

4. Indoor Air Quality

Most people spend a large of their time indoors, which makes indoor spaces important microenvironments when addressing risks from air pollution. Most of a person's daily exposure to many air pollutants comes through inhalation of indoor air, both because of the amount of time spent indoors and because of the higher pollution levels indoors. The air quality inside buildings is affected by many factors. In an effort to conserve energy, modern building design has favoured tighter structures with lower rates of ventilation. By contrast, in some areas of the world only natural ventilation is used; in other areas mechanical ventilation is common. Factors that can have a negative effect on health and comfort in buildings range from chemical and biological pollutants, to occupant perceptions of specific stresses such as temperature, humidity, artificial light, noise and vibration.

Although there is a tendency to use similar types of construction all over the world, especially for office buildings, indoor problems are often different in developed countries when compared with less developed countries. While in the former most of the problems arise from low ventilation rates and the presence of products and materials that emit a large variety of compounds, the inhabitants of many less developed countries face problems related to pollutants generated by human activities, in particular by combustion processes.

If health effects of air pollution are being considered, it does not matter if a pollutant is inhaled by breathing outdoor or indoor air. However, outdoor air has a different pollutant composition than that found in indoor air. Traffic-generated emissions are an example of outdoor air pollution; indoors, pollution sources include tobacco smoke and combustion products generated with biomass-fuelled stoves. Not all of these compositions have been taken into account in developing the air quality guidelines, and they may not be applicable under **all** circumstances, so care should be taken to avoid misinterpretation.

4.1 Indoor air pollution in developed countries

4.1.1 Important indoor air pollutants and their sources

Important sources of chemical indoor pollutants include outdoor air, the human body and human activities, emissions from building materials, furnishings and appliances and use of consumer products. Microbial contamination is mostly related to the presence of humidity. The heating, ventilating and air conditioning system can also act as a pollutant source, especially when it is not properly maintained. For example, improper care of filters can lead to re-emission of particulate contaminants. Biological contamination can proliferate in moist components of the system and be distributed throughout the building.

Indoor air pollutants can be classified in different ways. One approach is to divide them into chemical, physical and biological agents. Another approach is to classify them according to their origin. The origin of a particle has an important impact on its composition, which may include chemical and biological agents besides the physical nature of the particle itself. For example, combustion-generated tobacco smoke contains a complex mixture of pollutants.

The sources of indoor air pollution and the principal pollutants, grouped by outdoor and indoor origin, are summarized in Table 4.1. This is not a complete listing of all sources of indoor air pollutants, as there is continuous air exchange between indoors and outdoors, and most pollutants present in the outdoor air are also found indoors. Moreover, indoor sources may lead to an accumulation of some compounds that are rarely present in the ambient air. The most important compounds in indoor air environments include SPM, SO₂, NO_x, CO, photochemical oxidants and

lead. In developed countries, pollutant concentrations indoors are similar to those outdoors, with the ratio of indoor to outdoor concentration falling in the range 0.7-1.3. Concentrations of combustion products in indoor air can be substantially higher than those outdoors when heating and cooking appliances are used. This is particularly true in developing countries where ovens and braziers are used with imperfect kitchen and stove designs.

Table 4.1. - Principal pollutants and sources of indoor air pollution, grouped by origin

Principal pollutants	Sources, predominantly outdoor
SO ₂ , SPM/RSP	Fuel combustion, smelters
O ₃	Photochemical reactions
Pollens	Trees, grass, weeds, plants
Pb, Mn	Automobiles
Pb, Cd	Industrial emissions
VOC, PAH	Petrochemical solvents, vaporization of unburned fuels
Principal pollutants	Sources both indoor and outdoor
NO _x , CO	Fuel burning
CO ₂	Fuel burning, metabolic activity
SPM & RSP	Environmental tobacco smoke, resuspension, condensation of vapours and combustion products
Water vapour	Biological activity, combustion, evaporation
VOC	Volatilization, fuel burning, paint, metabolic action, pesticides, insecticides, fungicides
Spore	Fungi, moulds
Principal pollutants	Sources, predominantly indoor
Radon	Soil, building construction materials, water
HCHO	Insulation, furnishing, environmental tobacco smoke
Asbestos	Fire-retardant, insulation
NH ₃	Cleaning products, metabolic activity
PAH, Arsenic, Nicotine, Acrolein	Environmental tobacco smoke
VOC	Adhesives, solvents, cooking, cosmetics
Mercury	Fungicides, paints, spills or breakage of mercury-containing products
Aerosols	Consumer products, house dust
Allergens	House dust, animal dander
Viable organisms	Infections

Adapted from Suess 1992; WHO 1995i.

4.1.2 Concentrations of indoor air pollutants

Indoor concentrations of air pollutants are influenced by outdoor levels, indoor sources, the rate of exchange between indoor and outdoor air, and the characteristics and furnishings of buildings. Indoor concentrations of air pollutants are subject to geographical, seasonal and diurnal variations.

In developed countries indoor levels of NO₂ for example, are affected by gas heaters and cooking ranges (used in 20-80% of houses in some countries). In five European countries, the average NO₂ concentrations (over 2-7 days) were in the range of 20-40 µg/m³ in living rooms and 40-70 µg/m³ in kitchens, for dwellings with gas equipment and 10-20 µg/m³ in dwellings without gas equipment. These values may be doubled in rooms facing streets with heavy motor traffic. These exposure levels may have an effect on respiratory function, as discussed in Chapter 3. People may be exposed to higher NO₂ levels

under certain circumstances, such as in dwellings equipped with unvented cooking ranges. In addition, short-term measurements reveal NO₂ concentrations that may be five-fold higher than those averaged over several days. Peak values of up to 3800 µg/m³ for 1 minute have been measured in the Netherlands in kitchens with unvented gas cooking ranges (ECA 1989; Seifert 1993).

In general, average short-term CO concentrations at kerbside locations in developed countries are about 60 mg/m³ for 30 minutes or 30 mg/m³ for 1 hour. In kitchens with gas stoves, short-term values of up to 15 mg/m³ have been measured. High values were also measured in bars and pubs, where smoking is common, with average concentrations of 10-20 mg/m³ and peak levels up to 30 mg/m³ (Seifert 1993).

In five developed European countries HCHO concentrations in indoor air were reported to range from 9-70 µg/m³. Higher values are occasionally encountered, especially in dwellings with urea-formaldehyde foam insulation (ECA 1990).

In general, average indoor levels of radon are 20-70 Bq/m³ (ECA 1995), although they may be ten times higher in certain areas.

Exposure to environmental tobacco smoke is an important factor in indoor air quality assessment. The particle and vapour phases of environmental tobacco smoke are complex mixtures of several thousand chemicals, including known carcinogens such as nitrosamines and benzene. One of the most commonly used indicators of environmental pollution by tobacco smoke is the concentration of PM₁₀. This is 2-3 times higher in houses with smokers than in other houses (Schwartz and Zeger 1990). Nicotine is present in the vapour phase, with concentrations of up to 10 µg/m³ in houses with smokers. Data from nine European countries revealed that 33-66% of households had at least one smoker. The proportion of children with mothers smoking at home varied from 20-50%, and the proportion of children with fathers smoking at home ranged from 41-57%. Tobacco smoke, and particularly the exposure of children, is therefore a major problem for indoor air quality and environmental health.

4.1.3 Health effects and symptoms

Most indoor air pollutants directly affect the respiratory and cardiovascular systems, and have been discussed in detail in Chapter 3. In this section, health effects of indoor air pollutants not discussed in Chapter 3 will be summarized.

The direct human health effects of indoor air pollution on the respiratory system vary according to both the intensity and the duration of exposure, and also with the health status of the population exposed. Certain parts of the population may be greater risk, for example, the very young and elderly, those already suffering from respiratory disease, hyper-responders and people exercising.

The active and passive inhalation of tobacco smoke can lead to reduced pulmonary function, to an increased incidence of respiratory symptoms and infections, and to an increased incidence of lung cancer.

Inhalation of infectious microorganisms discharged by people and animals is a primary mechanism of contagion for most acute respiratory infections. In indoor environments characterized by reduced ventilation and increased use of untreated recirculated air concentrations of microorganisms may increase.

Outdoor allergens, house dust mites, and moulds in indoor environments of high humidity can cause allergic asthma (reversible narrowing of lower airways), allergic rhinoconjunctivitis in children and young adults, and recurrent bouts of pneumonitis or milder attacks of breathlessness.

The main acute effects of HCHO include odour perception and irritation of eyes, nose and throat. Discomfort, lacrimation, sneezing, coughing, nausea and dyspnea have also been observed, depending on the HCHO concentration.

Health effects reported for VOC range from sensory irritation to behavioural, neurotoxic, hepatotoxic and genotoxic effects. Concentrations at which identified health effects occur are usually much greater than those measured in indoor air. Exposure to mixtures of VOC may be an important cause of Sick Building Syndrome (SBS).

Asbestos and other mineral fibres may be a cause of an increased incidence of lung cancer. Acute exposure to asbestos and glass fibres can cause severe skin irritation.

More complex health effects are SBS and Building Related Illnesses (BRI). SBS is the occurrence of specific symptoms with unspecified aetiology, and are experienced by people while working or living in a particular building, but which disappear after they leave it. Symptoms include mucous membrane, skin and eye irritation, chest tightness, fatigue, headache, malaise, lethargy, lack of concentration, odour annoyance and influenza symptoms. SBS usually cannot be attributed to excessive exposure to known contaminant or to a defective ventilation system. A number of factors may be involved:

- Physical factors, including temperature, relative humidity, ventilation rate, artificial light, noise and vibration,
- Chemical factors, including environmental tobacco smoke, HCHO, VOC, pesticides, odorous compounds, CO, CO₂, NO₂ and O₃.
- Biological and psychological factors.

It is assumed that the interaction of several factors, involving different reaction mechanisms, cause the syndrome, but there is yet no clear evidence of any exposure-effect relationship.

BRI is an illness related to indoor exposures to biological and chemical substances (e.g. fungi, bacteria, endotoxins, mycotoxins, radon, CO, HCHO). It is experienced by some people working or living in a particular building and it does not disappear after leaving it. Illnesses include respiratory tract infections and diseases, legionnaires' disease, cardiovascular diseases and lung cancer.

4.2 Indoor Air Quality in Less-Developed Countries

Air quality in buildings in developing countries can have similar problems to those found in developed countries, particularly in the large modern urban areas in developing countries. As smoking rates in developing countries increase, exposure to environmental tobacco smoke can also be expected to increase. In addition, some hazardous materials, particularly pesticides, are becoming so widely used in developing countries that there may be higher indoor exposures than in developed countries.

There can be significant and widespread indoor exposures to many of the classical air pollutants, specifically sulphur dioxide, particulate matter, carbon monoxide, and nitrogen dioxide, in developing countries. A particular issue for developing countries is exposure to emissions from cooking and heating which may produce the highest air pollution exposures to many pollutants. Today about half the population of the world continues to rely for cooking and associated space heating on simple household stoves using unprocessed solid fuels that have high emission factors for a range of health-damaging air pollutants. This section briefly summarizes what is known about the emissions, exposures, and health effects. Possible ways of managing the problems are discussed in Chapter 6.

4.2.1 Emissions

Although part of human experience since the first controlled use of fire, air pollution from simple open combustion of biomass has been scientifically characterized only in the last two decades, largely due to rising concerns about woodsmoke pollution in developed countries. Studies have shown high emission factors for many important pollutants, including respirable particulate matter, carbon monoxide, polycyclic aromatic hydrocarbons, such as benzo-a-pyrene, and volatile organic compounds, such as formaldehyde and benzene. Biomass fuels emit hundreds of chemicals during small-scale combustion, such as in household cooking or heating stoves (Smith 1987).

By comparison to modern cooking fuels, such as kerosene and gas, unprocessed solid fuels produce 10-100 times more respirable particulate matter per meal as the result of low (combustion and heat-transfer) efficiencies. Although biomass makes up only 10-15% of total human fuel use, compared to modern fuels a much larger fraction is burned indoors, since nearly one-half of humanity cooks and/or heats with simple stoves burning traditional biomass fuels (WHO 1997a).

Household use of coal is common in China and Eastern Europe. In Eastern Europe, coal is used mainly for heating in devices and emissions are vented outdoors, a process usually resulting in less human exposure than from using coal for cooking.

4.2.2 Concentrations

It is not known what fraction of biomass-burning households cook indoors on unvented stoves, although it is clear that many hundreds of millions do so during some or all seasons of the year. There is also little information about the ventilation rates in the many thousands of housing types in developing countries or countries in transition.

Unfortunately, relatively little monitoring has been done in these indoor environments and none of it has been done in a way to provide statistically valid samples of large populations. The results that have been obtained, nevertheless, are striking. Table 4.1, for example, lists results for particulate matter in indoor air obtained in a number of indoor air quality studies. Other classical pollutants also reach significant levels in these circumstances.

Important non-classical pollutants, such as formaldehyde, polycyclic aromatic hydrocarbons, benzene, and 1,3-butadiene also have been found to reach levels much higher than any but occupational settings in developing countries. In some areas of China and India, household coal use leads to high indoor concentrations of fluorine and arsenic with consequent health effects.

4.2.3 Exposures

Population exposure to an air pollutant is defined here as the simple combination of the concentration of the pollutant in air being inhaled, the duration of time over which it is inhaled, and the number of people exposed. As half the households in the world use solid fuels on a daily basis and it is activities such as cooking that generate most indoor emissions, there is a confluence of emissions, people, and time in places which may have relatively little ventilation. Consequently, globally there are high levels of indoor exposure to emissions from solid fuels (Smith 1993).

These high exposures are suggested by the data on personal exposure concentrations experienced by women during cooking over solid fuel stoves listed in Table 4.2.

4.2.4 Health Effects

Relatively few studies have been conducted to determine the health effects of indoor exposures to air pollutants in developing countries. Enough data has become available in recent years, however, to obtain some preliminary information on the type and very approximate magnitude of effects (Chen et al. 1990).

The following categorizes some major categories of effects where there is reasonable evidence from smoking studies, urban air studies, and multiple studies of solid-fuel use in developing countries. Also listed, where known, are the apparent odds ratios comparing the risk of these diseases between people living in houses using unvented biomass fuel and similar households not using such fuels. All the odds ratios reported here are statistically significant results, mostly of multivariate analyses in which a number of potentially confounding variables were included:

Acute respiratory infections in children: This is the chief cause of ill-health in the world and strongly associated with indoor use of solid fuels for cooking in a number of studies in Asia and Africa (OR = 2 - 6) (e.g., Pandey et al. 1989; Collings et al. 1990; Mtango et al. 1992; O'Dempsey et al. 1996).

Chronic obstructive pulmonary disease: This has been shown to be strongly associated with use of solid fuels in non-smoking women often along with *cor pulmonale* in studies from Latin America, South Asia and Saudi Arabia (OR = 3.4-15) (e.g., Dennis 1996; Dossing et al. 1994; Pandey 1984; Sandoval et al. 1993; Albalak et al. 1999)

Lung cancer: Lung cancer has been shown in many Chinese studies to be statistically associated with use of coal for cooking and heating, but not biomass fuels (OR = 3-9) (Smith and Liu 1994; Shields et al. 1995).

There is some evidence from studies of solid-fuel use in developing countries indicating a relationship between adverse pregnancy outcomes, the third most important category of ill-health in the world, and smoke exposure. After multivariate analyses, stillbirth has been associated with biomass fuel use by pregnant women in one Indian study (OR = 1.5) (Mavalankar et al. 1991) and with low birth-weight in Guatemala (Boy et al. 1999). After multivariate analyses, TB and blindness (cataracts) have been shown to be related to use of biomass fuels in two national and two local studies in India (Mishra et al. 1999a; Gupta et al. 1997; Mishra et al. 1999b; Mohan et al. 1989). Unfortunately all these studies relied on the type of stove or fuel as the indicator of pollution. More studies are needed that measure concentrations and exposures to indoor air pollutants so that exposure-response relationships can be more firmly determined.

4.2.5 Application of Air Quality Guidelines to Indoor Air Pollutant Exposure

The magnitude and population distribution of indoor air pollution exposure from unvented solid fuel use tends to differ from the outdoor urban air pollution exposures that have been the basis of most of the health effects research cited in Chapter 3. In many situations, for example, exposure levels may be high during cooking periods, with relatively low exposures between cooking periods.

Classical Gaseous Pollutants

All of the classical gaseous pollutants except ozone can be found in indoor solid fuel smoke and these can be a health concern in households with poor ventilation. Although there have been relatively few measurements of gaseous pollutants in developing countries, emissions estimates from solid fuel burning suggest that levels exceeding the air quality guidelines may be widespread in developing countries (WHO 1992c; WHO 1997a).

Particulate matter

The WHO air quality guidelines and most other particulate matter standards do not specify the chemical composition of particles. However, the health effects may vary with differences in particle compositions (see Section 2.4). Most of the epidemiological studies used to derive the air quality guidelines for particulate matter were conducted in cities where fossil-fuel particulate matter dominated and some even had significant contributions from coal burning, sometimes at household scale. Thus, it is important to consider the chemical composition of indoor air particulate matter when considering health effects of emissions from solid fuel combustion.

Very high concentrations of particles in indoor air can occur, sometimes for short duration, such as during cooking over solid fuel fires in rooms with poor ventilation. As discussed in Section 2.4, extrapolations of the air quality guidelines health impacts slope for particulate matter beyond $150 \mu\text{g}/\text{m}^3$ PM_{10} must be done with extreme care because there may be a flattening of the exposure/response slope at higher exposure concentrations.

Although some epidemiological studies of particle air pollution were conducted in cities with significant emissions from woodsmoke during some seasons, there is insufficient information to consider the applicability of the new air quality guideline for particulate matter to biomass smoke. Many researchers believe that the chemical composition of fresh biomass smoke from open fires is too different from the aged fossil-fuel particulate matter upon which most of the epidemiological studies have been based to make such an extrapolation with current knowledge. At this stage, no judgment can be made about whether biomass particulate matter is less or more unhealthy than the same exposure concentration of urban outdoor particulate matter, but only that they may induce a different response because of their different composition. Thus, even though it is clear from the existing epidemiological literature that significant ill-effects do occur, it is not possible at this point to be confident about the precise exposure-response relationships.

Tobacco smoke is a fresh biomass smoke, which has been studied far more than any other pollutant mixture. In the form of ETS, it is associated with adverse health impacts in adults and children at particle concentrations similar to those at which the epidemiological studies of health effects of outdoor particulate matter have been conducted (Section 3.4). Even though it is not clear whether particulate matter is the best single measure by which to characterize ETS, the large health impact at concentrations commonly found leads to the conclusion that no level above zero could be considered acceptable (see Section 3.4). It should also be kept in mind that exposure to ETS and other air pollutants can act synergistically to produce adverse health effects (WHO 1999c).

There are similarities between ETS and biomass smoke from stoves, as hundreds of the organic compounds they both contain are similar. This supports evidence that exposure to biomass smoke from open stoves causes considerable human ill-health world wide. Nevertheless, until more evidence becomes available from studies done in biomass-using households, it is considered prudent not to extrapolate the guidelines described for particulate matter in section 3.1 to higher PM concentrations but rather use a conservative approach or alternatively apply the 1987 Air Quality Guidelines for particulate matter (WHO 1987).

Table 4.1. Indoor particle air pollution from biomass combustion in developing countries: partial list of studies measuring area concentrations (Smith 1996).

Country	Year of publication	Description of sample	Concentration [mg/m ³]
Papua New Guinea	1968	n=9, overnight, floor level	5200
	1974	n=6, overnight, sitting level	1300
Kenya	1971/2	n=8, overnight, highlands/lowlands	4000/800
		thatched/iron roof	n=64, 24 h, 1300/1500 (R)
India	1982	n=64, 30 min, wood/dung/charcoal	15,800/18,300/5500
	1988	n=390, cooking, 0.7m/ceiling	4000/21,000
	1992	n=145, cooking/non-cooking/living	5600/820/630
	1994	n=61, 24 h, ag-resid/wood	2800/2000 (I)
	1995	n=50, breakfast/lunch/dinner	850/1250/1460 (I)
	1996	n=136, urban, cooking/sleeping	2860/880 (I)
Nepal	1986	n=17, 2 h	4400 (I)
China	1986	n=64	2570
	1987	n=4, 8 h	10,900 (I)
	1988	n=9, 2 houses, 12 h	2900
	1988	n=12, 4 houses, dung	3000 (I)
	1990	15 houses, dung, winter/summer	1670/830 (I)
	1991	straw, avg summer-winter, kitchen/living room/dung	1650/610/1570 (I)
	1991	1-story/2-story houses	80/170
	1993	4 kitchens	1060 (I)
Gambia	1988	n=36, 24 h, dry/wet season	2000/2100 (I)
Zimbabwe	1990	n=40, 2 h	1300 (I)
Brazil	1992	n=11, 2-3 h, trad/impr	1100/90 (I)
Guatemala	1993	n=44, 24 h, trad/impr	1200/530 (I)
	1996	n=18, 24 h, trad/impr	720/190 (I), 520/90 (R)
	1996	n=43, 24 h, trad/impr	870/150 (R)
South Africa	1993	n=20, 12 h, kitchen/bedroom	1720/1020
Mexico	1995	n=31, 9 h	335 (R)/439 (I)

(Woodfuel, rural, and TSP unless otherwise stated; I=inhalable=cutoff at approx. 10mm; R=respirable=cutoff at 5mm or smaller; Trad/impr=traditional open stove compared to improved stove with flue)

Table 4.2. Indoor particle air pollution from biomass combustion in developing countries: partial list of studies of individual breathing area concentrations (women during cooking, unless otherwise stated) (Smith 1996).

Country	Year of publication	Description of sample	Concentration [mg/m ³]
India	1983	n=65, 4 villages	6800
	1987	n=165, 8 villages	3700
	1987	n=44, 2 villages	3600
	1988	n=129, 5 villages	4700
	1991	n=95, winter/summer/monsoon	6800/5400/4800
	1996	n=40, two urban slums, infants, 24 h	400/520 (I)
Nepal	1986	n=49, 2 villages	2000
	1990	n=40, trad/impr	8200/3000
Zambia	1992	n=184, 4 h, urban, wood/charcoal	470/210 (R)
Ghana	1993	n=143, 3 h, urban, wood/charcoal	590/340 (R)
South Africa	1993	n=15, 12 h, children, winter/summer	2370/290

(Woodfuel, rural, and TSP unless otherwise stated; I=inhalable=cutoff at approx. 10mm; R=respirable=cutoff at 5mm or smaller; Trad/impr=traditional open stove compared to improved stove with flue)

Table 4.3. Particle concentrations and exposures in the eight major global microenvironments (Smith 1996).

Region	Concentrations		Exposures		
	Indoor (µg/m ³)	Outdoor (µg/m ³)	Indoor (%)	Outdoor (%)	TOTAL (%)
<u>Developed</u>					
Urban	100	70	7	1	7
Rural	80	40	2	0	2
<u>Developing</u>					
Urban	250	280	25	9	34
Rural	400	70	52	5	57
		TOTAL (%)	== 86	14	100

Note: Population exposures expressed as a percentage of the world total. Here exposure is defined to equal to the number of people exposed multiplied by the duration of exposure and the concentration breathed during that time.