

Indoor Air Quality (IAQ), Pollutants, Their Sources and Concentration Levels

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The paper presents a comprehensive review of problems related to indoor air quality (IAQ), based on literature data. Main sources of indoor air pollution have been presented. Health effects of the most important pollutants have been discussed. A particular attention has been paid to volatile organic compounds. Measures taken to improve the IAQ have been briefly treated, including methods of elimination of indoor air pollution. Also presented are several aspects of indoor air analysis. On this background selected problems related to IAQ and its improvement in Poland have been shown using Gdansk as an example.

1. INTRODUCTION

SEVERAL interesting reviews on the concept of human exposure assessment and the role of non-occupational indoor air quality (IAQ) in the total human exposure have been published in the recent years [1-7]. The problem as a whole, however, is still not well recognized. This is due among others to the increasing possibilities of measuring still lower concentrations of various compounds occurring in air, and to the growing amount of evidence that numerous compounds considered till now as neutral for human organisms at small doses are as a matter of fact very harmful. The effect is particularly pronounced for compounds that can accumulate in organisms.

2. GENERAL CONSIDERATIONS

When talking about air quality, it is most often atmospheric air or workplace atmosphere that is meant [8]. Hygienic standards determining the threshold limit values of various pollutants in air have been set in most countries. They concern mainly the so-called priority air pollutants, i.e. sulphur oxides, nitrogen oxides, dust, hydrocarbons (HC), and sometimes also photochemical oxidants. The greatest number of standards determining the Threshold Limit Values for various chemical substances have been prepared for workplace atmospheres. Determination of these values has been described previously [9]. Threshold Limit Values have been set for over 1000 substances, the number continuously increasing [10]. Attention has been also paid to the fact that,

according to various estimations, man spends from 70 to 90% of his time indoors [1, 8, 11-13].

The following are considered to be 'interiors' [11, 14]:

- dwellings with living rooms, bedrooms, rooms for do-it-yourself activities, crafts and sports, basements, kitchens, bathrooms;
- offices and other places of work in buildings, inasmuch as these are not subject to control of air pollution according to labour protection regulations;
- area open to the public such as public buildings, i.e. hospitals, schools, nursery schools, homes for the elderly, sports centers, libraries, restaurants, hotels, theaters, cinemas, and often buildings for public events;
- closed spaces in motor vehicles and all types of public transportation (cars, lorries, buses, railway carriages and aircraft).

Thus, these 'mobile interiors' should be included in a report on indoor air pollution. However, there is one important difference to the interior of buildings. The main consideration in the latter case is with sources of air pollution located within the buildings and the associated effects of immission, outdoor air being only of secondary interest. In contrast, outdoor air is of far greater significance for the interiors of vehicles. There are also 'endogenous' sources of the contamination of air in vehicle interiors. These include smoking by occupants, emissions from upholstery and other materials, from paints and varnishes, adhesives, cleaners and preservatives, and also evaporation of fuel from tank, emergency tank and fuel pipes. The resulting air pollution in small-volume vehicle interiors such as cars or closed railway carriage compartments reaches potentially harmful concentration levels more rapidly than in large-volume spaces [14]. These spaces often contain population (children, the elderly) that may be more sensitive to air pollutants [15]. Therefore IAQ can significantly affect human health and the quality of life (in the most general

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meaning). The significance of air hygiene in residential and office areas was recognized by Max van Pottenkoffer more than one hundred years ago [14]. People occupying these microenvironments are exposed on a continuing basis to air whose quality is dependent on [11]:

- the quality of the outdoor air at the location of the building or vehicle;
- the 'tightness' of the building or vehicle construction;
- human activity within the microenvironment.

It is not surprising that outdoor air pollution was first recognized as a hazard to human health, since the visible emissions of large and multiple outdoor sources disperse over large areas and may accumulate up to disturbing levels during unfavorable conditions [1].

Cave dwellers were perhaps the first to be concerned with the quality of indoor air, when they built fires inside their caves. By cooking and heating over open flames, they probably exposed themselves to toxic vapours from various chemicals, including formaldehyde. They may have partially solved the problem simply by building the fire at the entrance to the cave [16]. Modern man confronts problems of indoor air quality that resemble those of cave dwellers. People now build well-sealed homes and install insulation and other materials to conserve energy. This reduces movement of air through a building and increases the concentration of many indoor pollutants. Our problems of indoor air pollution are more complex than those faced by our ancestors.

On the basis of literature data [17] it can be stated that the interest in indoor air pollution started as early as in 1903, but at first it was limited to the airborne microflora and to the effect of air filtration in relation to asthma and hayfever. Measurements of chemical contaminants indoors or both indoors and outdoors started in the middle 1950s. The measurements have been conducted for the following three reasons:

- to determine the dust balance in houses with or without air cleaning system;
- as a background for investigation of the health status of chronic patients;
- as a basis for establishing safe distance of residences from pollution sources.

At the time the penetration of outdoor air pollution to the indoor environment was the main preoccupation, and only water vapour, CO₂, odours, microorganisms and redispersed dust were considered as indoor generated pollutants.

It was probably in 1965 when it was established for the first time [18] that indoor generated air pollutants might be responsible for health effects attributed to the outdoor air pollutants. First attempts to evaluate the real human exposure to air pollutants were carried out in 1963 [19]. It was attempted to correlate the CO exposure of two subjects, a smoker and a nonsmoker, over 24 hours in various places and during various activities, measuring carboxyhemoglobin levels simultaneously. However, no one seemed to be ready to grasp entirely these considerations at that time. It has been also attempted [20] to assess the total workers exposure to lead by taking annual means of outdoor lead levels as a measure of their non-occupational part of exposure, aiming at obtaining

a general relationship between lead in air and lead in blood.

Investigations on indoor-outdoor air quality relationships were also carried out [21]. It has been noticed that "the exposure of a person to air pollutants does not stop as soon as he enters an enclosed space". In spite of the quoted findings and statements, in the papers on exposure monitoring presented at the International Symposium on Recent Advances in the Assessment of the Health Effects of Environmental Pollution in Paris in 1974 and in the discussion that followed, the idea still prevailed of the outdoor monitoring network approach offering solutions for improving 'exposure assessment' such as more outdoor stations, more elaborate instruments, more meteorological measurements for calculating dispersion models, siting the instruments relative to the outdoor emission sources, etc. It was very difficult to change the traditional beliefs, established over many years. A turning point in human exposure assessment philosophy was finally reached at the International Conference on Environmental Sensing and Assessment in Las Vegas in 1975 where a critical appraisal was made of air pollution measurements carried out in the past with the aim to relate them to health effects in order to develop air quality standards. It became obvious that measurements made at monitoring stations, giving levels and trends of air pollution outdoors on which air quality preservation and control policy in an area were based, explain only a small part of actual human exposure. This is due to the fact that most people living in urbanized areas spend on the average more than 90% of time indoors and move from one place to another. A further point was that people are exposed simultaneously to more than one pollutant. Finally many toxic materials reach the human body through more than one route.

Evaluation of indoor air pollution problems requires an understanding of several factors, including [22]:

- the source of the indoor pollutants;
- emission characteristics of the source;
- air exchange between the building and the outside;
- air movement within the building;
- interaction of the pollutant with surface within the building (i.e. sink effects);
- chemical or physical interactions affecting the pollutant concentration.

The knowledge of these factors would allow investigators of 'sick buildings' to perform a systematic assessment of possible sources within the building and to determine their potential for causing the levels of pollutants measured within the buildings.

As an example, Table 1 lists indoor/outdoor concentration ratios of some substances, for randomly selected dwellings [14].

Indoor air quality was examined in some houses with and without internal sources by measurement of CO₂, suspended particles and NO₂ [23]. As for NO₂, elevated concentrations were detected in some houses without gas appliances, due to infiltration of outdoor NO₂. On the other hand, some gas heaters and gas stoves produced extreme values of NO₂ caused by an inadequate supply of fresh air and/or by an incomplete removal of flue gas.

Both particles and gases can contribute to corrosion

Table 1. Indoor/outdoor concentrations ratio of some substance for randomly selected dwellings [14]

Substance/group of substances	Ratio of concentrations indoors/outdoors	Remarks
Sulphur dioxide	≈ 0.5	
Nitrogen dioxide	≤ 1	
Carbon dioxide	2-5	NO ₂ source indoors
Carbon monoxide	1-10	
	≤ 1	
Suspended particles	1-5	CO source indoors
	0.5-1	excluding tobacco smoke
	2-10	including tobacco smoke
Formaldehyde	≤ 10	
Higher aliphatic HC	2-5	
Aromatic hydrocarbons	1-3	
Volatile halogenated HC	10-50	
Polychlorinated biphenyls	5-10	
Radon	up to 5	living rooms
	up to 10	basements
N-nitrosodimethylamine	≤ 1	excluding tobacco smoke
	< 1	including tobacco smoke

of metals indoors. There the accumulation of corrosion products and particles is continuously additive in the absence of cleaning. This contrasts with the outdoors situation, where rain and dew often rinse the corrosive water soluble substances from the surfaces [24]. For this reason indoor surfaces often bear higher concentrations of corrosive contaminants than many outdoor surfaces. However, even common experience shows that indoor corrosion rates are usually less than outdoor rates. The reduced rates are largely attributable to the lower relative humidity (RH) typically encountered indoors.

Indoor air quality and health in two office buildings with different ventilation systems has been studied [25]. Table 2 presents a comparison of the prevalence of health symptoms between the two offices. It shows that significantly more workers in the air conditioned building complained of problems of sleepiness, difficult concentrating, cold/flu-like symptoms, eye focusing problems and nasal irritation.

The following part of the paper contains a discussion of the principal indoor air pollutants and basic sources of their emission.

3. VOLATILE ORGANIC COMPOUNDS (VOCs) IN INDOOR AIR

In the 1970s a sharp increase in nonspecific complaints by office workers and school children was noted in several countries. As the symptoms seemed to result from exposure in schools or office buildings, the term 'sick building syndrome' was applied to them. Although the cause of sick building syndrome remains unknown, organic chemicals are highly suspect. Many chlorinated solvents, light aromatic hydrocarbons, and pesticides, are known to have effects (at high concentrations) similar to sick building syndrome.

The Sick Building Syndrome (SBS) is one of many terms used by occupants to describe symptoms of reduced comfort or health related to the indoor atmospheric environment. Many poorly defined synonymous

terms, including the 'sick buildings', have been used by different investigators for these buildings. A more systematic grouping of the problem buildings is suggested [26]. Sick Building Syndrome almost unheard of 20 years ago, now commands attention in a number of different disciplines, including epidemiology, chemistry, engineering, occupational hygiene and medicine [27]. SBS consists of a group of non-specific symptoms, including, according to a World Health Organization (WHO) definition, any of the following: eye, nose or throat irritation, a sensation of dry mucous membranes, dry skin, rash,

Table 2. Comparison of health symptoms for workers in offices with different ventilation systems [25]

Symptom	Air conditioned offices (% usually)*	Naturally ventilated offices (% usually)*
Sleepiness	68	49
Headache	68	62
Fatigue	66	62
Difficult concentration	54	38
Cold/flu symptoms	52	37
Eye irritation	50	48
Sore throat	47	36
Backache	43	44
Eye focussing	43	31
Nasal irritation	42	30
Neckache	39	36
Cold extremities	37	37
Tension	35	31
Depression	29	30
Skin dryness	24	13
Muscular aches	22	17
Dizziness	22	19
Weakness	22	11
Nausea	19	8
Respiratory problems	10	10
Chest tightness	10	9
Fever	8	1
	(n = 489)	(n = 97)

* % usually consists of % always + % sometimes.

mental fatigue, headaches, nausea, dizziness, coughing, hoarseness, wheezing or itching and unspecific hypersensitivity reactions. The natural history of SBS is unclear. The duration or detectability of preclinical SBS is unknown. The incidence of SBS is also unknown. The WHO estimates that this illness will appear in 30% of all new buildings and afflict 10–30% of their occupants [27]. The Swedish government estimates that as many as two million out of a total population of eight million may be affected. The equivalent figure for Canada would be approximately six million people. An estimate of workplace prevalence in Canada suggests that as many as a half million may be affected.

There are three main reasons of SBS [27]:

- biological causes (it has been demonstrated that Legionnaires Disease, Pontiac Fever and Pittsburgh Pneumonia are caused by species of the Legionella bacterium and Actinomyces—bacterium is one of a number of microorganisms involved in humidifier fever);
- chemical causes (formaldehyde and VOCs are capable of provoking many symptoms of SBS);
- physical causes (indoor temperature, humidity, air velocity and air ionization).

For about ten years the emission of volatile organic compounds from building materials has been recognized as a source of indoor air pollutants and has been studied by several researchers [28]. The first paper on this topic was probably published in 1979 [28].

There is a wide variety of sources of VOCs in indoor air. In some cases, contributions from outdoor air can be an important component through leakages and makeup air in ventilation systems. Indoor sources vary tremendously depending on the nature of the facility and are too diverse for any simple classification. Some broad categories may be identified [29]:

- Combustion. Gas-fired appliances and kerosene heaters are typically not vented and can contribute to indoor levels of VOCs;
- Smoking. Smoking is probably the most visible source of indoor air pollutants. A number of heavy organics, such as naphthalene, aniline, pyridine and acrolein are emitted along with noxious gases;
- Building materials. Formaldehyde from insulation applications is an important pollutant in this class. Emission rates of VOCs from materials of construction are of particular importance;
- Office machines. Photocopying machines, printers and others machines in use in office environments may be significant sources of VOCs because of the nature of the chemicals needed for their operation;
- Other sources. Termicides, cleaning compounds, adhesives, furnishings, paints and human activities are all potential sources of toxic pollutants.

Generally it can be stated that:

- an extremely wide variety of organic compounds is found in the indoor environment;
- the range of measured concentrations between different organic compounds is extremely wide, often two or more orders of magnitude. The range of con-

centration for a specific compound can vary widely between measurements;

- in many cases the concentrations of specific organic compounds exceed the outdoor concentration, indicating that the source of the compound is indoors;
- the sources of organic compounds are quite numerous within any indoor environment and vary depending on the type of building studied.

Table 3 lists some specific indoor sources of organic vapours [16, 29–34]. Various studies of indoor quality (IAQ) have identified more than 250 different organics at a level exceeding 1 ppb. Many hundreds of additional compounds undoubtedly exist at lower levels. Houses and buildings have their own specific 'fingerprints' independent on the location and time of sampling [40]. Within the same building the fingerprints of air sampled at different locations were found to be similar, except locations near particular VOCs sources such as a cooking stove in the kitchen, paints and solvents in the basement or deodorants in the washroom. Fingerprints at different times of the day, on different days and in different seasons were also similar, although the total amount of VOCs varied by the amount of fresh air intake into the building. In many office buildings and in one apartment house a specific fingerprint appeared repeatedly.

In 1980 U.S. EPA recognized the need to organize the available data into a single cohesive format so that their quantity, quality and significance could be assessed. A VOC national ambient data base was first prepared in the early 1980s and published by EPA. In 1986, when the data base needed to be expanded to include the large amount of ambient VOC data published since 1980. EPA contracted to upgrade and expand the earlier study. Concurrently, powerful personal computers (PCs) that could be conveniently used for such data bases became available. As a result of this study outdoor, as well as indoor data are now available in a unified form for PCs and can be used to screen for many environmental problems, including exposure to VOCs [12]. The final data base includes a total of 320 VOCs with 261 VOCs measured in the outdoor air and 66 measured indoors. The entire data base contains about 175,000 records occupying about 19 megabytes of storage. The diskettes include software utilities designed to facilitate searching, sorting, editing and analysis. Information regarding chemical names, common names, formulas, molecular weights and conversion factors are also included in supporting files. The 122,820 records of outdoor air data for 261 VOCs represent 300 cities from 42 states. The indoor data base is much smaller than the outdoor base at 52,810 records; it represents 30 cities from 16 states. Figure 1 [12] provides the distributions of the median concentrations of VOCs contained in the data base for both outdoor and indoor environments. It is evident that we are dealing with very low concentrations. 50% of the chemicals present fall in the 0.01–1.0 ppb concentration range. In only 10% of the cases for outdoor air and 25% of the cases for indoor air did the median concentration exceed 1 ppb.

In other investigations [11] carried out indoors in large metropolitan areas using grab sample collection techniques, over 250 different chemical compounds are ident-

Table 3. Specific indoor sources of organic vapours [16, 29-39]

Compound	Source material(s)
Paradichlorobenzene	moth crystals, room deodorants
Methylene chloride	paint removers, solvent usage
Formaldehyde	pressed wood products, foam
Styrene	insulation, textiles, disinfectants, plastics, paints
Acetaldehyde	glues, deodorants, fuels, preventives, mold growth on leathers
Acrolein	component of oak wood, by-product of the combustion of wood, kerosene and cotton
Toluene diisocyanate	polyurethane foam, aerosols
Phthalic acid anhydride	
Trimellitic acid	
Triethylene tetraamine	
Benzyl chloride	epoxy resins
Benzal chloride	
Ethylene oxide	vinyl tiles plasticized with butyl benzyl phthalate
Amines (cyclohexylamine, diethylaminoethanol, morpholine)	sterilizers (hospitals)
Volatile amines	volatilize with the steam boiler systems (corrosion inhibitors of steam pipes and other equipment)
Benzene	putrefactive degradation of casein-containing building materials
Tetrachloroethylene	smoking
Chloroform	wearing or storing dry-cleaned clothes
1,1,1-trichloroethane	chlorinated water (showering, washing clothes, dishes)
Carbon tetrachloride	wearing or storing dry-cleaned clothes, aerosol sprays, fabric protectors
Aromatic hydrocarbons (toluene, xylenes, ethylbenzene, trimethylbenzenes)	industrial strength cleaners
Aliphatic hydrocarbons (octane, decane, undecane)	paints, adhesives, gasoline, combustion sources
Terpenes (limonene, α -pinene)	paints, adhesives, gasoline, combustion products
Chlorpyrifos (Dursban)	scented deodorizers, polishes, fabrics, fabric softeners, cigarettes, food, beverages
Chlordane, heptachlor	household insecticides
Diazinon	termicide
PCBs	termicide
PAHs	transformers, PCB-containing fluorescent light ballasts, ceiling tiles
Polychlorinated dibenzofurans (PCDFs)	combustion products (smoking, woodburning, kerosene heaters)
Polychlorinated Dibenzo-p-dioxins (PCDDs)	incinerator stack emission
Acrylic acid esters, epichlorohydrin, vinyl chloride	contamination of pentachlorophenol used as wood preservative monomers may escape from polymers
Alcohols	aerosols, window cleaners, paints, paint thinners, cosmetics and adhesives
Ketones	lacquers, varnishes, polish removers, adhesives
Ethers	resins, paints, varnishes, lacquers, dyes, soaps, cosmetics
Esters	plastics, resins, plasticizers, lacquer solvents, flavors, perfumes
Pentachlorophenol	wood preservative agent
Lindane	wood preservative formulations

ified or tentatively identified. Nearly all chemical compound classes are represented with one noticeable exception: organic acids. The explanation for this is that the acids were probably present at low concentrations or not at all due to their high solubility in water. Secondly, the acids are not very volatile and their high polarity would cause them to be held tenaciously by most surfaces with which they come in contact. All alkanes from C_3 to C_{16} were detected. Some of the more unusual compounds found were: ketene, a severe pulmonary irritant derived from the thermal decomposition of acetone, acetonitrile, acrylonitrile, butylnitrile and other nitrogen

containing compounds, all of which are poisonous; carbon disulphide, a neurotoxin; benzene, trichloroethylene, tetrachloroethylene, styrene and mono- and dichlorobenzene, all suspected carcinogens.

Table 4 [32] presents volatile organic concentrations in indoor air in Germany and the Netherlands compared to personal exposures in the U.S.A.

The amount of the emitted compounds depends obviously on the age of a building. A new office building had concentrations of aromatic and aliphatic hydrocarbons that were two orders of magnitude greater than the concentrations observed five months later [15]. Half-lives of

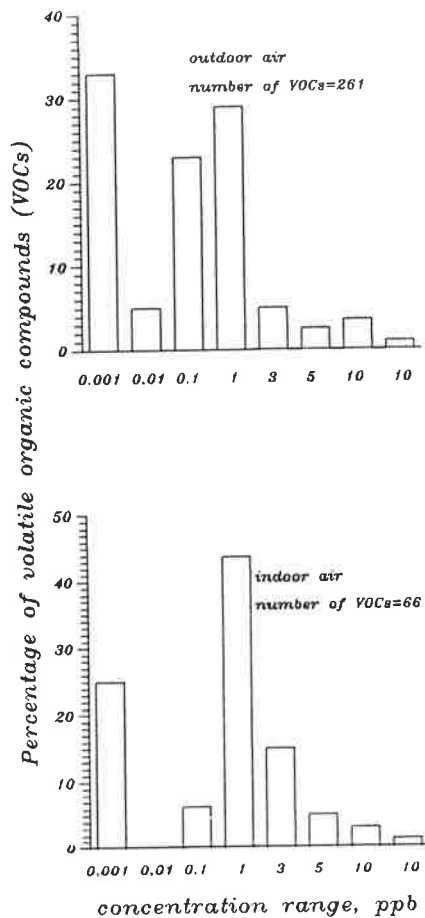


Fig. 1. Distributions of the median concentrations of the VOCs contained in data base for both outdoor and indoor environments [12]. 0.001 represents the range from 0.000 to 0.001. 0.1 represents the range from 0.001 to 0.01, and so forth.

many organics occurring in indoor air ranged from 2 to 8 weeks. Thus the time required for this building to approach the outdoor concentration would range from 3 to 12 months. This finding supports the Scandinavian decision to require 100% outdoor air as makeup air for the first 6 months of a new building's life. Table 5 lists the chemicals present at elevated levels in a new office building [15]:

Chemicals used as termiticides can also be a source of indoor air pollution [33]. In the U.S.A it has been decided to stop the production of chlordane and heptachlor for termite control after 15 April 1988. They recognized the concern regarding the use of organochlorine insecticides to protect buildings from termite damage. This concern regarding the potential effects on human health through the levels of termiticides in indoor air in dwellings previously treated with these compounds has continued to increase during the three decades that chlordane and heptachlor have been used for termite control.

Both chlordane and heptachlor are insoluble in water and both are considered moderately volatile. The precise mode of their action in biological systems is not known. In humans acute intoxication signs are primarily related to the central nervous system. The interest concerning the use of these chemicals as termiticides increased significantly during the 1970s energy crisis due to their levels in indoor air and the reduction of air exchanges in buildings. Termiticides use and indoor air quality has been very extensively discussed in a recently published paper [33].

Human environment saturates gradually with plastic articles. The amount of objects of a synthetic origin in dwellings, nurseries, schools, offices, etc., continuously increases. Floors, wall-papers, furniture, carpets and curtains, and often also window and door frames are made of plastics. In spite of numerous advantages, plastics

Table 4. Volatile organic concentrations in indoor air in Germany and the Netherlands compared to personal exposures in the United States [27]

Compounds/class	Arithmetic mean		Median Nethl.	Maximum		
	F.R.G.	U.S.A.		F.R.G.	U.S.A.	Nethl.
CHLORINATED						
chloroform	nm	3	nm	nm	210	nm
1,1,1-trichloroethane	9	52	nm	260	8300	nm
trichloroethylene	11	6	< 2	1200	350	106
tetrachloroethylene	14	16	< 2	810	250	205
p-dichlorobenzene	14	25	1	1260	1600	299
AROMATIC						
benzene	10	16	6	90	510	148
styrene	2	3	nm	41	76	nm
ethylbenzene	10	9	2	160	380	138
o-xylene	7	9	10	45	750	753
m + p-xylene	23	26		300	3100	
toluene	84	nm	35	1710	nm	2252
ALIPHATIC						
octane	5	4	1	92	122	533
nonane	10	12	4	140	177	407
decane	15	6	10	240	161	905
undecane	10	8	6	120	385	445
dodecane	6	4	2	72	72	118
TERPENES						
α -pinene	10	4	nm	120	208	nm
limonene	28	43	30	320	2530	773

nm—not measured.

Table 5. Volatile organics in a new office building [15]

Chemical	Concentration ($\mu\text{g}/\text{m}^3$)			
	July	Indoors September	December	Outdoors all trips
ALIPHATICS				
Decane	380	38	4	2
Undecane	170	48	13	1
Dodecane	47	19	5	0.2
AROMATICS				
<i>m+p</i> -Xylene	140	19	9	2
<i>o</i> -Xylene	74	8	4	1
Ethylbenzene	84	6	5	1
Benzene	5	7	7	3
Styrene	8	7	4	1
HALOCARBONS				
1,1,1-Trichloroethane	380	100	49	6
Tetrachloroethylene	7	2	3	1
Trichloroethylene	1	38	27	0.3
Carbon Tetrachloride	1	1	1	1
Chloroform	1	2	18	6
<i>p</i> -Dichlorobenzene	1	1	1	ND
Total of 14 organics	1300	326	150	25

reveal also certain drawbacks, e.g. low thermal resistance and chemical changes induced by air and light. Oxygen combined with solar radiation induces thermooxidative destruction of macromolecules and their decomposition accompanied by evolution of volatile products [41]. Practically all plastics undergo this process during normal use. There are hypotheses that thermooxidative decomposition of plastics proceeds as radical chain reactions with degenerated chain branchings. Volatile products are formed mainly as a result of decomposition of primary oxidation products, viz. hydroperoxides. The composition of volatile products can be very diversified and depends on the kind of plastic, the applied additives and the conditions of the oxidation process. Apart from the thermooxidative decomposition products, also other volatile chemicals can evolve, viz. substances introduced during the production and processing (e.g. solvents). Evolution of volatile chemicals from plastics even at ambient temperature causes a pollution of microenvironments of dwellings, rest-rooms, offices, etc. The problem of investigation of volatile substances evolving from plastics arose in the late 1960s. First investigations in this field have been carried out in relation to space research programme and the construction of nuclear submarines, where humans have to remain for prolonged periods in small areas without any contact with the surrounding environment. In Poland the research on the evolution of toxic substances from plastics and on the pollution of indoor air started in the early 1970s [42]. In order to determine the chemical composition and the amount of substances emitted from the particular materials, they are examined in tightly sealed containers. Temperature is the main factor determining the amount of substances emitted from the particular materials indoors. Under normal conditions the temperature of indoor areas ranges from 20 to 25°C, and it seldom exceeds 30°C. However, plastic can be sometimes locally subject to much higher temperatures, reaching even 90°C in the vicinity of central heaters, electric heaters, etc. Lab-

oratory investigations carried out at constant temperature and under precisely determined experimental conditions allow a comparison of various plastics with respect to the amount of noxious substances emitted to the environment. For example, Table 6 [41] presents the concentrations and the level by which they exceed the Threshold Limit Values of volatile substances emitted from a particle board covered with a nitrocellulose varnish. Table 7 gives the same values for substances emitted from a particle board covered with a polyester varnish.

Table 8 [43] summarizes the emission rates from 31 materials collected from a new office building. Although some solvent-based materials were the highest emitters, as might have been expected, other solvent-based materials such as linoleum tile cement and joint compound emitted none of target VOCs. Some solid materials, particularly rubber and vinyl molding, linoleum tile and telephone cable also emitted significant quantities of the target VOCs [43]. Common emissions included xylenes, ethylbenzene, trimethylbenzenes, ethyltoluenes, decane, undecane and dodecane. 24 of 32 target chemicals were emitted by at least one material; and 24 of 31 materials emitted at least one target chemical. Some chemicals such as xylenes and trimethylbenzenes were emitted by as many as 18 or 19 materials, while some materials such as latex caulk and cove adhesive emitted as many as 17 of the target chemicals. This finding confirms the findings of an earlier EPA study [44].

In Table 9 the emission rates from particle board/carpet are given [45]. The sum of the quantified compounds represents > 80% of the total FID response expressed in area counts. In addition to the quantified compounds, 18 additional compounds have been identified, whereas 13 further compounds could not be identified. Thus the total number of compounds emitted from this material and observed under the experimental conditions is 53. Table 10 presents emission rates from gyp-

Table 6. Concentrations and the level by which they exceed the TLV of volatile organic substances emitted from a particle board covered with a nitrocellulose varnish [41]

Determined compound	Concentrations in air [mg/m ³]			Fold of TLV		
	Temperature [°C]			Temperature [°C]		
	20	30	60	20	30	60
Acetone	< 1	< 1	< 1	< 3	< 3	< 3
Formaldehyde	21.7	30.5	292.5	434	610	5850
Methanol	112	364	2750	224	728	5500
Benzene	< 0.5	0.5	13.9	< 7	7	199
Toluene	15.1	35.9	1620	75	180	3100
Xylene	< 1	2	22.7	< 10	20	227
Carbon monoxide	< 5	10	50	< 5	10	50
Sum of TLV fold				758	1558	19,929

sum board/wall paper [45]. The peculiarity in these results is the unexpected relatively high emission of formaldehyde. The emission is related mainly to the paper-glue layer. In addition to the quantified compounds, a further 13 compounds have been identified [45].

Toxicity of volatile organic compounds present indoors has been extensively discussed in a paper published in 1981 [16].

Many investigations of personal exposure suggest that common activities such as smoking, driving, visiting dry cleaning shops, using room air deodorizers and even using hot water can increase personal and indoor air exposures and the resulting body burden for many VOCs. However, these studies were not designed to determine the magnitude of the increases. Therefore a controlled study was carried out [31] to determine the effects of each of approximately 25 activities on personal exposure, indoor air concentrations and exhaled breath. It has been established that some of the activities increased the exposures by very large amounts. Table 11 lists these activities [31].

Two types of health effects may be associated with the elevated concentrations of organic gases and particles

[15]. First, chronic health effects, including cancer, may be caused by long-term exposure to some of these compounds. Benzene is a recognized human carcinogen; chloroform, trichloroethylene, tetrachloroethylene, carbon tetrachloride and *p*-dichlorobenzene are animal carcinogens and therefore possible human carcinogens. The second type of health effect is acute, consisting of eye, nose and throat irritation, headaches, neurotoxic symptoms such as depression, irritability and forgetfulness, and general malaise—a group of symptoms often described as the sick building syndrome (SBS). Although the cause or causes of SBS are unknown, several hypotheses implicate low-level concentrations of VOCs as a possible cause [46]. The economic effect of SBS may be considerable if a large proportion of workplaces are affected. One nationwide survey in the U.S. has reported that 25% of American workers feel the quality of air at their workplace affects their work adversely. If so, economic production may be lowered by a significant amount.

The equipment and the procedure employed for the qualitative and quantitative determination of volatile organic compounds emitted from samples of building

Table 7. Concentrations and the level by which they exceed the TLV of volatile organic substances emitted from a particle board covered with a polyester varnish [41]

Determined compound	Concentration in air [mg/m ³]			Fold of TLV		
	Temperature [°C]			Temperature [°C]		
	20	30	60	20	30	60
Acetone	15	21.4	371.7	43	61	1062
Methyl ethyl ketone	< 1	1	28.4	< 1	3	95
Formaldehyde	13	19.5	250	260	390	5000
Methanol	77	219	1360	154	438	2720
Buthanol	0.6	1.6	39.7	1	4	79
Benzene	< 0.5	0.5	16.2	< 7	7	231
Toluene	22.8	29.6	1458.1	114	148	7290
Xylene	< 1	2.3	187.4	< 10	23	1874
Styrene	< 0.2	1.5	32.7	< 10	75	1635
Buthyl acetate	< 1	11.6	399.6	< 10	116	400
Carbon monoxide	< 5	10	25	< 5	10	25
Sum of TLV fold				615	1275	20,411

Table 8. Emission rates from 31 materials collected from a new office building [43]

Sample*	Emission rate ($\mu\text{g}/\text{m}^2 \cdot \text{h}$)			
	Aliphatic and oxygenated aliphatic hydrocarb.	Aromatic hydrocarb.	Halogen. hydrocarb.	All target compounds
Cove adhesive	*	*	*	> 5000
Latex caulk	252	380	5.2	637
Latex paint (Glidden)	111	52	86	249
Carpet adhesive	136	98	†	234
Black rubber molding	24	78	0.88	103
Small diameter telephone cable	33	26	1.4	60
Vinyl cove molding	31	14	0.62	46
Linoleum tile	6.0	35	4.0	45
Large diameter telephone cable	14	20	4.3	38
Carpet	27	9.4	—	36
Vinyl edge molding	18	12	0.41	30
Particle board	27	1.1	0.14	28
Polystyrene foam insulation	0.19	20	1.4	22
Tar paper	3.2	3.1	—	6.3
Primer/adhesive	3.6	2.5	—	6.1
Latex paint (Bruning)	—	3.2	—	3.2
Water repellent mineral board	1.1	0.43	—	1.5
Cement block	—	0.39	0.15	0.54
PVC pipe	—	0.53	—	0.53
Duct insulation	0.13	0.15	—	0.28
Treated metal roofing	—	0.19	0.06	0.25
Urethane sealant	—	0.13	—	0.13
Fiberglass insulation	—	0.08	—	0.08
Exterior mineral board	—	0.03	—	0.03
Interior mineral board	—	—	—	—
Ceiling tile	—	—	—	—
Red clay brick	—	—	—	—
Plastic laminate	—	—	—	—
Plastic outlet cover	—	—	—	—
Joint compound	—	—	—	—
Linoleum tile cement	—	—	—	—

* Emission rate for cove adhesive is a minimum value; sample was overloaded. It is estimated that cove adhesive is one of the highest emitters of volatile organics.

† No detectable emission.

and furnishing materials are described [45, 47]. The equipment includes two small test chambers (0.45 m^3) with accurately controlled temperature, humidity and air flow rate, and instrumentation for sampling and analysis. To find quasi-steady-state emission conditions, the procedure includes the determination of the time profiles of the organic compounds concentration, which develop after the introduction of the sample into the chamber. A best-fitting, double exponential equation is used for this purpose. Similar approach is reported also in other papers [48]. The only difference is that exposure chambers of a much larger volume, reaching even 1.9 m^3 , are used.

3.1. Formaldehyde

Formaldehyde, an important industrial chemical, is a well-known irritant and a suspect carcinogen [50]. Occupational exposure occurs in the range 0.1–5 ppm formaldehyde in air. People are also exposed to formaldehyde in their homes. Formaldehyde is a large volume chemical used in the manufacture of building materials such as particle board, fibreboard, plywood (pressed wood products) made of urea-formaldehyde bonding resins [50–54] and urea-formaldehyde foam (UFF) insulation [52]. Typically 0.01–0.1 ppm have been found in conventional housing, although the 'normal'

level of formaldehyde in private residences is largely unknown [55]. The odour threshold has been determined to be about 0.05 ppm and pronounced sensory reactions to concentrations less than 0.3 ppm have been reported. There is a growing concern regarding the impact of formaldehyde emissions on indoor air quality. Table 12 summarizes the results of formaldehyde determination at various sampling locations [49]. Concentrations of formaldehyde indoors almost always exceed those outdoors, when both measurements are made simultaneously. Formaldehyde has been linked with the SBS, an increasing problem in connection with energy-efficient houses with reduced air-exchange rates. In recent years the importance of environmental parameters such as temperature and relative humidity on formaldehyde concentration in houses has been recognized [56]. Recent concern is due to the fact that exposure to low levels of HCHO may cause a severe allergic response in 4% to 8% of the population [57] and that it may be carcinogenic. The perceived need to protect residential indoor air quality by maintaining low concentrations of HCHO and other air pollutants can conflict with energy conservation goals. The controversy over the use of urea-formaldehyde foam insulation was an example of this conflict until the use of this material was banned by the US consumer

Table 9. Emission rates ($\text{mg m}^{-2} \text{h}^{-1}$) from particle board/carpet [45]

Compound	Mean	Std. deviation	(%)
Ethanol, 2-(2-butoxyethoxy)-, acetate	2.44	0.068	(2.8)
Acetone	0.51	0.0014	(0.3)
Acetic acid*	0.22	0.018	(8.2)
Ethanol, 2-(2-butoxyethoxy)-,	0.20	0.014	(7.3)
Formaldehyd†	0.077	0.0	(0.0)
Hexanal, 2-ethyl-	0.073	0.004	(5.3)
1-Butanol	0.069	0.0013	(2.0)
Hexanal	0.068	0.0	(0.0)
Toluene	0.061	0.00092	(1.5)
Acetaldehyd†	0.051	0.0	(0.0)
Butanal†	0.047	0.0013	(2.8)
Longifolene	0.038	0.0	(0.0)
Pentanal†	0.031	0.00049	(1.6)
Acetic acid, ethyl ester	0.025	0.0	(0.0)
Benzaldehyd†	0.024	0.00092	(3.8)
Formic acid, butyl ester	0.014	0.0	(0.0)
Caryophyllene	0.013	0.00014	(1.1)
Propanal†	0.011	0.00042	(3.8)
Octanal†	0.011	0.0013	(12.8)
α -Pinene‡	0.0068	0.00078	(11.5)
Acetic acid, 2-ethylhexyl ester	0.0067	0.00050	(7.4)
Heptanal†	0.0064	0.00092	(14.4)

* Determination carried out by ion chromatography 3 weeks later than the other compounds.

† Determination by HPLC.

‡ Estimated, because co-eluting with benzaldehyde.

product safety commission [58]. Oak Ridge National Laboratory (ORNL) derived an empirical formaldehyde emission-rate model that generalized Fick's Law model, predicting surface emission rates of pressed-wood products for various combinations of ambient temperature, RH and formaldehyde concentrations from knowledge of the surface emission rate under standard conditions [53].

Data listed in Table 13 illustrate the statement that the concentration of pollutants in indoor air can often exceed those in outdoor air [41]. The occupation period had been calculated from the moment of furnishing the rooms with furniture and other appliances. The dwellings and the offices were localized in new buildings. The measurements lasted for 4 hours. Before the measurements the indoor spaces remained unvented for 24 hours in order

Table 10. Emission rates ($\text{mg m}^{-2} \text{h}^{-1}$) from gypsum board/wall paper [45]

Compound	Mean	Std. deviation	(%)
Pentanedioic acid, bis(2-methylpropyl)ester	0.60	0.0011	(1.9)
Hexanedioic acid, bis(2-methylpropyl)ester	0.050	0.0024	(4.8)
Butanedioic acid, bis(2-methylpropyl)ester	0.018	0.00035	(2.0)
1-Propanol-2-methyl	0.0053	0.00023	(4.4)
Benzaldehyde	0.00047	0.00003	(6.0)
Formaldehyde	0.0088	0.00025	(2.9)

to establish equilibrium. The measurements of outdoor air were carried out in the vicinity of the examined buildings. Dwelling no. 1 was examined twice, after 4 months and 1.5 years of exploitation. The results obtained after 1.5 year exploitation are lower, even when a correction for the temperature difference is taken into account. This proves that the emission rates of toxic substances decrease in time. The effect is even more pronounced in the case of dwelling no. 2, where the formaldehyde measurements were carried out after 10 years of occupation. The measurements revealed that in the case of dwelling no. 1 even a slightly open window during the measurements caused only a minor decrease of the pollutants level. Table 14 shows some of the factors that may affect the offgassing of formaldehyde from wood products [16].

Apart from formaldehyde, also other carbonyl compounds have been found in indoor air. These compounds may be present in the air inside a building as a result of their generation indoors or by infiltration from outside. A summary of the tests carried out and carbonyls detected is given in Table 15 [49].

3.2. Environmental Tobacco Smoke (ETS)

Environmental Tobacco Smoke (ETS) is one of the most widespread and harmful indoor air pollutants. ETS comes from secondhand smoke exhaled by smokers and sidestream smoke emitted from the burning end of cigarettes, cigars and pipes. ETS is a mixture of irritating gases and carcinogenic tar particles. It is a known cause of lung cancer and respiratory symptoms, and has been linked to heart disease. Breathing in ETS is also known as 'involuntary' or 'passive' smoking [59].

In the United States, 50 million smokers annually smoke approximately 600 billion (american) cigarettes, 4 billion cigars and the equivalent of 11 billion pipesful of tobacco [59]. Since people spend 70–90% of their time indoors [8, 12, 59], this means that about 467,000 tons of tobacco are burned indoors each year. Because the organic material in tobacco does not burn completely, cigarette smoke contains more than 4700 chemical compounds, including carbon monoxide, nicotine, carcinogenic tars, sulphur dioxide, ammonia, nitrogen oxides, formaldehyde, radionuclides, benzene, vinyl chloride, hydrogen cyanide, arsenic and Respirable Suspended Particles (RSP). These chemicals have been shown in animal studies to be highly toxic. Many are treated as hazardous when emitted into outdoor air by toxic-waste dumps and chemical plants. There are 43 carcinogenic compounds in tobacco smoke. In addition, some substances are mutagenic, which means they can cause permanent, often harmful changes in the genetic material of cells. Higher levels of mutagenic particles are found in homes with ETS than in homes with wood stoves or in outdoor urban environments with numerous diesel trucks and buses. The effect of smoking on indoor air quality is also testified by the number of organic compounds in breath. Cigarette smokers breath levels of benzene and styrene are about 5–10 times the levels of nonsmokers or pipe or cigar smokers [31].

Due to the broad spectrum of compounds contained in ETS, its level indoors is determined on the basis of the level of a one particular compound, called tracer (or

Table 11. Activities resulting in increased exposures [31]

Activity	Chemical	Measured exposure ($\mu\text{g}/\text{m}^3$) ³
Painting and removing paint	<i>m+p</i> -Xylene	1200
	Ethylbenzene	450
	<i>o</i> -Xylene	400
	Decane	350
	Undecane	150
	Benzene	30
Use of engine cleaner	<i>m+p</i> -Xylene	1200
	Ethylbenzene	800
	<i>o</i> -Xylene	400
	Tetrachloroethylene	200
Dry cleaning	1,1,1-Trichloroethane	1000
	Tetrachloroethylene	50
Use of toilet bowl deodorizer	<i>p</i> -Dichlorobenzene	500
Use of liquid deodorizer	<i>p</i> -Dichlorobenzene	30
	<i>o</i> -Dichlorobenzene	30
Use of spray deodorizer	<i>p</i> -Dichlorobenzene	30
Washing dishes or clothes	Chloroform	30
Household cleaning	1,1,1-Trichloroethane	200
Smoking	Benzene	100
	<i>m+p</i> -Xylene	20
	Styrene	5
Occupation: Chemist	Undecane	250
	Decane	150
	<i>m+p</i> -Xylene	150
	Trichloroethylene	100
	1,1,1-Trichloroethane	100
	Chloroform	100
	Ethylbenzene	60
	<i>o</i> -Xylene	50
	Benzene	30
	Chloroform	100
Occupation: Lab technician		

marker). The following compounds are used as tracers: nicotine [60], solanesol [13], carbon monoxide [61], oxides of nitrogen [62], nitrosamines, aromatic hydrocarbons and RSP [63]. All of these tracers with the exception of RSP occur at extremely low concentrations, which makes their detection and quantification difficult, unreliable or very expensive. Although total RSP can be reliably determined, it too is not specific to tobacco smoke.

4. OTHER INDOOR AIR POLLUTANTS

4.1. Sulphur dioxide

It follows from the investigations [64] that the indoor SO_2 level in the center of Kraków (Poland) is much lower than in outdoor air. Table 16 lists the range of the determined levels of SO_2 in dwellings and outdoors, while Fig. 2 presents the fluctuations of mean monthly SO_2 concentrations within the measuring period (8 months) [64]. The indoor/outdoor ratios of maximal 30-minute, mean diurnal and mean monthly SO_2 concentrations are equal to 0.24, 0.44 and 0.24, respectively. Slightly smaller indoor/outdoor level differences have been found in other European cities [18, 65]. A decrease of the SO_2 concentration indoors is due to better mixing of air and to absorption of SO_2 by building materials and furnishing, which causes their accelerated destruction [66].

4.2. Nitrogen oxides

Investigations carried out in Kraków [64] revealed that mean indoor concentrations of nitrogen oxides were 1.6 times higher compared to outdoor values. Increased indoor levels of nitrogen oxides are due to combustion of gas [67, 68]. Smoking also increases the indoor levels of nitrogen oxides.

4.3. Carbon oxides

Increased indoor levels of carbon oxides (CO and CO_2) are due to any processes of burning, e.g. combustion of gas or cigarette smoking. In cases when garage is situated in the same building as the flat, carbon oxides migrate indoors together with exhaust gases. Carbon dioxide is an indicator of the general level of air pollution related to the presence of humans indoors.

4.4. Suspended particulate matter

It follows from the papers of many authors [18, 65] that indoor suspended particle concentrations are lower than outdoors. The indoor/outdoor concentration ratio ranges from 0.69 to 0.8. Different conditions of diffusion, sedimentation and coagulation of dust particles indoors favour their accelerated removal.

Asbestos in form of tiny fibers has been also found in indoor air. It originates from building and insulation materials.

Table 12. Formaldehyde concentrations in homes and offices [49]

Sample	Method	Formaldehyde conc.		Std. dev. (indoor data)	
		Outdoors ($\mu\text{g}/\text{l}$)	Mean indoors ($\mu\text{g}/\text{l}$)		
10 houses surveyed	DNPH	0.029	0.034	0.015	
	DNPH	0.020	0.057	0.029	
Winter					
Summer					
9 houses sampled on an ad hoc basis	DNPH	0.005	0.044	0.023	
Two homes for the elderly	DNPH	0.002	0.026	0.021	
	MBTH	0.007	0.045	0.042	
Multi-storey air conditioned A offices B	DNPH	< 0.003	0.023	0.008	
	DNPH	0.010	0.034	0.015	
	MBTH	0.02	0.04	0.01	
naturally ventilated offices (carpet) (sk) (d)	DNPH	—	0.109	—	
	DNPH	0.006	0.065	—	
	DNPH	0.01	0.013	—	
2°C	DNPH	< 0.003	0.056	0.033	
	MBTH	—	0.14	—	
	CA	—	0.04	—	
	10°C	DNPH	0.007	0.62	0.029
	10°C	MBTH	—	1.35	—
	20°C	DNPH	—	0.97	—
	20°C	MBTH	—	1.43	—
	20°C	CA	—	1.05	—
	MBTH	0.007	0.057 0.114 (UF)	0.051 0.121	
	CA	0.005	0.023 0.06 (UF)	— —	

4.
-benzothiazolone hydrazone.
dehyde.

Table 13. Results of determination of indoor concentrations of toxic substances [41]

Sampling site	Exploitation period (years)	Air temp. ($^{\circ}\text{C}$)	Humidity (%)	Conc. (mg/m^3)		TLV fold		Remarks
				HCHO	CH_3OH	HCHO	CH_3OH	
Dwelling I	0.3	24	45	0.322	0.78	6.4	1.6	Open window
	0.3	24	43	0.338	0.74	6.7	1.5	
	0.3	25	42	0.366	0.86	7.3	1.7	
	0.3	22	49	0.218	0.45	4.4	0.9	
Outdoor air	—	17	82	0.008	0.05	0.2	0.1	
Dwelling I	1.5	12	55	0.138	0.42	2.8	0.8	
	1.5	21	55	0.138	0.39	2.8	0.8	
	1.5	22	52	0.156	0.48	3.1	1.0	
Outdoor air	—	15	90	0.006	0.05	0.1	0.1	
Dwelling II	10	23	48	0.125	0.32	2.5	0.6	
	10	24	46	0.131	0.28	2.6	0.6	
Outdoor air	—	18	86	0.004	0.05	0.1	0.1	
Office	1	23	48	0.190	0.29	3.8	0.6	After 1 hour venting
	1	24	44	0.218	0.31	4.4	0.6	
	1	26	37	0.271	0.38	5.4	0.8	
	1	23	48	0.120	0.15	2.6	0.3	
Outdoor air	—	17	84	0.004	0.05	0.1	0.1	

Table 14. Factors influencing the liberation of formaldehyde from particle board, pressboard and plywood [16]

1. Free formaldehyde content in the adhesive
2. Moisture content of the glued wood chips or woods
3. Amount and type of hardener added
4. The amount of adhesive resin applied
5. Presence of other chemicals in the resin and product
6. Compression time and temperature used during the curing of the product
7. The exposed surface area of the panel in relation to the space and ventilation available in that enclosed space
8. Temperature and humidity of the product in relation to those of the immediate environment

4.5. Radon

Radon is a noble gas. It acts as gas indoors and in the ground. The gas is difficult to lock in or out and therefore exists nearly everywhere in higher or lower concentrations. Radon gas cannot be smelt by a human being and is invisible. It is soluble in water to some extent, at least in the sense that it can be transported by water from one place to another. The characteristics of noble gases means that radon is difficult to bind in a chemical compound and consequently is more difficult to detect.

The radiation from radon and its daughters produces a risk of lung cancer by inhalation of air with high radon and radon daughters concentrations over a long period of time. The time scale for cancer is about 25 years [69] at a radon daughter (RnD) activity of $400 \text{ Bq} \cdot \text{m}^{-3}$. This activity corresponds to about $2 \cdot 10^8$ radon daughter atoms per m^3 of air. This number is tremendously small in comparison with $2.5 \cdot 10^{25}$, which is the approximate number of air molecules in 1 m^3 of air at normal pressure and room temperature. The activity of $400 \text{ Bq} \cdot \text{m}^{-3}$ of RnD indoors is adopted as a level of health risk in Sweden [69]. It is estimated that about 40,000 houses in Sweden (2.5%) have RnD activities exceeding this level. It is difficult to calculate the risk of lung cancer from radon [70].

The radon isotope ^{222}Rn is the main or only constituent of indoor radon. This isotope is one of the elements of the uranium series. Both radon and some of its daughters are α -radioactive. The common isotopes of radon are ^{222}Rn and ^{220}Rn . ^{220}Rn is however prevented from spreading indoors or streaming from outside into a house by its short half-life of 54 s. The ^{222}Rn half-life is 3.82 d.

Household water is one of the sources of radon [69, 71, 72]. If the water comes from areas with enhanced uranium content in the soil or bedrock, radon may be transported by the water into the house. The half-life of the gas determines the possible distance of transport. The radiation damage is negligible if the water is consumed (for example, the maximum range of α -particles from radon or radon daughters in water is 30–70 μm). However, radon may be released when water is tapped [73]. Building materials are a second radon source [69, 71]. Light-weight (aerated) concrete may, at least in Sweden, contain uranous alum shale. Many houses in Sweden have negligible or reduced air exchange rates in order to minimize the costs of heating, especially in the winter season. This means an increased risk of high radon and radon daughter levels in houses built with light-

weight concrete. This building material may be used in outer and interior walls. Sometimes the material is crushed and used as a filling between the storeys. The emanation of radon gas from the light-weight concrete is affected by meteorological factors, like temperature changes, humidity and pressure drops [74]. A steady underpressure in the dwelling may facilitate the emanation of the gas. If the light-weight concrete is in pieces of suitable size, the emanation area is increased and it is more effective [75].

A third radon source is the ground beneath the house. The soil or bedrock then must contain enhanced amounts of uranium. In Sweden for example alum shale and some sorts of granites are the most common kinds of uranous rocks. There is a possibility for long distance transport of the gas from uranium deposits far beneath the ground level [76]. The radon gas is transported into the buildings by diffusion and streaming. The gas may pass into a building along the water or gas conduits, the sewers or the power supply cables. For houses without crawl space the cracks in the concrete mat are also ways of leakage into the house.

Health effects of inhaled radon which is known to cause lung cancer have been discussed previously [77]. The available information concerning the health effects of radon is extensively compared to many other environmental contaminants. Perhaps it is a case of too much information, because the range of detail and the completeness of the data render it often difficult to sort out information originating from studies involving different data gathering circumstances or where the data are in outright conflict. There is so much data that, in fact, different conclusions can be reached when different data sets are used. Widespread apathy appears to be the public's reaction to information on the health risks of radon [78]. This reaction is curious since the public health implications of this information seem to be serious. In the past several years numerous articles, papers and discussions in the media have focused on the health consequences of indoor air levels of radon and the US EPA estimates as many as 20,000 lung cancer fatalities may occur each year due to indoor air. Some examples of public reaction to radon are [78]: reluctance to mitigate the problem, forgetting to put out the testing device which a few have purchased, suspicion about the testing firms viability or competence, failing to relate housing prices and high radon levels and minimal and decreasing interest in services like testing and mitigation.

4.6. Heavy metals

Exposure to heavy metals has been known for many years to occur in the occupational area. The exposure of the non-working population, however, has only recently become a matter of concern due to a growing interest in the reasons for higher heavy metal levels in special population groups. Since one parameter indicating exposure is the metal concentration in blood, this parameter has been determined in various studies of the Federal Health Office of Federal Republic of Germany, in which the exposure of the population to heavy metals in the vicinity of secondary smelters and metal-processing plants was evaluated [79]. During these studies, it could be observed that house dust is a very good indicator for

Table 15. Possible sources of carbonyls [49]

Source type	Source description	Test	Carbonyls detected	Amount: total μg collected or $\mu\text{g}/\text{ml}$ product		
Combustion	Tobacco smoke	Burning of whole king size cigarette (test not representative of human smoking behaviour)	formaldehyde	57		
			acetaldehyde	717		
			acrolein	200		
			acetone/propanol	169		
			crotonaldehyde	48		
			butanal	NQ		
			2-methylpropanol	NQ		
			5-methylfurfuraldehyde	NQ		
			methyl vinyl ketone	24		
			butanone	23		
			diacetyl	NQ		
			Motor vehicle exhausts	Collection of 5 l air near tall pipe of petrol driven 1300 cc saloon car	formaldehyde	3.5
					acetaldehyde	8.6
					acrolein	0.4
furfuraldehyde	5.6					
propanal/acetone	2.4					
crotonaldehyde	2					
2-methylpropanal	NQ					
benzaldehyde	3.2					
Gas cooker	Sample of 30 l air from vent of domestic gas oven (excess carbonyls over control)	formaldehyde	4.2			
		acetaldehyde	0.3			
Perfumes	0.025 ml added to 20 ml DNPH (4 samples)	formaldehyde	1.6-80			
		acetaldehyde	0-63			
		benzaldehyde	0-1,355			
		acrolein	0-78			
Household products	Hair spray	0.2 ml added to 20 ml DNPH (2 samples)	acetaldehyde	58, 82		
	Air freshener spray	0.25 ml in 20 ml DNPH	anisaldehyde	NQ		
			methylglyoxal (glyceraldehyde)*	NQ		
	Insecticide spray	0.2 ml in 20 ml DNPH reagent	acetone/propanal	413		
			formaldehyde	28-800		
	Spray furniture polish	0.1 ml in 20 ml DNPH (5 samples)	none	none		
	Liquid floor polish	0.1 ml in 20 ml DNPH	none	340		
Nail varnish remover	0.4 ml in 20 ml DNPH	acetone	60			
Nail varnish	Headspace test using 60 l air and 1 ml varnish	formaldehyde	60			
Materials	Particle board 15 mm thick	Headspace test using 30 l air over 5 x 5 cm sample	formaldehyde	93		
			acetaldehyde	0.4		
	Urea formaldehyde foam cavity wall insulation (sample taken from building)	Headspace test using 30 l air over 5 x 5 x 5 cm block of foam	formaldehyde	55		
			acetaldehyde	2.4		
	Textiles used for curtaining	Headspace test using 60 l air and 10 x 10 cm samples (3 samples A, B, C)	formaldehyde	A 59 B 24 C 1		
	Carpets both wool and man-made fibre	Headspace test using 60 l air and 25 cm ² sample (4 samples A, B, C, D)	formaldehyde	A none B none C none D none		
Paint (alkyd gloss thinned with white spirits)	Headspace test using 30 l air and 400 cm ² film of alkyd gloss	Acetaldehyde	1			
		acetone/propanal	2.3			
		butanone	7			
		C ₅ ketone	NQ			
		C ₆ ketone	NQ			

NQ—Not quantified
*—probable identity.

Table 16. Indoor and outdoor SO_2 concentration range ($\mu\text{g}/\text{m}^3$) (Kraków—city center). Measurement period: July 1986–February 1987 [64]

Concentration	Indoors	Outdoors
30-minute	nd*–165.0	5.0–758
mean diurnal	nd*–170.0	5.0–380.0
mean monthly	2.1–49.7	9.7–204.4

* not detected.

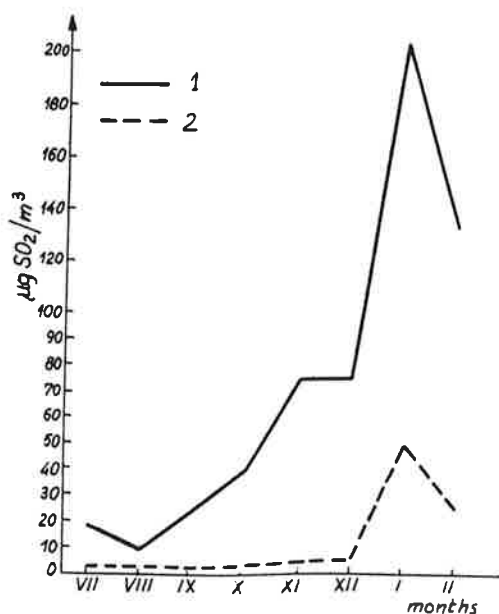


Fig. 2. Mean monthly outdoor and indoor SO_2 concentrations [50]. 1—outdoors; 2—indoors.

characterizing the exposure of population groups. It was found for example that the blood lead level of children was elevated in those houses where one member of the family was working at a smelter. This apparently resulted in the introduction into the home of metal-laden dust fixed on clothing [80, 81].

4.7. Microorganisms

Most modern commercial, industrial and institutional buildings of any size incorporate mechanical systems for the supply and distribution of fresh air which may be filtered, heated or cooled, and humidified as required. Mechanical extraction and/or filtration systems may also be used to control the air quality by the removal of atmospheric contamination. These and the water distribution network form the contemporary building service system. Such building service systems and cooling towers/evaporative condensers used in industry sometimes afford favourable conditions for growth and dissemination of ubiquitous organisms (bacteria, fungus spores). When such microorganisms are pathogenic or allergenic and are disseminated as aerosols, human respiratory ailments, such as Legionellosis, humidifier fever and hypersensitivity pneumonitis can result. The incidence of such illnesses has been reported and the circumstances in which the causal organisms can survive or multiply has been described [82]. Other important

sources of microorganisms and allergens are human beings (bacteria, viruses), small domestic animals and indoor plants (fungus spores). House dust and aerosols are usually the carriers of these species in indoor air [14]. Strategies for sampling airborne biogenic contaminants including fungi, bacteria, viruses and protozoa should include specific considerations for each group and very often for different species within these groups [24]. The determination of target pollutants and sampling strategy is based on preliminary investigation of the indoor environment by a walk-through inspection and clinical, epidemiological and immunological features of health effects. The principal sampling techniques are based on sedimentation, filtration, impingement, precipitation, centrifugal separation and impaction.

5. METHODS OF ELIMINATION OF INDOOR AIR POLLUTANTS

Taking into account the harmfulness of indoor air pollutants, it is crucial to find a method enabling at least a complete removal, then at least a significant reduction of their level. Four basic groups of methods can be mentioned herein [29]:

- Ventilation. Increasing the ventilation rate is one of the methods that have been proposed for indoor air pollution control—another instance of the "dilution is the solution to pollution" theory. Unfortunately, increased ventilation rates can lead to increased energy usage, making these an economically unattractive option.
- Material/product selection. The levels of volatile organic vapours in the indoor environment can be affected by the selection of materials and products. Most modern products have not been sufficiently characterized to allow such selection to be made.
- Material/product use. The manner in which products are used can impact on indoor organic vapour concentration. Emissions of formaldehyde from pressed wood products decline with time, thus curing or conditioning of such products prior to installation would reduce emissions. Solvent-containing materials (e.g. paints, adhesives, caulks, paint removers or wood preservatives) should be used in well ventilated areas. Manufacturer's instructions should be followed. Some activities such as hobbies, woodworking and paint stripping which use high-emission products should be isolated and separate exhaust fans provided. Solvent and solvent-containing products should be stored in airtight containers; outside storage is preferred.
- Other methods. The following can be mentioned:
 - Building 'bake out', the process by which newly renovated buildings are heated and ventilated prior to occupancy;
 - formaldehyde removal by fumigation.

Air tightness, air infiltration and indoor air quality in different houses have been measured [84, 85].

It is apparent from the above discussion that practical methods need to be developed for the removal of organic vapours from indoor air environments. Adsorption, absorption, incineration and catalytic conversion are removal techniques for pollutant gases. All have been

strated applicability in conventional pollution control applications. A recent study reports on a low-temperature catalysts used in room air filtration device. However, adsorption on activated carbon seems to be the most popular technique currently in use for indoor applications. A review [86] discusses in detail the applicability of carbon adsorption to pollution control.

A practical strategy is outlined for investigating office environments in which the occupants are complaining about the indoor air quality and where traditional industrial hygiene TLVs cannot cope [87]. In such situations the available budget, time for conducting an investigation, and the monitoring resources are often quite limited. Attention focuses on ventilation, microorganisms and VOCs. Ensuring proper functioning of the air handling unit is essential. Simple procedures are given for determining ventilation needs by measuring CO₂ concentrations. Complaints should be minimal if the fresh air supply is at least 10 dm³/s per occupant and the CO₂ concentration remains below 1000 vpm [87].

6. SAMPLING AND ANALYSIS OF AMBIENT AND INDOOR AIR

The objectives of ambient and indoor air analyses are to measure concentration levels of pollutants, identify their sources and control the compliance with air quality standards and guidelines. Analytical results depend mainly on three factors [88]:

- the sampling procedure,
- the analytical procedure,
- the sampling strategy.

The importance of sampling strategy is sometimes largely underestimated. Besides the selection of sampling site, both frequency and duration of sampling will have an important influence on the reported result.

A serious obstacle to investigators of pollutants in indoor environments has been the lack of simple, accurate and inexpensive systems for determining the concentrations of those pollutants in air. At present, most sampling involves the use of water contained in bubblers or impingers, filters, sorbent tubes and pumps for sampling [89, 90]. Passive sampling (by permeation or diffusion) is ideal for this work [91]. In recent years diffusive sampling has been recognized as an efficient alternative to pumped (active) sampling in occupational and indoor hygiene. Recently diffusive samplers have been used for example for monitoring ambient and indoor concentrations of organic vapours, formaldehyde, nitrogen dioxide [92, 93] and heavy metals [79].

Gas chromatography-mass spectrometry (GC-MS) technique has now become an important analytical tool in environmental monitoring of organic substances. Several reports on the application of the GC-MS technique for the analysis of atmospheric air samples both ambient and indoor are found in recent literature [94].

The development of still more sensitive methods of analysis of atmospheric pollutants will for sure enable the detection and determination of other, yet unknown indoor air pollutants.

7. IAQ CONTROL IN POLAND USING GDAŃSK AS AN EXAMPLE

Indoor air quality measurements started in the Tricity (urban agglomeration comprising three cities—Gdańsk, Gdynia and Sopot in northern Poland) in 1973. The direct reason for them were numerous complaints of the occupants about noxious odours in lodgings. The evaluation has been carried out for 257 flats and 18 public buildings, built using industrialized technologies (mainly large panel technology), basing on 7651 individual chemical analyses. The determined parameters were the concentrations of phenol, sum of phenol and chlorophenols, and formaldehyde. The TLV values for these compounds in Poland are equal to 0.01 mg/m³, 0.01 mg/m³ and 0.05 mg/m³, respectively.

It has been established that the threshold limit concentration of phenol was exceeded in 10% of flats, while that of sum of phenol and chlorophenols—in 20% of flats. The situation was even worse for formaldehyde, whose TLV was exceeded in 50% of flats. In the worst cases the formaldehyde concentration found was 10 times higher than the respective TLV, which could result in a permanent endangerment of health and life of the inhabitants. In the case of public buildings the situation was quite similar [93].

Occupational Safety and Health authorities in the Tricity accomplished also a project concerning the health condition of the child population. Children from two groups of flats were compared, i.e. flats built between 1969 and 1976 using industrialized technologies (I group), and flats built between 1912 and 1967 using classical technologies (II group). All the flats were located in the same district of Gdańsk. The investigations started from the evaluation of the IAQ in the flats examined, based on phenol, sum of phenol and chlorophenols, and formaldehyde concentrations. The TLV values in the flats from the II group in general were not exceeded, contrary to flats from the I group. The health condition of children living in both types of flats was then examined vs. the background of the IAQ measurements. It has been established that children from the I group much more often suffered from bronchitis and infections of the upper respiratory tract. On the other hand, children from the II group practically did not complain about headaches, drowsiness or conjunctiva irritation [94].

8. SUMMARY

In all measures adopted to ensure the purity of air, a distinction must be made between the air in 'indoor spaces' and the outside air. Up to now, the only indoor spaces to receive the attention of experts and the general public spaces to receive the attention of experts and the general public are those in which professional work and labour take place—these indoor spaces are subject to supervision under occupational safety legislation. Other indoor areas in dwellings, in public buildings such as hospitals, schools, restaurants, theaters, cinemas, nurseries, homes for the elderly, churches and vehicle interiors have drawn comparatively little attention as a part of the environment, despite the following facts:

—indoor air is often polluted to a greater extent than the outside air;

—children, the elderly, pregnant women and the chronically diseased (so-called risk groups) react more sensitively to air pollutants, and these groups spend longer periods of time indoors, especially in winter.

All indoor air pollutants can impair health depending on the type and duration of their effect on humans and on the sensitivity of those affected. Special attention should be paid to substances which cause cancer, for which threshold doses cannot be defined. Tobacco smoke contains many carcinogenic substances which the non-smoker involuntarily inhales (passive smoking). It has

been shown that passive smoking probably causes lung cancer and that small children more frequently suffer from diseases of the respiratory tract if their parents smoke.

The importance of indoor air pollution cannot be assessed at the present. This is due to the fact that the type, duration and magnitude of indoor air pollution vary greatly and that representative data are not available.

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