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INDOOR AIR POLLUTANTS: SOURCES, CONCENTRATIONS AND CONTROL

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ABSTRACT

Besides man himself as a source of pollutant emissions (carbon dioxide, body odours, microorganisms), the major sources of indoor air pollutants can be divided into three categories: (a) outdoor air penetrating indoor spaces via infiltration or ventilation, (b) building products and other continuously emitting items, (c) intermittently operated sources.

Although the "classical" inorganic air pollutants well-known from outdoor air studies may also be found in indoor air at elevated concentrations if there are active sources, it is a special feature of indoor air that it generally contains a large variety of organic compounds at concentrations much higher than those found in outdoor air. In some cases the concentrations of some of these organics are high enough to affect human health and comfort. However, exposure rather than concentration needs to be considered to evaluate health effects.

Of the three remedial options, viz. dilution by ventilation, reduction by air cleaning, and prevention of emissions by product amelioration, the latter should always be given preference. Only in cases where already installed materials and products are responsible for elevated concentrations, may ventilation or air cleaning be appropriate tool.

The paper ends by identifying areas for future research.

1. INTRODUCTION

Like other compartments of the environment, indoor air is polluted by a large variety of 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 magnitude. According to the occurring concentrations and the resulting exposure, there may or may not be a need for controlling the sources.

In the following text the existing knowledge with regard to sources and concentrations of selected indoor air pollutants is compiled*). Such knowledge forms the background of a sound indoor air quality management. It also provides the basis for decisions on future research programmes.

*) Throughout this article, no individual references are given. The reader is referred to general publications, e.g., to the respective parts of the proceedings of the international INDOOR AIR conferences: IA '84 in Stockholm, IA '87 in Berlin, IA '90 in Toronto.

2. SOURCES OF INDOOR AIR POLLUTANTS

To be able to properly characterize the indoor environment, it is important to understand the sources of indoor air pollutants. Table 1 gives an overview of the most important of these sources which can be divided into the following categories: outdoor air, man and his activities, materials.

Table 1: Important sources of indoor air pollutants and the major compounds emitted by them

Source	Emitted compounds or classes of compounds
Outdoor environment	
Air	Common outdoor air pollutants,
Soil	Radon, Volatile organic compounds
Water	Volatile organic compounds
Man and his activities	
Man himself	Carbon dioxide, Water vapour, Body odours
Energy production	Nitrogen oxides, Carbon monoxide, Carbon dioxide, Water vapour, Volatile organic compounds, Suspended particles and Semi-volatile organic compounds
Smoking	same as for Energy production, in addition: Nicotine, Nitrosamines
Household and hobby products	Volatile organic compounds, Semi-volatile organic compounds
Materials	
Building and renovation materials	Volatile organic compounds, Fungicides, Asbestos and other fibres
Furnishings	Volatile organic compounds

2.1. Outdoor environment

All buildings exhibit a more or less pronounced exchange between outdoor air and indoor air. In buildings with natural ventilation this exchange is highest if windows are opened, but takes also place - although at a reduced level - if they are closed (infiltration through cracks and interstices). In the case of mechanically ventilated buildings the ventilation system forces outdoor air (unless indoor air is recirculated) into the building shell to guarantee the air exchange.

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 an important source of indoor air pollution. In addition, outdoor air may also contribute to indoor air pollution under special meteorological conditions (air pollution episodes). Whereas in naturally ventilated buildings the decay of pollutants on walls, material surfaces, etc. generally provides a protection under these circumstances, mechanically ventilated buildings (unless the ventilation system is equipped with effective filters) normally do not have this protective function.

A special case of contamination from outdoors is the migration of gaseous substances into the building from the soil surrounding it. The most prominent example is radon, although a number of organic compounds may also play a role in houses built on waste sites.

Finally, the outdoor environment may contribute to indoor air pollution through a number of 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.

2.2. Man and his activities

Man himself emits carbon dioxide and water vapour into indoor air. In addition, the human metabolism sets free a large number of compounds, many of which contribute to the body odour.

Energy production, e.g. by using gas appliances for cooking and heating, causes the presence of many indoor air pollutants among which the oxides of nitrogen and carbon have been widely studied. The combustion processes also generate suspended particulate matter, volatile organic compounds (VOC) and semi-volatile organic compounds (SVOC). In recent times, the formation of acid aerosols containing nitrite and nitrate as well as nitrous and nitric acids has been studied. The use of unvented kerosene heaters which leads to high concentrations of sulphur dioxide is much less widespread than in the United States. Open fireplaces should not substantially contribute to indoor air pollution if properly installed and maintained. However, elevated concentrations of polycyclic aromatic hydrocarbons (PAH) may occur.

Smoking is one of the most important sources of indoor air pollutants. Interestingly enough, side stream smoke contains more pollutants and at a higher level than main stream smoke. In addition to the compounds generally formed in combustion processes, nicotine is emitted which can be considered as an indicator substance for tobacco smoke.

The large variety of existing household and hobby products makes it impossible to list all possible 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.

2.3. Materials

While generally human activities lead to short-term intermittent emissions, the presence of building and renovation materials in a room mostly causes chemicals to be emitted into indoor air on a long-term, more or less continuous basis.

In the past, formaldehyde has been the most important compound 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, higher boiling compounds now added to the product may significantly contribute to the occurrence of SVOC. These will often be bound to dust particles.

Most of the emissions from new furnishings belong to the class of VOC.

3. CONCENTRATIONS OF INDOOR AIR POLLUTANTS

In indoor spaces - especially in private rooms - there is a large variety of different 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.

Table 2: Ranges of NO_2 concentrations in the air of 12 Dutch homes averaged over different periods of time

Location of sampler	Maximum concentration ($\mu g/m^3$) over		
	1 min	1 h	24 h
Kitchen	400 - 3800	230 - 2050	53 - 480
Living room	195 - 1000	100 - 880	49 - 260
Bedroom	57 - 800	48 - 720	22 - 100

From Lebret et al.: INDOOR AIR '87, Vol. 1, 435-440 (1987)

As an example of how much the duration of sampling and the location of the sampling equipment may affect the result, Table 2 gives the concentration intervals obtained for nitrogen dioxide in 12 Dutch homes The figures were obtained from real-time monitoring data. As can be seen, there is a clear gradient from the upper left to the lower right of the table, namely from very short-term measurements close to the source (gas appliance) to long-term measurements away from it. As real-time monitoring usually is not the rule in studies dealing with indoor air pollution, very few such experimental data exist so that the magnitude of the effect is difficult to be estimated for other compounds.

3.1. Concentrations of inorganic compounds and suspended particulate matter

Despite the difficulties in predicting the concentrations of indoor air pollutants, there is enough information in the scientific literature to attempt giving the order of magnitude of these concentrations. The figures given in Table 3 represent the author's best estimate and it is almost certain that there may be circumstances under which they will not apply. In particular, the peak concentrations given in the table do not necessarily represent the upper-bound limit of what can be found in practice. However, Table 2 clearly indicates that short-term peak concentrations may exceed average concentrations by factors between about 5 and 10 or even more. This is of particular importance in cases where a potential health effect is associated with a short-term exposure at elevated concentrations rather than with a long-term exposure at average concentrations.

Table 3: Estimate of concentrations of selected inorganic indoor air pollutants

Pollutant	Concentration *)	
	Average	High
Carbon dioxide (ppm)		
Occupied room	500 - 1000	3000 - 5000
No occupancy	300 - 400	300 - 400
Carbon monoxide (ppm)	2 - 5	10 - 20
Nitrogen dioxide ($\mu g/m^3$)		
Kitchen with gas	40 - 80	300 - 3000
Other room with gas	20 - 60	100 - 1000
Rooms without gas	10 - 40	50 - 100
Sulphur dioxide ($\mu g/m^3$)		
Without indoor source	10 - 20	50 - 100
With source	50 - 200	500 - 1000
Suspended particulate matter ($\mu g/m^3$)		
Without tobacco smoke	20 - 50	100 - 200
With tobacco smoke	40 - 80	500 - 1000
Radon (Bq/m^3)	20 - 60	5000 - 10000

*) "Average" is the value for long-term periods (24 h or more), whereas "High" represents values for short-term periods (1 to 2 h or less). For radon, both values given cover long-term periods, "Average" and "High" referring to the source strength (see text for details).

The case of radon needs separate discussion. In fact, differences between average and peak concentrations as large as those given in Table 3 will never be observed in one and the same building, but - as a consequence of varying geological conditions - only between buildings from different geographical areas. Therefore, for radon the "Average" column reflects the situation in houses built on "normal" ground, whereas the "High" column refers to levels encountered in houses in "hot spot" areas.

3.2. Concentrations of organic compounds

For organic compounds there is a much larger number of species 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 volatile organic compounds (VOC). Hence, Table 4 which is limited to VOC represents only a small portion of the "true" burden of indoor air in terms of organics. Most organics with higher boiling points, e.g. SVOC which are generally bound to dust particles, have until now not been sufficiently studied.

Table 4: Estimate of concentrations of selected volatile organic compounds in indoor air

Pollutant	Concentration ($\mu g/m^3$) *)	
	Average	High
Formaldehyde	30 - 60	200 - 500
Decane	10 - 20	50 - 100
Undecane	5 - 10	20 - 50
Benzene	5 - 10	20 - 50
Toluene	50 - 100	200 - 500
Naphthalene	1 - 3	5 - 10
1,1,1-Trichloroethane	5 - 10	50 - 100
Trichloroethene	5 - 10	50 - 200
Tetrachloroethene	5 - 10	50 - 100
p-Dichlorobenzene	5 - 10	50 - 500
a-Pinene	5 - 10	20 - 50
Limonene	20 - 30	100 - 200
Ethylacetate	5 - 10	20 - 100
Butylacetate	2 - 5	10 - 50

*) "Average" is the long-term concentration observed in most homes under normal living conditions. "High" represents values found regularly in a small percentage of buildings for various reasons. In periods of high source strength, e.g., during and after renovation works or the introduction of special sources, concentrations may be much higher also in average buildings.

The large variety of VOC makes it difficult to deal with each of them individually. Thus, the concept of total VOC (TVOC) has been developed.

Although this is an ill-defined term since the TVOC concentration depends on the analytical method used (without there being a standardised method) it 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 reduce the number of complaints from the occupants.

4. EXPOSURE TO INDOOR AIR POLLUTANTS

The mere knowledge of the concentration levels of pollutants in indoor air may give a wrong picture of where priorities have to be set in terms of reduction strategies. Rather, the concentration levels have to be combined with the time spent at these levels to obtain an information about exposure which is the parameter of importance for health effect considerations.

Although it is recognized that measuring personal exposure is the best way of getting such information, it is also known that personal exposure measurements are more difficult to be carried out than measurements at a fixed location. Hence, the latter - in combination with human activity patterns - are used to generate exposure data. Although progress has been made in the USA to get a better knowledge of people's time budget, such information is still scarce for the European situation.

The use of biomarkers to characterize exposure (e.g., cotinine in urine as a marker for environmental tobacco smoke) cannot be elaborated on in this paper. Similarly, the need for evaluating what part of total exposure is made up by exposure to indoor air pollutants can only be mentioned.

5. REMEDIAL ACTIONS

In the management of indoor air quality, there are three important options to reduce the concentration level of pollutants in indoor air:

(a) decrease the source strength by choosing more appropriate products and materials or removing already installed materials;
(b) reduce the level of contaminants using air with air cleaning devices;
(c) dilute the polluted air by ventilation.

Among these options, source control is certainly the most obvious because it reflects the general philosophy of environmental protection: preventing rather than curing. Only in cases where already installed materials and products are responsible for elevated concentrations, may ventilation or air cleaning be an appropriate tool. In some cases the only possibility to achieve acceptable indoor air quality may even be to completely remove the source.

Selecting a "safe" product or material is not an easy task. First of all, today there is only very limited information on product composition since manufacturers are generally not obliged to provide such information. Second, even if the full body of information on a product's composition were available, a rule would still have to be developed to evaluate this information. Such rule could have the form of an index. The index should be derived from both the toxicological and comfort-related properties of the product/material. The index would permit the ranking of products/materials to ease the selection of a product.

6. AREAS FOR FUTURE RESEARCH

Although much progress has been made in the past in the collection of information about sources and concentrations of indoor air pollutants, many questions are still without answer. The following list contains recommendations for research activities. All of these activities merit common European efforts, some in view of the Single European Market, others to save resources.

Table 5: Proposals for research activities

Sources and Source Control

Develop schemes for ranking of products/materials according to their potential effects on health and comfort.

Study the routine applicability of protocols to determine emission factors for solid and liquid products/materials.

Develop receptor models for source apportionment.

Study the usefulness of pre-conditioning procedures to obtain low-emitting products.

Study the effectiveness of coating procedures to prevent emissions from already built-in materials.

Develop satisfactory air cleaning devices.

Concentrations

Enlarge the data base of concentrations of polar and semi-volatile organic compounds.

Establish frequency distribution for concentrations of suspended particulate matter.

Study the decay behaviour of pollutants indoors to permit a more correct application of models to calculate concentrations from emissions.

Exposure

Study the links between concentrations at fixed indoor sites and personal exposure.

Establish activity patterns for the European population.

Validate models to predict exposure.