EUROPEAN CONCERTED ACTION

INDOOR AIR QUALITY & ITS IMPACT ON MAN

COST Project 613

Environment and Quality of Life

Report No. 6

Strategy for Sampling Chemical Substances in Indoor Air

Commission of the European Communities
Directorate General for Science, Research and Development
Joint Research Centre - Institute for the Environment

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Strategy for Sampling Chemical Substances in Indoor Air

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- Report No. 1: Radon in indoor air.
- Report No. 2: Formaldehyde emissions from wood based materials: guideline for the establishment of steady state concentrations in test chambers.
- Report No. 3: Indoor Pollution by NO_2 in European countries.
- Report No. 4: Sick building syndrome - a practical guide.
- Report No. 5: Project inventory.

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1. INTRODUCTION

In contrast to the situation encountered in outdoor air analysis, where the concentrations of a number of pollutants are monitored continuously, indoor air pollution can usually not be controlled on a continuous basis in view of the huge number of individual indoor spaces with different sources and pollution patterns. In general it is also not possible to introduce bulky or noisy analytical equipment into indoor environments. As a first consequence of this situation, analysis of indoor pollutants is usually broken down into a sampling step which is performed on-site with relatively small, silent and inexpensive equipment and to which this document will refer, and a separation/identification step which is performed in the laboratory using complex instrumentation if necessary.

As a further consequence, indoor air analysis has often to solve the difficult task of representatively characterizing the air in enclosed spaces by only a small number of samples or even by just one sample. Thus it is clear that the sampling strategy is of greatest importance in carrying out indoor measurements.

The sampling strategies described in this document apply to the case that a certain knowledge of the potential sources and pollutants is available. The document does not cover the procedures to be followed if the reasons for unspecific complaints have to be detected. Developing a sampling strategy means to answer the questions when, how often, for what period of time and where samples should be taken. The answer to these questions depends essentially on three parameters:

(a) the dynamics of the indoor environment, i.e. its particular features causing a great variability of indoor pollution levels in space and time;
(b) the objective of a measurement;
(c) the pollutant or pollutant class of interest.

A due consideration of the dynamics of the indoor environment, characterized by the variability of indoor spaces, of sources of pollution and of ventilation and climatic conditions, has to be at the origin of any design of a sampling strategy and influences the answers to all of the above questions.

The objective of a measurement, e.g., the identification of sources of complaints on poor indoor air quality, the determination of population exposure levels or the check of compliance with air quality criteria, decides on which pollutant(s) are of interest, and on whether maximum or mean concentrations or the variation of concentration with time have to be determined.

Interest in a given pollutant decides on the sources which have to be considered. Whether these sources emit pollutants in a continuous (e.g., building materials) or discontinuous way (e.g., human activities) will influence the decision on the time, duration and frequency of sampling.

Although the sampling strategy has a strong impact on the result of any indoor measurement, to date, it has only been discussed in a small number of publications (Seifert, 1984a, 1984b, 1987b; Corn, 1985; Thorsen and Mølhave, 1987). Furthermore, there is no general agreement - be it on the national or the international level - on what sampling strategy has to be used under what conditions. The proposals made in the following sections are intended to give hints for the set-up of an appropriate sampling strategy.

The document is divided into two parts. In the first part, a more detailed discussion of the dynamics of the indoor environment and of the objectives of indoor pollution measurements is given. In addition, general rules are derived for an optimal sampling strategy to answer the questions when, for what period of time, how often, and where samples should be taken. In the second part, these rules are applied to those pollutants or pollutant classes which for the time being are considered of major importance. As the same facts had to be viewed at from different angles, some repetition could not be avoided. However, such repetition was accepted to help a better understanding.

In principle, the information given below has been prepared for an assessment of chemical substances. However, much of the content of this document may also apply to microbiological indoor pollutants, although in the case of these agents, temperature and relative humidity will probably have a much more pronounced influence on the pollutant level than in the case of chemical substances. The specific problems concerning the sampling and detection of microorganisms will be discussed in a separate document.

2. GENERAL CONSIDERATIONS

There are a large variety of situations and pollutants in the different types of indoor spaces, which would call for quite a large set of sampling procedures to be established. However, there are a number of general considerations which apply to most circumstances. These general considerations cover the dynamics of the indoor environment, the questions of why, when, how long and how often, and where sampling has to be carried out. The following sections deal with these topics and include also a brief discussion of basic requirements for quality assurance.

2.1 The dynamics of the indoor environment

The indoor environment in non-industrial buildings is a dynamic universe rather than a static one. The dynamics are characterized by the variability of source emissions, types of different indoor spaces, and different ventilation and climatic conditions. The situation is further complicated by the various types of pollutants. These are the following:

- Gases and vapours (inorganic and organic)
- Particulate matter
- Radioactive particles/gases (radon and its daughters).

The sources which contribute to indoor air pollution are summarized in Table 1. They can be divided into those with continuous emissions (long-term emission, constant source strength) and discontinuous emissions (short-term emission,

Table 1. **Sources of indoor air pollutants and their tentative assignment to emission types**

Source	Type of emission: Continuous	Discontinuous	Pollutant: VIC	VOC	PM	RA
<u>Building related:</u>						
Building materials	R		+	+	+	(+)
Renovation of building	R,I			+	+	
Furnishings	R			+	+	
Ventilation system	R,I	R,I		+	+	
Polluted soil/ground	R,I			+		+
Fungi, mold, mites	R			+	+	
<u>Product-related:</u>						
Household and consumer products		R,I		+		
Cleaning procedures		I	(+)	+		
Hobby works		I		+		
Various activities (cooking, smoking, etc.)		I	+	+	+	
<u>Others:</u>						
Bioeffluents		I		+		
Outdoor air, traffic		I	+	+		
Industries in the same building		R,I		+		
Occupational exposure (with subsequent exhalation and desorption from clothes and body)	R,I		(+)	+		
Car-related activities		I		+		
Combustion, heating		R,I	+	+	+	
<u>"Negative" sources:</u>						
Ventilation	R,I	R,I	+	+	+	+
Sinks (decay, fleecy surfaces)	R,I		+	+		
Deposition	R	I			+	(+)

R = Regular
I = Irregular
VIC = Volatile inorganic compounds
VOC = Volatile organic compounds
PM = Particulate matter
RA = Radon and daughters

variable source strength). These two groups may further be subdivided into those emitting regularly (R, constant time pattern) and those emitting irregularly (I, variable time pattern) (Seifert and Ullrich, 1987a). While the magnitude of emissions from continuous sources often depends on temperature, relative humidity, and sometimes air velocity, and varies within a time-scale of months, discontinuous emissions are much more time-dependent and may change within hours or minutes .

An understanding of the dynamics of the indoor environment is important to be capable of designing a proper sampling strategy as well as to evaluate the results. In selecting the parameters of the sampling strategy one should also take into account that parameters not related to the measurement itself (e.g., building and occupant related variables, such as outdoor sources, variability in source strenght, ventilation rate, etc.) have an impact on the measured concentration. Table 2 illustrates how all these parameters are interrelated.

Table 2: **Interrelationship between different indoor parameters illustrating the dynamics of the indoor environment**

Parameter	Outdoor air	Ventilation rate	Ventilation efficiency	Source strength	Sinks
Sampling-related					
time of sampling	+			+	
duration of sampling	+	+		+	
frequency of sampling	+			+	
sampling location	+		+	+	+
Building-related					
age of building		+		+	+
source strength		+	+	+	
temperature				+	
rel. humidity	+			+	
Occupant-related					
activity pattern		+		+	
number of persons		+	+	+	+
Other					
season	+	+			

2.2 Sampling objective

As the sampling objective determines the procedure to be followed during sampling, it is of utmost importance to define it clearly before starting sampling. Among the possible objectives, the following play the most important role: determination of population exposure, reaction to complaints (including the identification of emission sources), control of the success of mitigation measures, and check of compliance with reference or guide values.

To determine the exposure of the population, either average or maximum exposure levels may be needed. If a sufficiently large number of cases chosen at random are investigated, a frequency distribution of the concentrations can be established, from which both the "normal" and the extreme concentrations can be derived. A recent compilation of VOC data (WHO, 1988) shows that population exposure to VOC is comparable in different countries.

In many instances, the air inside an enclosed space is analysed following a request from complaining occupants. In most of these cases, acute effects, such as eye irritation, irritation of mucous membranes or bad odour perception, play a dominant role. To check if such complaints may be caused by a pollutant, it is often most useful to get information on the maximum concentration likely to occur in a room, i.e. on the worst case situation. Such worst case considerations are especially important if groups at risk are to be looked at. They can be simulated by reducing the ventilation rate or by changing other indoor climate parameters provided these parameters increase the emission rate. As an example, the increase of formaldehyde concentrations at higher temperature or relative humidity may be mentioned. However, care has to be taken not to choose conditions never encountered in practice. If significant levels of pollution are observed in a room, it is generally desirable to know the sources in view of mitigation measures. As more than one single building material, piece of equipment, etc. may be responsible for the emissions, the sampling strategy would have to be adjusted properly (see 2.5).

Controlling the success of mitigation measures does not call for special conditions provided the two measurements (one before and the other after the mitigation measures have been taken) are carried out under comparable conditions.

Table 3 presents a matrix which relates the sampling objectives and different parameters to be considered in developing an appropriate sampling strategy.

As in many cases the ultimate goal of indoor air measurements is an evaluation of potential negative health impacts, the sampling procedure may have to be adjusted to these needs. Table 4 is a summary of the interdependencies between the potential adverse health effects, the information one would like to have available on the exposure situation, and the sampling procedures to be applied.

As concerns the checking of compliance with a given guide value, the boundary conditions defined together with this value have to be respected. If such boundary conditions have not been defined, the sampling strategy should be adjusted according to the rules given in the following sections.

Table 3: **Matrix relating sampling objectives and different parameters to develop a sampling strategy**

Sampling objective	Sampling condition	Time of sampling	Duration of sampling	Minimum number of samples	Minimum number of sampling points
Population exposure					
average concentration	normal	two seasons	long-term	2 - 4	1 - 2[2]
maximum concentration	worst case	any time	short-term	1 - 2	1 - 2
Complaints					
chronic effects	worst case	any time[1]	long-term	1 - 2	1 - 2
acute effects	worst case	any time[1]	short-term	1 - 2	1 - 3
Effect of remedial actions	normal	before and after	short/long-term	1 - 2	1
Test for compliance	normal or worst case	any time	period of reference value	2 - 3	1

1) According to activities, etc.
2) Personal sampling

Table 4: **Matrix relating health effect, exposure situation and sampling procedure to be applied**

Potential health effect	Desired information on exposure	Type of sampling	Condition of sampling	Examples
Irritation	average exposure	long-term	real-life conditions	passive sampling: formaldehyde nitrogen dioxide
	peak exposure	short-term	worst-case	active sampling (continuous monitoring): formaldehyde nitrogen dioxide
	exposure above fixed level	repeated short term	real-life conditions	continuous monitoring: nitrogen dioxide
Toxic effect	exposure above fixed level	repeated short term	real-life conditions	continuous (personal) monitoring: carbon monoxide
	average exposure	long-term	real-life conditions	active or passive sampling: pesticides
Carcinogenic effect	average exposure	long-term	real-life conditions	active or passive sampling: radon, benzene

2.3 Time of sampling

The variation with time of the concentration level of a pollutant in an indoor environment is a well-known phenomenon. Parameters like the age of the building, the season, the time of the day etc. (see Table 2) all influence the result of an indoor air measurement. Therefore, it has to be considered carefully when such measurements are carried out.

It is clear that different results will be obtained under otherwise identical conditions if one sample is taken in a room with the doors and windows closed and the other following an extensive ventilation of the room. Furthermore, the occupants may contribute to the level of pollutants in one way or the other, e.g. through their various activities (an example is the increase in suspended particulate matter concentrations in an occupied room). Over-night measurements in empty rooms may then be meaningless. Thus, the history of a room prior to and during sampling is of utmost importance and must be documented.

It is difficult to give a definite, but generally valid recommendation as to the time of sampling which could apply under all circumstances. However, the way of proceeding described in the following example is likely to be applicable also in a number of other cases.

It is assumed that the concentration of formaldehyde emitted into the air of a naturally ventilated room from continuous sources has to be determined in a quick way (e.g. by short-term sampling). From Figure 1 it can be seen how the concentration of formaldehyde is likely to build up in the air after a room has been ventilated thoroughly. According to this figure, a short-term sample taken three hours after closing the windows will give a reasonable estimate of the

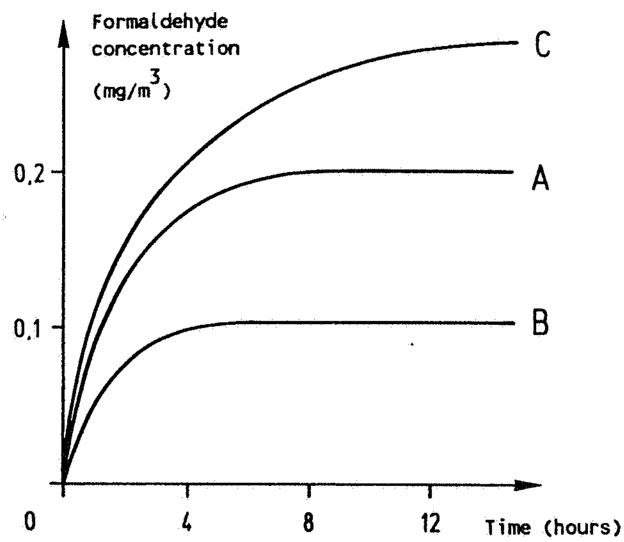

Figure 1: Formaldehyde concentration in a 23 m3 test chamber following the installation of particle board (1 m2/m3) at different air exchange rates A: 0.5 h^{-1}; B: >0.5 $^{-1}$; C: <0.5 h^{-1} (from Seifert, 1984a)

average level representative for the room. The figure also shows that this statement is only valid for an air exchange rate of 1 h^{-1}. At lower rates, more than three hours will be needed to get close enough to the equilibrium concentration.

It should be emphasized that indoor pollutant concentrations and their variation in time may also be influenced by the level of outdoor air pollution. Hence, it is necessary to have information about the quality of outdoor air if it is likely that it contains significant amounts of the pollutants studied (e.g. NO_2 or hydrocarbons emitted from vehicles under perhaps unfavourable meteorological conditions). The polluted outdoor air reaches the indoor air with a certain time lag depending on the air exchange rate. Thus, care has to be taken if short-term indoor measurements are carried out in the course of an episode of elevated pollution levels in outdoor air, not to assign elevated indoor concentrations erroneously to indoor sources when infiltration processes are the main cause.

2.4 Duration and frequency of sampling

The term "duration and frequency of sampling" addresses the questions of how long and how often samples are to be taken. Duration of sampling is the time period over which the sampler collects a sample. The sampling frequency is defined as the number of samples taken over a given time interval (e.g. one year).

Although it is beyond the scope of this text to go into details of sampling techniques, it should be mentioned that short-term measurements are mostly carried out through active sampling, e.g. by drawing air through a collecting medium, while long-term averages (one day or more) are generally obtained through passive sampling, which does not require a pump. It should be noted, however, that active sampling can also be used if long-term averages are required, as is the case for sampling suspended particulate matter.

As the analytical result gives the average concentration of the pollutant over the sampling period (time weighted average concentration), extending the duration of sampling will result in an increasing leveling out of peak concentration and lead to a loss of information on fluctuations of pollutant levels (see Figure 2).

The time which is required to take an air sample depends on:

- the lower detection limit of the analytical method,
- the potential health effect of the pollutant(s) in question (acute or chronic),
- the emission characteristics of the source(s) and other factors influencing the concentration levels,
- any specific objectives of the measurement.

In practice, the lower bound of the duration of sampling is solely determined by the minimum mass of pollutant in a sample required to exceed the detection limit of the analytical method. The analytical laboratory should be consulted about the sampling requirements given the available analytical method.

Since low volume sampling is preferred in view of minimizing any annoyance of the occupants, often long durations of sampling have to be admitted in order to collect a sufficiently large amount of air. Particularly for diffusive samplers, durations of sampling of up to several days may be required.

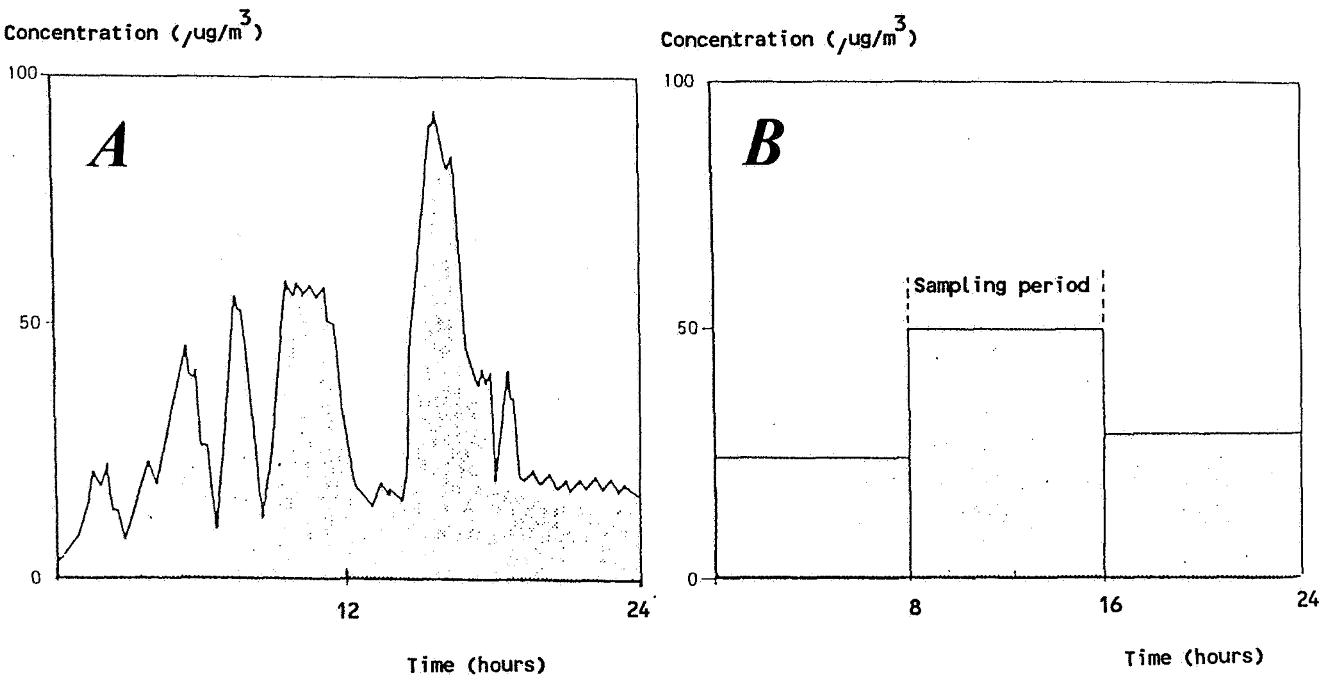

Figure 2: Loss of information on size and duration of peak concentrations with increasing duration of sampling for the same situation.
A: Sampling duration 1 min (continuous monitoring)
B: Sampling duration 8 h

The upper bound of the duration of sampling is highly dependent on the objective in question. If sampling objectives are aimed at the assessment of health risks the sampling duration should preferably not exceed the averaging time of guideline values (see WHO, 1987). In general, for pollutants with chronic effects the average exposure is of interest and relatively long sampling durations (> 24 h) are preferable. However, when acute effects (e.g. irritation) are concerned, peak exposures are important and sampling duration should be as short as feasible (< 1h); occasionally one would even prefer a direct-reading instrument, if available. For worst-case situations (maximum concentration likely to occur) the duration of sampling should be less or equal to the period during which a source is active and/or a factor influencing source emissions (e.g. temperature or humidity) or air concentration (e.g., reduced ventilation rate) is present. When compliance with a reference value or action level is to be checked, one should always sample over the full period for which the value is defined.

The frequency of sampling or the number of samples taken at different times necessary to characterize the air in a given space depends on the individual case.

As occupant activities and ventilation characteristics may vary from day to day or display a seasonal pattern, no single sample taken at one particular time can give a reliable indication of the overall distribution of exposures. Only detailed observation and knowledge of the factors influencing the concentration level can give a clue to whether a single sample represents the high, medium or low side of the exposure distribution. However, the benefits gained from taking a larger number of samples over a certain period of time has to be looked at in the light of the increasing costs of sampling and analysis involved.

A single sample or two consecutive samples on one day may suffice if the factors influencing concentration levels are controlled or simulated to suit the purpose of the measurement. For instance, information on the maximum concentration likely to occur can be obtained by simulating a worst-case situation.

However, there are other sampling objectives that require more samples to be taken. One of these is the assessment of average exposures or exposure distributions. Since generally seasonal patterns are likely to exist, at least two sampling periods should be selected, one in summer and one in winter. In each period several independent samples may be needed. The total number of samples required depends on the desired confidence limit of the results.

Another example relates to measurements carried out to demonstrate non-compliance with a reference value or action level in order to justify remedial actions. In view of the sometimes high costs of such actions, the result of a single measurement may easily be challenged of not being representative. In this case taking more samples covering different (simulated) conditions is recommended. In practice three independent measurements will suffice to prove the probability of non-compliance.

2.5 Sampling location

As in most instances the ultimate goal of indoor measurements is an exposure assessment, the best location of a sampler is the person whose exposure has to be determined. However, this strategy can only be applied in a very limited number of cases.

If measurements are carried out at fixed indoor locations, practical constraints generally limit the number of air analyses. Consequently, not every room in a flat or a building can be controlled. The decision which room(s) should be given priority is easy if the source, the emissions of which are to be measured, is present in only one room.

The situation is more difficult if more than one room is concerned. In such cases, the decision where to sample has to be taken in the light of the sampling objective. As an example, one could mention the determination of nitrogen dioxide emitted from a gas stove. If the maximum concentration is required, sampling should be carried out in the kitchen. If one has to assess the general exposure of a young child or a sick person, the bedroom will probably be more appropriate.

Besides varying from one room to the next, concentrations of indoor pollutants may also vary within one and the same room, e.g. due to a poor ventilation efficiency or the presence of a strong source, e.g., a gas appliance. This leads to the question as to where in a room the appropriate sampling location is. Again, the answer to this question depends on the objective of the measurement. If no special objective is foreseen, as a general rule, the sampler or the probe should be located in the centre of the room at breathing height (e.g., 1 - 1.5 m). However, especially in the case of long-term measurements, a somewhat higher location (1.5 to 2 m) may be appropriate to avoid interferences by or annoyance of the occupants. Only if one has to assume a pronounced concentration gradient due to a strong source would it be necessary to deviate from this rule. Again, emissions from gas stoves may serve to illustrate this situation: it has been shown that nitrogen dioxide concentrations resulting from gas stove emissions are significantly higher above than below the stove (Seifert, 1984b; Goldstein,1988).

If another location than the centre of the room is chosen for special reasons, possible differences in ventilation efficiencies should also be considered carefully. Furthermore, in the case of some passive samplers (those with large collection surfaces), accurate results can only be expected if the air surrounding the passive sampler exhibits a minimum of turbulence (see section 2.6). Hence, locating these passive samplers in a corner or close to pieces of furniture should be avoided unless there are special reasons to do so, as described in the next paragraph.

The higher pollutant concentrations which are likely to occur close to an emission source can also be used to localise such source. An appropriate procedure would be to divide the room into sub-spaces, each containing only one source. If measurements take place in steady-state conditions, there will be a concentration gradient between sub-spaces with and without the source. Using this procedure in connection with passive samplers, a shelf could be identified as the major source of toluene in a room (Abraham et al., 1981).

To be able to evaluate the measured concentration level of indoor pollutants, it may be useful to foresee an additional measurement in the outdoor air close to the building. The respective sampler should be located at a sheltered place at reasonable distance from the outer walls of the building or -in the case of an air-conditioned building - from the air intake (minimum: 2 m; maximum: 5 m).

2.6 Quality assurance

Due to financial and other constraints, there is a tendency to evaluate the quality of the air in a room based on a minimum of analytical results. This tendency can be understood if one considers that often parameters not linked to the sampling and analytical procedure, e.g. the ventilation rate, will have a greater impact on the result than analytical parameters. Therefore, analytical quality assurance often plays a minor role in practical indoor air analysis. However, depending on available funds, it is strongly recommended that full quality assurance be guaranteed.

The parameters which should be included in a quality assurance programme of indoor air sampling are summarized in Table 5. Since they are comparable to those used in the quality assurance programmes for outdoor and workplace air investigations, reference is made to the practice established in these fields

Table 5: **Parameters to be considered in the quality assurance of indoor air sampling using various sampling procedures**

Parameter	Sampling procedure applied		
	Grab sampling	Active sampling (pump)	Passive sampling (diffusion)
Blank value of sampling equipment	x	x	x
Break-through volume *)		x	
Uptake rate			x
Desorption efficiency	x	x	x
Storage stability	x	x	x
Sample flow/volume	x	x	
Air velocity near sampler			x

*) Of particular importance for highly volatile compounds

(IUPAC, 1982). However, one of the parameters mentioned in Table 5 deserves a special remark, since it is related exclusively to the indoor environment. The air velocity observed in some rooms may be so small that a depletion of monitored vapours may result in the close vicinity of a passive sampler. Such depletion will result in an (apparent) increase in the diffusion path length of the sampler, thus reducing the diffusion rate.

The required minimum air velocity depends to a large extent on the diameter of the sampler's opening. For a passive sampler with a small opening of only 7 mm^2 (diameter: 3 mm) and diffusion rates between 4 and 8 cm^3/h, quantitative sampling was achieved down to the lowest measurable air velocity of <0.1cm/sec (De Bortoli et al., 1987). With commercially available samplers minimum air velocities required for quantitative sampling vary between <0.7 and 7 cm/sec (Matthews et al.,1987).

3. SPECIAL CASES

In the past, a number of indoor pollutants such as formaldehyde, nitrogen dioxide, suspended particulate matter, asbestos, radon or volatile organic compounds (VOC) have attracted the special interest of scientists and of the general population. However, no attempt to harmonise the conditions of sampling has been made up to now. The following sections may serve as a basis of such harmonisation.

3.1 Formaldehyde

Formaldehyde is an indoor pollutant which - besides being discussed as a potential human carcinogen - may induce acute illnesses. It may be emitted into indoor air from discontinuous sources related to human activities, such as tobacco smoking, cleaning or disinfecting. However, in many cases continuous sources like particleboard or urea-formaldehyde foam insulation are by far the most important contributors to indoor formaldehyde levels. The following considerations apply to this type of source.

The characteristics of materials like particleboard imply that, unlike the concentrations of many other contaminants found in indoor air, the formaldehyde concentration varies widely with temperature and relative humidity under otherwise constant conditions. Other important parameters influencing the formaldehyde concentration have been discussed by Godish (1985). Table 6 (see Appendix, p. 22) gives recommendations for the conditions under which the sampling of formaldehyde vapours in indoor air should be carried out. It should be emphasized that these recommendations describe minimum requirements.

3.2 Nitrogen dioxide

Nitrogen dioxide (NO_2) is both an indoor and outdoor pollutant, and may cause both acute and chronic adverse health effects, primarily in the airways (WHO, 1987; Lindvall, 1985). The major sources of outdoor NO_2 are vehicles and industry, while indoor NO_2 is generated by combustion processes such as gas cooking, tobacco smoking, or heating with unvented appliances. A number of studies have been carried out to determine the impact of elevated indoor NO_2 concentrations on human beings, especially on children (e.g. Ogston et al., 1985; Englert et al., 1987; Marbury et al., 1988; and references quoted in these publications).

The emission characteristics of the above-mentioned combustion processes need to be taken into account if nitrogen dioxide is measured in indoor air. Generally, these sources are operated discontinuously. Thus, a real-time monitor would be the appropriate measuring device to record concentration changes. However, as such monitors are expensive and noisy, most indoor studies have been carried out using passive samplers. As a result of the relatively long sampling intervals involved with the use of passive samplers, a leveling out of peak concentrations must be accepted (cf. Fig. 2 in Section 2.4). Since the averageing procedure is likely to render more difficult the detection of acute effects caused by short-term exposure to peak concentrations, new instrumentation to monitor personal exposure is being developed.

Emissions from combustion processes generally cause marked concentration gradients in space of the various pollutants. Thus it is of primary importance to consider the location of the sampler in a room. Since nitrogen dioxide sources like gas stoves are generally present in only one room of a home and the distribution of the flue gases to the other rooms leads to a gradient in the nitrogen dioxide concentration, the type of room in which sampling takes place has also to be considered. It should be mentioned that to a certain extent modeling can be helpful in obtaining information on the probable concentration in rooms adjacent to the investigated room. Again, the aim of a study decides on the final strategy. Table 7 (see Appendix, p. 23) gives some general recommendations.

3.3 Suspended particulate matter

This section addresses the sampling procedures to be followed for the analysis of suspended particulate matter (SPM) excluding asbestos, which is dealt with in the following section. Among the inspirable particles, the smaller ones which penetrate into the lower respiratory tract (respirable suspended particles, RSP), are usually distinguished from the larger ones which are deposited preferentially in the upper respiratory tract (non respirable suspended particles, NRSP). Both RSP and NRSP may induce long-term effects, such as carcinogenesis (particularly RSP), and/or short-term effects, such as irritation and allergic effects. Therefore, it is useful to determine the total of the inspirable particles, and in addition, differentiate between RSP and NRSP, whenever this is feasable.

SPM is often emitted from discontinuous sources related to human activity, mainly tobacco smoking and dusting, the latter leading to resuspension. However, in many cases semi-continuous sources like woodburning in winter may be the main contributor to SPM levels. Furthermore, mechanical ventilation systems and a high air velocity as well as certain activities in a room may exert an influence on the indoor SPM concentration. Generally, the average indoor level of the larger particles is less important indoors than outdoors. In contrast to this, short-term activities in a room may lead to concentrations which exceed the background level considerably. As an example it can be mentioned that smoking may easily result in RSP levels of the order of > 1 mg/m^3.

Table 8 (see Appendix, p. 24) gives recommendations for the conditions under which sampling of total SPM should be carried out. For the determination of the average concentration it is possible to sample either all inspirable particles or, if the respective equipment is available, to collect the fractions separately. In the case of continuous monitoring, the commercially available instruments (light-scattering or piezobalance monitors) will only permit the determination of the RSP fraction. It should be emphasized that low-cost determinations by gravimetric analysis generally ask for sampling periods of at least 24 hours.

Long-term sampling will also be necessary to collect enough sample material if a chemical analysis of the dust is foreseen.

3.4 Asbestos

Respirable asbestos fibres are known to be a human carcinogen.These fibres occur in indoor air as well as in outdoor air (brake-lining emissions, weathering of asbestos cement roofing material, industrial emissions). Indoors the major sources are found in public buildings and offices where asbestos-containing materials have been used as fire protection of structural units, as thermal and acoustical insulation, and as a cost-efficient building material (asbestos cement).

Asbestos fibres may be released by air movement over the gradually deteriorating surface of the material (continuous emissions) or by mechanical action causing damage to the material (peak emission followed by continuous emission).

Secondary emissions will occur when settled dust is resuspended by human activities (walking, cleaning). The heating, ventilating and air-conditioning system will disperse airborne fibres throughout the building. The actual emission sources are often difficult to locate. In order to satisfy analytical requirements (e.g. fibre loading of filters), it is recommended for indoor sampling to take simultaneously a full period sample and two consecutive samples covering the full period. Sedimentation samples will give an indication of the risk of exposure to secondary emissions (resuspended particles).

Since outdoor sources may significantly contribute to the indoor concentration of asbestos fibres, it is recommended to take an outdoor sample as well (duration of sampling: 4-8 h).

The recommended conditions for sampling asbestos are given in Table 9 (see Appendix, p. 25)

3.5 Radon

Radon originates from the radioactive decay of uranium. Its decay products are associated with an increase in the risk of developing lung cancer. Radon can be found in high concentrations in soils and rocks containing uranium, granite, shale, phosphate and pitchblende. If a building is constructed on a ground of this type, gaseous radon can seep into it through cracks in the floors and walls, floor drains, joints, etc. It may also enter into indoor air from tap water if the water supply is from a private well drilled into radon-containing soil. The release of radon from building materials or from water, except in special cases, is generally not considered to be a major source of indoor radon.

The speed of movement of radon through the soil depends on the permeability of the soil and the difference of the pressures inside the building and in the surrounding soil. As radon emanates from the soil, it is clear that higher radon concentrations are found in the lower parts of a building, especially in basements and crawl spaces, than in its upper parts. Thus, lowering the pressure in one part of a house, e.g. by an exhaust fan in the kitchen, may result in an increase of the radon concentration in that part.

General information on radon and its decay products in indoor air as well as on occurring concentration levels has been published very recently (Commission of the EC, 1987; COST project 613, 1988; Nazaroff and Nero, 1988).

The half-life of radon, which is approximately 4 days, requires well-defined knowledge of ventilation conditions prior and during sampling if short sampling intervals are chosen to determine the radon concentration in indoor air.

Table 10 (see Appendix, p. 26) provides information on the conditions recommended for sampling radon in indoor air.

3.6 Volatile organic compounds

As shown in Table 11 (WHO, 1989; see Appendix, p. 27), volatile organic compounds (VOC) are one group of organics occurring in the air of enclosed spaces. To date several hundred VOC have been identified in indoor air (Berglund et al., 1986). Their concentrations are generally by a factor of up to 10^3 greater than those found in outdoor air.

Besides the potential of certain VOC to irritate mucous membranes and the respiratory tract, specific organics may give rise to the perception of (bad) odour. While some VOC may cause acute effects, such as mucous membrane irritation or reduced overall performance (Mølhave et al., 1986), others are more likely to induce chronic effects, e.g. carcinogens.

The major sources of VOC are either building- or product-related as shown in Table 1. Many other sources, including occupant activity, also contribute to the VOC level. The emission characteristics of these sources may be either continuous or discontinuous and will strongly depend on parameters like temperature, relative humidity, etc., as shown in Table 2.

The measured VOC concentration will not only vary with these parameters, but also change according to the sampling strategy applied. Short-term variations including factors of up to 500 relative to a background level have been reported. (McKone, 1987; Seifert et al., 1987c; Wallace et al., 1987; Wolkoff, 1987). Generally, long-term measurements, e.g. over one week, are suited for VOC which are likely to cause chronic or other long-term effects. In contrast, short-term (or continuous) measurements permit to follow more rapid changes in concentrations, which is important for VOC causing acute effects. Table 12 (see Appendix, p. 28) gives recommendations for carrying out measurements of VOC. It should be emphasized, however, that - depending on the objective of the respective measurement - different conditions might have to be chosen.

Concentration levels are generally reported as the individual concentration of each VOC or class of VOC. Sometimes, the VOC concentration is expressed as equivalents of toluene. Although this is not recommended, it may be the only way of giving a result if peaks in the chromatogramme could not be assigned to individual VOC.

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Table 6: Recommended conditions for sampling formaldehyde in the air of private homes and public buildings (n.v. = natural ventilation; a.c. = air conditioning)

Parameter	Objective of measurement	
	Average concentration	Maximum concentration
Ambient temperature	normal living/working conditions	25 °C 1)
Relative humidity	normal living/working conditions	60% 1)
Ventilation status		
before sampling	n.v.: normal for season 2)	n.v.: establish status as during sampling at least 5 h before sampling
	a.c.: normal for season 2)	a.c.: close HVAC system over week-end and turn on 2 h prior to sampling
during sampling	n.v.: normal for season 2)	n.v.: doors and windows closed 2)
	a.c.: normal for season 2)	a.c.: maximum likely recirculation rate/minimum likely ventilation rate
Occupancy		
test for stationary sources	normal, without formaldehyde-producing activities	no persons in room
test for all sources	normal, with formaldehyde-producing activities (smoking)	normal
Sampling location 3)	- centre of room at 1-2 m height - (outdoors)	- 1 m from source - (outdoors)
Time of sampling	summer and winter	any time
Duration of sampling	≥ 1 day	30 - 60 min
Minimum number of samples 4)		
for orientation	1 in summer and winter	1
for control of compliance	3	3

1) Or maximum room temperature and relative humidity possible in the room.
2) Avoid sampling at time of extreme meteorological conditions, e.g. during periods of stormy weather.
3) In the case of large (office) rooms, concentration gradients may develop; choose most polluted areas and/or install several samplers.
4) Duplicates are desiderable.

NOTE: If the objective of the measurement is to check the compliance with a guide value, the boundary conditions linked to this value have to be chosen even if they deviate from those given in this table.

Table 7: Recommended conditions for sampling nitrogen dioxide (indoor sources) in the air of private homes

Parameter	Objective of measurement: Average concentration	Objective of measurement: Maximum concentration
Ambient temperature	normal living/cooking conditions	normal conditions
Relative humidity	normal living/cooking conditions	normal conditions
Ventilation status		
before sampling	no requirement	establish status as during sampling at least 30 min before sampling
during sampling	normal for season 1)	as normally encountered; no mechanical ventilation: doors and windows closed 1)
Occupancy	normal	normal
Source status	normal use	heavy use 2)
Sampling location	- centre of room at 1-2 m height - outdoors, 2-5 m from building envelope/air intake	room with source, 1 m from most relevant source, at 1.5 to 2 m height (breathing zone)
Time of sampling	summer and winter	during activity of source
Duration of sampling	≥ 1 day	30 - 60 min 3)
Minimum number of samples 4)		
for orientation	1 in summer and winter	1
for control of compliance	3	3
for personal exposure	1/person	to be taken from continuous measurements

1) Avoid sampling at time of extreme meteorological conditions, e.g. during periods of stormy weather.
2) Temperature and relative humidity will rise in such experiments. Beware also of rising carbon monoxide concentrations.
3) Direct reading instruments allow further interferences to be made, e.g. exceedance of 1 h limit values, decay rates, etc.
4) Duplicates are desiderable.

NOTE: If the objective of the measurement is to check the compliance with a guide value, the boundary conditions linked to this value have to be chosen even if they deviate from those given in this table.

Table 8: **Recommended conditions for sampling suspended particulate matter in the air of private homes and public buildings (n.v. = natural ventilation; a.c. = air conditioning)**

Parameter	Objective of measurement	
	Average concentration	Maximum concentration
Ambient temperature	normal living/working conditions	normal living/working conditions
Relative humidity	normal living/working conditions	normal living/working conditions
Ventilation status [1]		
before sampling	n.v.: normal for season	n.v.: establish status as during sampling at least 3 h before sampling
	a.c.: normal for season	a.c.: close HVAC system over week-end and turn on just prior to sampling
during sampling	n.v.: normal for season	n.v.: doors and windows closed
	a.c.: normal for season	a.c.: minimum likely ventilation and different conditions of recirculation rate [2]
Occupancy	normal living conditions	normal living conditions to create resuspension
Source status	normal occupant activity	maximum likely occupant activity
Sampling location [3]	centre of room at 1-2 m height	centre of room closest to suspected source
Time of sampling	summer and winter	during maximum source activity
Duration of sampling	> 24 h [4]	n.v.: 30 min a.c.: [5]
Minimum number of samples [6]		
for orientation	1 in summer and winter	n.v.: 1 a.c.: 2
for control of compliance	3	n.v.: 2 a.c.: 4
for personal exposure	1 per person	to be taken from continuous measurements

1) Avoid sampling at time of extreme meteorological conditions, e.g. during periods of stormy weather.
2) Test 2 conditions: minimum and maximum likely recirculation rate.
3) Concentration gradients may develop; choose most polluted area and/or install several samplers.
4) If gravimetric is used.
5) Use direct-reading instruments (piezo balance or light scattering aerosol monitor) during at least 2 h after HVAC system is turned on.
6) Duplicates are desiderable.

Table 9: **Recommended conditions for sampling asbestos fibres in the air of public buildings and private homes**

Parameter	Objective of measurement	
	Average concentration	Maximum concentration 1)
Ambient temperature	normal	normal
Relative humidity	normal	40 ± 10 %
Ventilation status	normal	mechanical ventilation: max. recirculation, additional stirring with fan
Occupancy	normal occupant activities	maximum activity incl. dry dusting to create resuspension
Sampling location	- centre of room (2 rooms) - outdoors	- centre of room closest to suspected source (2 rooms) - outdoors
Time of sampling	during working hours	during period with low make-up air, maximum activities and mechanical stirring
Duration of sampling 2)	8 h or 2 consecutive 4-h samples	4 h or 2 consecutive 2-h samples
Minimum number of samples 2)	1 (2)	1 (2)
Additional samples	sedimentation samples (1-2 weeks)	sedimentation sample (overnight)

1) Hypothesis: Worst cases will occur during maximum resuspension of settled dust; any source manipulations should not be permitted.
2) Depends highly on the analytical method used and cost/effectiveness considerations.

NOTE: If the objective of the measurement is to check the compliance with a guide value, the boundary conditions linked to this value have to be chosen even if they deviate from those given in this table.

Table 10: Recommended conditions for sampling radon in the air of private homes and public buildings (n.v. = natural ventilation; a.c. = air conditioning)

Parameter	Objective of measurement	
	Average concentration	Maximum concentration
Ambient temperature	normal living/working conditions	normal living/working conditions
Relative humidity	normal living/working conditions	normal living/working conditions
Ventilation status		
before sampling	n.v.: normal for season 1) a.c.: normal for season 1)	n.v.: establish status as during sampling at least 1-2 days prior to sampling a.c.: close HVAC system over week-end and turn on 2 h prior to sampling
during sampling	n.v.: normal for season 1) a.c.: normal for season 1)	n.v.: doors and windows closed 1) a.c.: maximum likely recirculation rate / minimum likely ventilation rate
Occupancy	normal	normal
Sampling location 2)	room on ground floor; at 1-2 m height, distant from doors and windows	basement/room on lowest floor at 1-2 m height, distant from doors and windows
Time of sampling	any time	any time
Duration of sampling 3)	1-3 months (passive: alpha-track detection, electret charge dissipation) 1-7 days (passive: charcoal adsorption, alpha-track detection, electret charge dissipation) 24 h (quasi-continuous monitor)	≥ 1 (active sampling with charcoal adsorption, quasi-continuous monitor)
Minimum number of samples 4)		
for orientation	1	1
for control of compliance	1 in both summer and winter	2

1) Avoid sampling at extreme meteorological conditions, e.g. during periods of stormy weather.
2) The radon concentration exhibits a negative concentration gradient from the basement to the uppermost floor.
3) Depends on applied technique.
4) Duplicates are desiderable.

NOTE: If the objective of the measurement is to check the compliance with a guide value, the boundary conditions linked to this value have to be chosen even if they deviate from those given in this table.

Table 11: Classification of organic indoor pollutants (WHO, 1989)

Category	Description	Abbreviation	Boiling point range from °C	to °C*)	Sampling methods typically used in field studies
1	Very volatile (gaseous) organic compounds	VVOC	<0	50-100	batch sampling, adsorption on charcoal
2	Volatile organic compounds	VOC	50-100	240-260	adsoprtion on tenax, carbon molecular black or charcoal
3	Semi-volatile organic compounds	SVOC	240-260	380-400	adsorption on PUF**) or XAD-2
4	Organic compounds associated with particulate matter or particulate organic matter	POM	>380		collection on filters

*) Polar compounds are at the higher side of the range
**) Polyurethane foam

Table 12: Recommended conditions for sampling volatile organic compounds in the air of public buildings and private homes

Parameter	Objective of measurement	
	Average concentration	Maximum concentration
Ambient temperature	normal conditions	normal conditions
Relative humidity	normal conditions	normal conditions
Ventilation status		
before sampling	normal	no ventilation; doors and windows closed
during sampling	normal	no ventilation; doors and windows closed
Occupancy	normal activity	maximum occupancy
Source status	normal use	heavy use [1]
Sampling location	centre of room at 1-2 m height	close to activity
Time of sampling	anytime	during activity
Duration of sampling	5-14 days	30-60 min
Minimum number of samples [2]		
for orientation	1	1
for control of compliance	2	3

1) However, attention has to be payed to **instructions and warnings** for the use of products to avoid potential health damage. In case of combustion sources, temperature and humidity will rise in such experiments. Beware also of rising carbon monoxide concentrations.
2) Duplicates are desiderable

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EN

The document addresses the questions when, for what period of time, how often and where samples should be taken for the in-fiel analysis of chemical compounds in indoor air. It is divided into two parts. In the first part, a more detailed discussion of the dynamics of the indoor environment and of the objectives of indoor pollution measurements is given. In addition, general rules are derived for an optimal strategy to answer the above mentioned questions.

In the second part the general rules are applied to those pollutants or pollutant classes which for the time being are considered of major importance, and specific recomendations are given.