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Scandinavian Experiences with Indoor Air Pollution

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The building illness syndrome (BIS) with complaints about dryness and irritation of the mucous membranes of the eyes, nose and throat, and headaches is very common in Scandinavian buildings. The causes for BIS may be psychosocial, biological, physical or chemical factors in the indoor environment. Of these the chemical factors are considered to be the most important.
BIS can be caused by formaldehyde, but the main sources of this emission are now controlled in the Scandinavian countries. As BIS complaints still are common, organic gases and vapors are considered to be the most important cause of BIS today. These gases and vapors are emitted from many building materials, and mixtures of these have been shown to be irritating in concentrations about 5 mg m^{-3}, a concentration which is often found in new buildings. It is still an unsolved problem if BIS is due to the mixture of the organic gases and vapors themselves, or decomposition products in low concentrations, as for example peroxyacetyl nitrates known from outdoor air pollution.
Irrespective of the cause, the rational approach would be a reduction of the emissions of organic gases and vapors from building materials or an increase of ventilation rates. The latter solution is not desirable due to the economic burden and to the need for energy conservation. We therefore suggest that building materials should be tested for emission of pollutants, so that materials emitting high concentrations of toxic substances can be identified and replaced by materials emitting less toxic substances and with emissions of a lower rate.

(Key Words: Buiding illness syndrome (BIS), eye and airway irritation, indoor emissions, building materials, ventilation)

INTRODUCTION

In addition to the well-known and well-investigated indoor air pollution problems in the workplace, there has been during the last decade a world-wide increase in the number of complaints about indoor air quality in non-industrial workplaces and in homes.

The main complaints from occupants in these "sick buildings" are headaches and complaints about dryness and irritation of the mucous membranes in the eyes, nose and throat. Also fatigue, nausea, dizziness, and other vague symptoms are mentioned (14).

It is encouraging that the non-industrial occupational indoor air pollution as well as the indoor air pollution in the home have become a matter of international concern during the last 5–6 years. The intensity of major international meetings on this topic clearly shows this development (table 1). Indoor air pollution is a problem of greater complexity than outdoor air pollution, and a worldwide research effort is needed if we in a few years shall be able to reduce this type of pollution.

Number of complaints

Outdoor air pollution has never been a serious problem in the Scandinavian countries, for which reason we already ten years ago focused our air pollution research on indoor air problems. At that time we identified one major problem-the emission of HCHO from chipboard and other glued building materials (1), but even if these emissions were brought under control, the number of complaints about bad indoor air quality was still high.

To obtain information about the nature and extent of indoor air pollution problems in Denmark we decided in 1978 to introduce a centralized free service at the Building Research Institute to help people complaining about the indoor climate. People were advised about how to handle their indoor climate problems, and

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detailed technical information was mailed to them. The only condition was that they should first fill out a questionnaire which covered medical questions about symptoms, diseases, etc., and technical questions about building construction, building materials, etc. During 2 1/2 years 1270 subjects filled out this questionnaire. The complaints were symptoms from the eyes and upper airways (35%) and headaches (5%). The remaining 60% were complaints about the indoor environment-high humidities (22%) indoor air pollutants (18%), static electricity (12%), and others (8%). The analysis revealed significantly more problems in buildings less than 4 years old and in buildings with outer walls of concrete (13).

To obtain knowledge about the true extent of the problem we in Denmark in May 1981 did a nationwide survey on a statistical sample of the population older than 16 years. 1100 subjects joined the investigation. Of these 8% had eye and upper airway irritation at least once a month in the home, whereas 22% had these complaints at work. Fifteen per cent had headaches at least once a month in the home and 23% at work. For both complaints the difference between homes and workplace was significant. Both complaints were experienced by females twice as often as by males. Farmers and others with outdoor work did not have these complaints (15).

POSSIBLE CAUSES FOR COMPLAINTS ABOUT INDOOR AIR QUALITY

Except for formaldehyde we have today not established a cause-effect relationship for the complaints in "sick buildings", but the cause has to be *either* psychosocial factors, biological factors, physical factors, chemical factors, *or* a mixture of these. I will discuss these possibilities but exclude pollutants generated by human subjects (odors, smoking, etc.).

Psychosocial factors

It is often stated that the complaints in sick buildings should be considered as "mass hysteria" or more precisely "mass psychogenic illness" (MPI). Such outbreaks are defined as "the collective occurrence of a set of physical symptoms and related beliefs among two or more individuals in the absence of an identifiable pathogen" (5).

Some of the descriptors for MPI fit with the building illness syndrome (BIS), but there are decisive discrepancies (table 2). BIS is characterized by symptoms from mucous membranes, gradual onset and long duration (14), whereas MPI is characterized by headaches, a sudden start preceded by a triggering event (e.g. strange odor) and a duration of days to weeks. We therefore feel that BIS and MPI are two different syndromes with different causes, and that the main factor in BIS is irritation of the trigeminal nerve endings.

Biological factors

The type I allergic diseases bronchial asthma and rhinitis occur in 4 and 8% of the Danish population, respectively. The majority of our asthma patients are allergic to the house dust mite (Dermatophagoides pteronyssinus), for which reason the research has focused on the house dust ecosystem. It has been shown that the number of mites is higher in "asthma homes" than in control homes, and that this is due to higher humidities here than in control homes (7). Our knowledge about the possible significance of these allergens and microfungi for the BIS is at present limited, but they do not seem to provide a plausible explanation for the syndrome, as the complaints are often most pronounced in newly erected buildings.

Physical factors

Asbestos has only been used for insulation in Danish buildings in very few cases and has furthermore for several years been banned from general use due to the easy substitution with man-made mineral fibres. Therefore asbestos fibres are rarely found in the Danish indoor atmospheres.

Our main particle problem is complaints of the BIS type and itching in rooms where compressed man-made mineral fibres are used as a ceiling material. Itching is probably caused by fibre-fall-out on all horizontal room surfaces. These fibres will, either due to direct skin contact or indirect contamination of e.g. the fingers come into contact with the skin or the eyes and then penetrate and irritate the skin or the conjunctiva.

In the air in such rooms we find from 1–10 respirable fibres per liter air ($d < 3\ \mu m$) and from 0.1–1 non-respirable fibes per liter air,

which is 10–100 times lower than those found at the production lines for man-made mineral fibres or at insulation work. These high concentrations of airborne fibres cause some symptoms (12), but not all exposed subjects are affected, for which reason another route of contamination than the air is probable. However, more research is needed before we know the importance of man-made mineral fibres for causing BIS.

Chemical factors

It has already been mentioned that BIS due to formaldehyde emissions no longer is a major problem in Scandinavia, as most indoor environments now have formaldehyde concentrations below 0.15 mg/m^3. This improvement of the air quality, however, has not diminished the number of complaints, for which reason we have been looking for other chemicals able to cause these symptoms. The use of gas for cooking without a hood and the use of unvented gas stoves is very limited, for which reason the NO_x production from such sources is only a minor problem. Instead, we have found that organic solvents are present in almost any indoor environment. The sources are building materials, fixtures, furniture, etc. In samples from ordinary Danish homes and offices we find concentrations of organic vapor from 0.04 to 3 mg m^{-3} with an average of about 1 mg m^{-3}. We have up to now identified 75 different compounds, the most frequent being toluene, xylene and alfa-pinene. The emissions from building materials have also been studied in emission tanks, where test pieces are placed. Totally 62 compounds were identified, the most common being toluene, xylene, and terpenes, the same compounds found in the air of homes and offices. Most of the compounds emitted were eye and airway irritants, and some were carcinogens.

For a standard room and for standard building materials we have then developed a mathematical model enabling us to estimate the indoor concentrations of organic gases in the air, when the amount and type of building materials is known.

We have made our calculations for three model rooms, models I to III, built of common building materials. From fig. 1 it appears that the concentrations of organic gases in these three types vary with a factor 10 from model I to the other two models. It also appears that the concentrations at low air changes as for example 0.25 h^{-1}, which is found very often in offices and homes without mechanical ventilation due to a high degree of sealing, are from 2 to 20 mg m^{-3}. In these calculations it is assumed that the emission rate is not influenced by the air change rate. We conclude from these studies that building materials probably are the main source of organic gases and vapor indoors, and that it is possible to test and classify building materials according to the nature and size of their emission of pollutants (9).

But will indoor concentrations of organic vapors have an adverse health effect in concentrations from 2 to 20 mg m^{-3}? If we think in equivalents of toluene (the substance most often found), these concentrations would be 1–5% of the toluene TLV of 375 mg/m^3. We have recently studied the effects of spectroscopy grade toluene in 16 young healthy subjects exposed for 6 hours to either clean air or 37, 150 or 375 mg m^{-3} (10, 40 & 100 ppm) toluene (3). At the 375 mg m^{-3} exposure there was irritation in the eyes and in the nose, but at the lower concentrations no irritation was experienced. However, there was an impression of bad air quality and of odor even at the lowest concentration of 37 mg m^{-3}. This concentration is only a few times greater than the concentration normally found indoors when emissions are high and ventilation is low. The effect would probably be greater if sensitive subjects or asthma patients were exposed instead of yound healthy subjects, and if technical grade toluene, which contains several % of impurities, had been used instead of spectroscopy grade. Toluene is the least irritating of the alkylbenzenes, and among these the potency increases with chain length up to at least C_6 (11).

It is possible that the addition effect of the many different organic solvents found in indoor air is sufficient to cause the BIS symptoms. Another possibility is that a mixture of the solvents is more irritating than should be expected from a summation of the irritation effects of the single substances. Evidence is found in the printing industries, where symptoms very similar to those of the BIS are found. A study (4) showed that printers had significantly more eye, airway, neurological and general symptoms than the

controls, even if their exposure to organic solvents was far below legal limits-the average exposure was 0.36 x TLV. The air in the workrooms contained 32 different substances, toluene, ethanol and decane were found most often.

Further, it has recently been found in a study under controlled conditions in a Danish climate chamber (10) that exposure to a 5 mg m^{-3} mixture of 21 solvents found in building materials caused significant eye and airway irritation in healthy adults. Five mg m^{-3} correspond to the average concentrations found in new Danish homes, so we now think that it is very probable that at least a significant part of the BIS is caused by the organic gases and vapors in the indoor air. The concentration of organic vapors indoors, however, seems to be too low to cause all the BIS complaints if we do not suppose that a prominent potentiation effect takes place. Therefore we feel that it is necessary also to consider the possibility of the existence of one or more very strong irritants in very low concentrations. Such substances may be directly emitted from the building materials or the emittants may be precursors in a chemical reaction generating highly irritant substances in very small concentrations in the complex indoor atmosphere. For this we have a parallel in outdoor air pollution (6).

The concentration of organic gases and vapors far exceeds the American standard for hydrocarbons in outdoor air, which is 0.16 mg/m^3. This value is not set due to the effects of the hydrocarbons themselves; they act as a substrate from which the photochemical smog, known so well from outdoor air in Los Angeles, is generated.

In this outdoor pollution ecosystem very strong eye and upper airway irritants are produced. These are formaldehyde, acroleine, and acyl nitrates (PAN's). The latter is a family of unstable, highly oxidized organic nitrogen compounds. Peroxyacetyl nitrate (PAN) is formed from the reaction of NO_2 with peroxyacetyl radicals formed in hydrocarbon -NO_x photooxidations. PAN is relatively stable, but is only about twice as strong an irritant as formaldehyde. Most sensory irritants are aromatic in nature with their reactive groups toward nucleophiles located fairly close to the ring. Therefore we should consider other compounds as peroxybenzoyl nitrate (PBzN). This substance produces eye irritation at concentrations about 200 times lower than formaldehyde-that is in the range from 5–10 ppb, which is equivalent to HCHO concentrations of 1–2 ppm. PBzN has been measured in outdoor air at these very low levels (8).

We do not know today if a chain reaction of the LA pollution type takes place indoors. However, the symptoms of BIS and of Los Angeles smog are very much alike, and all the necessary ingredients are present indoors-hydrocarbons, ozon, nitrogen oxides, and UV radiation from sunlight and fluorescent tubes. Sunlight contains UV, even after filtration through a window, and fluorescent lamps radiate due to their mode of action a measurable amount of radiation in the UVA region and in some cases in the UVB region. Due to the high complexity of indoor air pollution, future studies should focus on the combined effects of the multitude of pollutants present in the indoor environment. In this connection the possibility of atmospheric reactions should also be studied.

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Table 1 Some major international meetings on non-industrial indoor air pollution

1978	1st International Indoor Climate Symposium, Copenhagen, DK
1979	1st WHO Meeting, "Health Aspects Related to Indoor Air Quality", Bilthoven, NL
1980	Formaldehyde Toxicity, Raleigh, US
1981	Luftqualität in Innenräumen, Berlin, D
1981	2nd International Symposium on Indoor Air Pollution, Health and Energy Conservation, Amherst, US
1982	2nd WHO Meeting "Sick Building Syndrome", Nördlingen, D
1984	3rd International Conference on Indoor Air Quality and Climate, Stockholm, S
1984	3rd WHO Meeting, Stockholm, S

Table 2 Comparison of descriptors for BIS and MPI

Descriptors	Building illness syndrome (BIS)	Mass psychogenic illness (MPI)
Symptoms		
Eye, nose and throat irritation	+ + +	+
Headache	+ +	+ + +
Mental fatigue	+	+ +
Nausea	+	+ +
Dizziness	+	+ +
Physical signs	–	–
Laboratory investigation	HCHO, HCℓ	–
Onset	gradual	sudden
Duration	years	days—weeks
Female/male	2/1	9/1
Occupational environment	non-industr.	Industr. and non-industr.

+ : low frequency, + + medium frequency, + + + high frequency.

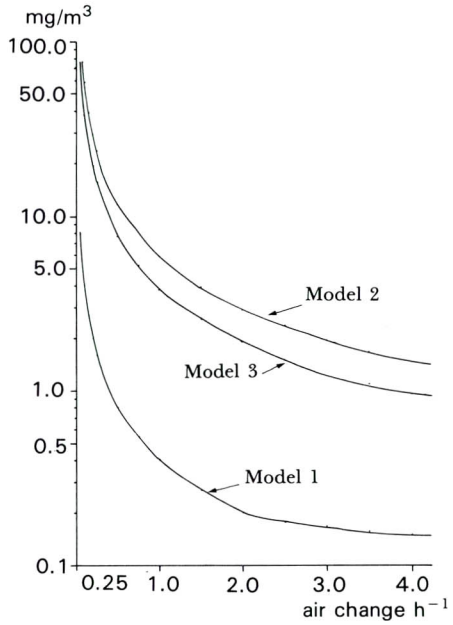

Fig. 1 The concentration of organic gases and vapors in relation to the air change rate in three model rooms built of new, common building materials.