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International Energy Agency
Energy Conservation in Buildings
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Air Infiltration and Ventilation Centre

Indoor Air Pollutants

Part 1: general description of pollutants, levels and standards

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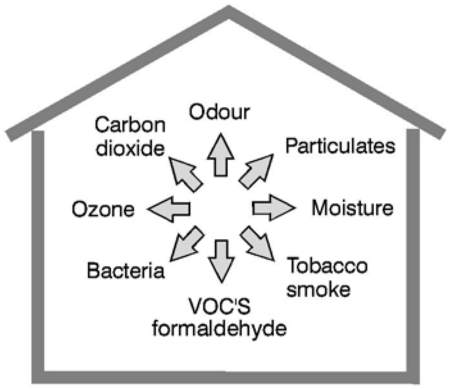

1 Introduction

Pollutants found in indoor air are often several times higher than outdoors. Indoor air pollutants cause effects ranging from odor, annoyance, and irritation to illness, cancer, and even death. Since people spend the majority of their time indoors, it is important to recognize and control indoor air pollution. Some indoor air pollutants also adversely affect materials in the building and the building structure itself. The majority of indoor pollution comes from the building itself, its contents, or its occupants and their activities. Building materials and consumer products are important sources of indoor air pollutants. Some outdoor air pollutants enter with ventilation air. Interactions between substances in indoor air can also produce pollutants and some of these are more odorous, irritating, or hazardous than the chemicals that forms them. Reducing or eliminating pollution sources best achieves control of indoor air quality. Appropriate ventilation strategies can reduce concentrations of pollutants that can't be eliminated by source control.

2 How is indoor air pollution defined?

Indoor air quality and indoor air pollution are usually defined by describing the concentrations of selected pollutants. Concentrations are reported in either mass per unit volume of air, e.g., milligrams per cubic meter (mg/m^3), or in parts of the pollutant per million parts of air (ppm). Concentration limits or guidelines exist for many chemicals and for particles within defined size ranges, but most of the available guidelines were not developed for specific application in indoor air. Therefore, it is important to be aware of the source and intended application of any such guideline when applying it to indoor air.

2.1 *Interpreting indoor air quality measurements*

Since the effects of indoor air pollution on human comfort and health are related to the dose received, then the concentration and the time of exposure are important aspects in the evaluation of concentrations. Furthermore, since ventilation can change the concentration more or less proportionally to the number of air changes per hour, it is important to know the ventilation at the time concentrations are measured and the potential range of ventilation and concentration in the building or buildings of concern.

3 Major types of indoor air pollutants

The major types of indoor pollutants are chemical, physical, and biological. But there are many different types of each of these. There is considerable connection between these categories since gases can form particles or adsorb to particle surfaces. Some bioaerosols are metabolic products of living organisms in gaseous or particle form. Nevertheless, for convenience, indoor pollutants are divided into three distinct categories of indoor air pollutants: gases, particles, and bioaerosols.

Chemicals may be in the gas, liquid or solid phase; *e.g.*, water can be ice, liquid, or vapor. The phase or state of a chemical is determined by its vapor pressure and the temperature and atmospheric pressure where it exists. Chemicals tend to change from solid to liquid to gas, or directly from solid to gas, as their vapor pressure increases. The most important organic chemicals pollutants are found in the gas phase at typical indoor environmental conditions. There is also concern about some gases that can go back and forth from the liquid or solid state to the gas state.

Physical pollutants include particles, fibers, and biological aerosols. The particles range in size from ultra fine (<0.1 micrometer - µm) to fine particles (>0.1 µm<2.5 µm) to coarse particles (>2.5 µm). Particles less than 10 µm are considered respirable. Most health concern is about respirable particles since they can be inhaled and especially the fine particles since they can penetrate into the respiratory tract. The smaller they are, the greater the likelihood that they will actually reach the lungs rather than be deposited in the nose, mouth, trachea, or bronchial areas.

Biological aerosols include pollen, mold spores, bacteria, and viruses. These particles are abundant and many of them cause allergies and diseases.

Gases include both organic and inorganic types. These include many human and microbiological metabolic products as well as chemicals used to manufacture many modern building materials, furnishings, and consumer products. These include a range of organic chemicals with varying volatility – the more volatile, the larger the fraction found in the air. Some with low volatility known as semi-volatile organic chemicals (SVOCs) are among the most toxic (*e.g.*, pesticides, fire retardants, plasticizers, and some combustion by-products). Inorganic gases include many combustion by-products, emissions from minerals, radioactive radon gas, and many others.

The species of a microorganism is normally reported and is very important to interpreting the measurement results. Again, like organic chemicals where specific compounds must be identified and quantified, the specific organism must be identified since its effects will be specific to itself. Measurements of biological aerosols – microorganisms found in air – depend on the method used. The use of an inappropriate method can result in inaccurate and misleading results. The collection system, timing, and location and the media for culturing viable organisms all have important impacts on the accuracy of the measurements.

Table 1: Major Types of Indoor Pollutants

Type	***Examples***
Gases: Organic	Volatile organic compounds (VOCs) Semivolatile organic compounds (SVOCs) Polycyclic aromatic hydrocarbons (PAHs) Microbial VOCs (MVOCs)
Inorganic	Carbon dioxide (CO_2) Nitrogen dioxide (NO_2) Ozone (O_2)
Particles: Bioaerosols	Viable (molds, viruses, bacteria, pollen) Non-viable (dead biological material)
Inorganic	Minerals, metals, soil, fibers
Radon	Radioactive gas

Most authorities now believe that absolute concentration limits for microbial contaminants in indoor air can be very misleading. Instead, they recommend comparing indoor concentrations of each species to their concurrent outdoor concentrations. If the indoor/outdoor ratio is significantly above one, then it is assumed that the organism is reproducing indoors and the source should be found and eliminated. Usually eliminating the source of excess moisture will control growth of most mold species.

3.1 Indoor Air Pollutants Measurements

Pollutant concentration measurements are highly dependent on the method used. There are usually several methods for measuring each type of pollutant, and comparison of results to other measurements must always be done with caution to be certain that the measurement methods used produce comparable results. Pollutant concentrations vary greatly over time and in space within a building. Therefore, the measurement methods and protocols must be carefully selected to produce useful results. Pollutant measurement methods range from very short-term including direct reading instruments and "grab" samples analyzed later to longer term sampling periods either directly analyzed and averaged or stored and analyzed later, also giving an average reading. Sampling times can range from less than a second to several hours, days, or even weeks. Gases, particles, and bioaerosols may be sampled and analyzed by various methods, and the methods can strongly influence the specificity and accuracy of the results

Volatile organic chemicals (VOCs), defined as those organic chemicals that are encountered in the gas phase at typical ambient conditions, are often reported by the concentration of each specific organic compound identified and quantified. The measurement of individual compounds is necessary to assess the potential health effects of organic chemicals. Many investigators report the total of all measured VOCs and report it as a Total VOC concentration, or TVOC. However this measurement cannot be used as an indicator of potential health effects since the content and proportions of the mixture of VOCs can vary greatly from one sample to another. In fact, a sample may be dominated by one, innocuous organic chemical and have a very high value or may have one very toxic chemical along with a few others at low concentrations resulting in a very low TVOC concentration.

Biological aerosols include the three classes of microorganisms -- fungi, viruses, and bacteria -- as well as pollen and animal metabolic products.. Microorganisms are identified by genus and species and their concentrations are reported as the number of colony forming units per unit volume of air, e.g., cfu/cm^3 or cfu/m^3, although other units are also used. Viable and non-viable bioaerosols are separately measured and characterized. The species of the microorganism is very important to interpretation of the measurement results. The probable health effects of exposure to airborne microorganisms is available only for a small fraction of all the organisms found in indoor air. Authorities believe that absolute concentration limits can be misleading. Instead, they recommend comparing indoor concentrations of each species to their concurrent outdoor concentrations. If the indoor/outdoor ratio is significantly above one, then it is assumed that the organism is reproducing (amplified) indoors. In these cases, the source should be found and eliminated. Usually eliminating the source of excess moisture will control growth of most mold species.

Particles (also referred to as particulate matter) are classified by aerodynamic size and reported either as mass per unit volume of air (e.g., micrograms per cubic meter - µg/m^3) or by number of particles per unit volume of air. Particle sizes are roughly divided into respirable and non-respirable size fractions. Particles that are too large to be inhaled (i.e., >10 micrometers -- µm) are considered non-respirable. Among the respirable particle (<10 µm), sizes, the classes include coarse (>2.5 or 3.5 micrometers -- µm), fine (<2.5 µm), and ultra-fine (<0.1 µm).

The specific measurement method used to determine air pollutant concentrations in turn determines which pollutants are identified and quantified. The measurements may have relatively high uncertainty. No method currently in use measures all organic compounds that may be of interest. For example, formaldehyde and many highly toxic compounds would not be detected by typical TVOC procedures. Considerable variation exists in the methods used for bioaerosol measurement. Particle counts cannot be reliably translated into mass concentrations. Standard methods allow comparisons, but there will still be many contaminants not measured.

3.2 Effects of Major Indoor Air Pollutants:

Pollutants in indoor air are of importance due to their potential impacts on occupant health and comfort and impacts on materials and equipment. The health effects of indoor air pollutants span the range from irritation to cancer. In equipment, indoor air pollutants can cause deterioration of materials and failures that not only result in permanent damage to the equipment but secondary effects such as loss of services provided by the equipment or even releases of harmful substances into the environment.

Table 2 summarizes the health effects of major indoor air pollutants. More detail on the health effects of indoor pollutants can be found in numerous publications available on-line and in printed form. Examples include the World Health Organization (www.euro.who.int/document/e71922.pdf), the U.S. EPA's website, (http://www.epa.gov/iaq/index.html), several state web sites, and Spengler, Samet, and McCarthy, 1999.

Table 3 summarizes concentrations of concern of major indoor air pollutants. The levels in the table are not regulatory in nature but reflect authoritative sources from peer-reviewed scientific literature. They are presented here only for guidance purposes and are not proposed as standards or regulatory values. Regional, national, and other laws and regulations as well as non-regulatory guidance should be consulted where available. Appendix A lists various guideline values for a selected set of important indoor air pollutants.

3.3 Outdoor Sources

The common sources of contaminants that are introduced from outside buildings include motor vehicles, commercial and manufacturingactivities, public works/utilities, agriculture, construction, building exhaust, water, birds, rodents, building maintenance, and ground sources. Contaminants from these sources frequently find their way inside through the building shell, openings, or other pathways.

Table 2: Common types of indoor pollutants and associated health effects

Pollutant	***Health effects***
Carbon Monoxide (CO)	Reduces ability of blood to bring oxygen to body cells and tissues; cells and tissues need oxygen to work. Carbon monoxide may be particularly hazardous to people who have heart or circulatory problems and people who have damaged lungs or breathing passages.
Formaldehyde (HCHO)	Acute and chronic inhalation exposure to formaldehyde in humans can result in eye, nose, and throat irritation, respiratory symptoms, and sensitization. Limited human studies have reported an association between formaldehyde exposure and lung and nasopharyngeal cancer. Animal inhalation studies have reported an increased incidence of nasal squamous cell cancer. EPA has classified formaldehyde as a Group B1, probable human carcinogen of medium carcinogenic hazard,
Lead (Pb)	Brain and other nervous system damage; children are at special risk. Some lead-containing chemicals cause cancer in animals. Lead causes digestive and other health problems.
Nitrogen Dioxide (NO_2)	Lung damage, illnesses of breathing passages and lungs (respiratory system).
Odors	CO_2 concentration can be used as a surrogate for occupant odors (odorous bioeffluents).
Ozone (O_3)	Breathing problems, reduced lung function, asthma, irritates eyes, stuffy nose, reduced resistance to colds and other infections, may speed up aging of lung tissue.
Particles ($PM_{2.5}$)	Lung damage, early death.
Particles (PM_{10})	Nose and throat irritation, lung damage, bronchitis, early death.
Radon (Rn)	Lung cancer.
Total Volatile Organic Compounds (TVOCs)	Odor and irritation responses to organic compounds are highly variable. Average indoor concentrations in most buildings are well below 1000 $\mu g/m^3$. If a value for design is selected by the designer and owner of the building, it should include consideration of the timing in relation to installation of new materials and furnishings and the introduction of other sources.
Volatile Organic Compounds (VOCs)	Concentrations of concern range from less than 1 part per billion (ppb) for some very toxic compounds or for compounds having very low odor thresholds up to concentrations several orders of magnitude higher Not all compounds can be identified, and toxicological data are incomplete for many compounds.

Table 3: Concentration of Interest for Selected Contaminants

Contaminant	Concentrations of interest	Comments
Carbon monoxide (CO)	9 ppm (8-hr)	Sustained indoor concentrations exceeding outdoor concentrations may merit further investigation. Many carbon monoxide measuring instruments have limited accuracy at low levels.
Formaldehyde (HCHO)	0.1 mg/m^3 (0.081 ppm) 0.05 ppm 76 ppb (1-hr) 27 ppb (8-hr)	WHO Air Quality Guidelines for Europe, Canadian Residential Air Quality Guidelines Established to avoid irritation in allergic and asthmatic individuals (residential) and as a value that is reasonable to achieve in light of formaldehyde's potential carcinogenicity (California Air Resources Board). Based on the current acute 1-hour Reference Exposure Level (REL) of 76 ppb (94 µg/m^3), an exposure level of 27 ppb (33 µg/m^3) is derived for an 8-hour exposure period (Cal-OEHHA)
Lead (Pb)	1.5 µg/m^3	Based on adverse effects on neuropsychological functioning of children, average exposure for 3 months (WHO: 0.5-1 µg/m^3 for 1 year).
Nitrogen dioxide (NO_2)	100 µg/m^3	Based on providing protection against adverse respiratory effects, average exposure for 1 year.
Odors	Acceptable to >80% of occupants	Indoor minus outdoor CO_2 concentration can be used as a surrogate for occupant odors (odorous bioeffluents). For sources other than people, source control is recommended.
Ozone (O_3)	100 µg/m^3 (50 ppb)	Ozone present at levels below the concentration of interest may contribute to the degradation of indoor air quality directly and by reacting with other contaminants in the indoor space..
Particles ($PM_{2.5}$)	15 µg/m^3	Based on protecting sensitive members of the general population exposed to ambient air pollution.
Particles (PM_{10})	50 µg/m^3	Based on protecting against respiratory morbidity in the general population and avoiding exacerbation of asthma, average exposure for 1 year, no carcinogens. Indoor concentrations are normally lower; guideline level may lead to unacceptable deposition of "dust".
Radon (Rn)	4 pCi/liter	Based on lung cancer, average exposure for 1 year.
Total Volatile Organic Compounds (TVOCs)	Typical buildings: 250 – 500 µg/m^3 >1000 µg/m^3 should indicate the need for further analysis	Odor and irritation responses to organic compounds are highly variable. Average indoor concentrations in most buildings are well below 1000 µg/m^3. If a value is selected, it should include consideration of the timing in relation to installation of new materials and furnishings and the introduction of other sources. During occupancy, measured TVOC concentrations above 1000 µg/m^3 should trigger further analysis to determine whether concentrations of individual compounds are above levels of concern.
Volatile Organic Compounds (VOCs)	Must be determined for each individual compound-	Individual volatile organic compounds may be contaminants of concern. Concentrations of concern range from less than 1 part per billion (ppb) for some very toxic compounds or for compounds having very low odor thresholds up to concentrations several orders of magnitude higher Not all compounds can be identified, and toxicological data are incomplete for many compounds.

4 Pollution transport

Contaminants reach occupant breathing-zones by travelling from the source to the occupant by various pathways. Normally, the contaminants travel with the flow of air. Air moves from areas of high pressure to areas of low pressure. That is why controlling building air pressure is an integral part of controlling pollution and enhancing building IAQ performance. Air movement should be from occupants toward a source and out of the building rather than from the source to the occupants and out the building. Pressure differences will control the direction of air motion and the extent of occupant exposure.
The investigation, design, and management of pollutant transport focuses on driving forces and pathways. Major driving forces include the wind, stack effect, HVAC/fans, flues and exhaust, and elevators. The major indoor pathways include stairwell, elevator shaft, vertical electrical or plumbing chases, receptacles, outlets, openings; duct or plenum; duct or plenum leakage; flue or exhaust leakage; and room spaces. The major Outdoors-to-Indoors pathways include indoor air intake; windows/doors; cracks and crevices; substructures and slab penetrations;

5 For further information

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Appendix A. Guideline values for indoor air pollutants

Table 4: Comparison of Regulations and Guidelines Pertinent to Indoor Environments

	Enforceable and/or Regulatory Levels			Non-enforced Guidelines and Reference Levels			
	NAAQS/EPA (ref. A-1)	OSHA (ref. A-2)	MAK (ref. A-3)	Canadian (ref. A-4)	WHO/Europe (ref. A-5)	NIOSH (ref. A-6)	ACGIH (ref. A-7)
Carbon dioxide		5,000 ppm	5,000 ppm 10,000 ppm [1hr]	3,500 ppm [L]		5,000 ppm 30,000 ppm [15min]	5,000 ppm 30,000 ppm [15min]
Carbon monoxide [c]	9 ppm [g] 35 ppm [1hr] [g]	50 ppm	30 ppm 60 ppm [30min]	11 ppm [8hr] 25 ppm [1hr]	90 ppm [15min] 50 ppm [30min] 25 ppm [1hr] 10 ppm [8hr]	35 ppm 200 ppm [C]	25 ppm
Formaldehyde[h]		0.75 ppm 2 ppm [15min]	0.3 ppm 1 ppm][i]	0.1 ppm [L] 0.05 ppm [L] [b]	0.1 mg/m^3 (0.081 ppm) [30 min][p]	0.016 ppm 0.1 ppm [15min]	0.3 ppm [C]
Lead	1.5 µg/m^3 [3 months]	0.05 mg/m^3	0.1 mg/m^3 1 mg/m^3 [30min]	Minimize exposure	0.5 µg/m^3 [1yr]	0.1 mg/m^3 [10h]	0.05 mg/m^3
Nitrogen dioxide	0.05 ppm [1yr]	5 ppm [C]	5 ppm 10 ppm [5min]	0.05 ppm 0.25 ppm [1hr]	0.1 ppm[1hr] 0.004 ppm [1 yr]	1 ppm [15min]	3 ppm 5 ppm [15min]
Ozone	0.12 ppm [1hr][g] 0.08 ppm	0.1 ppm	[j]	0.12 ppm [1hr]	0.064 ppm (120 µg/m^3) [8hr]	0.1 ppm [C]	0.05 ppm[k] 0.08 ppm[l] 0.1 ppm[m] 0.2 ppm[n]
Particles[e] <2.5 µm MMAD[d]	15 µg/m^3[1 yr][o] 65 µg/m^3 [24 hrs][o]	5 mg/m^3	1.5 mg/m^3 for <4 µm	0.1 mg/m^3 [1hr] 0.040 mg/m^3 [L]			3 mg/m^3
Particles[e]<10 µm MMAD[d]	50 µg/m^3[1 yr][o] 150 µg/m^3 [24 hrs][o]		4 mg/m^3				10 mg/m^3
Radon	See Table 3[f]				2.7 pCi/L [1yr]		
Sulfur dioxide	0.03 ppm [1yr] 0.14 ppm [24hr] [g]	5 ppm	0.5 ppm 1 ppm [i]	0.38 ppm [5min] 0.019 ppm	0.048 ppm [24h] 0.012 ppm [1yr]	2 ppm 5 ppm [15min]	2 ppm 5 ppm [15min]
Total Particles[e]		15mg/m^3					

Notes for Table 4: Comparison of Regulations and Guidelines Pertinent to Indoor Environments

[a] [ ] Numbers in brackets refer to either a ceiling or to averaging times of less than or greater than 8 hours (min = minutes; hr = hours; y = year; C = ceiling, L = long-term). Where no time is specified, the averaging time is 8 hours.

[b] Target level is 0.05 ppm because of its potential carcinogenic effects. Total aldehydes limited to 1 ppm. Although the epidemiological studies conducted to date provide little convincing evidence that formaldehyde is carcinogenic in human populations, because of this potential, indoor levels should be reduced as much as possible.

[c] As one example, regarding the use of values in this table, readers should consider the applicability of carbon monoxide concentrations. The concentrations considered acceptable for nonindustrial, as opposed to industrial, exposure, are substantially lower. These lower concentrations (in other words, the ambient air quality standards, which are required to consider populations at highest risk) are set to protect the most sensitive sub-population, i.e., individuals with pre-existing heart conditions.

[d] MMAD = mass median aerodynamic diameter in microns (micrometers). Less than 3.0 µm are considered respirable; less than 10 µm are considered inhalable.

[e] Nuisance particles not otherwise classified (PNOC), not known to contain significant amounts of asbestos, lead, crystalline silica, known carcinogens, or other particles known to cause significant adverse health effects.

[f] USEPA guideline.

[g] Not to be exceeded more than once per year.

[h] The U.S. Department of Housing and Urban Development adopted regulations concerning formaldehyde emissions from plywood and particleboard intended to limit the airborne concentration of formaldehyde in manufactured homes to 0.4 ppm. [24 CFR Part 3280, HUD Manufactured Home Construction and Safety Standards]

[i] Never to be exceeded.

[j] Carcinogen, no maximum values established.

[k] TLV® for heavy work.

[l] TLV® for moderate work..

[m] TLV® for light work.

[n] TLV® for any work, ≤2 hours

[o] 62FR38652 - 38760, July 16, 1997

[p] Epidemiological studies suggest a causal relationship between exposure to formaldehyde and nasopharyngeal cancer, although the conclusion is tempered by the small numbers of observed and expected cases. There are also epidemiological observations of an association between relatively high occupational exposures to formaldehyde and sinonasal cancer.

Table 4 References

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The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim is to promote the understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in the design of new buildings and the improvement of the existing building stock.