would take into account the chronic and acute toxicological properties of the material or product as well as the material's influence on the human sensory system. A proposal using a similar approach has been published recently by Dieter et al. (1990) for the setting of priorities in the clean-up of chemically contaminated sites.

2.1.3. Bans. The most categoric decision which can be taken with regard to an anthropogenic pollutant is to prohibit its production and/or use. Generally, one would expect the decision for a complete ban to be preceded by qualitative and quantitative proof of the detrimental effect of this pollutant. In practice, however, in the few cases in which substances have been banned from the indoor environment, the decision was not based on definite proof but rather on apparent evidence, to some extent perhaps even on public pressure.

A good example is environmental tobacco smoke (ETS). The qualitative evidence of the unhealthy properties of ETS and the results of the majority of the known epidemiological studies on passive smoking have led to a ban on smoking in many places, although no individual case of lung cancer has up to now been and most probably never will be, traced back to the influence of ETS exposure. There can be no doubt that prevention is the driving force in the development of regulations creating smokefree atmospheres.

The difficulty that generally comes along with the ban of a substance or product is the lack of sufficient knowledge of the properties of potential substitution products. Although science tries hard to

forecast any negative properties of a substitution product, the pathways and cross-connections from the first step in the manufacturing of a product to its ultimate disposal are mostly so complex that they are not all well understood.

Despite these difficulties inherent in substitution, it seems as if the development of mankind has been nothing but a continuous series of substitution processes, which from early days on was mostly driven by the desire to make life more comfortable but tends more and more also to take into account the aspect of guaranteeing a healthy environment for all. The question is whether the struggle between these two sides of the coin can ever be solved.

2.2. The removal approach

There are cases of indoor pollution in which the emissions of the source(s) cannot be avoided. One of the best examples is the emission caused by the occupants of a room themselves which include carbon dioxide and body odours. While the former is even toxic at elevated levels, the latter can be highly annoying. Another frequent example is the situation in a room where an already present material or product is only recognized later as being harmful. In both cases ventilation and air cleaning offer a possibility to reduce the pollution level.

2.2.1. Ventilation Standards. Eq. 1 defines the relationship which exists between the emitted amount of a pollutant and its final concentration in indoor air. To lower this concentration, one can either diminish the source strength or use ventilation. In fact, ventilation has been and will continue to be one major option to reduce pollutant concentrations indoors. However, the need for saving energy calls for as low a ventilation rate as possible. Thus, attempts have been made to specify minimum ventilation rates to provide acceptable indoor air quality (IEA 1987).

The recently published ASHRAE Standard 62-1989 (ASHRAE 1989) describes a ventilation rate procedure which specifies the outdoor air requirements for ventilation and is thought "to provide acceptable indoor air quality, ipso facto". Although not legally binding, ASHRAE 62-1989 reflects the state-of-the-art engineering knowledge and forms the basis of the lay-out of ventilation systems not only in the USA.

2.2.2. Air Cleaning Devices. Sometimes indoor air pollution problems can be traced back to the presence of special materials and products. Examples include the use of formaldehyde-emitting particleboard used for construction and the application onto wooden panels of preservatives such as pentachlorophenol. As in such cases the removal of the source is not easy, air cleaning devices may offer a possibility to lower the level of pollutants. However, the efficiency of some of these devices has sometimes to be questioned even if so claimed by the manufacturer.

2.3. Limit values for indoor air pollutants

It goes without saying that there are many limits in daily life, some of them being more stringent, others less. The same applies in the

field of air pollution. Some limit values have a more binding character than others: while the first ones are called "standards", the others are "guideline values".

2.3.1. Standards for Indoor Air Quality. Many countries have set standards for outdoor (ambient) air pollutants. However, worldwide there are no standards for indoor air pollutants. Although there can be no doubt that standards contribute to establishing legal guaranties, two major criticisms can be brought forward against the setting of standards for chemicals (and microorganisms) in indoor air:

1. The existence of a standard favors the impression of having a limit below which there is no reason for concern.
2. The enforcement of a standard is virtually impossible due to the large number of indoor spaces which would needed to be checked.

In addition, the large variety of conditions encountered inside buildings makes it difficult to define the boundary conditions to be associated with the standard. One compound for which these difficulties apply is formaldehyde. The formaldehyde concentration in the air of a room depends critically on temperature and relative humidity. An increase or decrease of the room temperature of only 1 ^{o}C changes the formaldehyde concentration by roughly 10 %. Thus, one and the same room may fulfil the requirements of a standard at 20 ^{o}C but not at 23 ^{o}C. However, both temperatures being within the generally accepted range of thermal comfort, an individual cannot be obliged to live at 20 ^{o}C simply because at this temperature the standard - if defined for 20 ^{o}C - would be respected.

Due to the absence of standardized ventilation requirements for naturally ventilated buildings, which show a wide variety of ventilation rates, similar difficulties would arise in practice if standards were defined for a specific ventilation rate.

2.3.2. Guideline Values for Indoor Air Quality. As the word "guideline value" indicates, such a value should provide guidance and, thus, is much weaker than a standard. In contrast to a standard, a guideline value generally will not take into account socioeconomic or political aspects.

As has been pointed out by the World Health Organization (1987), "inhalation of an air pollutant in concentrations and for exposure times below a guideline value will not have adverse effects on health". However, since by nature guideline values do not define a sharp borderline and generally do not take synergisms into account, compliance with these values "does not guarantee the absolute exclusion of effects at levels below such values". Consequently, a strategy including two values may be adopted under some circumstances. While the first value would define an action level, the second would indicate a target level to be reached in the future.

Larger sets of air quality guideline values for individual substances - either applicable to or expressively developed for indoor air - have been published by the World Health Organization (1987), Canada (Health and Welfare Canada 1987) and Norway (Helsedirektoratet 1990). In addition to these values guideline values for a number of individual substances have been been published in some countries. In the formaldehyde, a concentration of 0.1 ppm has been adopted in the majority of West European countries, a few of them having set higher levels (up to 0.4 ppm under certain circumstances) (COST 613 1990).

The existing guideline values have been derived on the basis of available knowledge of direct or indirect health effects of individual substances. Besides the fact that such a substance-by-substance approach is very time-consuming, it does not take synergistic effects into account, which are likely to be especially important with mixtures of volatile organic compounds.

Besides indicating the level of concern with regard to an indoor air pollutant, guideline values can serve the very important purpose of setting emission standards (cf. section 2.1.1).

3. A PRACTICAL EXAMPLE: TETRACHLOROETHENE

The various possibilities that exist to regulate indoor air can be used to complement each other. This approach has been chosen recently in the Federal Republic of Germany to reduce the concentration of tetrachloroethene (TCE) in rooms adjacent to dry-cleaning shops and is described in the following. For easy reference, the different keywords relating to what has been explained in the course of Chapter 2 are underlined.

Following complaints of the population living in the vicinity of dry-cleaning shops indoor air measurements were made in adjacent homes which showed TCE concentrations of up to several mg/m^3 (7-day average). These levels were elevated by far above the median of 0.015 mg/m^3 which had been observed in about 500 randomly distributed German homes (Krause et al. 1987). In an expert hearing (cf. Anonymous 1988), a guideline value of 5 mg/m^3 was derived from toxicological considerations which could be used as an action level demanding immediate countermeasures. Below this level, no immediate action was considered to be necessary. However, control measures were recommended to lower the TCE concentration. As it seemed very likely that technical changes on the dry-cleaning machines (source control) would permit the achievement of an indoor TCE concentration of 0.1 mg/m^3, this value was recommended as the target level.

Following these recommandations an Ordinance was issued in December 1990 in which an emission standard of 20 mg TCE/m^3 was defined for dry-cleaning machines (Anonymous 1990). The Ordinance also specifies that the TCE concentration in the air of rooms adjacent to dry-cleaning shops should not exceed 0.1 mg/m^3 (7-day average). If this level is found to be exceeded, measures have to be taken within 6 months to lower the concentration. Existing installations are given a 2-year period to fulfil the requirements.

Recently, a report was issued containing the results of repetitive TCE measurements which were taken 18 months after the first measurements, during which time control measures had been performed (Hauptgesundheitsamt Bremen 1990). The percentage of rooms in which the target level had been reached was small: in some cases the authors observed even higher concentrations than during the first campaign. It is not clear to what extent the analytical procedure and/or the sampling strategy contributed to these findings. However, these results do not exclude the possibility for a need to completely ban dry-cleaning machines from apartment houses in the future if no technical means can exclude an exposure of the population.

4. REFERENCES

Anderson, I., Lundqvist, G.R. and Mølhave, L. (1975) Indoor air pollution due to chipboard used as a construction material, Atmos. Environ. 9, 1121-1127.

Anonymous (1988) Empfehlung des Bundesgesundheitsamtes zu Tetrachlorethen in der Innenraumluft (Recommendation of the Federal Health Office concerning tetrachlorethene in indoor air), Bundesgesundheitsbl. 31, 99-101.

Anonymous (1990) Verordnung zur Emissionsbegrenzung von leichtflüchtigen Halogenkohlenwasserstoffen (2. BImSchV) (Ordinance on the limitation of emissions of halogenated hydrocarbons), BundesGesBl I, 2694-2700, 10 Dec. 1990.

ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) (1981) Thermal environmental conditions for human occupancy. ASHRAE Standard 55-81, Atlanta.

ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) (1989) Ventilation for Acceptable Indoor Air Quality. ASHRAE Standard 62-1989, Atlanta.

ASTM (American Society for Testing Materials) (1989) Standard Guide for Small-Scale Environmental Determinations of Organic Emissions from Indoor Material/Products. Draft, Subcommittee D 22.05 on Indoor Air.

COST 613 (1989) Formaldehyde emission from wood based materials: Guideline for the determination of steady state concentrations in test chambers. European Concerted Action "Indoor Air Quality & Its Impact on Man", Report No. 2 (EUR 12196 EN). Office for Publication of the EC, Luxembourg.

COST 613 (1990) Indoor Air Pollution by Formaldehyde in European Countries. European Concerted Action "Indoor Air Quality & Its Impact on Man", Report No. 7 (EUR 12219 EN). Office for Publication of the EC, Luxembourg.

Covello, V.T., Slovic, P. and von Winterfeldt, D. (1987) Risk communication. A review of the literature. Nat. Acad. of Sci., Washington.

Covello, V.T. (1989) Communicating right-to-know information on chemical risks, Environ. Sci. Technol. 23, 1444-1449.

Dieter, H.H., Kaiser, U. and Kerndorff, H. (1990) Proposal on a standardized toxicological evaluation of chemicals from contaminated sites, Chemosphere 20 (1-2), 75-90.

European Communities (1989) Council Directive on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products, Off. J. EC L 40/12, 11 Febr. 1989.
Fanger, P.O. (1970) Thermal Comfort, Danish Technical Press, Copenhagen.
Fülgraff, G. (1989) Akzeptanz von Umweltrisiken (Acceptance of environmental risks), Lecture 25th Anniversary Länderausschuß für Immissionsschutz (German Interstate Committee for the Protection of Ambient Air), Düsseldorf, 11 April 1989.
Hauptgesundheitsamt Bremen (1990) Bericht über die TCE-Belastung bei Anwohnern chemischer Reinigungen (Health Directorate of the City of Bremen, FRG: Report on the TCE exposure of persons living close to dry-cleaning shops).
Health and Welfare Canada (1987) Exposure Guidelines for Residential Indoor Air Quality, Dept. of Nat. Health and Welfare, Ottawa.
Helsedirektoratet (1990) Retningslinjer for inneluft-kvalitet (Guidelines for indoor air quality). Helsedirektoratets utredningsserie 6-90, Norvegian Health Directorate
IEA (International Energy Agency) (1987) Energy Conservation in Buildings and Community Systems Programme, Annex IX: Minimum Ventilation Rates, Final Report of Phases I and II.
ISO (International Organization for Standardization) (1984) Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort, ISO Standard 7730, Geneva.
Krause, C., Mailahn, W., Nagel, R., Schulz, C. and Seifert, B. (1987) Occurrence of volatile organic substances in the air of 500 homes in the Federal Republic of Germany, in: B. Seifert et al. (eds.), INDOOR AIR '87, Proc. 4th Internat. Conf. Indoor Air Quality and Climate, Berlin (West), 17-21 August 1987, Vol. 1, Inst. for Water, Soil and Air Hygiene, Berlin, pp. 102-106.
McIntyre, D.A. (1980) Indoor Climate, Appl. Science Publications, London.
O'Riordan, T. (1989) Anticipatory environmental policy - Impediments and opportunities, Environ. Monit. Assess. 12, 115-125.
Pettenkofer, M. (1858) Über den Luftwechsel in Wohngebäuden (On the air exchange in appartment buildings), Cotta, München.
Renn, O. (1998) Risk communication at the Community level: European lessons from the Seveso Directive, JAPCA 39, 1301-1308.
Ricci, P.F., Cox, L.A., Dwyer, J.P. (1989) Acceptable cancer risks: probabilities and beyond, JAPCA 39(8), 1046-1053.
Seifert, B. (1991) Guidelines for Material and Product Evaluation, Ann. New York Acad. Sci. (in the press).
Wadden, R.A. and Scheff, P.A. (1983) Indoor Air Pollution, John Wiley & Sons, New York.
World Health Organization (1987) Air Quality Guidelines for Europe, WHO Regional Publ., Europ. Series No. 23, Copenhagen.

CONTROLLING SOURCES OF INDOOR AIR POLLUTION

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ABSTRACT. Source control is the preferred approach to providing indoor air quality for public health protection. Source control includes judicious product selection, modification, or use restrictions that eliminate or reduce emissions of harmful substances into indoor air. In many cases source control may be more cost-effective than removal of contaminants from indoor air by dilution or exhaust ventilation, filtration, and air cleaning. Identification of important sources should be based on their potential health effects resulting from building occupant exposures to their emissions. Insufficient knowledge exists regarding emission rates, exposure distributions in buildings and among target population groups, and the expected public health consequences. Effective source control requires understanding emission processes, acquiring emissions data useful in manufacturers' product development and data useful for architects and others who select building materials and other products that are sources of indoor air pollution. Scientists, government, and industry are accelerating efforts to develop and improve emissions test methods to characterize the chemical characteristics and health effects of significant indoor pollutant sources.

Introduction

People are devoting more and more attention and resources to indoor air pollution sources. Some architects, engineers, and interior designers as well as facility managers, are increasingly trying to specify healthier materials (Levin, 1989). Manufacturers are creating new, lower emitting products and eliminating carcinogenic chemicals from their products. Government agencies in the United States, Canada, and several European countries are funding improved measurements and understanding of source emissions. Many governments are developing or using guidelines, standards, and even regulations to control sources (ASTM, 1990).

In Denmark, scientists are conducting comprehensive testing programs to determine chemical emissions, human subjective and physiologic responses, and animal responses predictive of human irritation (Johnsen, 1990; Wolkoff, 1990). They are also developing "healthier" products by substituting safer chemicals for constituents known to cause adverse human responses. Throughout Europe source testing is being conducted to evaluate products for domestic use, export, and import.

DISAGREEMENT ABOUT SOURCE CONTROL

Not everyone agrees about the importance of source control. There are large differences of opinion about some important indoor air pollution source control questions; these include the following:

Is source control more effective than ventilation?

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Is source control practical?

Is source control cost effective?

Even if people agree on the answers to these questions and decide to focus efforts on source control, one important question remains: What sources are important to control? Three critical issues are important to consider in answering that question. They are 1) Control options - why source control is critical to controlling indoor air quality; 2) Understanding sources and their significance - identifying the important sources, their emission patterns, and their effects on humans; and, 3) Emission factors - how properties of building materials (and other products) affect a source's significance.

Source Control Options and Alternatives

What are the indoor air pollution control options? Essentially, there are three: reduction or elimination of emissions from sources, ventilation to dilute or exhaust the pollutants in indoor air, and filtration or air cleaning to remove pollutants. Conceptually, it seems obviously less efficient to allow the contaminants to disperse in air, then attempt to collect the contaminated air in order to exhaust or filter it. But not everyone advocates source control.

Those who manufacture and sell products that are indoor air contaminant sources frequently implicated in IAQ problems do not advocate source control and sometimes argue against source control . Instead, they advocate a so-called "building systems approach." By that, they mean we should focus on the ventilation system, not the building materials, furnishings, appliances, consumer products, tobacco smoking, and other sources of contaminants. They claim that inadequate ventilation causes most indoor air quality problems. Many advocates and supporters of this argument are chemical manufacturers, tobacco companies, and consultants. Their argument and advocacy are supported and advocated by manufacturers of ventilation and air cleaning equipment. (Levin, 1991a)

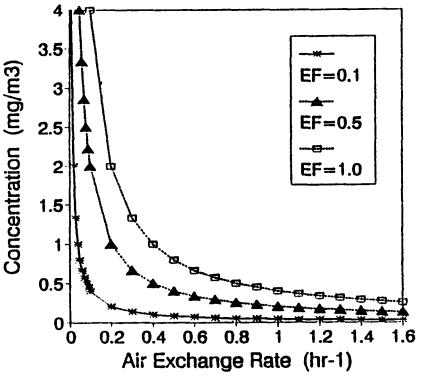
By directing our attention away from source control, these advocates diminish the likelihood that their product or their client's product will be restricted or removed from the marketplace either by regulation or by market forces. Furthermore, they decrease, at least in the short run, the risk of legal and financial liability associated with manufacturing, sales, installation, and use of the products. They influence policy-makers as well as building designers, builders, and operators. While the advocates of the so-called "building systems approach" lobby against source control, most public health authorities promote source control. This is the case not only in the United States and Canada but also in several European countries active in the indoor air field (Levin, 1981a).

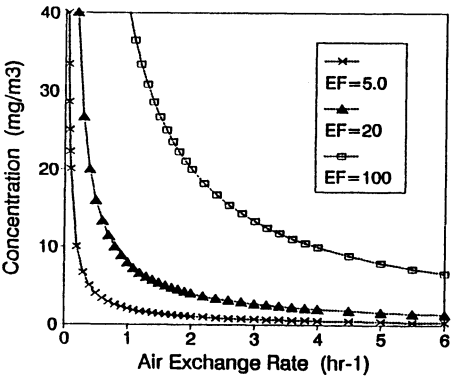
"AN OUNCE OF PREVENTION..."

Viewed comprehensively, source control is the most effective general means to improve indoor air quality (IAQ). Source control is the primary thrust of most public health and environmental protection programs. Examples are abundant in preventive medicine programs, hazardous materials programs, water pollution programs, and ambient air pollution control programs. By eliminating or reducing sources of indoor air contaminants, requirements for exhaust or dilution ventilation and air cleaning can be minimized. Generally it turns out to be more cost effective to control pollution at the source than to try to remove it once it has been disseminated into the environment or dispose of it once it has been collected.

Source Control and Ventilation. Figures 1 and 2 show the relationship between ventilation rate and indoor air VOC concentrations over a wide range of source VOC emission rates. Clearly, the stronger the source, the more ventilation required to lower the VOC concentration to a given

level. Note that for the source strengths shown here, when outside air ventilation rates are above about 1 air change per hour, increasing ventilation a little produces very little reduction in concentration. However, as ventilation rates decrease, small changes have larger effects on concentrations. When ventilation rates are less than one-half air change per hour, small reductions in ventilation produce significant changes in VOC concentrations. The same general relationships hold for specific VOCs and for other contaminants.





Figures 1 and 2. Air concentrations of chemicals emitted from generic weak (Figure 1) and strong (Figure 2) indoor pollution sources as functions of the air exchange rate and emission rates. EF = emission rate in $mg/m^2\text{-}h^{-1}$.

Note that with the very common variable air volume (VAV) ventilation supply, the design of many buildings types such as offices, stores, and residences frequently produce low air exchange rates. They operate at air exchange rates less than 1 h^{-1} when outdoor air temperatures approach or exceed the indoor air temperature if cooling is required indoors. That is the case for many buildings, especially larger ones, much of the time. Also when heating is required for most of these same buildings, outdoor air exchange rates also tend to be low when outdoor air temperatures are below the indoor temperatures. Thus, for these buildings, indoor air concentrations are extremely sensitive to the source emission rates.

Of course either ventilation or filtration/air cleaning is necessary to achieve and maintain good IAQ. Ventilation is necessary whenever people occupy buildings, no matter how extensive or effective the source control programs. But good IAQ cannot be achieved in an economically, socially, and environmentally responsible fashion without an effective source control program that minimizes the amount of ventilation required. Filter and adsorbent manufacturers believe that filtration and air cleaning could be effectively used more than currently. In many situations, they are correct. But heating, ventilating, and air-conditioning (HVAC) system designers have generally favored air dilution and exhaust of contaminants rather than air cleaning and filtration for most non-industrial indoor air applications. We will use the term "ventilation" here in its admittedly more ambiguous popular sense to include not only outdoor air supply and room air exhaust, but also typical *current* filtration practice.

Building Owners' Perspective. From the perspective of the developer, building owner, or operator, effective source control can often be accomplished without excessive costs. Sometimes design changes or product substitutions that minimize emissions cost little or nothing; some can even save money, energy, or other resources. In many cases it is more economical to control emissions at the source than to provide extra ventilation, filtration, or air cleaning. Source control is often a one-time, front-end action while increasing ventilation requires increased first costs for up-sizing HVAC systems and on-going operating costs that reflect energy costs.

Product Manufacturers' Perspective. In many instances, marketing pressures are forcing source control through creation of 'healthier," low-emitting products or withdrawal of high emitters and those with carcinogenic or very toxic emissions. In others, some government intervention has occurred before effective action was taken. Some source improvements can actually reduce manufacturing costs, and they certainly reduce potential product liability while increasing market appeal. However, many manufacturers fear that product modifications will increase their manufacturing and marketing costs, diminish their sales, or require them to abandon their investments in existing product manufacturing processes or marketing programs.

IS POLLUTION PREVENTION THE ANSWER?

Some authorities promote a general strategy of minimizing source strengths without special regard for the composition of emissions or the knowledge of their particular impacts on occupant health. This is sometimes called "pollution prevention," and has become a major U.S. EPA program. It sidesteps the deficiencies that result from failing to determine health effects, a costly and time-consuming process. Absent more detailed information on various characteristics of most sources, pollution prevention may be a reasonable approach.

Total VOCs. One way manufacturers reduce VOC emissions might be by replacing some VOCs with smaller quantities of more toxic or irritating ones. From a public health perspective, such a reduction in emissions might be harmful. This raises the issue of what should be measured in emissions test. It indicates the importance of measuring emissions of individual chemical species rather than total VOCs alone. Most scientists agree that identification of at least the most prevalent compounds is essential to evaluate emissions adequately. TVOC measurements are faster, cheaper, and easier, but they can be quite misleading. TVOC measurements are a legacy of ambient air and industrial hygiene air sampling. In outdoor air total hydrocarbon measurements are important to indicate the presence of photochemical smog precursors. In a typical industrial situation, the contaminants of concern were usually known and limited to one or two compounds. For those purposes, measuring TVOC may have been quite adequate for evaluating air quality to protect outdoor air quality or industrial workers. The complexity of indoor air mixtures and the diversity of the exposed human population requires more detailed knowledge of the chemicals present.

Understanding Sources and Their Significance

It is necessary to assess the significance of various sources and control them accordingly. Scientists have used different approaches during the past fifteen years. However, since the number of sources is extremely large and the source strengths can vary so greatly over time, it is important to do our best to prioritize target sources for mitigation strategies. The remainder of this article is an effort to do that. One approach is to identify the most effective control strategy based on the type of source rather than the emissions themselves.

In Denmark, efforts to understand, categorize, and control sources and their emissions have been on-going since the mid-1970s. There, particleboard and other composite wood products using cheap formaldehyde-resin based binders became very popular materials for building construction and for furnishings. Around the same time energy conservation efforts were undertaken due to the high cost of fuel. Ventilation rate reductions combined with increased use of formaldehyde and other contaminant sources resulted in indoor air pollution and a heightened awareness of indoor air quality problems and government efforts to address them.

Ib Andersen (1982) of the Danish National Institute of Occupational Health presented a framework for understanding sources in relationship to their generation category, timing, and effective control strategies. His framework is presented in Table 1. Andersen's scheme shows the need for dilution ventilation to control human metabolic products and the need for dilution and exhaust ventilation to control the emissions from many processes that occur indoors. But removal or restriction is the preferred control strategy for chemical releases from materials, products and tobacco smoking. Although Andersen's scheme is more than a decade old, it is still basically sound.

Table 1. Emission Sources and Control Strategies (Based on Andersen, 1982).

Emission Source Category (Emission)	Control Strategy (Method)
Human metabolism	Ventilation
Water vapor	Dilution
Carbon dioxide	Dilution
Odors	Dilution
Particles	Dilution
Processes	Ventilation
Food preparation	Local exhaust and dilution
Work (e.g., school, office, retail)	Local exhaust and dilution
Laundery	Local exhaust and dilution
Personal hygiene	Local exhaust and dilution
Chemical release	Source control
Tobacco smoking	Removal or restriction
Household products	Removal or restriction
Furniture, textiles	Removal or restriction
Building materials	Preventive measures

TYPES OF EMISSION PATTERNS

In the mid-1970s, a large research group at the University of California's Lawrence Berkeley Laboratory (LBL) under the direction of the late chemist, Craig Hollowell, investigated ventilation and indoor air quality with funding from the U.S. Department of Energy. They adapted ambient air and industrial hygiene sampling and analytical methods to study indoor air quality in residences and in public buildings. Many of their seminal studies published in the early 1980s are valuable sources of information today.

Types of Emission Time Patterns. Robert Miksch, Hollowell, and Schmidt (1982) presented a simple description of three types of temporal emission patterns. Using a first order, one com-

partment ventilation model, they analyzed the different behavior patterns of pollutant exposure levels for different generation patterns. The three types of generation patterns they examined are 1) constant, 2) workday, and 3) episodic. The results are very distinct exposure patterns. Substituting the word "workday" with the word "periodic" extends the applicability of the classification scheme to non-workplace environments.

Important determinants of the timing of emissions include the useful life and replacement frequency of a material or the materials in an assembly; the total embodied emitable constituents of the materials; the physical configuration of the product itself and of its use in the building; the environmental exposure of the material as installed in the building; and the quality of maintenance of the installed material(s).

Location Pattern Variations. To these patterns we can add variations in locational patterns from sources depending on whether they are point sources or distributed sources. Examples of point sources are gas-fueled combustion appliances, burning cigarettes, and photocopiers. Distributed source examples include thermal insulation materials, furnishings, and floor coverings. Combining the temporal patterns with the spatial patterns yields a two-by-three matrix with nine total cells. Table 2 shows some examples for each cell of this matrix.

Table 2. Typical Indoor Air Pollutant Sources: Temporal and Spatial Generation Distributions

	TEMPORAL PATTERNS		
SPATIAL PATTERNS	Constant	Periodic	Episodic
POINT	Gas pilot light Moth crystals	Copier operation Showers Laundery	Hobby activities Tobacco smoking
DISTRIBUTED	Carpet Insulation	Vacuum cleaning	Painting Pest control Carpet shampoo

Occupant-Activity Generated Sources. Charles Rhodes and his colleagues (1991) discussed the importance of sources resulting from occupant activities. The emissions from these sources are episodic, either irregular or periodic. They are point sources located close to occupants so that exposure of the occupant performing the activity may be quite large compared to other occupants in the space or building.

SOURCE CONTROL AND HEALTH EFFECTS

A decision to control a source should be based on information including the health effects that might occur from exposure to its emissions. Scientists understand the health effects from exposure to a small percentage of chemicals found in indoor air, and even less is known about

most exposures at the concentrations commonly found in indoor air. Such information is not only scarce currently, but it is unlikely to be available for the foreseeable future.

The Danish National Institute of Occupational Health publishes lists classifying chemicals as carcinogens, irritants, and odorants (Danish National Institute of Occupational Health, 1990). The listings represent qualitative identification and categorization of effects, but no data on thresholds, effective doses, or significant exposure levels for indoor air is provided. The lists are used as the basis for regulatory actions when emissions test reveal the presence of regulated substances.

Bioassays to Test Emissions' Effects. Some scientists are developing and utilizing methods to assess odor, irritation, and other subjective responses to emissions from products, materials, furnishings. While some such work is occurring, far too few products are sufficiently well-characterized to form the basis of decision-making at this time. Researchers in the U.S.A. and in Denmark have used a mouse bioassay to assess potential irritancy of emissions from building materials and other products. The method has been standardized as ASTM E 981-84 (Levin, 1991b; ASTM, 1984). Anderson Laboratories in Massachusetts has tested a number of indoor air pollution sources as well as air samples from problem buildings. They found a positive dose response relationship between mouse respiratory rate and exposure to air from the problem building. The U.S. Environmental Protection Agency (EPA) is examining bioassay methods to test emission. In the next few years, it is certain that far more will be done in this area. As mentioned above, Danish researchers have conducted mouse bioassays as part of a comprehensive panel of emissions tests including human subjective response and odor evaluation, examination of changes in the eye, and chemical measurement of emissions (Wolkoff, 1990; Johnsen, 1990).

SETTING SOURCE CONTROL PRIORITIES

It is important to establish criteria for prioritizing source control efforts. Lacking more detailed and extensive health effects information, we might select those control options that appear to yield the greatest reductions in exposure, that are most feasible, and that are applicable in new construction and retrofit applications respectively. Additionally, we might restrict use of products that emit known carcinogens. But because the task of evaluating the products available for a particular use (e.g., paints, adhesives, floor covering) is so large for any one product, it is important that we attempt to rank the potential indoor air significance of various types in order prioritize efforts to understand them better.

The remainder of this article will focus on building materials and furnishings as the products of concern. Other indoor air pollution sources of interest include appliances, especially combustion appliances, equipment, office machines, consumer products. Building cleaning, housekeeping, and maintenance products are also very important sources that should be evaluated but are beyond the scope of this article.

The importance of emissions from a given source is a function of the following:

1) Human exposure (average, peak, and distribution in population).
2) Health and comfort effects expected from exposure.
3) Control options available in new construction/renovation/remediation.

Human Exposure. Exposure is a function of concentration times time. The relative importance of a material is a function of the amount of its emissions in the air, and the time people spend in that air. In general, the nature and quantity of its emissions will be determined by its area, mass, and emission factor over the life of the product in the building. Actually, for less volatile compounds, condensation or adsorption on surfaces and subsequent human contact will also be an important determinant of health effects. For the sake of simplicity, we will not address the

concerns raised by semi-volatile compounds (such as human body odor, some combustion by-products, pesticides, and fire retardants) in this article.

During a building's life cycle, emissions from a material, surface, or product are not only a function of the chemicals in the original product; they are also functions of the life expectancy, maintenance requirements, resurfacing requirements, and removal/disposal process emissions.

Health and Comfort Effects. If more were known about the health effects of exposure to indoor air pollutants, the importance of a source could be determined based on the health effects of exposure to its emissions. Even the strength of source emissions is not well understood for most products, although some generalizations can be made based on emissions testing that has been done and on the chemical composition and physical characteristics of most products.

Source Control Options. The source control options for building materials and furnishings include the following:

1) Chemical substitution or product reformulation: Danish researchers have identified hazardous ingredients in some paints and created reformulations with substitution of less hazardous ingredients. U.S. carpet adhesive manufacturers have developed low-VOC products that do not use solvent carriers for the resins. U.S. paint manufacturers have been reducing the VOC content of their products to meet California standards designed to minimize VOC emissions into ambient air as precursors to smog. Low-formaldehyde emitting particleboards have been available for several years in Europe and North America.

2) Product substitution: An example is the use of a exterior grade plywood instead of particleboard to minimize formaldehyde emissions. Another is the use of baked enameled coatings on furnishings such as office work stations or use of steel rather than wood kitchen cabinets.

3) Product encapsulation: Completely laminating particleboard based work surfaces on all six sides will radically reduce emissions of formaldehyde. Wrapping asbestos pipe insulation material will minimize fiber release from incidental contact.

Building Materials' Emissions

We have discussed what is important about sources and identified factors for assessing sources. We still need to define criteria for evaluating sources in a building design, operation, or investigation process. There are hundreds to thousands of products used to construct and furnish buildings. It is virtually impossible to obtain and evaluate enough information in a timely way to carefully select every product in a building. Furthermore, products are being re-formulated all the time, so data may not be relevant if it does not apply to the product being considered in any particular situation. Building designs are often completed months and even years before certain elements are completed. Many product formulations will change between the design and the construction. Others will leave or enter the market. Since there is such a growing concern about IAQ, manufacturers are evaluating their own products' emissions and many are modifying them voluntarily. Others will be forced to do so by regulatory action or market forces brought about by their competitors.

Much of the attention to source control has focused on building materials and furnishings, yet they may contribute relatively little to total occupant exposure to indoor air contaminants over the life of a building compared with other sources.

DETERMINANTS OF EMISSIONS

The factors that determine the emissions from building materials are as follows:

1) Useful life or replacement frequency.

2) Total quantity of embodied emissable constituents in a unit or volume.
3) Chemical and physical properties of the embodied chemicals.
4) Physical configuration of the product itself.
5) Quantity used in the building.
6) Environmental exposure of the material as installed.
7) Quality of maintenance.

Useful Life or Replacement Frequency. Building materials tend to have useful lives ranging from as little as two to five years for some surface coverings and coatings up to twenty or thirty years and even far more for products such as structural components. Even so, there is an enormous range among the useful lives of alternative formulations or productions of similar products.

Total Quantity of Embodied Emissable Constituents. All materials emit chemicals, albeit stone emits (radon) more slowly than wood (emits resins), and hardwood generally emits more slowly than softwood. The quantity of embodied chemicals that are potentially emitted is a function of the volatility of the ingredients of the product as it is installed in the building and the physical characteristics of the installed product. The composition of a product changes over its life, and these changes are generally much larger for products that are installed wet compared to those installed dry. They are likely to be larger for soft or flexible materials than for rigid ones, although there are notable exceptions to this rule.

Chemical and Physical Properties of Embodied Chemicals. The location of the volatile components in the installed product relative to its exposed surfaces and the characteristics of the chemicals themselves will affect the emission rates. Thick solid materials such as composite wood products may have very slow emission rates because chemicals must migrate by diffusion from deep within the material to the surface before they can evaporate into the air. The processes are very different for "wet" and for "dry" products.

Wet products go through two or three fairly distinct phases as follows: initial burst, reservoir depletion, and long-term emissions.

1) Initial burst and surface drying: usually a matter of hours, sometimes only minutes, others a matter of days).

2) Reservoir depletion (sometimes): molecular movement through the drier material closer to the surface and to the surface of the from the reservoir of liquid phase material which may be contained by a skim coat on the surface.

3) Long term evaporation. In this phase, formerly wet products behave a lot like materials that may have been installed as dry, solid materials.

Physical Configuration of the Product. A denser material will present a greater barrier to migration (diffusion) of gas phase molecules. Thicker products take longer to emit their ingredients than thin ones. This might be particularly important during the rapid initial drying phase of wet products such as paints, adhesives, sealants and other thin surface coatings. The amount of surface area of the material will create more or less pathways for a molecule to evaporate. Thus, a rough, textured surface will be associated with higher emissions than a smooth one.

Quantity Used in the Building. Clearly the total quantity (mass and surface area) of a material or product will be a major determinant of life cycle emissions. Even though their emission rates may be far lower, large mass materials may emit more total contaminants during their lifespan than some materials whose mass may be significantly smaller.

Environmental Exposure of the Installed Material. Higher emissions will generally occur from materials that are exposed to the circulating air in the building as opposed to an enclosed space (e.g. inside a wall or floor cavity, or in a furred-out column). This is because the air adjacent to the material surface will be replaced more frequently with air that has a lower concentration of the chemicals being emitted. This will result in a higher rate of evaporative flow from the material to the air. Materials that are fully encapsulated will have relatively low emission rates. An example is that completely sealing particleboard can reduce its formaldehyde emissions by more than 90%. Temperature changes result in vapor pressure changes, thereby affecting emission rates. Sunlight striking a material can cause significant surficial heating and raise the vapor pressures of the chemicals at and near the surface. Ultraviolet light from sunlight or other sources can degradate materials and increase emission rates.

QUALITY OF MAINTENANCE

Evaluating materials and products as sources of indoor air contaminants also requires evaluation of the maintenance required to protect and sustain them throughout their lifespans. Maintenance materials and procedures can be sources of emissions themselves. These emissions may be substantial and, due to some of the products involved, may result in emissions of irritating and toxic substances. Maintenance can also inhibit or increase emissions. For example, wetting the surface of formaldehyde emitting materials is likely to increase emissions because formaldehyde is readily soluble in water. Vacuuming carpets may encourage evaporation by agitating the fibers and re-positioning, thus creating more direct paths to the atmosphere.

ENVIRONMENTAL FATE OF EMITTED CHEMICALS

To understand the importance of various sources, it is essential to know the not only the nature of the emissions process but also the environmental fate of emitted substances. The elements of the entire process are chemical transport through the material and into the air (evaporation and diffusion), environmental factors (temperature, air movement, air exchange rate, humidity), sinks (for adsorption and subsequent re-emission), and removal (by dilution or exhaust ventilation, or by chemical reaction).

Emissions Testing

Source chemical emissions tests and biological systems assays can be useful at several points in a building's life or during its design. The potential uses include the following:

1) Before selection in order to make informed decisions

2) After selection to estimate contributions to indoor air pollutant burden in order to develop the pollutant load estimate (a) for design of ventilation to achieve air quality control during installation and after occupants move-in; and, (b) for determination of the curing period required before occupancy under defined air quality conditions.

3) During investigations of air quality complaints to determine source strengths and source apportioning of airborne concentrations.

Test results for chemical emissions are available for at least a few products in most of the major types of products. However, these test results are not necessarily comparable due to a wide range of test methods, product acquisition, test specimen preparation, and other factors. Furthermore, some investigators report emission factors or emission rates at a given point in time or averaged over some defined sampling period. Others provide emission factors at multiple time points. If enough is known about the emission patterns for a product or material type, an emission decay rate can be defined that will allow calculation of the emission rate at any

given point in the product's life. Many tests have been conducted by using ASTM D 5116-90, Standard Guide for Small-Scale Chamber Determinations of Organic Emissions from Indoor Materials/Products (ASTM, 1990).

EMISSIONS RESEARCH SURVEY

The Swedish National Testing and Research Institute in Boras has critically reviewed the international literature on chemical emissions from building materials. Their report includes 24 cases studies in which building materials were identified as major emission sources (Gustafsson, 1991). The reports authors found that it is difficult to estimate the relative VOC concentrations due to the building materials alone because so few studies have been done in unfurnished, unoccupied buildings. Variations over time are large due, for example, to temperature changes and their effects on emissions.

Paints and Floor Coverings. Gustafsson reports that "[c]ertain building materials have been identified as major emissions sources in buildings. Especially solvent- or monomer-containing surface materials such as paint and [floor coverings] are reported as emission sources." Linoleum (containing cured linseed oil) "...can sometimes give rise to an unpleasant smell due to oxidation of fatty acids. Linoleic acid and other unsaturated fatty acids in [the linoleum] are split to aldehydes with lower molecular weight." Alkyd paint (based on linseed oil) "...may emit aldehydes to the indoor air and even [emit] carboxylic acids at increased temperatures on radiators." Acrlyic paint intended for outdoor use applied indoors releases butylmethacrylate.

The most common control measure to reduce emissions is source removal. In the case of floor coverings, removal of the adhesive may also be necessary. In some cases where contaminant compounds remain in the concrete, a covering layer of poyurethane or epoxy lacquer has been successful in controlling emissions.

Semi-volatile Compounds. One of the report's findings is that compounds adsorbed on dust can be released when the dust is heated by electric light bulbs, radiators, and cooling panels on refrigerators. When dust and other airborne particles settle on these devices, semi-volatile compounds such as phthalates, TXIB, and PCBs can be released. Electronic and other office equipment are also potential heat sources. Therefore, the notion that concentrations and exposure to such compounds should typically be low due to their low volatility requires re-evaluation.

Recommendations. Gustafsson made five recommendations based on his research.

1) When buying building materials, require information about the manufacturer's quality assurance system, "...especially for products based on solvents and monomers." Without this information, single emission test data are less valuable.

2) Protect building materials from moisture during construction and afterwards. Materials particularly susceptible to moisture-induced problems include carpet, mineral wool, casein-based floor topping compounds [a problem documented in Sweden for several years], and vinyl flooring with high plasticizer content. Be sure concrete is dry before applying floor covering.

3) Do not apply building materials for unspecified uses. In particular, do not install indoors sealants and paints manufactured for outdoor use. Use moisture repellents for exterior walls with caution.

4) Re-formulate building materials during product development to improve their overall performance including emissions characteristics. For example, substitution of constituents in waterborne paints can minimize long-term emissions.

5) Building producers should learn more about the chemical mechanisms influencing VOC emissions. Producers should also incorporate emerging emissions test methods in product development activities.

EMISSIONS TEST DATA

Appendix A contains an extensive compilation of emissions data -- most of it on building materials and furnishings. It is drawn from nine published studies. Although other data are available, these are the more extensive ones that have been published in the open literature to date. Reported emission rates vary enormously. Many of the variations is due to the timing of the test in relation to the product manufacture and environmental exposure, but some of the large variations result from differences among products and product types. Too much importance should not be placed on the data presented here. The variations among test methods and materials tested may easily be greater than some of the test results differences. On the other hand, the data may be useful for making some generalizations about emissions within and among product or material types.

A wide range of test methods have been used and test samples have varied in age and preparation. Emission rates vary over the life of a product or material, but even the nature of the variation (emissions decay curve) varies greatly for different products. Sources can be present in vastly different quantities or in different installations or uses that result in significant differences in their emissions and the resulting occupant exposures. In spite of these variables, a reasonable picture of relative source strengths, potential exposures, and possible health effects can be described for most of the major sources of indoor air contaminants.

Nearly all material emissions decay to a relatively constant rate, although the time required to reach this stable period is very different for different types of products. It is important to know both how long it will take to reach the stage, what the emissions will be until this stage is reached, and what the rate will be over the long term at this quasi-steady state emission rate.

Assessing the Sources that Cause SBS

William S. Cain (1990) believes that "...if SBS were caused by frank irritants (such as acids) we would understand it by now. But, in fact, most authorities assume it is caused by lots of low level irritants that reach some critical mass. Right now researchers are looking for hypotheses, gathering data." Cain's studies of irritation and odor responses show that threshold concentrations are pretty high for irritancy (compared with thresholds for odor detection, for example). Yet people are complaining of irritation effects in buildings. That happens, according to Cain, either by sensitization or by exposure time.

Irritation vs. Odor Intensity. Cain's studies illustrate the relationship between the intensity of odor and irritation responses to formaldehyde during a one hour exposure to 1 ppm. During the first half of the time, the intensity of odor decreased while the intensity of the irritation increased. The intensity of the irritation was far lower than that of the odor at the beginning, they came closer together toward the middle, and began to separate again toward the end. Both effects trailed off during the final portion of the test period. Understanding irritation is probably a far easier task than some of the others such as understanding acute neurotoxicity.

W. Gene Tucker, (1991) Manager of the U.S. EPA's Indoor Air Branch, assesses the state of source characterization as follows:

1) Source control is the most effective strategy.
2) Emissions from indoor sources are almost always complex chemical mixtures.
3) These mixtures are not created toxicologically equal.
4) Low-emitting is not necessarily low-impact.

Tucker thinks the following questions still need to be answered:

1) What are the health effects of concern?

2) How well can we estimate those effects from existing toxicological knowledge of individual constituents?
3) Does it make sense to have source characterization methods that measure health and comfort effects more directly?
4) What sorts of methods are available for physiological effects?

Tucker is optimistic that either animal or human testing could be useful in characterizing indoor source. *In vitro* approaches might still end up being useful for screening products and materials as well.

Studying Irritation Responses. Investigations have been conducted by an interdisciplinary group of Danish researchers. Gunnar D. Nielsen of the Danish National Institute of Occupational Health, summarized some experimental work on sensory irritation of the upper airways (1990). At a 1990 conference at Yale University, Nielsen reviewed a variety of assays to screen materials and structure-activity relationships.

Reflexively Induced Effects. Eye blinking, tear production, and involuntary disruption of breathing all are reflex reactions that scientists have been able to correlate to human exposure to chemicals. Furthermore, reflexively induced involuntary disruption of breathing correlates to perceived irritation. Some scientists have suggested that the involuntary disruption of breathing could be used as an objective measure of sensory irritation.

The decrease in respiratory rate is the basis of a bioassay using mice in a controlled laboratory experiment. This bioassay is the basis of ASTM standard E981-84 (Standard Test Method for Estimating Sensory Irritancy of Airborne Chemicals). This method has been used to evaluate consumer products and has now received consideration as a method for testing sources of indoor air pollutants. According to Nielsen, the ASTM method can be "calibrated" to predict the level of response in humans. By comparing the results obtained with the bioassay to Threshold Limit Values (TLVs) for chemicals that are known sensory irritants in humans, scientists have found that an excellent correlation exists.

The relationships between concentrations and effects are close to those found in psychophysical studies in animals and close to the concentration at which disruption of human breathing occurs. According to Nielsen, "All the animal models used for investigation of sensory irritation have about the same sensitivity and close corresponsdence with human sensitivity." Nielsen concludes that "highly different potencies of emitted substances [from building materials] can be revealed by the ASTM method. Furthermore, information about the duration of the emission can be obtained." By using the method several times over a period of hours, days, or weeks after preparation of a sample, characteristics of the emissions process can also be inferred. By analyzing the time of response, characteristics of the emitted chemicals themselves might also be deduced or inferred.

A disadvantage of the ASTM animal bioassay method, according to Nielsen, is that it has "a lower sensitivity than that of the human sensory irritation reaction." However, he suggests this problem can be overcome by using higher loading factors for the materials in the test chambers. Alternatively, a closed loop exposure system or the use of a more sensitive strain of mice can also overcome the difference, Nielsen says.

Andersen Laboratories in Massachusetts test emissions from building materials, furnishings, and consumer products using the mouse bioassay for respiratory irritancy test -- ASTM Standard E981, Standard Test Method for Estimating Sensory Irritancy of Airborne Chemicals (Andersen, 1990). This test provides information on the sensory irritation potential of chemical vapors and gases by examining the decrease in respiratory rate of a group of four mice exposed to controlled concentrations of the chemicals. Andersen's system gives an assessment of the potential of a material or product to cause sensory irritation in laboratory mice.

Examples Of Mouse Bioassay Results. Figures 3 and 4 show the type of system used and results obtained using the mouse bioassay.

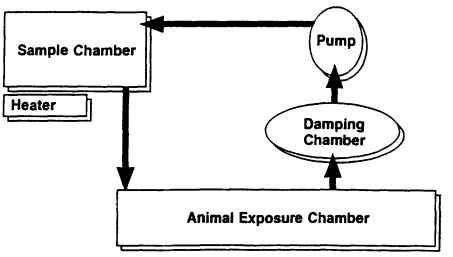


Figure 3. Test system for ASTM E 981-84.

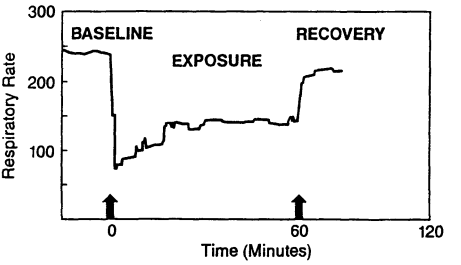


Figure 4. Typical respiratory response pattern to irritant in the ASTM E 981-84 bioassay, mean of four exposed mice.

Promising New Developments. Now Andersen Labs has found they can use a test atmosphere grab sample of indoor air collected in Tedlar bags and obtain reproducible results (Andersen, 1991). They also found a correlation between the air in "sick building" and the mouse response. There were numerous complaints of headaches, fatigue dry eyes, nose, mouth, and difficulty breathing that have been going on for years. This, she says, is an extremely promising development because it provides a linkage between the reported human symptoms of irritation and the ability of that atmosphere to cause such symptoms. This is what has been missing in the straight chemistry approach. While this work is only preliminary and requires more detailed follow-up, the results are extremely clear and strongly suggest that the technique will be a useful one.

One criticism of the method is that the concentrations are not controlled or, usually, even measured. Instead, the researchers vary the amount of material exposed to the air stream and contributing to the test air. For example, a certain area of flooring or wall covering or painted gypsum board might be used to generate the test atmosphere. The tests rely on standardized generation of the test atmosphere rather than standardizing concentrations to which the mice are exposed.

Bruce Tichenor of EPA questions how to correlate the exposure of the animals in the test chamber to what people are exposed to in indoor air. (Tichenor, 1991) The time-varying nature of concentrations that occur due to most sources is not accounted for in the mouse bioassay. Would there be the same response for an exposure to one concentration at ten hours as there would be for ten times that concentration for one hour? The total exposure would be the same, but the timing would be different.

Another important question concerns the correlation between the response of the mouse and the human health effects from exposure to emissions from the same or similar products. Extensive work by various researchers has shown that a reasonably good correlation exists between the results of the mouse bioassay and Threshold Limit Values for individual chemicals based on irritation. Andersen says that since most SBS symptoms are associated with sensory irritation, the test is extremely useful in gaining insight into IAQ problem sources.

Contaminant concentrations causing respiratory rate changes measured by the ASTM test correlate well with ACGIH TLVs that are based on irritation. And the dose-response curves for most substances when plotted on a graph are parallel indicating that the tests do provide comparable dose-response information.

Dr. Rosalind Andersen says that it is essential to know what is important to investigate first, then get into the details of the chemical components. She argues that getting all the details of the chemical composition of emissions first before knowing whether there is a health effect from exposure is starting at the wrong end of the problem.

Dr. Tichenor says that ithe absence of any other information, emissions data is useful. It allows predictions of how that will product will impact the indoor environment. It allows comparison of products. It appears to be at least one useful tool in attempting to improve the quality of indoor air. Furthermore, health scientists need the detailed chemical information and request it from EPA's laboratory.

The regulation of chemical substances rather than products or indoor air is largely responsible for EPA's approach. There is real value in doing the chemical tests, but total volatile compound concentrations by themselves may not adequately indicate the potential for adverse reactions. Individual chemical compounds (species) must be identified, and, where information is available, assessed. In the future, mouse (or other) bioassays will help to evaluate air quality for sensory irritation potential more quickly, economically, and reliably than the more prevalent elaborate chemical analyses that dominate today. But the chemical analyses are essential for determining other potential health effects including carcinogenicity, immuno-toxicity, teratogenicity, and neuro-toxicity. Furthermore, odor perception will remain an important evaluation for chemicals and chemical mixtures in indoor air.

Psychophysical Methods. Scientists use psychophysical methods to evaluate sensory irritation in humans. The results are in terms of the proportion of individuals responding (e.g., rating as acceptable or not) or the magnitude of the perceived intensity. Scientists have used these methods to evaluate single chemicals, two components mixtures, and indoor air in buildings. Scientists have developed an animal model using trained mice to study irritant effects at different concentrations. This method is about as sensitive as the ASTM mouse bioassays for sensory irritation.

Electrophysiological Methods. Scientists using electrophysiological methods to study sensory irritation responses in humans found correlations with surface potential changes in the nasal mucosa. These responses appeared independent of odor, since odorous stimulants were not effective. The surface potential changes correlated to simultaneous pain sensations. Another method involves measuring evoked potentials in the human cerebral cortex to study effects of substances with simultaneous olfactory and trigeminal nerve stimulation. This bioassay using measurement of the trigeminal nerve stimulation is also about as sensitive as the ASTM method.

Structure-Activity Relationships. Scientists believe that sensory irritation can occur in one of two ways: either substances react chemically with the receptor or substances adsorb physically to the receptor. Most studies have used laboratory animals. Investigators have successfully determined the chemical activation mechanisms for several compounds including derivatives of styrene and aliphatic amines, among others. The ASTM method has been extensively validated by developing information about the sensory irritation of reactive chemicals as well as non-reactive chemicals.

Scientists have determined various structure activity relationships for non-reactive substances using thermodynamic activity as the descriptor or using the boiling points among other methods. A recently proposed theory using modern solubility theory and linear solvation energy

relationships not only provides a correlation between the potency of irritants in animals and humans, it also allows deduction of the types of adsorption mechanisms involved.

Conclusion

Existing emissions measurement and evaluation methods coupled with developing technologies for identification of chemical compounds and with the new methods for health and comfort effects can readily advance understanding of IAQ problem buildings. The results can also be applied in the development of healthier building materials, furnishings, equipment, and consumer products.

References

Andersen, I., L. Seedorff, and A. Skov, 1982, "A Strategy for Reduction of Toxic Indoor Emissions," *Environmental International*, Vol. 8, 11-16.

Andersen, Rosalind (1991). Andersen Laboratories Inc., Dedham, MA 02026. Personal communication, October 1991.

ASTM (1984) Standard 981-84, Standard Test Method for Estimating Sensory Irritancy of Airborne Chemicals. Philadelphia: American Society for Testing and Materials.

ASTM (1990). Standard D 5116-90, Standard Guide for Small-Scale Chamber Determinations of Organic Emissions from Indoor Materials/Products. *Annual Book of ASTM Standards*, Vol. 11.03. Philadelphia: American Society for Testing and Materials. 480-491.

Black, M.S., W.J. Pearson, L.M. Work (1991). "A Methodology for Determining VOC Emissions from New SBR Latex-Backed Carpet, Adhesives, Cushions, and Installed Systems and Predicting Their Impact on Indoor Air Quality." in *IAQ '91 - Healthy Buildings*, Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., pp.

Cain, William S., (1990). Presentation at Yale University conference on sources, October 22-24, 1990.

Colombo, A., M. DeBortoli, E. Pecchio, H. Shcauenburg, H. Schlitt, H. Vissers (1990) "Chamber Testing of Organic Emission from Building and Furnishing Materials," *The Science of the Total Environment*, Vol. 91, pp. 237-249.

Danish National Institute of Occupational Health (1990). Lists of dangerous substances; neurotoxins, allergens, and reproductive toxins.

Gustafsson, Hans (1991). "Building Materials Identified as Major Emission Sources," in *Proceedings of IAQ '91 - Healthy Buildings*. Atlanta: American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc. pp. 259-261.

Johnsen, C.R. et al (1990) "Controlled human reactions to building materials in climatic chambers. Part I: Performance and comfort." In, *Indoor Air '90, Proceedings of the Fifth International Conference on Indoor Air Quality and Climate, Volume 1*, pages 269-274.

Levin, Hal (1989) "Building materials and indoor air quality," In Hodgson, M. and Cone, J., (Eds.), *State of the Art Reviews in Occupational Medicine: Problem Buildings*, 4(4), Fall. Philadelphia: Hanley & Belfus, Inc. 667-693.

Levin, Hal (1991a) *Indoor Air BULLETIN*, 1(1), 1-5.

Levin, Hal (1991b) *Op. Cit*, 5-8.

Levin, Hal (1991c) *Op. Cit*, 10-13.

Miksch, Robert, Craig D. Hollowell, and H.E. Schmidt, 1982, "Trace Organic Chemical Contaminants in Office Spaces." *Environmental International*, Vol. 8, 129-137.

Molhave, L. 1982, "Indoor air pollution due to organic gases and vapours of solvents in building materials." *Environment International.*, Vol. 8, pp. 117-127.

Nielsen, Gunnar D. (1990). Presentation at Yale University conference on sources, October 22-24, 1990.

Rhodes, Charles E., et al, "The Significance and Characteristics of the Personal Activity Cloud on Exposure Assessment Measurements for Indoor Contaminants. *Indoor Air* 1, 123-145.

Saarela, Kristina, and Erik Sundell (1991). "Comparative Emission Studies of Flooring Materials with Reference to Nordic Guidelines," in *IAQ '91 - Healthy Buildings*, Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., pp. 262-266.

Strobridge, J.R., M.S. Black, (1991). "Volatile Organic Compounds and Particle Emission Rates and Predicted Air Concentrations Related to Movable Partitions and Office Furniture." in *IAQ '91 - Healthy Buildings*, Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., pp. 292-298.

Tichenor, Bruce (1991). Personal communication.

Tucker, W. Gene (1988). "Air Pollutants from Surface Materials: Factors Influencing Emissions, and Predictive Models." in *Healthy Buildings: Volume 1, State of the Art Reviews*. Proceedings of Healthy Buildings '88, September 5-8, 1988. Stockholm, Sweden. Stockholm: Swedish Council for Building Research. pp. 149-157.

Tucker, W. Gene (1991). Personal communication.

Wallace, Lance A., Edo Pellizari, Brian Leaderer, Harvey Zelon, Linda Sheldon, (1987). "Emissions of Volatile Organic Compounds from Building Materials and Consumer Products," in *Atmospheric Environment*, Vol. 21, No. 2, pp. 385-393.

Wolkoff, Peder et al (1990) "Controlled human reactions to building materials in climatic chambers. Part II: VOC measurements, mice bioassay, and decipol evalution." In, *Indoor Air '90, Proceedings of the Fifth International Conference on Indoor Air Quality and Climate, Volume 1*, pages 331-336.

Appendix. Tables of measured emission rates for sources of indoor air pollutants.

Product type MISCELLANY	Material or product description (Time of sample during chamber test)	VOC emission (ug/m2-hr)	Age @ acquisition, description Comments	Ref #
Cement block	Cement block	0.54		3
Cement flag	Cement flag	73		1
Cable	Small diameter telephone cable (new)	60	Standard wall to telephone	3
Cable	Large diameter telephone cable (new)	38	Bundled wire, computer or network	3
Pipe	PVC pipe	0.53		3
Vapor barrier	Tar paper	6.3		3
Subfloor	Concrete subflooring	<5		7
Trim	Black rubber moulding	103	Age < 124 days, from construction	3
Cove base	Vinyl cove moulding	46	Age < 98 days	3
Cove base	Vinyl edge moulding	30		3
Textile	Floor and wall covering, textile	1600		1
Cleanser	Spray cleanser for carpets	50400	Initial emission rate	4
Cleanser	Liquid cleanser/disinfectant	34900		4
Cleanser	Liquid floor detergent (initial)	2200		4
Pesticide	Moth cake (p-DCB) @ 23 C.	14000000		2
Dry-cleaning	Dry cleaned clothes ((0-1 day)	100		2
Dry-cleaning	Dry-cleaned clothes (1-2 days) Perc	50		2
Office chair	High back chair with arms (1 h)	1060	1 h	8
Office chair	High back chair with arms (981 h)	100	981 h	8
Office furniture	Tackable acoustical partitions (HCHO) (1 h)	158	1 h	8
Office furniture	Tackable acoustical partitions (2.5 h)	74	2.5 h	8
Office furniture	Tackable acoustical partitions (HCHO) (48	37	48 h	8
Office furniture	Tackable acoustical partitions (581 h)	6	581 h	8
Workstation	Workstation	3200	1 h	8
Workstation	Workstation	10	912 h	8
Workstation	Workstation (HCHO)	1470	1 h	8
Workstation	Workstation (HCHO)	830	336 h	8

KEY TO REFERENCES USED IN TABLES
(Complete references at end of text)
1 = Molhave, 1982
2 = Tucker, 1988
3 = Wallace, 1988
4 = Colombo, 1990
5 = van der Wal, 1990
6 = Saarela, 1991
7 = Black, 1991
8 = Strobridge, 1991
9 = Davidson, 1991

Tables of measured emission rates for sources of indoor air pollutants (continued).

Product type WET PRODUCTS	Material or product description (Time of sample during chamber test)	VOC emission (ug/m2-hr)	Age @ acquisition, description Comments	Ref #
Adhesive	Wall and floor glue (24 hr)	271000	Water-based EVA	1
Adhesive	Adhesive, wall and floor (24 hr)	270000		1
Adhesive	Floor adhesive	220000		2
Adhesive	Carpet adhesive (24 hr)	99000		7
Adhesive	Carpet adhesive (24 hr)	90000		7
Adhesive	Carpet adhesive (24 hr)	76600		7
Adhesive	Carpet adhesive - Low VOC (24 hr)	698	Low VOC formulation	7
Adhesive	Carpet adhesive (144 hr)	17200		7
Adhesive	Carpet adhesive (144 hr)	11900		7
Adhesive	Carpet adhesive (144 hr)	3950		7
Adhesive	Carpet adhesive - Low VOC (144 hr)	76	Low VOC formulation	7
Adhesive	Carpet adhesive (7 d)	234		3
Adhesive	Cove adhesive, (7 d)	5000	Methanol based vinyl adhesive	3
Adhesive	Primer/adhesive (7 d)	6.1	Wall primer/adhesive	3
Adhesive	Floor adhesive (10-100 hrs)	<5000		2
Adhesive	Texture glue, PVA, water-based (24 hr)	2100		1
Seam sealant	Carpet seam sealant (1 h)	2960	Seam sealant only	9
Seam sealant	Carpet seam sealant (24 h)	249	Seam sealant only	9
Seam sealant	Carpet seam sealant (144 h)	10	Seam sealant only	9
Caulk	Silicone caulk (<10 hrs)	13000		2
Caulk	Silicone caulk (10-100 hrs)	<2000		2
Caulk	Filler, PVA, glue-cement (24 hr)	10200		1
Caulk	Filler, sand, cement, hardener (24 hr)	730	Water based hardener	1
Caulk	Latex caulk (7 d)	637	Interior/exterior latex caulk	3
Caulk	Sealing agent - putty strips (24 hr)	340	New	1
Caulk	Tightening fillet (24 hr)	160	Neoprene/polyethylene	1
Caulk	Caulk - plasticized PVC/polyethylene (24 hr	56	New	1
Caulk	Heat-expanding neoprene (24 hr)	17	New	1
Caulk	Tightening fillet, heat-expanding neoprene	16	New	1
Paint	Paint, acrylic latex	430		1
Paint	Latex paint, "high profile" (7 d)	249		3
Paint	Latex paint, "vinyl flat white" (7 d)	3.2		3
Stain	Wood stain (<10 hrs)	10000		2
Stain	Wood stain (10-100 hrs)	<100		2
Varnish	Polyurethane wood finish (<10 hrs)	9000		2
Varnish	Floor varnish, 2-part isocyanate (24 hr)	4700		1
Varnish	Floor varnish, clear epoxy (24 hr)	1300		1
Varnish	Floor varnish, acid hardener (24 hr)	830		1
Varnish	Polyurethane wood finish	<100		2
Sealant	Sealing agent plastic compound (24 hr)	72000		1
Sealant	Sealing agent silicone compound (24 hr)	26000		1
Sealant	Urethane sealant	0.13		3
Polish	Spray polish for furniture	27100		4
Wax	Floor wax (<10 hrs)	80000		2
Wax	Floor wax ((10-100 hrs)	<5000		2
Wax	Floor wax paste (initial emission rate)	1880		4

Tables of measured emission rates for sources of indoor air pollutants (continued).

Product type CONSTR. MTLS.	Material or product description (Time of sample during chamber test)	VOC emission (ug/m2-hr)	Age @ acquisition, description Comments	Ref #
Fiber board	Woodfiber board (12 mm)	120	New	1
Fiber board	Fiber board, glass fiber polyester reinforce	17	New	1
Gypsum board	Calcium Silicate board	64	New	1
Gypsum board	Plaster board	26	New	1
Gypsum board	Plaster board (12 mm, paper coated)	26	New	1
Gypsum board	Gypsum board	26	Age unknown	2
Gypsum board	Water repellant mineral board	1.5	Age unknown, from construction site	3
Insulation	Insulation foam, polystyrene	1400	New	1
Insulation	Polystyrene foam A	260		5
Insulation	Insulation foam, polyurethane	120	New	1
Insulation	Polystyrene foam B	30		5
Insulation	Polystyrene foam insulation	22	Purchased retail, age < 76 days	3
Insulation	Insulation batt (mineral wool)	12	New	1
Insulation	Fibrous glass insulation	0.8	From construction site	3
Insulation	Duct insulation	0.28	Purchased retail	3
Laminated board	Laminated board (plastic)	0.4	New	1
Particleboard	Particleboard (new) formaldehyde	2000		2
Particleboard	Particleboard (24 hr)	952		7
Particleboard	Particleboard (144 hr)	837		7
Particleboard	Particleboard	200	2 yrs	2
Particleboard	Particle board	140	New, from manufacturer	1
Particleboard	Particleboard (urea-formaldehyde glued)	130	New, from manufacturer	1
Particleboard	Particleboard	130	New, from manufacturer	1
Particleboard	Particleboard (urea-formaldehyde glued)	120	New, from manufacturer	1
Particleboard	Particle board	120	New, from manufacturer	1
Particleboard	Particle board	28	Age < 98 days	3
Plywood	Plywood B	1450		5
Plywood	Plywood A	900		5
Plywood	Plywood C	725		5
Plywood	Plywood D	215		5
Sheathing	Exterior mineral board	0.03		3
Chipboard	Chipboard (age unknown)	130		2
Panelling	Plywood paneling HCHO	100	New	2
Panelling	Plywood panelling (teak)	44	New	1
Wall covering	Vinyl and fiberglass wall paper	300	New	1
Wall covering	Wall paper, PVC foam	230	New	1
Wall covering	Wall covering, PVC	100	New	1
Wall covering	Wallpaper (age unknown)	100		2
Wall covering	Vinyl coated wallpaper B	95		5
Wall covering	Vinyl wall paper	40	New	1
Wall covering	Printed wall paper	31	New	1
Wall covering	Vinyl coated wallpaper A	20		5
Wall covering	Wall covering, Hessian	5.4	New	1

Tables of measured emission rates for sources of indoor air pollutants (continued).

Product type FLOORING MTLS.	Material or product description (Time of sample during chamber test)	VOC emission (ug/m2-hr)	Age @ acquisition, description Comments	Ref #
Carpet	Floor and wall covering, textile	83	New	1
Carpet	Floor covering, synthetic fibers/PVC	120	New	1
Carpet	Carpet, UF backing (1 h)	411	No seam	9
Carpet	Carpet, UF backing (1 h)	62	New, direct from manufacturer	9
Carpet	Carpet, UF backing (1 h)	98	Aged	9
Carpet	Carpet, UF backing (24 h)	202	No seam	9
Carpet	Carpet, UF backing (24 h)	35	New, direct from manufacturer	9
Carpet	Carpet, UF backing (24 h)	26	New, direct from manufacturer	9
Carpet	Carpet, UF backing (140 h)	20	New, direct from manufacturer	9
Carpet	Carpet, UF backing (140 h)	111	No seam	9
Carpet	Carpet, UF backing (140 h)	6	New, direct from manufacturer	9
Carpet	Felt carpet	80	New	1
Carpet	Latex-backed carpet (336 hrs) 4-PC	80		2
Carpet	Carpet, SBR latex backed (144 hr)	45	New, direct from manufacturer	7
Carpet	Carpet	36	<92 days	3
Carpet	Felt carpet (Synthetic fibers/plastic backing	11	New	1
Carpet assembly	Carpet, adhesive3 on concrete (24 h)	153000	Single stick, new products	7
Carpet assembly	Carpet, adhesive1, pad1 on concrete (24 h)	145000	Double stick	7
Carpet assembly	Carpet, adhesive1, on concrete (24 h)	98000	Single stick, new products	7
Carpet assembly	Carpet, adhesive2 on concrete (24 h)	88300	Single stick, new products	7
Carpet assembly	Carpet, adhesive4 on concrete (24 h)	783	Single stick, new products	7
Carpet cushion	Carpet, pad3 on concrete (24 h)	775	No adhesive, new materials	7
Carpet assembly	Carpet, pad1 on underlayment (24 h)	549	No adhesive, new materials	7
Carpet assembly	Carpet, pad1 on concrete (24 h)	136	No adhesive, new materials	7
Carpet cushion	Cushion P-3 (144 hr)	8110	New from factory	7
Carpet cushion	Cushion P-3 (24 hr)	3360	New from factory	7
Carpet cushion	Cushion P-2 (24 hr)	240	New from factory	7
Carpet cushion	Cushion P-1 (24 hr)	123	New from factory	7
Carpet cushion	Cushion P-1 (144 hr)	59	New from factory	7
Carpet cushion	Cushion P-2 (144 hr)	12	New from factory	7
Vinyl	Vinyl floor covering	22280		5
PVC	Central European PVC	7034	1-3 yrs, subject of complaint	6
PVC	Floor covering, homogeneous PVC	2300	New	1
PVC	Finnish PVC-covering	2192	0.5 yrs, unused from roll	6
PVC	Finnish PVC-covering	1629	1 yr, unused, from roll	6
PVC	Finnish PVC-covering	1443	<0.5 yrs, unused 2nd quality from roll	6
Rubber	Floor covering, rubber	1400	New	1
PVC	English PVC-covering	1122	1 yr, unused, taken from roll	6
PVC	Finnish PVC-covering	273	2-3 yrs, subject of complaint	6
PVC	Swedish PVC-covering	91	1-2 yrs, subject of complaint	6
Vinyl	Vinyl tile	45	Age < 98 days	3
Soft plastic	Floor covering, soft plastic	590	New	1
Linoleum	Linoleum floor covering	220	New	1
Linoleum	Linoleum	64	30 yrs, subject of complaint	6
Linoleum	Floor covering (linoleum)	22	New	1
Wood	Pine, industrial (1 mo.)	682	0.1 yrs, experimental surface coating	6
Wood	Birch, industrial	272	0.1 yrs, experimental surface coating	6
Wood	Pine	264	1 yr, UF-lacquered on site	6
Wood	Pine, untreated	216	New, in plastic wrapping	6
Wood	Birch, industrial	157	0.1 yrs, experimental surface coating	6
Cork	Cork	805	0.3 yrs, new material	6
Cork	Cork	7	2 yrs, subject of complaint	6

CONSTRUCTION AND HEALTH – CRITERIA, STANDARDS AND TECHNIQUES AGAINST INDOOR POLLUTION

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ABSTRACT: criteria for healthy buildings concern both choice of materials and technical solutions during construction, morphology, and lay-out.
Not only it is important to analyze the construction phase, but it is also important to consider the whole cycle of a building (realization, management, maintenance and, sometimes, demolition).
We must remember also that buildings can harm inhabitants in an indirect way, too; thus, "healthy buildings" prevent problems for their inhabitants, and mantain the characteristics of the ecosystem, also.
Design criteria require a vast amount of data about the positioning of various elements inside the building, the materials' behaviour, the characteristics of the products used for laying and maintenance, indoor ventilation, and the location of the building itself outside.
The data must be then translated into operable information.
After data classification and codification, it is necessary to create a mathematic model for the evaluation of the potential global pollutant load.
Unfortunately, the model is so complex that the vast number of interactive elements make it difficult to determine the correct value of single factors.
All this demonstrates the necessity of a computer program capable of encompassing all the variables.

1. Introduction

Nowadays architects must face an important verification process concerning technical choices which often cannot supply the performance required. The performance regards both building health and the inhabitants comfort, and the possible harmful impact that buildings have on the environment.
This verification process involves many different specialists such as epidemiologists, chemists, physicists, ecologists, researchers in environmental psychology, services designers and technicians. The work of all these specialists is to solve problems analytically, and to supply answers to specific questions (for example, what is the human reaction to VOC exposition?).
On the other hand the architect's job is to make choices or to make a synthesis from all the factors given by the specialists.
However, it is necessary to add that "specific answers" are not final (for example, the toxic verification of building materials) and the questions asked by the inhabitants about environmental quality must also be taken into consideration by architects.

H. Knöppel and P. Wolkoff (eds.),
Chemical, Microbiological, Health and Comfort Aspects of Indoor Air Quality – State of the Art in SBS, 343–360.

2. Building as system

A typical characteristic of the architect's job is totality of approach, which requires the analysis of the indoor area and the building as a parts of a larger environment.
The main factors relating to indoor quality (indoor air and health of the buildings) are the following:

- Site
- Rooms layout
- Technical solutions
- Furnishings
- HVAC

An addition, the careful choices for "indoor air quality" can induce inhabitants to behave in a correct way. The factors concern their behaviour, the layout and technological choice.
Criteria for healthy buildings concern both choice of materials and technical solutions during construction, and morphology and lay-out.
Not only is it important to analyze the construction phase, but it is also important to consider the whole cycle of a building (realization, management, maintenance and, sometimes, demolition).
The usual question asked by builders, purchasers, and owners (in general everyone who is connected to the building) is, what the healthy and harmful materials are.
The problem is complex: as laboratory analyses show, between laboratory tests and *in situ* measurements, there are different results.
This implies the necessity of giving each result of the design phase a correct relative importance in order to reach the final objective of a healthy building.
To give an example, is it better to have a well oriented building (good window disposition and good indoor air circulation) with some pollutant sources, or a healthy building, which is badly oriented?
In addition we must remember that the definition of healthy at the moment of the construction, changes during cleaning and maintenance.
Some materials have an identical pollutant rate during their whole life, whereas others, the natural ones, for example, can increasing the general level of pollution as they age.
One asks then, is it correct to choose a material that insures building heath but damages the ecosystem ?

3. Building as a part of the ecosystem

But, even if this last point risks widening the theme of the meeting, it is important to put the right stress on it. In fact, it is relevant to consider that buildings can harm their inhabitants indirectly as well as exerting a negative influence on environment. Moreover, attention must be paid to the problem of the critical moment when materials are sold after demolition of the building.
Even if the study of disease in relation to indoor pollution may seem a limted problem compared to the Amazon forest destruction , the ozone depletion, the greenhouse effect, acid rains, inner city pollution, etc, which are mayor problems, still it must not be underestimated because choice of materials, and of installations have repercussions on the environment.
People have become very conscious of these problems.
An important English research center, BRE (Building Research Establishment), has defined a new method of building certification in which well designed buildings are rewarded (1).

Some of the main evironmental issues that BRE considers in making building evaluations are the following:

- the impact of the building on global atmospheric pollution through, for example, the "greenhouse effect", acid rain, and ozone depletion (buildings are responsible for a significant proportion of sulphur oxyde and nitrogen emissions, and of chlorofluorocarbons);

- the impact of the building on the local outdoor environment such as depletion of resources and the effects on local ecology as, for example, the use of natural materials for building;

- the influence of the building on the health, comfort and safety of its occupants; the indoor pollution level becomes one of the main parameters of this issue;

- the impact of the building on climate change; for example, changes in winds or climate changes as a result of inddor cooling.

Though only the third point of this sequence seems to be related to our work-objective, it is important in good design process not to neglect the others.
As we know, the SBS problem was born after the introduction of sealed buildings, created in order to save energy. If the consequences had been known before, the SBS would be non-existent.
Keeping in mind the relationship of health to building, it is essential to find up-to date solutions that will be valid over the years.
Unfortunately, we care about social costs only when it is possible to convert them into money.
The SBS problem became evident only when the cost of absenteeism became up to eight times greater than the money gained through energy-savings!
At this point, the social cost of some ecological damages is still not calculable; thus there are no direct consequences on design responsibility yet.
However, the time is coming when technical choices will be evaluated in an economic way.

4. Air quality interactive factors

4.1 MORPHOLOGICAL AND TECHNOLOGICAL ASPECTS

Coming back to the building itself, there are several different and interactive parameters that could have direct or indirect weight on indoor air quality:

Site context:
external relationships (streets and buildings), presence of pollutant sources, (industry, powerplants, electrical lines, airports, motorways, garages, parking lots, etc..);

humidity, soil pollutant factors such as cementeries and dumps, hydrological and radon risks; orientation, climate conditions, directions and intensity of main winds.

Building features:
protective system from water and dampness (groundwork and external walls), thermal insulation of the external building, vapour barriers; wall and roof ventilation to avoid dampness and dangerous solar radiation effect.

Plan organization: skyscrapers, terraces, detached houses, semi-detached houses, villas.

Characteristics of the flats:
crowding index, relation of area to rooms; floor layout, floor height, window distribution; ventilated rooms, Wc numbers, kitchen position and layout; terraces, balconies, bay-windows, internal saircases, etc...

4.2 CHARACTERISTIC OF MATERIALS

Going back to the connection between materials and products used during construction we can see that their responsibility for indoor pollution differs according to their placement in the building, and that their effect on the occupants can be direct or indirect.
One must also consider the extension of the material in relation to its volume, and the different kinds of product finishings, and all this must be linked to microclimate conditions.
Therefore product constitution and composition have great importance and must be related to all the other factors.
The quickest method is to make a data-sheet evaluating building materials and construction techniques in line with a number of parameters of varying importance.
Here, we have an example of the main factors of a data-sheet (Fig.1).

- Composition-constitution analysis, pollutant load evaluation.

This data-sheet shows if there are any dangerous substances in the tested products.
The first part shows that design criteria require a vast amount of data about the positioning of various elements inside the building, the materials' behaviour, the caracteristics of the products used for laying and maintenance, and the location of the building itself.
This data must be rendered operable.
The product's chemical composition and physical constitution are analyzed (for example, cork-board, insulating board, sandwich board, etc..).
Some dangerous situations are:

- Particulate matter release

- Harmful or noxious vapour and gas exhalation.

- Product laying.

There are good products, that during the laying lose part of their good characteristics; on the other hand there are harmful product that lose part of their bad qualities during the laying.
It is therefore necessary to estimate all these different conditions (laying method, post-application finishings, storage method, etc..)

- Product performance analysis.

The pollutant load can alter with changing conditions or with time.
Weighting of some of the external factors that can act on indoor pollution, is necessary

5. The importance of a computer program

After data classification and codification, it is necessary to create a mathematic model for the evaluation of the potential global pollutant load.
Unfortunately, the model is so complex that the vast number of interactive elements, make it difficulties to determine the correct value of single factors.

ANALISYS ON THE TECHNICAL FEATURES OF BUILDING MATERIALS AND PRODUCTS.

The following analisys has been based on the 89/106/CEE standard, about the autocertifications of buildings products.
These are the main qualifications:

- resistance and stability
- Fire resistance
- hygiene, healthy and envirement
- noise resitance
- energy saving and heating retentions

The elaborations of the main results is based on the 8690/3 UNI standards which say the right way to make a techinical card.

3 TECHNICAL INFORMATIONS ABOUT THE PERFORMANCES OF THE PRODUCT

Performances:

4 INFORMATIONS ABOUT THE RIGHT WAY TO USE THE PRODUCT

Product's use:
Cautions and advices:
Laying (specify: ways and materials):
Prefinished product
(specify substances and treatments):
After laying finishing
(spec. substances and treatements):
Maintenace and cleaning (Technique and products)

6 INFORMATIONS ABOUT THE ECONOMICAL AND COMMERCIAL ASPECTS OF THE PRODUCTS

General supplying:
time delivery:
quality guarantee of the finished products
sale system:
assistance and laying system:
after sold system:

TECNOLOGICAL UNITS: INTERNAL FINISHINGS
KIND:

QUALIFICATIONS AND TECNICAL PERFORMANCES

		0	1	2	3	4
1	Stability	x				
2	crash resistance		x			
3	fire reactions		x			
4	fire resistance					
5	fume's actions on the body		x			
6	water resistance		x			
7	thermic-proofing				x	
8	odour emmissions					x
9	noise resistence				x	
10	pplmnbgfc			x		
11	absence of superficial defect		x			
12	colour uniformity		x			
13	brilliant homogeneity		x			
14	dirtness homogeneity		x			
15	termic comfort		x			
16						
17	clean		x			

Fig.1: Technical standard-sheet for evaluation of material

The structure is tree-like with many interactions between different branches of the trees.
The feed-back process may substantially change choices materials and initial technical decisions.
This shows the necessity of program which encompasses all the variables.
This program can evaluate the pollutant load of different elements (materials, products, furniture, layout, ventilation, etc..).
The working approach seems us to be similar to the events that occur in the biological field since we face a sequence of pre-existing causes which are impossible to resolve separately.
Thus, it is necessary to simplify the job with a methodical approach concerning the identification of significant data collection, while maintaining the complexity of the environment.
From the operative point of view, to simplify things, we proceed step by step starting with the study of individual rooms, then the apartment, and finally the whole building.
The room is the smallest element of the building system, yet it is the most significant and complex one.
In fact, by starting with the room it was possible to consider the apartment as a sum of rooms and similarly the building as a sum of apartments. (Fig.2.3.4)
Naturally, at every step, it was necessary to add correction factors.

5.1 PROBLEMS IN WEIGHTING

The first problem is to find weightable values.
Scientific data aren't enough to evaluate the whole indoor pollution score; qualitative data must also be used; therefore, two problems must be faced: qualitative data must be empirically quantified and different data must be compared using the same scale.
Another problem is that important factors taken into consideration by our program are presumed risks during the laying, but so far it has been impossible to quantify their effect since no laboratory tests are available.
As another example, we know that indoor distribution of the rooms and orientation of the living spaces can have a positive influence in neutralizing some of the polluting sources.
Again these effects are not quantifiable by scientifically proved values.
We have lab-tested data, emission rates, empirical data and other data coming from different scientific fields (chemical-physical analysis, site design) which somehow had to be unified in a unique comparable scale.
To fix an evaluating scale, we followed some existing evaluation models and an English guide.
This guide concerns the harmful effects that construction materials may have on the health of users and occupants, and provides a building data-sheet (3, Fig 5).

The scale is devided into four levels:

- 0 none reasonably forseeable
- 1 slight/not yet qualified by research
- 2 moderate
- 3 unacceptable

This scale is to be applied to three different categories;

(A) the potential health hazard to the occupants when the material is in position in the building.

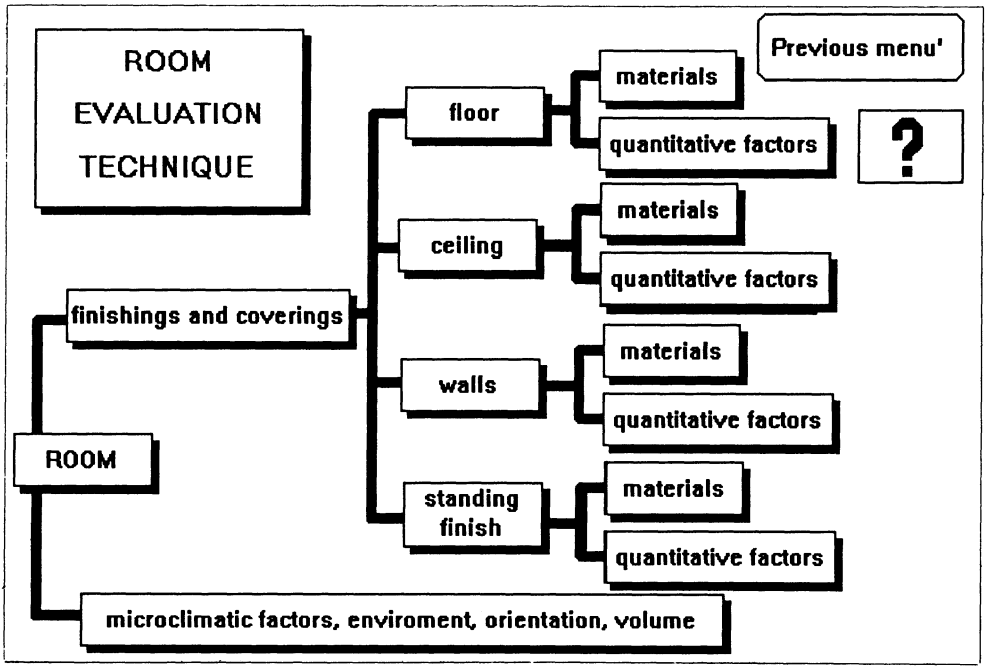


Fig 2 : Computer program scheme. A hierarchic diagram connecting various phases (Room).

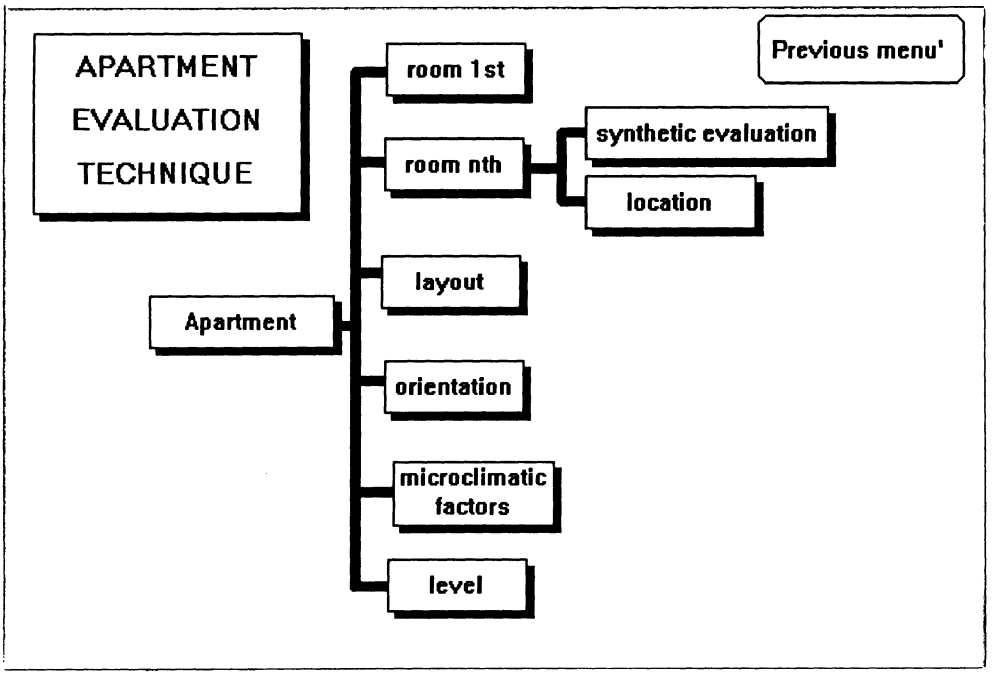


Fig 3: Computer program scheme. A hierarchic diagram connecting various phases (Apartment).

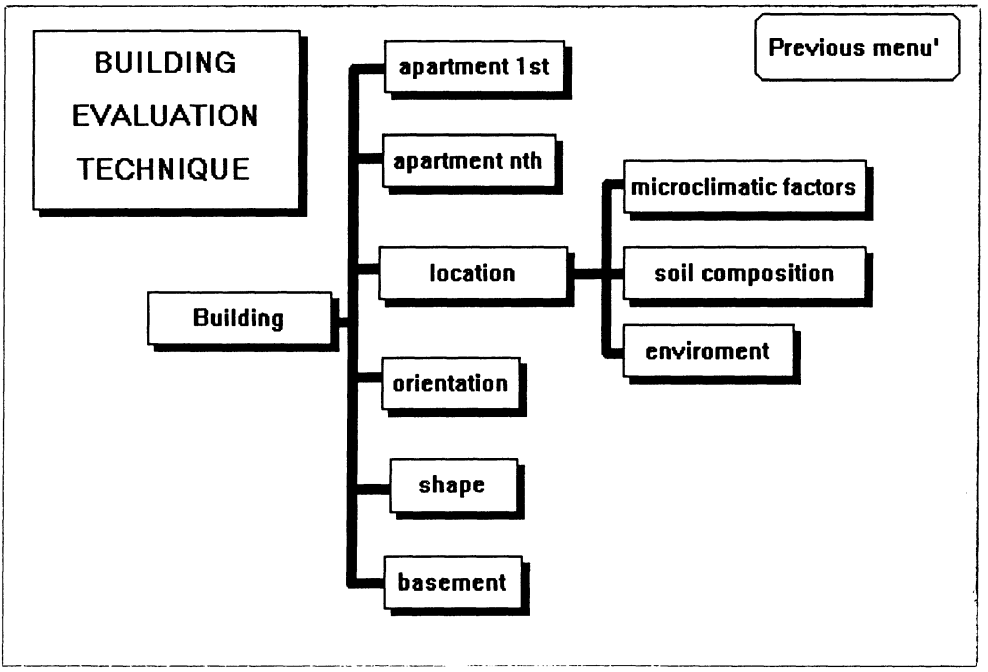
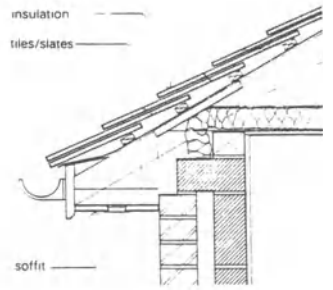


Fig 4: computer program scheme. A hierarchic diagram connecting various phases (Building).

Application 7.3

EAVES SOFFIT

Typical Situation



Technical Requirements

Close off space at eaves between fascia and top of external wall. Span between and nail fix to rafters at normal spacing, 400 mm – 600 mm centres, without excessive shrinkage or sag. Allow provision of ventilation holes and permit decoration. Ease of cut and fit essential. Water resistance and good fire properties, i.e. not readily penetrated by or involved in fire, an advantage.

Decay and Degradation Factors

Fairly protected on underside of eaves. Abrasion from rubbing down prior to repainting. Wild life. Fire, particularly above window openings.

Guidance Notes

There is little to choose between most of the alternatives from a technical/cost standpoint. Boards which have good fire properties might be preferred technically, but due to current requirements to ventilate roofs via openings in soffits, the effectiveness of non-combustible or low flame spread materials in this location may well be negated.

As asbestos cement board is not the cheapest non-combustible alternative its use cannot be justified on general environmental grounds or on cost. It should also be noted that even though the material is not thought to pose a risk to the health of the occupier once in position it is necessary for the building operative to cut and fit the material thus putting himself at risk (unless suitable protective measures are taken). The material is also slightly more difficult to fix than the majority of the alternatives as it requires pre-drilling prior to fixing in place.

Natural finish or painted asbestos board surfaces in existing buildings should not be abraded (sanded down), drilled or cut during alterations. Careful removal and disposal is necessary on replacement and demolition – see Section IV.

Alternatives	Health Comment	Rank
1 Asbestos cement board	Asbestos release on weathering, wear, maintenance and disposal. Maintenance potential hazard. Occupants may put themselves at risk by DIY activity. General environmental hazard.	0/3/3
2 Plywood	No hazard foreseen, except for very minimal risk from wood dust generated from maintenance and alteration.	0/0/0
3 Softwood	No hazard foreseen, except for very minimal risk from wood dust generated from maintenance and alteration.	0/0/0
4 Calcium silicate board	Uncertain health status of any fibrous inclusions.	0/1/1
5 PVA Cement board	No hazard foreseen.	0/0/0
6 Unplasticized polyvinyl-chloride (uPVC)	No hazard foreseen.	0/0/0
7 Glass reinforced cement board	No hazard foreseen.	0/0/0

Fig.5: Evaluation sheet (See: note Curwell S.R., March C.G., Hazardous building materials, E & F.N.S.P.O.N., (1986), London).

(B) the potential health hazard to the occupants when a reasonably forseeable disturbance of the material could occur due to maintenance, repair, replacement, fire and incorrect waste diposals.

(C) The long-term potential environmental impact from maintenance, repair, replacement, fire and incorrect waste disposal.

The assessment used for technical and aesthetic performance is rated from 1 to 10: 1 indicates the best material available according to a technical point of view, 10 indicates the the worst material as far as technical qualities and durability are concerned.
However, this scale doesn't cover every kind of material.
Architects must therefore exercise their own judgement in individual circumstances.

5.2 THE WEIGHTABLE VALUES SCALE AND THE COLOURS SCALE

Our scale goes from 0-4. The values assume a different sense when we classify technical performances or health hazards:

Value	pollution level	technical performance
0	no influence	perfect
1	allowable	good
2	moderate	ordinary
3	elevated	poor
4	unacceptable	unacceptable

As I've said before, one of the gravest problems is weight attribution because it seems impossible to find a scientific method.
For example, monitoring materials is a time consuming and difficult work because it is indispensable to create real conditions. In order to attribute values to the different factors, we have produced a synthesis of judgements expressed by various experts and information from existing documentation.
Since we don't have absolute values we elaborated a coloured scale, which is easy to understand for software users (fig 6,7,8).
The architect has the possibility to check his choice at any moment by controlling the colour scale of the single element as well as of the whole building.
The software offers a check on the architects' choices.

6 Design Criteria

The computer program is a complete operative system, useful both for designing and evaluation buildings.
But first, let's look at safety criteria which derive from studies made after W.H.O. and E.E.C. campaigns, and which will become norms for buildings.

6.1 "HEALTHY BUILDING" CHECK LIST

The following check-list has been presented by "Healthy building" meeting members (4):

Climate engineering

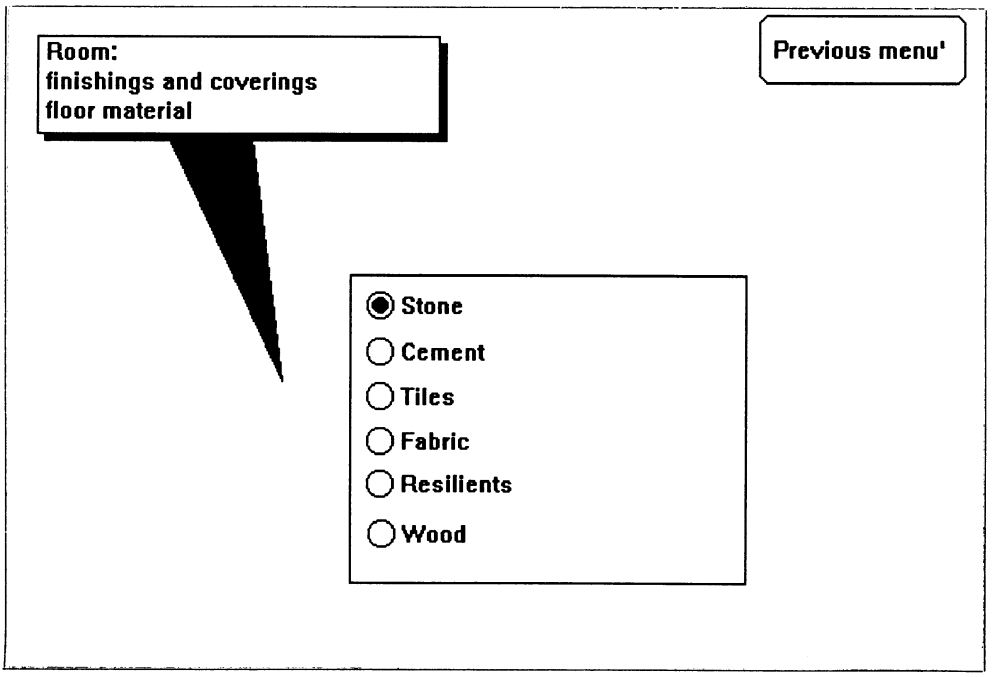


Fig 6: Computer program image. Menu concerning the choice of finishing and floor covering material.

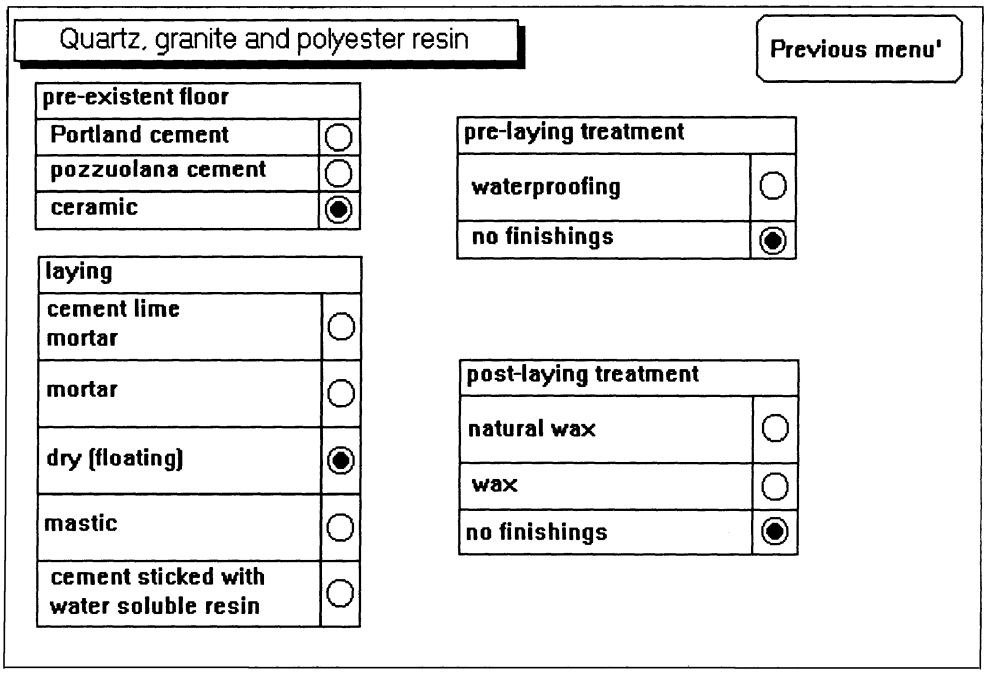


Fig 7: Computer program image. Menu concerning the choice of material and placement.

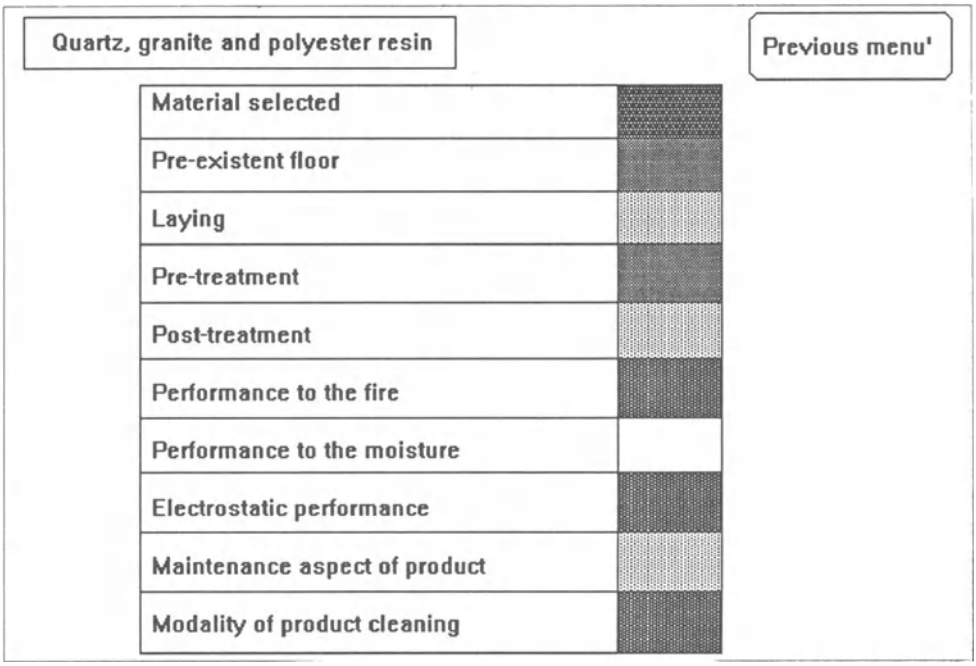


Fig 8: Computer program image. Menu for the material's final evaluation concerning its placement, finishing and performance (on a coloured scale)

- Ventilation must have a certain excess capacity to allow for "human" errors.

Make *sure* that:

- pollutants are taken care of at source (encapsulation, spot extraction etc.)
- the technology is simple and flexible to allow for changes of use of premises, to be comprehensive to the user
- windows are openable
- it is simple to inspect (fixed measurement points), finely adjust, clean and replace components
- the systems are decentralized and symmetrically constructed and with a high air exchange and ventilation efficiency
- the systems are silent and without low frequency noise
- balanced ventiulation systems with heat recovery do not recycle pollutants.

Avoid *risky* solutions such as

- re-circulated air systems
- natural ventilation systems (insufficient capacity, no channelling to individual rooms, draughts)
- exhaust air systems
- air humidification
- hot-air systems (spreading pollutants)
- rotary heat exchangers (recycling pollutants)
- heat exchangers which cannot be turned off in the summer
- insensitive or hypersensitive control and regulation components
- poorly maintained or adjusted and uncleanable installations
- ventilation ducts in flooring structures

<u>Building materials</u>

- Use known and low-emitting materials
- ask for a statement on pollutant emission
- make sure materials do not contain heavy metals, asbestos or biocides
- avoid large-surfaces such as wall-to-wall carpeting in public premises (high "fluff" factors)
- avoid materials which may be suspected of containing toxic substances in adverse concentrations
- avoid plastic wallpaper and painted glass-fibre fabric in wet rooms
- avoid flooring materials which entail a personal static

charge of more than 1,000 V at 22°C and 25%RH
- avoid agents which protect against biological degradation - design the building so that these agents are not necessary.

6.2 LAYOUT CRITERIA

The two principles which condition architects layout are the separation of areas with concentrated sources of pollution from built-up areas, and ventilation in general.
This is not quite as simple as it seems when you realize that there are several sources of pollution and these are not limited just to the better known ones such as combustion devices (5).
We can list:

- cooking places where NOx and CO are produced, and food storage places where the possible deterioration of food is a source of microorganisms; bath/toilet spaces where dampness, microbiological pollution and odors are produced;

- combustion devices, especially open gas flame devices, and fireplaces;

- closets and wardrobes where dry-cleaned clothing is placed; the clothing releases solvents.

- cabinets where household cleaning supplies are kept;

All of these places or sources of pollution need to be separated from the living areas. This is in contrast with the principles of internal layout from the fifties, which followed the idea of the complete communication of spaces.
The new criteria for distribution, hence, place a rigid separation of living spaces which must be used only for main activities which do not pollute, and service and support enviroments which are highly specialized, equipped with air cleaning devices if necessary, or other protective devices.
These latter areas are places where polluting activities, devices, or equipment can be found. In more detail, there will be:

- cooking cabinets, of less than 5 square meters;

- the bathroom's antechamber which avoids direct contact of the bathroom with living spaces;

- wardrobe and pantry spaces, for the storage of clothing, food and household products;

- spaces for telework or for the computer station;

- spaces for combustion devices.

It's also necessary that these specialized areas be ventilated.
The second criterion, ventilation, begins to take on importance here and has an important effect on the layout of the spaces;

- arranging accomodations in buildings and organizing the inside of the building so that a sufficient two way draught is obtained;

- creating ventilation possibilities apart from the accomodation's two way exchanges: places such as courtyards, galleries, open air passages, so that the service areas which contain pollution sources, have the possibility of being constantly ventilated;

- inserting some tubes for continous exhaust, especially when natural ventilation is not possible.

The need for creating constant and consistent ventilation does not just involve choices about distribution. Indeed, correct ventilation does not only depend on the quantity of incoming air, but it also depends on the good circulation of this air, avoiding a layering effect as much as possible.
The positions of the windows in comparison to the room's layout and height need to be carefully studied, as well as the type of window, so that the openings can guarantee constant ventilation of the rooms, although this form of ventilation is somewhat limited.

6.3 TECHNICAL CRITERIA

Design of construction details should be such that:

- all parts are easily accessible for maintenance, cleaning, or substitution;

- different elements can show up any of their defects or accumulations of dirt;

- the maintenance, substitution, and cleaning of the elements can easily be carried out by the inhabitants without resorting to the use of poisonous products;

- shapes which are too irregular are avoided.

6.4 CONCLUSIONS

When we try to come up with criteria for constructing "healty" buildings, the choice of building materials always come first: they must have low pollution potential.
The attention placed on the study of construction details and tecniques used in execution is of equal importance.
The intermediary materials used for laying (adhesives and sealers) take on a decisive importance just like the "main" material (covering or floor or insulating layer, etc.).This is why renovated areas and spaces that have been finished using "do-it-yourself" tecniques present the greatest risks.
The first criterion concerns the choice of materials as was said above: This does not just concern the surfaces which are in direct contact with the living spaces. The choice of materials must be subjected to a series of considerations which do not stop as just evaluating the intrinsically deleterious qualities of the material itself; they should also include all the ways the material can be actually used, issues such as its durability and the possibility of maintaining and cleaning it. These affect its potential harmfulness.
First of all the composition of the product has to be judged; this is then compared to the place where it is going to be used and the quantitative importance that this product assumes.
As has already been said, the way that the material is actually used in construction, the way it is warehoused, and the finishing touches required, are of equal importance. As to its durability, the risk of the material's eventual perishability, any need for protective treatment, and the ease of cleaning and maintenance in order to avoid the pollution of added dirt, all need to be judged. Therefore the way the material reacts to different agents is also very important.

Apart from the choice of the material, the durability of an element in construction depends on the study of its configuration, the accessibility of the element and it's parts concerning possible substitution, maintenance and cleaning.
Maximum attention must also be given to the covering of buildings because this is like skin for human beings: it is the part most responsible for a correct climatic exchange between the inside and the outside.
We can see how many internal pollution problems can be avoided just by being more careful during the designing of a building.
Apart from eliminating the most hazardous materials such as those which contain formaldehyde or asbestos, it is also necessary to compare the aesthetic and space needs with the needs for hygiene in living.
Even if this means harking back to space and construction criteria that are thought of as "passè" or technological solutions which were better known in nineteenth century constructions than in constructions today.

7. Notes and references

1. 'BREAM' (Building Research Establishment Environmental Assessment Method) can be applied to different types of buildings and is the result of a collaboration between the Building Research Establishment (BRE) and Municipal Mutual Insurance Ltd. The EC construction product directive 89/106/EEC defines also an Essential Requirement 'Hygiene, Health and the Environment' according to which a construction work must "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 ratiation
   - polution or poisoning of the water or soil
   - faulty elimination fo waste water, smoke solid or liquid wastes
   - the presence of damp in parts of the works or on surfaces wihtin the works".

2. The informatic model 'Control of residential indoor air quality' has been prepared for the National Research Council (CNR) by A. Baglioni, S. Piardi, M. Beretta, M. M. Bonecchi, N. Boschi, S. De Angelis, S. Piccinini, and M. Salvi.

3. Curwell, S. R. and March C. G. (1986). 'Hazardous building materials', E & F.N.S.P.O.N., London

4. See also: Swedish Council for Building Research (1987). 'The Healthy Building', report from a Nordic Seminar, Swedish Council for Building Research, Stockholm

5. (a) Baglioni A., Piardi, S. (1990). 'Costruzioni e salute', Franco Angeli, Milano, Italy
   (b) Baglioni A. (1990). 'Typology and technological models for acceptable indoor air quality', in F. Lussan and G. L. Reynolds (eds.), Indoor Air Quality and Ventilation, Ed. Selper Ltd, London

HEALTHY BUILDINGS -- WHERE DO WE STAND, WHERE SHOULD WE GO?

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ABSTRACT. The term "healthy building" has been popularized in recent years as a response to the previously popular term, "sick building." It is difficult to define healthy buildings or to establish criteria for classifying buildings as healthy without referring to the presence or absence of problems, occupant complaints, and illnesses. In practice, we generally define "sick buildings" by the prevalence rates of occupant health, and comfort problems. The complexity of modern buildings, the diversity of actors involved and processes for making them, and the importance of building environments for people in modern western societies present large challenges to those who would create healthy buildings. A new paradigm is needed to understand buildings, how they become unhealthy, and how to keep them from becoming "sick." "Building ecology" is a conceptual framework for understanding buildings and creating healthy ones. Practical steps are recommended to develop a more complete theoretical framework and application principles. A few criteria for healthy buildings can serve as examples for the development of a more complete set.

Introduction

Most of what is known about healthy buildings comes from looking at unhealthy buildings -- some people have called them "sick buildings, others have called them "problem buildings," or "complaint buildings." From those buildings we have learned much about what healthy buildings are not. It is difficult to define what is a healthy building? Nobody has done it. No wonder there are some many buildings that aren't healthy.

The complexity of modern buildings, the diversity of actors involved and processes for making them, and the importance of building environments for people in modern western societies present large challenges to those who would create healthy buildings. Some authorities have suggested how to create healthy buildings -- again, based largely on the mistakes that have been identified in unhealthy ones. While there is agreement that public health concerns in problem buildings warrant substantial investments in avoiding the conditions that create the problems, relatively little of what has been accomplished by the responsible governmental agencies and relevant professions and industries has penetrated their target audiences.

A new paradigm is needed to understand buildings, how they become unhealthy, and how to keep them from becoming "sick." A few criteria for healthy buildings can serve as examples for the development of a more complete set. We need at least a working definition of healthy buildings in order to provide criteria for their creation.

H. Knöppel and P. Wolkoff (eds.),
Chemical, Microbiological, Health and Comfort Aspects of Indoor Air Quality – State of the Art in SBS, 361–371.

WHAT IS A HEALTHY BUILDING?

We might ask several questions preliminary to developing criteria for healthy buildings. These are as follows: Is a healthy building one where there are no functional problems? Where everything just works right? Or is it one where the building is not known or believed to cause health or comfort problems for the occupants? We still are looking for the absence of problems or expressions, indications, clues that there are problems -- specifically health and comfort problems.

We might ask, is the building "healthy" or are its occupants in good health? That is different from whether the building can help make the occupants healthy by being a healthful building.

"HEALTHY" BUILDINGS ARE NOT "SICK" BUILDINGS

In fact, what is usually meant by the term "healthy building" is that there are no indications that the building is making people ill and no apparent reason to believe that it will. In practice, this seems to be an acceptable definition. But, as designers, we want to take steps that will ensure, to the degree we can, that the building will be a healthy one. Therefore, we want to assure ourselves that the building is a healthy one by carefully designing, constructing, and operating it. Using the model of preventive medicine or healthy life style, we want a periodical thorough examination (walk-through inspection, measurement, evaluation) of the building performance; we want to provide the maintenance of the building as a healthy system by taking good care of its working parts, its finishes, and its "guts"; and, we want to periodically replace components as they wear out (roofs, painted surfaces, textile floor and wall coverings, furnishings, etc.)

The expressions "healthy building," and "sick building" require that we anthropomorphocize the building, that is, we think of it as though it were an animate object -- a person or other type of living organism. In fact, although it is not living in a biological sense, it is dynamic, changing, evolving over time. It is a complex system of interconnected and interdependent parts. Like our bodies that get dirty and must be cleaned, that shed skin and replace body tissue, a building's surfaces get dirty and must be cleaned, and they wear out and must be renewed. A building's lungs, so to speak - the mechanical ventilation system of fans, ductwork, heating and cooling equipment, thermostats, pumps, and all - must be energized, nourished, and maintained. One can carry the analogy quite far, and it might even be useful to do so. It might lead to a better understanding and better care-taking. But for now, it is important to recognize not only the similarities but also the differences between a building and a living being.

WHO DEFINITION OF HEALTH

The Constitution of the World Health Organization Constitution (1946) defines health as follows. "A state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity." If we apply that definition to a building, or perhaps more practically, if we apply it to the occupants of a building as the criterion for determining whether the building is a "Healthy Building," we may never find one. There will always be some shortfall, some defect, some imperfection manifested in the occupants' responses. It is more reasonable to consider the definition as a motivational statement, but not as a working standard.

"HEALTHY BUILDINGS" CONFERENCE

The first "Healthy Buildings" conference was held in Stockholm in 1988. We can learn a lot from two of its organizers and a third collaborator who have written about the experience of organizing the conference and of publishing its proceedings (Berglund, Lindvall, Moghissi, 1991). "During the preparation of this conference," they write, "it became clear that sufficient scientific information was available to avoid most of the problems related to sick buildings." That repre-

sents a shift in focus from solving "sick building" problems to measures that could provide a comfortable and high quality life. At the conference, participants considered many new topics not normally included in assessing indoor air; topics like thermal comfort, functional requirements, noise, and lighting. The organizers wrote that "...the ultimate goal of environmental protection is not only to avoid adverse effects but to promote the positive qualities of the various environmental components."

In "Strategy options for the development of healthy buildings," they wrote: "A basic requirement for a healthy building is that the room air must not cause illness or discomfort during normal use. The building must also be able to withstand ... reasonable misuse by its occupants without giving rise to adverse health effects." Again, we see, they are defining a healthy building by the absence of "adverse health effects."

They continued: "Basically, indoor air quality can be controlled by a combination of

1) Adherence to guidelines or standards for air pollutant concentrations,

2) Source control of emissions,

3) Prescribed outdoor air flow requirements, and

4) Specific design requirements."

For commonly encountered and well-researched pollutants, concentration limits should be specified. However, there is a need for more toxicological knowledge about many pollutants at low levels and indicators of their presence. An area of considerable importance is adverse effects of mixture of indoor air pollutants. There is ample evidence that these effects are not necessarily additive. For healthy buildings, it is essential to choose building materials with minimum pollutant emission to the indoor air. These should be expressed in quantitative requirements.

Strategy for Healthy Buildings. The authors wrote that it appears logical to develop a strategy for healthy buildings. They urged consideration of the following parameters:

"1) Design, construction, and management of healthy buildings require a combination of proven experience and scientifically founded information.

2) Priority should be given to adverse health effects of major concern, such as building-related cancer and hypersensitivity reactions including allergy. Sensory reactions, discomfort, and annoyance reactions are frequent, widespread, and are early signs of adverse health effects. They are important parts of the health assessment.

3) Should a conflict arise between energy conservation and health, the health goal should prevail.

4) The target is to control human exposure and should be reached primarily by source control.

5) A ranking system is needed for buildings and consumer products. Fast-screening procedures should be developed for appropriate end points of health and comfort. Test facilities are needed to assist governments, manufacturers, builders, and consumers.

6) Microorganisms are important as allergens and causes of diseases including Legionnaire's Disease. Ideally, the presence of microorganisms must be kept to a minimum, yet avoiding exposures to hazardous biocides.

7) The physical planning is critical. If buildings are erected on poor grounds or close to sources of hazardous or annoying emissions, specific requirements must be met.

8) Feedback of experience must not be neglected. Inadequate design, poor materials, and actions during the construction that may cause problems for the users are examples of the experience which must be evaluated.

9) Technical systems in the built environment should either be simple and self-explanatory or automated in order to reduce the need for maintenance and control.

10) A national strategy must be realistic and must accept and compensate for the occurrence of failures in design, manufacture, installation, maintenance, and use of buildings and building components.

Criteria for Healthy Buildings: An Agenda for Action

Does it matter whether we can define "healthy building"? In fact, aren't we interested in creating buildings free of problems? Can we go beyond that? Can we create environments that promote health, not just avoid diminishing it? Is it an either/or proposition? In reality it is a continuum of environmental quality as a function of a very large number of factors. We propose that we identify the factors that are important to health, comfort, and productivity/satisfaction; prioritize them according to their significance for creating healthy buildings; and, then outline a basis for establishing acceptable values. Then we can define criteria for healthy buildings.

There are many precedents in laws, regulations, codes, standards, and guidelines (ASHRAE, 1981; 1989; Gorosomov, 1964; Banham, 1984; NKB, 1981, 1991; Swedish Council for Building Research, 1991). But codes and standards usually lag far behind the state of knowledge, and it is challenging to attempt to assemble existing knowledge into a new proposal for building performance.

It is not a trivial task, however, to integrate the vast array of considerations that must be undertaken in the design, construction, operation, maintenance, and use of a building to make it a healthy one. No integrated standard exists, and no effective effort to create one has been undertaken to date. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) is embarking on the task of developing a integrated environmental guideline. ASHRAE has announced establishment of a new guideline project titled "Achieving Acceptable Indoor Environments," to address the complete indoor environment and its effect on humans. The guideline will address "interactions among thermal comfort, indoor air quality, sound and vibration, and non-ionizing electromagnetic radiation. It will apply to office, light industrial and high-rise residential buildings, specifying indoor environmental criteria that minimize the potential for adverse health effects in human occupants."

IMPORTANT CRITERIA

The most important criteria will be for those factors that will make the most difference if they are not met. We can start with basic life support, move to security, health, comfort, and satisfaction. Similarly, the levels or values for each criterion can be established for a range of objectives from life support through satisfaction, or even health status enhancement.

For example, for life support, we might require 10% oxygen content in air and temperatures between 6 and 45 C. For security, we might require oxygen at 14% of air volume, and temperatures between 12 and 35 C. For comfort, we might require 16% oxygen, and temperatures between 19 and 22 C. And for satisfaction, we might require more than the "normal" oxygen level, say 18%, and temperatures of 21 C. (Of course questions arise regarding the composition of the remaining air, the possible presence of irritants, allergens, infectious agents, or carcinogens.) For comfort criteria, we might want to know the activity level and clothing ensemble of the individual, something about their metabolism, and something about the kinds of temperatures they are usually choose when given control.

Examples of general factors for which criteria should be considered include the following items:

Air Quality
Thermal Environment
Moisture
Light and Other Electromagnetic Radiation
Sound, Vibration, and other Mechanical Energy

DEVELOPING CRITERIA

It is necessary to understand the relationship between building environmental parameters and building occupants in order to define criteria for healthy buildings. That is how most criteria are developed, or at least the intention and design of most standard and guideline development processes. Often there is insufficient information to fulfill that intention, so we use our judgment. There may also be trade-offs between conflicting requirements. And individual human differences result in compromises, design for the "typical" person, design for some theoretical "normal" occupant. A full understanding of all the important parameters will take much research. Integrating the multitude of separate parameters in individual buildings or into a set of indoor environmental criteria will be an enormous challenge.

Meanwhile, we must look at available data and draw inferences from the results. A review of published reports of building factors that are associated with problem buildings (or elevated complaint rates in non-problem buildings) reveals that there are a very large number of factors investigators have associated with complaints. We must start by focusing on those that seem most frequently associated with elevated complaint rates and with those that intuitively are most likely to affect occupant responses. We must also identify those that are most amenable to our intervention and control.

Both source control and ventilation strategies to maintain good indoor air quality can only be fully rationalized when we have a more adequate understanding of the health effects of exposure. Nonetheless, source control is a preferred strategy, and ventilation rates can be established to accomplish various objectives (Levin 1991, 1992; Swedish Council for Building Research 1991). It is, therefore, an essential prerequisite to establish the objectives for a building before criteria can be established for its environmental parameters. This must be done by the building owner unless legal requirements prevail. The architect or occupant must negotiate with the building owner to establish the level of performance that will be expected in the building, whether new or existing, whether being constructed for the first time, renovated, or refurbished. Ultimately, the owner will make many of the most important decisions.

Ventilation and Indoor Air Quality. The relationship between ventilation and indoor air quality can be reasonably well characterized in most environments, substantial knowledge exists, and predictions can be made based on a fairly small amount of data. But establishing ventilation requirements without knowing emission source characteristics is difficult. We must know the strength and composition of emissions to address them with a prescribed ventilation rate. And we must have some idea of an acceptable indoor air concentration in order to determine the ventilation required to maintain a given level. Figure 1 shows the relationship between a wide range of source strengths, ventilation rates, and air concentrations.

Learning from the Past. Information is available on the relationships between source strengths, ventilation, and indoor air concentrations of many contaminants. Source emissions data are available for people, some building materials, and many processes and devices such as gas appliance water heating, space heating or cooking. Looking at the relationship between ventilation and typical source strengths, we conclude that establishing appropriate ventilation rates requires some understanding of the source strengths.

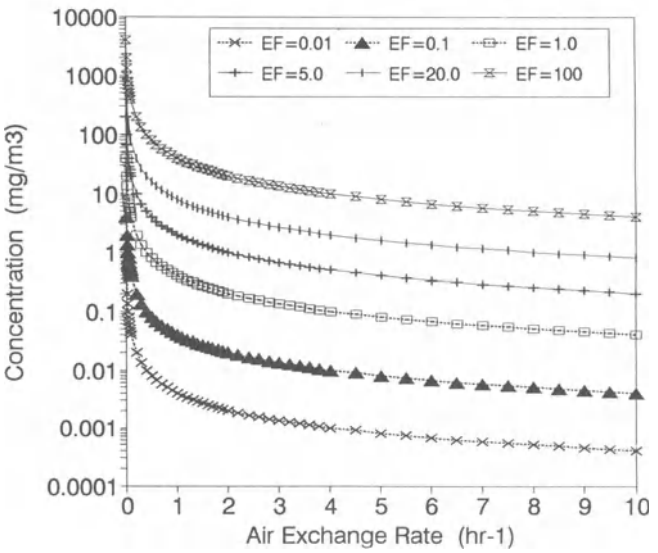

Figure 1. Air concentrations as functions of ventilation and emission rates.

The Need for a New Paradigm

Many building designers, operators, and investigators treat buildings as though they were static and unchanging. They see buildings as constants: rigid, predictable edifices that authoritatively define their internal and external environments. Many studies, investigations, and design analyses are implicitly based on this static view and, as a result, fail to determine the true causal factors of indoor environmental problems.

In fact, study after study has shown that buildings are complex, dynamic entities. They constantly respond to their occupants and occupant activities; changing thermostat settings can radically change ventilation patterns. They react, sometimes unpredictably, to substances brought into the buildings: moisture in the ventilation distribution system can promote microbial growth resulting in the circulation of irritants, allergens, and toxins from bioaerosols. Buildings also continuously interact with their surroundings -- the natural or built environment: wind patterns, traffic characteristics, or soil composition can each have a profound effect on a building's internal climate. The buildings in turn create exhaust and entrainment patterns that affect other, neighboring structures.

BUILDING ECOLOGY

We coined the term "Building Ecology" to describe a comprehensive systems approach to understanding building-environment-occupant interactions. In the science of biology, ecological studies investigate living organisms in relationship to each other and to their environments. From the standpoint of building ecology, we view the building as part of a larger system of interdependent elements and relationships: with building occupants, activities, and contents as well as the surrounding environment.

Others, internationally, are using the building ecology term in a variety of contexts. A continued, open discussion of the concept will improve the dialogue about what goes on in buildings and will stimulate more effective research designs and investigation protocols. We believe that

many existing research and investigation methods are inadequate precisely because they lack this comprehensive, ecological view of buildings. Most studies and analyses could be more effective if they reflected the principles we have set forth here. These views are in a preliminary and raw form; we hope that others will consider them and share their reactions with us.

FOUR PRINCIPLES OF BUILDING ECOLOGY

The concept of building ecology is an abstract and philosophical approach to understanding how buildings work. However, understanding it results in very practical applications. It can be applied to design, construction, operation, cleaning, maintenance, and analysis procedures. The architecture and maintenance of healthy buildings requires the application of four principles:

1) Buildings are dynamic.
2) Buildings are complex.
3) Buildings affect and are affected by their occupants and contents.
4) Buildings affect and are affected by the built and natural environments where they are situated.

Building Dynamics. Even buildings without HVAC systems or other mechanical equipment react to thermal, moisture, solar, wind and other features of their site. All buildings respond to their occupants' metabolic products, activities, and direct interactions with the structure. These are obvious and simple notions: they mean that buildings are constantly changing in response to the forces exerted on them, and that these forces may be intermittent and not entirely controllable or predictable.

That buildings are dynamic means that tests taken at any point in time or across any time span can only suggest what might occur during other time periods. Many studies in the literature support this view. Among them are studies of variations in formaldehyde or radon concentrations over time. The supporting data on variability exist for these two contaminants because these contaminants have been widely studied. Does this mean we can assume the same variations exist for other contaminants? We believe that what data do exist generally support the notion that most indoor air contaminant concentrations are generally not constant in time.

Further, we see abundant data suggesting that contaminant concentrations vary significantly in space. Even where indoor air is relatively well-mixed from an air supply distribution or air exchange perspective, unless sources are uniformly distributed, concentration gradients will exist within spaces and among spaces within buildings.

Building Complexity. That buildings are complex is indicated by the large number of diverse professionals, technicians, mechanics, and laborers required properly to construct, operate or maintain one. Design teams for large buildings we have participated in have included upwards of twenty specialized consultants in addition to the usual assembly of architects, mechanical, electrical and structural engineers, space planners, interior designers, specifications writers, cost estimators, and others. Competently investigating problem buildings may require engineers, industrial hygienists, chemists, geologists, medical doctors, epidemiologists, psychologists, statisticians, architects, and others.

A material used to control acoustic problems (such as duct liners, carpets, ceiling tiles, or fabric wall covering) can become a sink and re-emission source for VOC released from some of these same products or others. Many of these same materials and others may be substrates that support microbial growth. Even particle filters in the ventilation system may become sources of chemical, fiber, or microbial emissions into the air.

Air movement between spaces through concealed penetrations may carry contaminants to locations distant from their origin or source, thus misleading investigators. Chemicals used to

control microbial growth in cooling tower or humidifier water can inadvertently reach occupied spaces and cause adverse occupant responses.

Internal Interactions. A building doesn't just stand alone: it is built to house activities. And like a child pounding on the playroom walls, those activities may have a profound effect on the structure itself. When activities are not foreseen, the building may not be able to properly respond to the imposed loads. Unanticipated art, craft, or hobby activities or food preparation can generate contaminants that the building is not able to control or adequately dilute. Changes in occupant density impose greater thermal loads that may result in less outside air being supplied to the interior.

Material surfaces may not be designed to withstand spilled food or drinks, bodily function accidents by pets or even children. Proper, complete clean-up may require the application of chemicals that themselves contribute contaminants to indoor air.

External Interactions. Siting obviously affects buildings: sun exposures, wind patterns, precipitation or soil moisture, acid deposition, or ambient air contaminants can have significant impacts on the building shell and may have effects on the interior.

Building processes may release contaminants to ambient air that create problems for people outdoors or in adjacent buildings. Entrainment in building air supply of various building exhausts such as from toilet stacks, kitchens, boiler flues, chimneys, and other can result in indoor air contamination. Motor vehicle exhausts entrained in building supply air can cause significant pollution concentrations. Soil contents of radon, methane, or VOCs can penetrate the building shell and reach significant levels indoors.

Indoor air usually contains more contaminants and at higher concentrations than outdoor air. While increased outside air is often seen as the remedy to indoor air quality problems, there are many urban areas where outdoor air quality contamination is so common that increasing ventilation only results in changing the type of contaminants in the indoor air without necessarily providing healthier air. In urbanized southern California, high ozone levels outdoors during much of the year precludes high ventilation rates as an acceptable remedy to indoor air pollution. In many other U.S. urban areas, combustion by-products from power plants and motor vehicles are present at unacceptable concentrations in outdoor air.

Guidelines for Healthy Buildings

The following guidelines for healthy buildings have been developed on the basis of the principles of building ecology and our experience in the field. These guidelines are intended to maximize indoor environmental quality without compromising energy efficiency and economy of building operation.

1. Identify contaminant sources to be certain they are appropriately controlled. This must be done during design and construction and periodically throughout the life of the building. Contaminant sources may include the following:
    a. Building site: air, soil, and water supply.
    b. Building materials and equipment: emissions, adsorption, maintenance, life cycle.
    c. Occupants and their activities: schedules, timing of routines, peak loads.
2. Provide the necessary ventilation air, thermal control, and illumination when and where they are needed:
    a. Outside air supply quality must be controlled.

b. Outside air supply quantities must respond to the nature, timing, and location of contaminant loads.
c. Occupant- or activity-related air supply and illumination can be most responsive and energy efficient when controlled by users or by sensors with user override.
d. Air quality must not be compromised to achieve thermal control.

3. Operate and maintain buildings according to the changing activities and needs of the building occupants:
a. Schedule HVAC system operation to provide IAQ and climate control at all times buildings are occupied.
b. Inspect and maintain building equipment periodically as required by equipment design, condition, and usage patterns.
c. Conduct required professional cleaning to keep exposed surfaces free of excess chemicals, dust, moisture, and microorganisms.
d. Evaluate all changes in occupancy patterns (timing, activities, occupant densities) to determine necessary modifications to building operation, maintenance, and housekeeping services.

In sum, when the principles of building ecology are applied to the practical design, construction, operation, and use of buildings, the indoor environment will be healthier and the building will be more efficient and economical over its entire life cycle. Architects and builders benefit because the building is safer and less of a liability. Owners and operators benefit because the building is likely to be more cost-effective and easy to maintain. And, most importantly, occupants benefit because the building is a healthier, more productive environment in which to work and live.

A Fundamental Question: Who Decides What for Whom?

Some authorities have suggested that individuals who control their own environment are more likely to find the environment satisfactory (Turner, 1972; Stolwijk, 1984; Wyon, 1991). Since it is impossible to create an environment that will be pleasing or even acceptable to all occupants, it is likely that providing individuals with some control over their environment will enhance their degree of satisfaction. Furthermore, it is well-established that when humans or laboratory animals believe they are in control of their environment, whether in fact they are or not, they are less stressed and function better. Then it is important to ask: "Who decides what for whom?" (Turner, 1972).

Given the potential value of enhancing occupant control, it is easy to argue for the maximizing occupant control of indoor environments. Emerging technologies are facilitating creation of increased occupant control in office and residential environments alike. Office workstations are now available with built-in control of the thermal, light, and acoustic environment, air movement, and, of course, ergonomic furnishings. More such devices are being developed and marketed, and the trend is likely to increase.

The Future of Healthy Buildings: Where do we go from here?

In the past few decades, buildings have been designed first to provide thermal comfort, secondly to conserve energy, and lastly, if at all, to provide good indoor air quality. Buildings in the future will be designed to maintain indoor air quality to established standards, but this will not come for a long time. First we will need a better understanding of the effects of air contaminants and mixtures of contaminants on people. We may also need an understanding of the inter-relationships

and co-causality of various environmental factors. We will also need reliable, affordable sensors that can provide data to a microprocessor that controls the ventilation system.
We need a vastly improved understanding of the health effects resulting from exposure to individual chemicals and mixtures of chemicals found in indoor air. We desperately need better characterization of the distribution of exposures, and this can only come after the standardization of accurate, reliable, and economically and technically feasible monitoring methods.

Air Quality Controlled Ventilation. Source strengths vary considerably over time and space within and among buildings, so we will need sensors that control ventilation rates according to the contaminant loads. Perhaps the thermal control and the air quality control will be uncoupled so that each can be optimized. Lighting, sound control, thermal control, air movement, and air exchange are all environmental factors for which individuals have different preferences and needs depending on their health, experience, age, gender, and other factors. It makes most sense to provide individuals with the maximum possible control over these variables in their own microenvironment. Devices are now available from many manufacturers that allow designers to provide such equipment. Some authorities have argued that this is the most effective approach to improving indoor air quality and satisfaction. (Wyon, 1991)

Healthier Products. New products may result in much lower emissions from building materials. Testing emissions of chemicals from materials and evaluating their impacts on people and laboratory animals will lead to a reduction in exposure to the most offensive of these products as competition, liability, and regulatory actions all drive the manufacturers toward healthier, cleaner products. Ventilation should be responsive to indoor air pollutant loads just as heating and cooling systems respond to thermostats and humidistats. In the future, air quality control may be through an accessible device on the wall that monitors and allow settings for CO_2, VOCs, ozone, particulate matter, and other specific chemicals. Ozone will be a more important indoor air contaminant as scientists obtain more data on its indoor concentrations and understand its impacts on and interactions with occupants and on other chemicals, both airborne and on surfaces.

Materials science will bring new, cleaner, more durable materials. "Buckyballs," supermolecules of carbon (C_{60}) have been developed recently that hold promise to provide many new materials for use in technology of the future (Culotta and Koshland, 1992).

Attention to the health affects of exposures in buildings will increase, as it has already with the recognition of Legionnaire's Disease and Pontiac Fever. Other diseases are also being recognized as transmittable through indoor air. ASHRAE Standards intended primarily to control non-infectious indoor pollutants of human biogenic origin are only starting points. The range of guidelines presented earlier in this paper, especially some of those recommended or adopted by European Community member country agencies, are more likely to receive serious consideration. Cost effective means of reducing the risk of airborne transmission of infectious agents should be developed. These might include not only dilution, but also microfiltration or disinfection. (Brundage et al, 1988).

Conclusion

Attention to the productivity impacts of unhealthy buildings will increase as better data are obtained and confirmed in a variety of work, study, and other settings (Wyon, 1991). Such data will provide more convincing evidence to decision-makers including regulators, building owners and operators, and tenant organizations. From the new awareness of the real costs of unhealthy buildings will emerge a greater commitment to the creation and maintenance of healthy buildings. This, in turn, will stimulate the development of still better technology for accomplishing the goal.

References

ASHRAE Standard 62-1989 "Ventilation for Acceptable Indoor Air Quality." Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

ASHRAE (1981). Standard 55-1981 "Thermal Environmental Conditions for Human Occupancy" Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

ASHRAE (1989). Guideline 1-1989. "Guideline for Commissioning of HVAC Systems" Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Banham, Peter Reyner (1984) The Architecture of the Well-Tempered Environment, Chicago: University of Chicago Press.

Berglund, B., and Lindvall, T. (Eds.). (1988) Healthy buildings '88, volumes 1-4. Stockholm: Swedish Council for Building Research.

Berglund, Birgitta, Thomas Lindvall, A. Alan Moghissi (1991). "Healthy Buildings '88" in *Environment International*, 17(4).

Culotta, Elizabeth and Daniel E. Koshland (1992). "Molecule of the Year -- Buckyballs: Wide Open Playing Field for Chemists." *Science*. 254: 1706-1709.

Gorosomov, M. S. (1968). The physiological basis of health standards for dwellings. Public Health Papers 33, Geneva: World Health Organization.

Levin, H. (1981). "Building ecology." Progressive Architecture. Vol. 62, No. 4, pp. 173-175.

Levin, H. (1991). "Critical Building Design Factors for Indoor Air Quality and Climate: Current Status and Predicted Trends," Indoor Air: International Journal of Indoor Air Quality and Climate, Vol. 1, No. 1 (in press).

Levin, H. and K. Teichman (1991). "Indoor Air Quality for Architects." Progressive Architecture. Vol.72, No.3. (March).

Levin, Hal (1992). Source control. Presented at "Chemical, Microbiological, Health and Comfort Aspects of Indoor Air Quality - State of the Art in SBS." Commission of the European Communities, Joint Research Centre, Ispra, Italy. March 23-27.

NKB (1981). *Indoor Climate*, NKB Publication 41. Nordic Committee on Building Regulations.

NKB (1991). *Indoor Climate -- Air Quality*, NKB Publication 61. Esboo: Nordic Committee on Building Regulations.

Stolwijk, J.A.J. (1984). "The 'sick building' syndrome." In Berglund, B.; Berglund V.; Lindvall, T.; and Sundell, J. Indoor Air; Proceedings of the 3rd International Conference on Indoor Air Quality and Climate," Vol. 1, Recent advances in the health sciences and technology. Stockholm: Swedish Council for Building Research, pp. 23-29.

Swedish Council for Building Research (1991). Buildings and Health; Indoor Climate and and Effective Energy Use. Stockholm: Swedish Council for Building Research (Byggforskningsradt).

World Health Organization (1946). World Health Organization Constitution.

WHO (1983). Indoor air pollutants: exposure and health effects. EURO Reports and Studies 78. Report on a meeting of the Working Group on Assessment and Monitoring of Exposure to Indoor Pollutants Copenhagen: World Health Organization, Regional Office for Europe.

WHO (1986). Indoor Air Quality Research. EURO Reports and Studies 103. Report on a meeting of the Working Group on Indoor Air Quality Research, Stockholm. Copenhagen: World Health Organization, Regional Office for Europe.

WHO (1987) Air Quality Guidelines for Europe. Copenhagen: WHO Regional Office for Europe. WHO Regional Office Publications, European Series, No. 23.

Wyon, David (1991) Presentation at ASHRAE IAQ '91 - Healthy Buildings. Washington, DC, September 8.

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