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Health Aspects related to Indoor Air Quality

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This publication is dedicated to the memory of Dr Feliks Sawicki, Chairman of the Working Group, who unfortunately was killed in a car accident on 12 April 1979, after returning to his home country.

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WORKING GROUP ON HEALTH ASPECTS RELATED TO INDOOR AIR QUALITY

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1. SUMMARY

The health aspects of indoor air quality were reviewed by a Working Group (project ICP/RCE 304(1)), convened by WHO in collaboration with the Government of the Netherlands. It was recognized that indoor air quality depended on a number of factors operating simultaneously; these were examined separately and in relation to each other. The discussions took place in plenary sessions and meetings of 15 subgroups formed to consider different aspects of the problem.

Pollutants generated outdoors, such as sulfur oxides, nitrogen oxides and carbon monoxide particulates, photochemical oxidants and biologically active particulates, and their relationship to the indoor environment, were discussed as well as pollutants from both indoor and outdoor sources. Consideration was given to other factors affecting the indoor concentration of ambient pollutants, such as the intake of air from locations near outdoor sources which, during certain periods, could cause higher average concentrations indoors than outdoors.

A number of pollutants released from indoor sources were identified, such as formaldehyde from particle board and foamed insulation, radon from the soil or building materials, and fibres of asbestos. Indoor generation of nitrogen oxides, CO, CO_2, water vapour and particulates, through human physiological processes or use of unvented gas burning appliances, was considered.

The effects of tobacco smoke and its constituents on nonsmokers and of odours from the body and other sources, such as cooking materials, were discussed in relation to health.

Concern was expressed at the variety and speed of release of indoor contaminants in consumer products, particularly chemicals in personal hygiene articles, solvents and cleaners, biocides, air sprays, and hobby and homecraft materials.

It was felt that the adoption of current energy-saving proposals in many countries, whereby the present *minimum* ventilation rates in building codes would be lowered and in future be regarded as *maximum* rates, would aggravate existing problems of indoor air quality, create new problems and generally be detrimental to health, unless appropriate pollution control measures were taken simultaneously.

Noting that research on air contaminants had been concerned mainly with outdoor or occupational exposures, concern was expressed about the lack of data on the health effects of air quality in the nonoccupational indoor environment. Since man spends up to 70% of his time in that environment and air quality indoors was usually somewhere between that outdoors and in the occupational environment, it was felt that further studies should be made on indoor air quality, the factors governing it, and its role in the total adverse health effects of contamination of the atmosphere.

A number of recommendations were made for the development of research, for further evaluation of the existing data, for the formulation of guidelines on maximum concentrations of contaminants in indoor air, and for the limitation of emissions in the indoor environment.

2. INTRODUCTION

Usually air quality within buildings is closely connected with that outdoors in the community. Although it is possible to clean outdoor air before admitting it into a building, it is unusual to do so. It is also unusual to filter air which is exhausted from a building, and generally the outdoor atmosphere is relied on to dilute air contamination generated. Occupants and their activities tend to introduce contaminants into the air of a building. Other contaminants often emanate from the building materials and contents. In practice all these contaminants are usually eliminated from a building by natural or forced ventilation of the structure, whereby outside air displaces some of the contaminated air.

Clearly a high ventilation rate is advantageous in reducing indoor air pollution to a low level. There are, however, a number of factors which can interfere with this simple solution, and make it necessary to consider compromises, alternative solutions, and permissible levels or recommended maximum concentrations of air contaminants. The most important of these factors are the energy cost of ventilation in terms of heating, cooling or dehumidification, and intentional limitation of ventilation in some locations under certain conditions when the air outdoors may be more polluted than that indoors. Recently, many countries have taken measures to reduce ventilation rates in order to conserve energy.

Over the last two decades our knowledge of the sources of outdoor air pollution, its adverse effects and the methods required to improve ambient air quality has greatly advanced. Many countries now have standards or guidelines on ambient air quality and it has been improving.

It is important to recognize that in most societies people spend much of their time indoors. Von Rosenbladt (*1*) reported that in the town of Osnabrück on average only 29% of activities take place outside the residence, e.g., during work, vehicular transit and periods spent in public buildings. It is clear that people are exposed to the ambient outdoor air during only a minor portion of their total lifetime, and the quality of air within the built environment is thus more important for human health and welfare than the quality outdoors.

The concentration of an air pollutant indoors depends on a number of factors. With some simplification the following equation describes the relationship between these factors and indoor concentration:

$$V \frac{dC_i}{dt} = P - E - Q(C_i - C_o) \qquad (1)$$

in which

V = volume of air contained in the indoor space, in m^3

C_i = concentration of the pollutant indoors, in $\mu g/m^3$

P = rate of production, or release of the pollutant in the indoor space, in $\mu g/h$

E = rate of elimination of the pollutant in the indoor space through reaction, filtration or settling, in $\mu g/h$

Q = rate of air exchanged with the outside atmosphere, through infiltration, natural or forced ventilation, in m^3/h

C_o = concentration of the pollutant outdoors.

In the steady state the above expression reduces to:

$$C_i = C_o + \frac{P - E}{Q} \qquad (2)$$

indicating the important relationships between the indoor and outdoor concentration of a pollutant, and between the rate of production or release, the rate of absorption or inactivation and the rate of ventilation.

The relationships in (1) and (2) bear some resemblance to expressions governing pollutant concentration in outdoor air, the main difference being one of scale. Because of the much larger mixing volume in the outdoor atmosphere, the pollutants of primary concern there, such as particulates, sulfur oxides, nitrogen oxides, carbon monoxide and photochemical oxidants, are those released or created in large quantities through man's activities. Pollutants released to the atmosphere in small quantities do not usually reach concentrations of health concern, except immediately adjacent to the source.

In the indoor environment, because of the small mixing volume, even the release of small amounts of a pollutant can produce a high concentration which may affect health and wellbeing. In the control of air quality in the indoor environment all the factors in the term (P – E)/Q can be employed: elimination or reduction of emissions P, increased elimination by absorption or inactivation E, and an increased rate of ventilation or air change Q.

3. SOURCES OF POLLUTANTS IN INDOOR AIR

Although indoor air has not been analysed with sufficient thoroughness to allow a complete listing of the types and sources of all pollutants in indoor air, it is useful to discuss the pollutant categories which have been reported.

3.1 Pollutants primarily generated outdoors

Since in almost all inhabited spaces there is continuous air exchange with the exterior, all pollutants present in the outdoor air are also found indoors. Important pollutants in this category are:

Suspended particulates

Sulfur oxides

Nitrogen oxides

Hydrocarbons

Carbon monoxide

Photochemical oxidants

Lead.

Measurements of these pollutants have been made simultaneously indoors and outdoors by a number of investigators. Yocom et al. (*2*) measured suspended particulate, soiling particulate, CO and SO_2 in residences, office buildings and public buildings. They found that in most cases concentrations indoors were similar to those outdoors with the ratio of indoor/outdoor concentration falling within the range of 0.76 and 1.32. In a later study the same group of investigators (*3*) measured NO_2, NO and CO in four residences and compared indoor concentrations with simultaneous outdoor levels. They found that concentrations of CO, NO and NO_2 indoors could rise substantially above those outdoors, excesses of 10 000 $\mu g/m^3$ (9 ppm) for CO, 400 $\mu g/m^3$ for NO and 500 $\mu g/m^3$ for NO_2 being recorded when there was heavy use of a gas stove.

Biersteker et al. (*4*) came to similar conclusions on indoor/outdoor ratios of SO_2: usually they were below 1, except if indoor sources were active. Yocom et al. (*2*) noted that use of coal for space heating can lead to high SO_2 concentrations indoors, especially when there are leaks in the furnace flues.

Benarie et al. (*5, 6, 7*) measured indoor/outdoor concentrations of smoke and SO_2 (*5*), NO_2 (*6*) and particulates (*7*). They found that SO_2 concentration is consistently lower indoors, while the level of fine particulates tends to be the same inside and out. They reported that NO_2 concentration is lower indoors except in rooms where gas appliances are in use. The concentration of indoor particulates is low indoors in unoccupied spaces, but can reach high levels when the space is occupied by people. Indoor particulates may be quite different in composition from those found outdoors. Derouane et al. (*8, 9, 10*) made similar measurements and came to similar conclusions. Melia et al. (*11*) and Ferris et al. (*12*) found high concentrations of NO_2 in spaces with unvented gas appliances. Ferris et al. (*12*) found the level of respirable particulates higher indoors, dependent on the number of smokers in the space. Swanton (*13*) showed that the concentration of photochemical oxidants is generally lower indoors.

An elaborate series of indoor/outdoor monitoring observations in 16 buildings with measurements of CO, NO, NO_2, CO_2, SO_2, O_3, SO_4, NO_3, Pb, hydrocarbons, NH_3, total suspended particulates (TSP), and respirable suspended particulates (RSP), was reported by Moschandreas et al. (*14*). Indoor concentrations were often higher for CO, NO, CO_2, hydrocarbons and aldehydes, and either higher or lower for NO_2, TSP and RSP. Indoor concentrations of SO_2, O_3, SO_4, NO_3 and Pb were usually lower.

3.2 Pollutants generated or released indoors

Ultimately all internally generated air pollutants are the result of human action or choice. It is useful to divide such pollutants into two categories. In the first, the pollutants are released only in connexion with human activity or even presence, while in the second, they are released from building materials, land or contents, generally over long periods. Concentration tends to vary over time for pollutants of the first category and to be constant for those of the second, assuming constant air exchange rates. Thus control strategies for the two categories are likely to be different.

3.2.1 *Pollutants related to human activity or presence*

The number of compounds in this category is limited only by the inclination of human occupants to bring them indoors. Many compounds which occur in the industrial workplace can be introduced into the nonworking environment. Lippmann (*17*) points out that many such products enter the residential environment in connexion with hobby or craft activities. In many cases these are carried out without the protective measures required by regulations governing the industrial workplace. Randolph (*15*) listed cases associated with hypersensitivity to a variety of sources: gas appliances, hair spray, plastic furniture and curtains, chlordane, other pesticides, insecticides, petroleum distillate for house dust control, foam rubber and its adhesives, refrigerants, aerosol propellants, creosote, ammonia, bleaches, mothballs, etc. The concentration of such compounds varies in time and accumulated exposures depend on the level and duration of the activity with which the release is associated.

In areas where water is rich in radon, the release of this substance through piped supplies should be considered as a serious potential hazard.

Indoor air pollutants associated with propellants and active ingredients were identified and measured by Cote et al. (*16*) and Moschandreas et al. (*14*). A large number of chemicals can be associated with such household products.

Smoking is a major cause of indoor air pollution. Although the smokers themselves are exposed to mainstream smoke, nonsmokers in a space are also exposed to considerable increases in respirable particulates and carbon monoxide. Lippmann (*17*) provided a table of the compounds found in mainstream and sidestream smoke of cigarettes and their concentrations. Binder et al. (*18*) measured the exposure of 20 children equipped with personal air samplers, and found that suspended particulate exposure in homes with smokers was substantially higher than in those with nonsmokers (132 and 93 $\mu g/m^3$ respectively). As mentioned, gas heating and cooking appliances are sources of internally generated NO_2, NO and CO, and produce high indoor concentrations of these gases (*6, 10, 11, 12, 14*).

Human presence and activity bring further changes in the indoor atmosphere: metabolic activity reduces the concentration of oxygen and increases that of CO_2. Respiration, sweating and evaporation during food preparation all add water vapour to the indoor atmosphere. Cooking, like smoking, produces odours. Human bodies also produce a variety of odours as well as CO and other gases which are of particular concern in hermetically sealed indoor environments, as in submarines or space capsules.

The following table shows major contaminants found in space capsule simulators, equipped with absorption filters to eliminate contaminants generated by human occupants and various materials (*19*).

Indoor use of unvented space heaters, water heaters or cooking ranges fueled by gas not only produces nitrogen oxides and CO, but also reduces the concentration of oxygen and increases that of CO_2 and water vapour in the atmosphere. If the ventilation rate is low, concentrations of CO_2 and water vapour may rise above the recommended levels.

3.2.2 *Pollutants from buildings*

The pollutants in this category are released from building materials, and/or contents, regardless of human presence or activity. An important example

Contaminant	Concentrations encountered (ppm)
CO	12
CO_2	5000
Hydrocarbon	4
NH_3	4
Aldehydes	1
SO_2	0.5
H_2S	1.0
NO_2	0.5
O_3	0.03
Cl	0.1
Cyanides	1.0
Phosgene	0.07
Ethanol	2.5
Toluene	0.5
1 Ethyl butanol	1.0
Chloroform	0.5
Dichloromethane	2.5
Dioxane	1.0
Ethyl acetate	4
Trichloroethylene	1
Formaldehyde	0.05

is the emission of radioactive contaminants from products such as stone and granite aggregates, and from the ground beneath buildings. Roessler et al. (*20*) found that land reclaimed after mining for phosphate contained ten times as much ^{226}Ra as the original surface. Houses built on such land have high levels of the ^{222}Rn daughter. Similar observations have been reported in many countries and regions (*21,22*). Effective radon concentrations and human dosages will, of course, depend on release and ventilation rates but non-negligible radiation exposure, mostly to the lungs, can easily occur.

Formaldehyde is released from a number of building materials such as glued wooden beams and draperies (*54*). Andersen et al. (*23*) measured formaldehyde concentrations associated with particle board in Danish residences and found values as high as $2240 \mu g/m^3$. A common method for increasing thermal insulation in existing structures is to inject foamed plastic into wall voids. Excesses of the formaldehyde incorporated in many of these formulations can be released over long periods, depending on the temperature and moisture regimes.

Another example of a hazardous material which can be released is asbestos, used in a variety of building products for its special properties. Spray materials containing 10–30% asbestos have been used for fireproofing, and for decorative and acoustic purposes. Airborne asbestos fibre concentrations above the occupational exposure limit have been found indoors. Sawyer (*24*) found concentrations as high as 4 optical-microscope-visible fibres per millilitre in a school environment. Nicholson et al. (*25*) made similar observations.

3.3 Fate of pollutants in indoor air

Indoor air pollutants are eliminated mainly by exhaust to the outdoor atmosphere, followed by major dilution. This is true especially of pollutants released indoors. There are, however, other avenues of elimination which may be passive, by absorption and inactivation of the pollutants on materials and surfaces in the space, or active, by passage of the air through filter assemblies.

Walsh et al. (*26*) demonstrated the high capacity of surfaces of inhabited spaces to absorb SO_2 for long periods. Cox and Penkett (*27*) found that the relative humidity in a space had an appreciable effect on the rate of disappearance of ozone and sulfur dioxide. At greater humidity the absorption rates increased substantially. Derouane and Verduyn (*10*) studied the disappearance of tobacco smoke components and found widely differing rates, from slow for CO to rapid for smoke particles. Cote et al. (*16*) found a half-life of only half an hour for NO_2, compared with more than two hours for CO in a private home.

It is difficult to remove airborne pollutants from the indoor atmosphere economically. Methods were discussed by Richardson and Middleton (*28*) and more recently by McNall (*29*). Contaminants in gaseous form can be removed through active filters, and particulates through electrostatic precipitators as well as normal filters.

4. ADVERSE HEALTH EFFECTS OF INDOOR POLLUTANTS

Compared with the large number of studies on the adverse health effects of pollutants outdoors and in the workplace, only a few have been directly concerned with the health effects of indoor contamination. Examples of such studies are those of Melia et al. (*11,30*), who found excess disease of the lower respiratory tract in children living in homes with gas stoves. Bouhuys et al. (*31*) and Ferris et al. (*12*) described studies in which both indoor and outdoor air quality was measured in relation to lung function, so that any indoor effect could be accounted for.

In the total exposure to air pollutants, the indoor effect weighs heavily. Fugaš (*32*) estimated total exposure on the basis of the time spent and the concentrations experienced in the home, at work, in transit and outdoors. In most cases the average exposure was closer to levels in the home than those in other sites.

As shown in section 3, some pollutants such as SO_2 and O_3 are usually found indoors at concentrations substantially below those outdoors. It is therefore likely that most studies on the health effects of air pollution on the basis of outdoor concentrations of SO_2 and O_3 overestimated the population exposure by ignoring the high proportion of time spent indoors at lower concentrations.

With this reservation in mind, the data on the health effects of pollutants generated outdoors were reviewed extensively in air quality criteria documents of WHO and national health authorities, including those on sulfur oxides (*33*), particulate matter (*34*), sulfur oxides and suspended particulate matter (*35*), carbon monoxide (*36*), photochemical oxidants (*37,38*), hydrocarbons (*39*) and nitrogen oxides (*40,41*). Recommendations of the International Commission on Radiological Protection (ICRP) are the basis of most national laws on protection against radiation, including that from natural sources (*46*).

Although threshold limit values established for the occupational environment are of only limited application to the general indoor environment, the documentation is a rich source of observations on the adverse health effects of many chemical species (*42,51,52*).

Sterling and Kobayashi (*43*) made a comprehensive review of reports on indoor exposure to pollutants from outdoor and indoor sources.

4.1 Pollutants emitted by building materials

4.1.1 *Formaldehyde and organics*

Materials which release formaldehyde have been identified as:

- particle boards, especially boards prepared with urea/formaldehyde (phenol/formaldehyde formulations appear to be of lesser importance)
- other glued wooden products such as glued wooden beams
- surface coating materials such as paints and carpets
- textiles
- foamed insulation.

The main acute adverse health effects of formaldehyde are irritation of the eyes and the respiratory tract (*23*) although, in about the same concentration, odour annoyance has also been reported. Measurements of indoor concentrations were reported from Denmark, the Federal Republic of Germany and the Netherlands, with peak values of up to 2.8 mg/m^3 and average values below 0.5 mg/m^3. Residential environments in the Netherlands built without material which can release formaldehyde showed average concentrations of 0.04 mg/m^3 with peak values up to 0.1 mg/m^3. Even these values are well above outdoor values, indicating the presence of additional indoor sources.

In the Federal Republic of Germany measurements were made of pentachlorophenol levels in more than 100 homes containing some lumber treated with wood preservatives. The mean concentration was 6 $\mu g/m^3$ in a range of 1–50 $\mu g/m^3$. There is little information on the concentration of other organics released from building materials. The methodology described by Moschandreas et al. (*14*) could be used for such determinations.

A number of countries have adopted or recommended maximum values for indoor formaldehyde concentrations:

Czechoslovakia	0.10 mg/m^3
Federal Republic of Germany	0.12 mg/m^3
Netherlands	0.12 mg/m^3
Sweden	0.10 mg/m^3.

In Sweden the concentration must not exceed 0.7 mg/m^3 in older buildings. In most cases emission standards or guidelines are also being considered.

The Group found a lack of knowledge about the effects of low level exposure in the long term. It was considered desirable to develop models for relating material quantities and characteristics to indoor air quality, such as those described by Moschandreas et al. (*14*) and Shair and Heitner (*44*). A lack of knowledge was also noted concerning the effect of temperature and humidity on formaldehyde release and the nature of other organic pollutants released by building materials.

4.1.2 *Radon*

The Group assessed potential exposures to radon from a number of building materials, assuming in all cases that the house had 0.5 air changes per hour and that it was built mainly with the materials listed below.

Building material	Potential exposure to radon		
	High	Medium	Low
Stone — alum shale	x		
sandstone			x
granite	x	x	x
Brick — clay		x	x
other slag	x	x	x
Concrete — normal density, normal ballast		x	x
uranium mine tailings	x		
phosphate slag	x	x	x
Concrete — aerated alum shale	x		
iron slag		x	
sand based			x
Gypsum board	x	x	x

Domestic water, natural gas, underlying soil and groundwater can release substantial amounts of radon to the indoor atmosphere in certain regions. The most serious and likely adverse health effect is increased incidence of bronchogenic carcinoma from deposition of radon daughters, although radon gas might also be delivered to the bone marrow. Increased occurrence of bronchogenic carcinoma was found in several epidemiological studies of workers in atmospheres containing radon daughters in uranium or non-uranium mines, as shown in the 1977 report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (*47*). The following countries have reported sources of exposure, health studies and control measures.

The Group urged that suitable instruments, which have already been developed, be made available for measurement of radon inside buildings. A quantitative inventory of radon-releasing materials and soils should be made as well as a population risk assessment.

4.1.3 *Asbestos*

Asbestos, because of its desirable insulating and fire resistant properties, has been used in a variety of products such as electrical or thermal insulation, wall board, sprayed-on acoustic material, sprayed-on fire retardant for steel frame members, asbestos cement, vinyl-asbestos floor tiles. In some of these applications there may be continuing release of asbestos fibres to the indoor air (*24, 25*), and concentrations above those permitted in the workplace have been observed in indoor air.

Use of asbestos, especially in the form of fibres of >5 μm, has been shown to have adverse health effects ranging from asbestosis to bronchogenic carcinoma, especially in cigarette smokers. Even relatively short-term exposures can produce pleural or peritoneal mesothelioma after a delay of 15 years or more. The adverse health effects are so serious that strenuous efforts are justified to avoid the use of asbestos-fibre-releasing materials, and to eliminate or reduce releases to the indoor atmosphere of existing buildings. Even in the removal of asbestos from buildings, or in the demolition of buildings, releases to the workers or to the outside environment should be controlled. To protect the public, there is an urgent need for an assessment of the effects of small asbestos particles (<5 μm) combined with studies on the effects of degradation products of brake linings and other friction materials. Faster, cheaper and more specific methods to identify and measure the concentration of asbestos fibres are urgently needed. The formation of national tumour registries, giving emphasis to mesothelioma and bronchogenic carcinoma and containing detailed occupational, residential and smoking histories would be an important step. There is also a need to determine any adverse health effects of other inorganic fibrous materials such as glass fibres or rockwool.

Countries	Sources of radon			Studies		Control measures	
	Building material	Groundwater	Soil	Epidemiological (envisaged)	Clinical	Material selection	Ventilation of crawl space
Austria	x	x		x	x		
Canada	x	x	x	x			x
Denmark	x						
Finland	x	x		x	x	x	
Germany, Fed. Rep.	x					x	
Hungary	x		x				
Norway	x		x				
Poland	x						
Sweden	x	x	x	x		x	
USSR	x					x	
United Kingdom	x		x			x	
USA	x	x	x	x			

4.2 Pollutants generated by man and his activities in the indoor environment

4.2.1 *Carbon dioxide and water vapour*

CO_2 and water vapour are produced by metabolic, respiratory and thermoregulatory responses in man and animals, and by indoor combustion. Water for cleaning, washing and laundry can introduce substantial amounts of vapour into the indoor atmosphere (*45*). Air temperatures between 18° and 24°C are not thought to constitute risks to health at normal clothing insulation values and low levels of activity. Similarly, within this temperature range, water vapour pressures producing relative humidities between 20% and 70% are compatible with health. Preferred relative humidities are between 40% and 50%, and not below 30%.

A lowering of the water vapour content of air ($<$30% relative humidity at room temperature) will probably cause dryness of the mucous membranes, the eyes and the skin in general. Bacteria and moulds suspended in dry air may be less viable. There will be an increase in airborne hygroscopic dust and in static electricity giving rise to annoying shocks; tobacco smoke will cause greater annoyance and irritation than at intermediate or high relative humidity.

If the relative humidity rises above 70%, growth of moulds and bacteria, incidence of house dust mites and survival of airborne pathogens will increase. At temperatures above 24°C high humidity interferes with the evaporation of sweat, causing increasing thermal discomfort and strain which are health risks in vulnerable individuals.

Concentration of CO_2 is almost always high in occupied indoor spaces. If it exceeds 0.5%, compared with an outdoor level of 0.03%, there is reason to be concerned about long-term consequences of changes in the acid-base balance. Concentrations of more than 0.1–0.15% may cause headache and giddiness.

Decreasing ventilation rates produce higher water vapour concentrations indoors, with greater mould growth, especially in maritime climates (*45*). As CO_2 concentrations also tend to be higher under these conditions, the findings concerning the effects of moderate concentrations (0.1%–0.5%) should be re-examined.

4.2.2 *Odours and viable particles*

In any indoor environment odourants can easily reach perceptible concentrations. In itself, the perception of an odour is not to be considered a health effect, but annoyance caused by inappropriate odours, high concentrations of odourants or disagreeable odours can lead to stress and behavioural change. Under the WHO definition of health which includes wellbeing, odours under such circumstances should be classed as having an adverse health effect. In many countries odours or their reduction to acceptable levels are a basic factor in determining ventilation requirements. There is a need for development of more objective methods for odour assessments, as well as better studies of minimum ventilation requirements based on odour. It should also be noted that in many cases, odours are good warning signals of a malfunction in the ventilation system of a building.

Viable particles are introduced into the indoor air by man in the form of bacteria, viruses, fungi and parasites. Ventilation systems, humidifiers, aerosols and sprays can be sources of viable particles, as can carpets and draperies (*48*). Pets, rodents, insects and plants can also be sources of viable particles in the indoor environment. Such particles can produce infectious diseases, parasitic diseases and allergic ailments. Sometimes the source of the particles also produces a noticeable odour. In Denmark and the Netherlands the dust mite has been studied as an allergen. In the USA "legionnaires disease" appears to be associated with ventilation systems. Allergic reactions have been associated with humidifiers.

Common measures to control viable particles include elimination of the source, dilution of indoor air by fresh air to reduce the concentration and filtration. New buildings can be planned to reduce the spread of viable particles from one area to another. The Group was concerned about the possible effects of systematic changes in ventilation rates on transmission of infectious diseases, especially in hospitals. There have been few investigations on which to base an estimate of the effects, but it should be remembered that the incidence of many infectious diseases decreased with the introduction of better ventilation some years ago. It is important that changes in ventilation practices be studied in suitable populations such as families living in new buildings with low ventilation rates.

4.2.3 *Tobacco smoke*

The smoking of cigarettes, pipes and cigars is a major and widespread source of contaminants in indoor air. The discussion here is limited to effects on indoor air quality and the nonsmoking occupant. The adverse health effects on the smoker are obviously more serious. The passive smoker (nonsmoker exposed to the emanations of smokers) is subject to the effects of high CO levels, which are of particular consequence for cardiorespiratory invalids, and of possibly carcinogenic substances released to the atmosphere with tobacco smoke. Respiratory invalids in particular, but also normal populations, suffer eye irritation, coughing and possible nausea from aldehydes, NO_2 and small particulates (*49,50,53*). The odour of the smoke also produces complaints which reduce the wellbeing of the nonsmoker.

The Group felt that, as it is planned to reduce ventilation rates, more vigorous efforts than ever are required to curtail smoking, especially in public places. If smoking is to be allowed in certain spaces, they should be provided with exhaust ventilation or air cleaning systems. It was felt that investigation of the long-term health effects of passive smoking, by inclusion of this aspect in epidemiological studies, should be encouraged.

4.2.4 *Oxides of nitrogen and carbon monoxide*

Both of these gases are also produced outdoors, forming a background concentration which is increased by indoor releases. Indoor sources of NO and NO_2 considered were gas appliances such as cooking stoves, water heaters, lamps, fires and refrigerators. Heating appliances with faulty flues or vents that burn oil or coal, can release NO or NO_2 indoors. Electric arc welding can produce nitrogen oxides as well as ozone. Open coal, wood, coke or gas fires routinely release CO indoors, as do unvented gas appliances, especially when the flame strikes metallic surfaces. Automobiles in attached garages can produce substantial quantities of CO, some of which may enter the living space.

NO_2 is the only oxide of nitrogen found to have adverse health effects indoors, such as increase in respiratory illness and changes in pulmonary function, although these are likely to be related to peak values rather than long-term averages. As ventilation rates fall, indoor concentrations of NO_2 are likely to rise in a large number of households, and it is therefore important to undertake further epidemiological studies to supplement the few which have been reported.

The major effect of exposure to CO is the formation of carboxyhaemoglobin complexes which interfere with the oxygen transport function of the blood. Occupants of a space with cardiorespiratory disability are at the highest risk, and as little as a tripling of the minimum 0.8% level of physiologically produced carboxyhaemoglobin will accelerate exercise-induced angina. The effects of CO exposure combined with altitude or with low functional haemoglobin levels are synergistic.

The most common method of reducing exposure to internally generated NO_2 and CO is to increase ventilation. New ventilation guidelines aimed at energy conservation will have the opposite effect, and it will therefore be more important than ever to understand the health consequences of the exposure and to try to limit the internal release of these contaminants.

4.2.5 *Consumer products*

Only products consumed in the home, excluding food, clothing and furnishings, were considered. However, even with these exclusions, a large number of products contributing contaminants to the indoor air may be identified. Most emit more than one contaminant, and few have been adequately evaluated as to health hazards, especially in confined spaces or where usage is incorrect.

Personal hygiene or grooming products such as cosmetics, hair sprays, deodorants, cleaning agents, and nail polish and remover, contain a variety of volatiles and particulates, and many also use an aerosol propellant. Cote et al. (*16*) listed a number of propellants and active ingredients in this category as follows:

Product	Active ingredients
Furniture polish	Silicone, wax, morpholine
Deodorant spray	Hydrated aluminium chloride, talc, isopropyl myristate triglycerides
Hair spray	Vinyl acetate copolymer resins, polyvinylpyrrolide resins, ethanol, lanolin
Disinfectant spray	Triisopropanolamine, morpholine
Window cleaner	Sodium nitrite, isoprophyl alcohol, ethylene glycol, ammonium hydroxide
Shaving foam	Stearic acid, triethanolamine, menthol, glycerine
Oven cleaner	Potassium hydroxide, hydroxyethyl cellulose, polyoxyethylene fatty ethers
Air freshener	Propylene glycol, morpholine, ethanol

Propellants for these products include chlorinated fluorocarbons now banned in several countries, nitrous oxide, methylene chloride, vinyl chloride, butane and propane. Moschandreas et al. (*14*) reported measurements made by Dravnieks in a room after a scented oven cleaner had been used; he found a large number of organic chemicals, at least 13 of which could be traced directly to the cleaner.

Cleaning agents and surface maintenance agents such as waxes, polishes, bleaching agents and detergents usually have organic constituents which evaporate into the indoor air. In addition, these products are often scented to hide other odours or to add market appeal. Biocides and air fresheners are often combined since freshness and absence of odour are often associated with an absence of pathogens in the mind of the consumer.

As pointed out by Lippmann (*17*) many industrial processes take place in the home in the pursuit of hobbies and craft activities. Almost any solvent and adhesive, many monomers, plasticizers, paints and paint removers, soldering and brazing fluxes and welding materials can easily be introduced into the home and are likely to be used without the protective methods mandatory in an occupational environment. For many of these materials, industrial threshold limit values exist (*42*), but considerable caution is required in applying them to uses in nonoccupational space: a different population is at risk, the exposure may be longer, and inexperience or mishaps may cause high concentrations to occur.

The Group was unable to make an estimate of the health risks of this range of products because of the large numbers of constituents involved and the sometimes undetermined uses to which they are put. It is likely that most of the products have been formulated to minimize acute distress in their use, since this would decrease the market appeal. There would, however, appear to be less incentive for a manufacturer to try and minimize chronic and delayed damage even if he knew how to do so. The Group saw the effort to minimize long-term risks of consumer products as an important objective which could be achieved by prohibition of toxic chemicals in certain applications, product substitution, or appropriate product labelling and other educational approaches. A number of areas where preventive activities deserve high priority were identified.

5. ADDITIONAL CONSIDERATIONS FOR SPECIAL ENVIRONMENTS

5.1 Transportation and terminals

Transportation vehicles and terminals constitute a special type of indoor environment characterized by high rates of local energy conversion, relatively high occupant density, and a large throughput of otherwise unrelated people.

5.1.1 *Aeroplanes*

Aeroplanes present special problems. Most aircraft contain a high number of occupants per m^3 of cabin space and have built-in provision for high rates of ventilation. Consequently, an aircraft on the runway, lined up and waiting for take-off, may take in the exhaust from the aircraft ahead in line, which often contains unburned fuel, CO and NO_2. The cabin takes in very dry air at cruising altitudes. To this is added during flight an excess ozone in concentrations of up to 0.3 ppm at high altitudes. Tobacco smoke is a further problem, although more recently, nonsmoking areas have been designated on many airlines. Rapid changes in cabin pressure can cause difficulties for sensitive individuals.

5.1.2 *Trains*

Trains tend to have somewhat lower occupant densities than aeroplanes and correspondingly lower ventilation rates. Although they produce contaminants through their mode of traction, their interiors appear to be polluted mainly with tobacco smoke. Separate compartments have, however, been provided for smokers and nonsmokers for a long time.

5.1.3 *Cars and buses*

Cars and buses operate with relatively high ventilation rates when in motion, and usually much lower rates when stationary and idling. Since these vehicles tend to be used in close proximity, sharing the same roadway, they may be exposed to exhaust from those ahead. High levels of CO, CO_2 and NO_2 as well as oxidants have been recorded in moving vehicles (*43*). Stationary, idling vehicles, even with intact exhaust systems, have also been found to contain CO, in concentrations of 25–800 ppm for buses and up to 400 ppm for cars (*43*). Clearly, wind velocity and direction tend to influence the values measured. In tunnels for vehicular traffic, concentrations of 250 ppm CO and up to 30.9 $\mu g/m^3$ particulate lead have been recorded (*43*).

Some countries are reducing the lead content of automotive fuels, as well as CO and NO_2 emissions, through provisions on design of vehicles and compulsory inspection and maintenance programmes. The Group felt there should be better assessment of the atmosphere within vehicles, when in motion and when stationary. Further evaluations are also needed of particulate emissions from diesel engines, shown to have mutagenic properties in some tests.

5.1.4 *Terminals and garages*

Terminals and garages, because of the proximity of vehicles arriving, waiting and leaving within a completely or partially enclosed space, are likely to contain high concentrations of exhaust products. Radon levels in subway terminals and tunnels may be high. Such structures should be well ventilated. However, the air intakes for ventilation should not be at street level, as is often the case, since this produces the highest CO level that can occur without an internal source.

5.2 Public buildings

Public buildings can serve a variety of purposes, as schools, theatres, sport halls, houses of worship, libraries, offices, retail stores, restaurants, hotels, etc. They have features distinguishing them from the residential spaces considered so far. They can have high densities of occupation, but sometimes only for short periods at a time. They are likely to contain short-lasting congregations of a wide variety of people: young, old, carriers of different diseases, and the individual has little or no control over the indoor environment. There is a greater likelihood of centralized ventilation systems and higher ventilation rates are usually mandated. Sometimes there are special pollutants, such as paper dust in libraries or radon at high levels due to use of underground areas or granite. There may be high infection risks in premises such as physicians' offices.

Other causes of pollution in public buildings include concentrated smoking, and use of photocopiers or electrostatic air cleaners. Humidification equipment may support the growth of microorganisms and ventilating systems may add an odour-masking agent to the air.

There are special risks of infections spreading in public buildings, especially kindergartens and schools, and central forced ventilation systems may circulate infectious material through a building, especially if the outdoor air intake is reduced for energy conservation.

In several countries measures are being envisaged to deal with specific problems. Denmark and Sweden are considering restrictions on the use of carpets in public buildings. In the Scandinavian countries the needs of asthmatics and other sensitive groups are being taken into account in the determination of acceptable indoor air quality levels in public buildings.

The Group saw the need for better understanding of the characteristics of ventilation systems which affect transmission of communicable disease. The design of a ventilation system may, for instance, cause contaminants to spread throughout a building or to be limited to a small section.

The use of chemical additives to modify or improve the operation of a ventilation system, such as rust inhibitors, fungicides and odour-masking agents, should not be permitted unless studies show that it will not have adverse effects on air quality and health.

Where rates of outdoor air intake must be reduced for energy conservation, the development of effective and noncontaminating air purification systems should be encouraged.

6. CONCLUSIONS

In the light of its deliberations, the Group reached the following general conclusions relevant to all aspects of the relationship between indoor air quality and human health, and specific conclusions relating to factors of more immediate concern.

1. The ventilation rate is seen as an important factor in a number of the health concerns discussed. Current efforts in many countries to restrict rates of intake of outdoor air, while clearly offering advantages for energy conservation, must also be seen as potentially disadvantageous to health and well-being. The trend towards restriction of air intake will inevitably increase the concentrations of all pollutants released indoors, including pathogens transmitting communicable disease, unless the restriction is accompanied by effective measures to reduce emissions at the source.

2. Increasingly, contaminants are being introduced into the indoor atmosphere from new building materials, contents and furnishings, and from a growing range of consumer products which release chemicals. Other factors of pollution are an undiminished supply of tobacco smoke, and the generation of human and household odours, with effects that are increased by lower ventilation rates.

3. The lack, or scarcity, of valid health data on the indoor environment is a major concern. Before health authorities can make a responsible and effective contribution to the efforts of energy authorities to reduce energy use in buildings, more specific studies of the effects of indoor air quality on human health and wellbeing are needed. Similarly, in their efforts to limit or prevent the introduction of sources of air contaminants, such as building materials or consumer products, health authorities need much more study data than are now available.

4. Before it became the trend to reduce ventilation rates, the logical and relatively easy and effective response to problems of indoor air quality was to increase ventilation. Since engineers tend to design with a safety margin, the customary deviation used to be towards more ventilation than was specified yielding a bonus for health. If the new ventilation standards set a maximum ventilation rate, engineers will tend to design conservatively to obtain rates below the maximum, with additional risks to health; engineers and health authorities will find themselves working in opposition rather than as allies.

5. The emission of formaldehyde, radon and asbestos from building materials has sufficiently serious short-term and long-term consequences to warrant taking action to limit the problem by whatever means are feasible, in both new and existing buildings.

6. Appliances with unvented combustion produce CO, NO_2 and aldehydes which increase in concentration indoors as ventilation rates are reduced. It is important to gain a better understanding of the health effects of the use of these appliances, through specific research, and of the factors which govern such emissions. Similarly, there is a need to monitor the introduction of new household products and the emissions they produce.

7. Tobacco smoking is still a major threat to maintenance of indoor air quality and as such its reduction and curtailment should be pursued even more rigorously if ventilation rates are to be reduced.

7. RECOMMENDATIONS

The Group made the following recommendations.

1. Health authorities or WHO should establish a working group on guidelines for indoor quality to review current ambient air quality standards, examine threshold limit values for relevant substances and draw up guidelines on their indoor concentrations, taking into account the sensitivity of children, the aged and other groups at special risk, the mechanism of action and source of contaminants, etc.

2. Health authorities or WHO should then convene a working group to review the building codes and ventilation guidelines now being considered for energy conservation, and suggest how provisions to preserve and improve indoor air environments can be incorporated in them.

3. New ventilation practices will require greater efforts to curtail smoking. It should be prohibited in more public areas, and in places where it is allowed, special ventilation or air cleaning should be ensured. Where possible, epidemiological studies of health effects of air pollutants should be designed to improve our knowledge of the effects of passive smoking, in addition to their other objectives.

4. Studies on the nature and rates of emission of indoor contaminants, as well as the rates of their absorption and inactivation, are urgently needed. The findings may reveal problems before they grow to serious proportions. There is a need to monitor trends in the development and marketing of consumer products to determine their possible impact on indoor air quality and human health, taking into account the substances emitted, conditions of use and consumer behaviour. Consumer products containing materials of health concern should display a list of the materials and appropriate warnings.

5. The use of materials with high rates of emission of formaldehyde should be minimized, and standards or guidelines on such emission should be developed and applied. Studies on the health effects of chronic exposure should be encouraged.

6. The use of asbestos materials which can release asbestos fibres to the indoor atmosphere should be avoided in all new construction. Existing buildings should be surveyed for the presence of such materials, and measures taken to eliminate them or prevent them from releasing further fibres.

7. Radon-emitting materials remain active throughout the life of a building and their use in new construction should be minimized. Regions with soil

or water of high radium content should be identified, and new buildings designed to minimize radon exposure from these sources. The health risk in existing buildings containing suspect materials or located in regions of high radium content should be evaluated, and corrective measures taken if the radon levels are excessive.

8. The use of building materials such as plaster, with good absorbing or adsorbing properties, should be explored, especially in highly polluted areas. Studies should be carried out to determine the effectiveness and durability of various materials and surfaces in helping to improve indoor air quality.

9. Studies on the possible health effects of other mineral fibres, such as glass and rockwool fibres, should be encouraged. Although there is no conclusive evidence of health risks of such materials, their widespread use for insulation in buildings justifies research to provide a sounder basis for evaluation than is available today.

10. The association between moulds, house dust mites and allergic diseases should be studied in more detail. Occupants with such diseases will benefit from any measure such as increased ventilation which reduces the quantity of all allergenic substances. Educational measures which might help to reduce the level of allergens should also be developed and applied.

11. Studies of the effects of ventilation rates on infectious disease transmission should be encouraged. Schools with different air change rates might offer opportunities for such studies.

12. Further clinical and epidemiological studies of the effects of unvented combustion products are needed to expand and confirm existing data, with emphasis on the added effect of modified ventilation rates.

13. Methodologies should be developed to relate measurements of air quality indoors and outdoors to total human exposure to air pollutants, so that air quality criteria, standards or guidelines can be based on a proper assessment of such total exposure.

14. There is a need for effective personal monitors to show total human exposure to air pollutants, especially devices which can monitor several pollutants and record short-term peaks, as well as long-term averages.

15. Studies should be made of air quality in samples of buildings with no known complaints about the indoor environment. The results could then serve as a reference base for the evaluation of air quality data on buildings with complaints.

16. The criterion of odour as a determinant of minimum ventilation should be re-evaluated to reconcile the factors of demand for energy conservation, odour perception as a warning of potentially harmful pollutants, and annoyance caused by odours.

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Annex I

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