Polish J. of Environ. Stud. Vol. 15, No. 3 (2006), 383-393

Review

Organic Compounds in Indoor Environments

B. Zabiegała*

Gdańsk University of Technology, Chemical Faculty, Department of Analytical Chemistry
80-952 Gdańsk, 11/12 Narutowicza Str., Poland

Received: March 5, 2005
Accepted: December 27, 2005

Abstract

Caring for indoor air quality (IAQ) in so-called non-industrial areas has become increasingly common. Because of people's awareness of hazards related to the presence of different substances in indoor air. A review with 103 references concerning the presence of organic compounds in non-industrial indoor environments is discussed. The main sources of indoor air pollutants are presented. Topics discussed also include: total volatile organic compounds (TVOC) concepts in IAQ evaluation, concentrations of organic compounds in indoor and outdoor air, and the influence of outdoor air on indoor air quality expressed as ratios of indoor (I) to outdoor (O) concentrations (I/O).

Keywords: organic compounds, sources of organic pollutants, indoor air quality, outdoor air

Introduction

The development of civilization has caused the environment in which humans live to become increasingly critically polluted. Building construction has increasingly focused on energy efficiency and comfort. Central heating and cooling systems are the norm, and home and office construction has moved toward minimizing heat or cool air loss by making buildings more airtight. At the same time, more complex materials are being used for furniture, clothing, fabrics, cleaners, detergents, and preservatives. Due to these factors, more and more organic compounds (known and unknown) are in increased amounts introduced into indoor air, resulting in health problems in the human population and unpleasant odors that are a burden to humans [1].

In the last several years, growing scientific evidence has indicated that organic compounds can more seriously pollute indoor air than outdoor air [2-6]. This concerns not only rural and non-urbanized areas but also the largest and the most industrialized cities. Organic compounds present in indoor air include very volatile organic compounds (VVOCs), volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs) and non-volatile organic compounds (NVOCs) or organic compounds associated with particulate matter or particulate organic matter (POM) [7]. However, volatile organic compounds made up the group of indoor pollutants which was given the most attention in research to assess indoor air quality and its effects on living organisms, including human beings. Systematic studies on the subject have been conducted since the 1980s [2, 4, 7-25].

Sources of Organic Compounds in Indoor Environments

Organic pollutants present in indoor air are classified in many different ways; however, the classification met most often is based on the pollutant's origin. We identify pollutants of predominantly indoor origin (endogenous) and predominantly outdoor origin. Most important sources of organic indoor air pollutants grouped by their origin are given in Table 1 [23-38].

However, it should be emphasized that the list of sources of organic pollutants presented in Table 1 has al-

---

*e-mail: pszczola@chem.pg.gda.pl

Table 1. Sources of organic indoor air pollutant emissions (grouped by origin) [23-38].

Sources of organic pollutant emissions	
Endogenous (predominantly indoors)	External (predominantly outdoors)
Originating from the building: • building and furnishing materials, • building renovations, • elements of indoor equipment, • bacterial and fungal activities,	Chemical and petrochemical industry
	Transport: • means of transportation • fuel loading/unloading stations and terminals,
Originating from humans and human activities inside the building: • household and consumption goods (hygiene products, aerosols), • processes connected to indoor cleaning (preserving and cleaning chemicals), • food preparation (baking, frying, brewing); • hobbies and pets • recreational activities, • indoor plants ; • body perspiration and human/pet waste • household (stoves, ovens), • office appliances (printers, copiers), • ETS – Environmental Tobacco Smoke,	Small firms (dry cleaners, print shops)
	Short-term emissions: • break down of valves, pipelines and pumps, • leaks during loading/unloading, • safety valves, • cleaning of tanks,
	Emissions of biological origin: • green plants, • agriculture • global ocean surface,
	Surface and ground waters,
	Soil, pollution of grounds on which buildings are situated,
	Utilization and disposal of wastes: • waste storage sites, • wastewater treatment plants
Others: • industrial plants or production firms located in a building used for living quarters, • job-related exposure (desorption of pollutants from clothing and body), • related to motorization (garage inside a building used as living quarters), • combustion (heating systems, water heating systems), • water from a water supply system	

ways been incomplete and constitutes only the author's approach to the listing and the classification of sources of organic compounds in indoor environments. The relative importance of any single source of emission is different for individual compounds and locations and depends on how much of a given pollutant it emits (emission rate) and how hazardous the pollutant is. External factors controlling emission rates are: temperature, humidity, wind speed and occupant behaviour [39]. For predominantly indoor sources, factors such as the age of the source and whether it is properly maintained can also be quite significant [2, 14, 22].

Evidence from a variety of building investigations suggests that many of the materials used in buildings are the main source of organic compounds in indoor air. These materials have a profound effect on indoor air quality. On the basis of literary data, the assertion can be made that more than half of the organic compounds present in indoor air come from emissions from buildings and flooring materials [38, 40]. Their influence on the presence of organic compounds is mainly connected to form in large and thick surfaces, which can contribute high and long lasting emissions of organic compounds [41]. However, building and flooring materials not only emit pollutants but also affect the transport and removal of indoor organic compounds through a sink process, leading to a decrease in concentration of selected pollutants in indoor air [40-50].

Furniture is also regarded as a significant source of VOCs in indoor environments; the level of VOCs emitted from furniture depends on a room's loading rate of furniture. It is assumed that in private houses loading rates are *ca.* 0.5-7.0 m^2/m^3. The higher the value of the loading rates, the higher the participation of furniture in emission behavior [38, 39, 43, 44].

The level of VOCs present in indoor environments is also affected by the phenomenon of so-called secondary emissions. Secondary emission is any process that releases new airborne pollutants from existing sources, changes the total emitted mass of existing pollutants, or results in chemical reactions between compounds on surfaces and those in the air [40, 43]. Experimental studies have shown that much organic vapor initially released can be adsorbed into the surfaces of new furnishings or finishers in rooms containing high surface area materials, such as carpeting, ceiling tiles or free-standing partitions [38, 39, 43-45]. The quantities adsorbed depend on total surface area exposed and on the air exchange rate in the room. Secondary emissions may be based on sorption, oxidation, decomposition or other chemical reactions in or on a source and is influenced by such environmental parameters as humidity, temperature, air exchange rate and concentrations of emitted compounds [38, 39, 43, 44]. It is impossible to tell whether a compound present in indoor air comes from a primary or secondary emission process. However, emission rates in the case of secondary emissions are generally significantly lower than those of primary emissions. Primary emissions generally dominate for a period of up to some months for new or renovated buildings.

Atmospheric air is an external pollution source of organic compounds whose characteristics are determined by local industry (environmental quality). The data available in literature concerning determination of organic compound concentrations in atmospheric air confirm the general opinion that atmospheric air is not the most significant source of indoor air pollution. However, in some cases outdoor air can contribute to deterioration of indoor air quality by introducing significant amounts of organic pollutants into indoor air [5, 51-54]. The type and the amount of pollutants introduced depend on the presence of external emission sources in the immediate vicinity of the monitored building compartments.

Typical sources of common organic compounds found in indoor air, grouped in classes, are given in Table 2.

TVOC Concepts in IAQ Evaluation

Over two hundred organic pollutants, mainly volatile organic compounds, have been identified in the indoor environment. Considering this, it seems to be obvious that these group of compounds could affect the quality of indoor air in a significant way. On the other hand, monitoring the concentration of each single compound present in indoor air could be not only time- and labor-consuming but also costly. This is the reason why instead of determining individual concentrations of indoor air pollutants, total parameters are often used for the evaluation of indoor air quality. The VOC group is then treated as one entity, and is named TVOC, which stands for total volatile organic compounds. Most researchers agree that TVOC should be operationally defined as the sum of all compounds sampled and analyzed within the range of boiling points specified for VOCs [82-84]. However, one problem is that in practice, no standardized method exists for sampling and analyzing all compounds occurring within the boiling point range specified by the WHO [7]. Different authors have used different procedures for calculating TVOC and for interpreting obtained data. For that reason, the direct comparison of the results obtained have not been reliable. Due to this, in 1997 the ECA-IAQ Working Group 13 [84] gave a definition of total volatile organic compound (TVOC) concentration. Recently, according to ISO standard 16000-6, TVOC has been defined as all compounds eluting between hexane and hexadecane on non-polar or slightly polar stationary phases using gas chromatography with a flame ionization detector (GC-FID) [85,86]. VOCs are collected from indoor air on Tenax adsorbent and desorbed thermally, and at least one third of them must be quantified as individual compounds and the remainder as toluene. Though this definition still does not cover the entire spectrum of compounds in indoor air (e.*g*. reactive organic compounds as aldehydes, hydroperoxides and products of reaction of unsaturated VOCs with ozone/nitrogen dioxide [12]) it enables the comparison of the results obtained from different places distant from each other, which makes the definition more useful.

There are also many definitions determining the acceptable level of TVOCs in indoor air. The most important are presented in Table 3 [87-90]. In general, the proposed guideline value for the TVOCs in indoor air can vary between 200-600 $\mu g/m^3$. However, one should realize that the proposed acceptable levels for TVOC are valid for so-called established buildings (buildings with normal use). In renovated or completely new buildings, levels of indoor air pollution can be several degrees higher.

Organic Compound Concentrations in Indoor and Outdoor Air

The concentrations of organic compounds in any indoor environment can vary in time and space. They can also be subject to geographical, seasonal and diurnal variations. Therefore, instead of a directly measured analyte concentration, a concentration ratio of the analyte in indoor (I) and outdoor (O) air (I/O ratio) from concurrent measurements is also reported [56,58, 91-103].

The I/O value reflects the importance of outdoor versus indoor sources even better than absolute concentration. Such a calculated parameter allows us, with considerable approximation, to point to the causes of poor indoor air quality and indicates the origin of pollutant. Thus, $I/O >> 1$ indicates that mainly endogenous emission sources are responsible for indoor air quality; $I/O \approx 1$ points to the fact that internal and external sources influence indoor air quality to the same degree; and for $I/O << 1$ the quality of outdoor air determines the quality of indoor air in a predominant way. The concentrations of individual organic compounds present in indoor air in different locations are presented in Table 4. Table 4 also presents the concentration of the same compounds in outdoor air (outer and inner measurements were carried out at the same time) and concentration ratios of indoor to outdoor air (I/O ratio).

In general, in developed countries, pollutant concentrations indoors are similar to those outdoors, with the ratio of indoor to outdoor concentrations falling in the range 0.7-4. However, besides the geographical positions of a country (climate effect) determining the inhabitants' way of life and/or the application of different types of energy carriers, the I/O ratios can also be strongly dependant upon the economic situation of a country.

Table 2. Organic compounds typically present in indoor air and their origin.

Class of compounds	Organic compounds found in indoor environment	Source	References
Aliphatic hydrocarbons	n-propane, n-butane, isobutane	combustion appliances	50
	n-hexane, n-heptane, n-octane,	consumer and commercial products, paint, adhesives, building materials	15, 54
	n-nonane, n-decane, n-dodecane, n-undecane	petroleum-based indoor coatings: wood stain, polyurethane wood finish, floor wax, outside traffic	15, 54
Aromatic hydrocarbons	benzene, toluene, ethylbenzene, p-xylene, m-xylene, o-xylene, 1,2,4 trimethylbenzene, styrene	outside traffic, ambient air - soil gases (building located close to contaminated lands i.e. landfill sites, lands affected by contaminated soil or groundwater plumes); petroleum-based indoor coatings: wood stain, polyurethane wood finish, floor wax, polyacrylonitrile carpets, furniture coatings, polyester curtain, synthetic fibers and plastics, cleaning solutions, pharmaceuticals, dyes, Environmental Tobacco Smoke (ETS)	15, 53-57, 92, 93
Halogenated hydrocarbons	dichloromethane (DCM), 1,2-dichloro-1,1,2,2-tetrafluoroethane, vinyl chloride, ethyl chloride, trichlorofluoromethane, 1,1-dichloroethane, dichloromethane, 1,1-dichloroethene, 1,2-dichloropropane, trichloromethane, 1,2-dichloroethane, 1,1,1-trichloroethane, trichloroethene- tetrachloroethene (TCE),	tap water (water disinfectant byproducts), ground water, ambient air - soil gases (building located close to contaminated lands i.e. landfill sites, lands affected by contaminated soil or groundwater plumes); cleaning agents, insecticides, plastic products such as pipes and light fixtures, upholstery, carpets	15, 28, 58-61
Halogenated aromatic hydrocarbons	chlorobenzene, p-dichlorobenzene	ambient air - soil gases (building located close to contaminated lands i.e. landfill sites, lands affected by contaminated soil or groundwater plumes); cleaning agents, insecticides, degreasers	15, 28, 58
Alcohols, phenols	phenol, 2-methylpropan-1-ol butan-1-ol, 2-ethylhexan-1-ol, octan-1-ol, methanol, ethanol	building materials-particle board, finishing materials (paints and lacquers), PCV, human breath	39, 62-64
Organic acids	acetic acid, formic acids, fatty acids	carpet cushions, corks, paints (acrylic, latex), duct lines	39, 65
Ethers	methyl tert-butyl ether (MTBE)	outdoor air, gasoline combustion	53
Aldehydes and ketones	2 alkyl propanoates (mixture), pentanal, hexanal, heptanal, formaldehyde, octanal, acrolein, benzaldehyde, acetaldehyde, 2 butanone, 4-methyl-2-pentanone	materials used in ventilation ducts (thermal isolation), building materials -particle boards, vinyl floors, solvent-based paints, spray paints, auto-oxidation of fatty acid esters (in paints-acrylic, latex), furniture and decorating materials, wool based carpets, combustion, ETS, human body, human breath, outdoor air	15, 29, 37, 39, 63-70, 99
Amines	2-naphtylamine, 4-aminobiphenyl, o-, m-, p- toluidines, dimethylanilines	by-product of chemical manufacturing and contaminants of dyes, rubber, textiles; gasoline and coal combustion, water-based paints, water based liquid waxes	101
Terpenes	C-10, C-15 terpenes d-Limonene, 3-Carene, α-Pinene	building materials-particle boards, vinyl floors, alkyd paints, deodorants, cleaners, ETS	37, 97, 98
PAHs	naphtalene phenentrene	parquet glue, petroleum products, incomplete fuel combustion (domestic cooking stove), ETS (in coal tar as a component of tobacco smoke), outdoor air	33, 48, 55,70-73, 98, 100
PCBs		outdoor air: transformer oil, heat transfer fluids, dielectric fluids to capacitors, joint sealing based on polysulfide polymers, electrical appliances, leaks from ageing visual display units, fluorescent lights	20, 74, 99, 102
Pesticides	chlorpyrifos –O,O-diethyl O-[3,5,6-trichloro-2-pyridyl]phosphorothioate, DDT, PCP- pentachlorophenol	outdoor air: wood preservative for power line poles, railroad tires, fence posts; air-conditioning and ventilation systems	27, 47, 75-79
Miscellaneous	Nicotine, 1,3-Butadiene Nitrosoamines (NDMA, NDEA)	combustion of petrol and diesel in motor vehicle engines; combustion of fossil fuels and accidental fires, tobacco smoke, emission from tire manufacturing and atmospheric reactions between secondary or tertiary amines and NO_x	29, 33, 37, 48, 49, 55, 80, 81, 91

Table 3. The guideline value for the TVOCs proposed by different sources.

Source	The proposed guideline value for the TVOC
Molhave [87]	< 200 μg/m^3- *comfort range*; is assumed not to lower comfort; 200 – 3000 μg/m^3- *multifactoral exposure range*; is considered to be a health hazard; 3000-25000 μg/m^3 –*discomfort range*; brings strong discomfort; >25000 μg/m^3 - *toxic range*; is toxic;
Sheifert [88,89]	300 μg/m^3; no individual compound concentration should exceed 50% of its class target or 10% of the TVOC target guideline value.
Finnish Society of Indoor Air Quality and Climate	< 200 μg/m^3
National Health and Medical Research Council [90]	500 μg/m^3; no single compound contribution should be higher than 50%

Table 4. The concentrations of individual organic compounds present in indoor and outdoor air in different locations (average value given in brackets) and concentration ratios I/O (indoor to outdoor air).

Target pollutants	Concentrations [μg/m^3]		I/O ratio	Sampling site: City; Country	Reference
	indoor air (I)	outdoor air (O)			
aliphatic hydrocarbons					
hexane	<2.29	4.51	-	Helsinki, FIN	97
	25.6-79.1 (53.2)	9.5-47.6 (28.7)	1.9	Trombay, Mumbai, IND	49, 72
	43.5-125	5.2-60.7	1.5-11.7	Rio de Janeiro, BRA	98
heptane	4.1-14.8 (7.8)	<0.4-2.5 (0.8)	9.8	Trombay, Mumbai, IND	49, 72
	12.9-54.1	2.8-37.5	1.8-5.2	Rio de Janeiro, BRA	98
decane	5.26	1.11	4.73	Helsinki, FIN	97
	8.1-17.9 (12.8)	<0.6-1.7 (1.1)	11.6	Trombay, Mumbai, IND	49, 72
	13.0-53.3	nd-13.4	1.1-13.0	Rio de Janeiro, BRA	98
aromatic hydrocarbons					
Benzene	0.5-4.41 (1.64)	0.5-1.18 (0.33)	5.0	Gdańsk, POL	5
	3.4-63.7 (13.9)	0.7-29.8 (7.3)	3.4	Birmingham, UK	18
	2.3	1.3	1.8	Hamburg, DEU	56
	2.5	1.9	1.3	Erfurt, DEU	56
	5.9	3.9	1.5	Leipzig, DEU	56
	1-81	<1-14	0.92	Melbourne, AUS	26
	0.27-12.3 (2.38)	0.4-3.0 (1.3)	1.5	Hanover, DEU	54, 92, 93
	4.7-21	4.2-14	1.1-1.5	Modena, ITA	68
	3.52	1.66	1.5	Helsinki, FIN	97
	43.9-166 (103.4)	21.1-47.7 (31.7)	3.3	Trombay, Mumbai, IND	72
	3.7-18.4	3.5-11.1	0.5-2.8	HKG, CHN	21, 22
	15.9-34.5	3.3-12.2	1.6-4.8	Rio de Janeiro, BRA	98

Table 4. continued ...

Toluene	20.35	5.62	3.6	Helsinki, FIN	97
	8.8-99.3 (38.4)	2.2-75.7 (15.1)	4.0	Birmingham, UK	18, 19
	32.6	5.6	5.8	Hamburg, DEU	56
	53.2	7.0	7.6	Erfurt, DEU	56
	61.0	9.5	6.4	Leipzig, DEU	56
	4.49-509 (30.8)	1.1-5.1 (2.2)	9.2	Hanover, DEU	54, 92, 93
	2.3-60.8 (22.7)	0.5-20.03 (4.59)	3.0-4.6(4.9)	Gdańsk, POL	5
	11-53	11-72	1	Modena, ITA	68
	36.3-88.1 (61.1)	35.5-69.2 (47.8)	1.3	Trombay, Mumbai, IND	49, 72
	17.6-156	31.1-208	0.5-2.2	HKG, CHN	94, 95
	102-320	8.9-60.2	2.2-11.5	Rio de Janeiro, BRA	98
	14	5.5	1.8	Melbourne, AUS	86
Ethylbenzene	2.89	0.99		Helsinki, FIN	97
	0.6-6.5 (2.3)	0.2-8.4 (1.6)	2.3	Birmingham, UK	18, 19
	2.2	0.6	3.7	Hamburg, DEU	56
	2.8	0.9	3.1	Erfurt, DEU	56
	3.3	1.7	1.9	Leipzig, DEU	56
	0.62-32.0 (3.03)	-	6.2	Hanover, DEU	54, 92, 93
	0.5-42.36 (14.14)	1.81-3.5 (1.96)	7.2	Gdańsk, POL	5
	9.3-13.6	3.1-7.4	1.8-3.0	Rio de Janeiro, BRA	98
p,m,o- Xylenes	10.30	3.86	2.7	Helsinki, FIN	97
	2.2-27.8 (9.3)	0.9-37.4 (4.3)	2.1	Birmingham, UK	18, 19
	9.2	2.6	3.5	Hamburg, DEU	56
	8.4	3.9	2.2	Erfurt, DEU	56
	9.6	4.4	2.2	Leipzig, DEU	56
p,m,o –Xylenes	1.34-70.88 (7.15)	1.0-4.0 (2.0)	6.6	Hanover, DEU	54, 92, 93
	9.4-23.14 (13.77)	1.6-10.3 (5.57)	2.5	Gdansk, POL	5
	13-47	16-96	-	Modena, ITA	68
	17.6-33.5 (23.7)	10.3-23.7 (14.6)	1.6	Trombay, Mumbai, IND	49, 72
	24.4-60.6	3.7-19.9	2.0-6.6	Rio de Janeiro, BRA	98
	6.9	2.7	2.4	Melbourne, AUS	6, 26, 86
Styrene	nd-3.4 (0.8)	nd-4.4 (0.4)	4.3	Birmingham, UK	18, 19
	1.04-15.2 (1.17)	nd-6.68	1-2.3	Helsinki, FIN	97
	0.99-5.78 (3.52)	nd-3.91 (1.58)	2.2	Gdańsk, POL	5
	0.9	<2	-	Melbourne, AUS	26, 86
1,3-Butadiene	nd-10.8 (1.1)	nd-0.9 (0.3)	6.6	Birmingham, UK	18, 19
Terpenes					
α Pinene	16.08	2.11	7.6	Helsinki, FIN	97
	6.0-14.7	nd	-	Rio de Janeiro, BRA	98
Limonene	31.58	<1.13	-	Helsinki, FIN	97
	2.15-52.0	nd	-	Rio de Janeiro, BRA	98

Table 4. continued ...

Esters					
2-butoxyethanol	2.5	nd	-	Helsinki, FIN	97
Chloroorganic compounds					
Chloroform	2.0-6.2	nd-1.6	nd-2.4	Rio de Janeiro, BRA	98
	3.10 (0.111-101)	2.53 (0.117-97.7)	0.9-1.1	Shizuoka, JAP	58
	1.2-14.9	1.1-3.7	1.1-4.1	HKG, CHN	94, 95
Carbon tetrachloride	0.784 (0.489-4.28)	0.740 (0.514-1.35)	0.9-3.2	Shizuoka, JAP	58
Dichloromethane	2.6-5.2	nd-1.7	nd-2.6	Rio de Janeiro, BRA	98
Dichloromethane	17.9 (<0.36-10500)	9.04 (<0.36-15400)	1.9	Shizuoka, JAP	58
	0.6-19.5	1.3-14.3	0.1-8.3	HKG, CHN	94, 95
Aldehydes					
Formaldehyde	1.7-67.8	4.0-60.6	-	Modena, ITA	68
	12.2-99.7	7.1-21.0	1.1-4.7	Rio de Janeiro, BRA	98
	87.6-105.5* (ppb)	29-37	4.43-1.58	Greater Cairo, EGY	99
Acetadehyde	2.3-35.9	8.7-27.8	0.1-2.2	Rio de Janeiro, BRA	98
Hexanal	14-22	-	-	Melbourne, AUS	85
	11.55	2.14	5.4	Helsinki, FIN	97
Octanal	4.31	1.69	2.5	Helsinki, FIN	97
Nonanal	28-68	-	-	Melbourne, AUS	86
Total VOCs (TVOC)					
TVOC	136-854	247-895	-	Modena, ITA	68
	302-978 (570)	132-516 (286)	2.0	Gdańsk, POL	5
	304-1696 (803)	22.2-643 (216)	2.0-11.8	Rio de Janeiro, BRA	98
	970-2920	22.2-1520	-	KWT	103
	320	64	3.3	Melbourne, AUS	26, 86
Amines [ng/m^3]					
Sum of nine aromatic amines: 2-toluidine, 3- toluidine, 4- toluidine, 2,3- dimethylaniline, 2,4- dimethylaniline, 2,5- dimethylaniline, 2,6- dimethylaniline, 2-naphtylamine, 4-aminobiphenyl	57	55	1.03	Brindisi, ITA	101
aniline	259	129	2.0	Brindisi, ITA	101
***PAH* [ng/m^3]**					
Napthalene	200.0 -60 (800)	nd-900 (300)	4.2	Birmingham, UK	18, 19
	540-3890 (640)	nd -1310	3.0	Helsinki, FIN	97
	790-2694	450-2512	1.24	Hangzhou, CHN	100
	nd-183.5 (67.2)	nd-16.6 (6.4)	10.5	Trombay, Mumbai, IND	101
Benzo(a)pyrene	4.0- 21.0	1.0-19.0	1.90	Hangzhou, CHN	100
	nd-17.6 (6.9)	nd-2.0 (0.9)	7.6	Trombay, Mumbai, IND	101

Table 4. continued ...

Total PAH	3900-29850	2720-30680	1.12	Hangzhou, CHN	100
	25.2-373 (164)	23.0-45.6 (36.7)	4.5	Trombay, Mumbai, IND	101
	1489	391	3.8	JAP	100
	267	209	1.3	Taipei, TWN	100

Conclusion and Summary

Caring for indoor air quality in so-called non-industrial areas has become increasingly common today. The reason for this may be the consciousness of hazards related to the presence of different substances in indoor air as well as the fact that manufacturers of indoor materials (building, finishing and furnishing) care for the quality of their products. This care is evident in the application of modern technologies, which reduce the consumption of organic solvents in production processes, resulting in reduced emissions of organic compounds in indoor air during the usage of these products. However, the complete elimination of organic compounds is impossible. Therefore, it is necessary to monitor air quality, which humans spend over 16 hours per day doing.

It is apparent from the data presented in this review that organic compounds can be an important factor affecting indoor air quality and that more research is needed to determine the magnitude of this effect.

It is obvious that care for indoor air quality should begin at the building design stage, as building materials are regarded to be one of main contributors to emissions of organic compounds to indoor environments. Building a new house provides the opportunity to avoid or at least reduce indoor air quality problems. However, it can also result in exposure to higher levels of indoor air pollutants if careful attention is not given to potential sources of organic compounds and the air exchange rate.

Usually the most effective way to improve indoor air quality is to control the sources of pollution emissions. The best way to do this is to eliminate individual sources of pollutants or at least reduce their emission.

References

1. COHEN Y. Volatile Organic Compounds in the Environment: A Multimedia Perspective. Volatile Organic Compounds in the Environment, ASTM STP 1261, Wang W., Schnoor J., Doi J. (Eds.), American Society for Testing and Materials, pp. 7-32, **1996.**
2. JONES A.P. Indoor air quality and health. Atmos. Eviron. **33***,* 4535*,* **1999.**
3. NAMIEŚNIK J., ZYGMUNT B., KOZDROŃ-ZABIEGAŁA B. Some Aspects of Indoor Air Pollution and Analysis. Pol. J. Environ. Stud. 3 (4), 5, **1994**.
4. WALLACE L., NELSON W., ZIEGENFUS, R., PELLIZZARI E., MICHAEL L., WHITMORE R., ZELON H., HARTWELL T., PERRITT R., WESTERDAHL D. The Los Angeles TEAM Study: Personal exposures, indoor-outdoor air concentrations, and breath concentrations of 25 Volatile Organic Compounds. J. Expo. Anal. Environ. Epidemiol. **1***,* 157*,* **1991**.
5. ZABIEGAŁA B., GÓRECKI T., PRZYK E., NAMIEŚNIK J. Permeation passive sampling as a tool for the evaluation of indoor air quality. Atmos. Environ. **36***,* 2907, **2002**.
6. BROWN S.K. Occurrence of volatile organic compounds in indoor air', in Organic Indoor Air Pollutants, T. Salthammer (ed.), Wiley–VCH, Germany, Weinheim, pp. 171–184, **1999**.
7. WHO Indoor air quality: organic pollutants. Euro Reports and Studies No 111. World Health Organization, **1989**.
8. BERRY M.A. Population risk assessment for indoor air pollutants: in Pilot study on indoor quality.The implication of indoor air quality for modern society. Erice, Italy, February 13-17, CCMS Report No 183,77 **1989**.
9. ECA. Indoor Air Quality & Its Impact On Man, Environment and quality of life, Report No.10 Effects of indoor air pollution on human health, EUR 14086 EN, **1991**.
10. FERON V.J., WOUTERSEN R.A., ARTS J.H.E., CASSEE F.R., DE VRIJER F.L., VAN BLADEREN P.J. Indoor air, a variable complex mixture: strategy for selection of (combinations of) chemicals with high health hazard potential. Environ. Technol. **13**, 341, **1992**.
11. KOZDROŃ-ZABIEGAŁA B., PRZYJAZNY A., NAMIEŚNIK J. Determination of selected volatile organic compounds in indoor environment. Indoor Built Environ. **5**, 212, **1996**.
12. WOLKOFF P., NIELSEN D.N. Organic compounds in indoor air – their relevance for perceived indoor air quality. Atmos. Environ. **35**, 4407, **2001**.
13. LAGOUDI A., LOIZIDOU M., ASIMAKOPOULOS D. Volatile organic compounds in office buildings, Indoor Built Environ. **5**, 341, **1996**.
14. MOLHAVE L. Indoor Air Pollution due to Organic Gases and Vapours of Solvents in building Materials. Environ. Internat. **8**,117. **1982**
15. NAMIEŚNIK J., GÓRECKI T., KOZDROŃ-ZABIEGAŁA B., ŁUKASIAK J. Indoor air quality. Pollutants, their sources and concentration levels. Building and Environ. **27**, 339, **1992**.
16. PHILLIPS K., HOWARD D.A., BENTLEY M.C., ALVAN G. Impact of air quality in turn by personal monitoring of non-smokers for respirable suspended particles and Environmental Tobacco Smoke. Environ. Intern. **23** (6), 851, **1997**.

17. ZABIEGAŁA B., NAMIEŚNIK J., PRZYK E., PRZYJAZNY A. Changes in concentration levels of selected VOCs in newly errected and remodelled buildings in Gdańsk. Chemosphere **39**, 2035, **1999.**
18. KIM Y.M., HARRAD S., HARRISON R.M. Concentrations and Sources of VOCs in Urban Domestic and Public Microenvironments. Environ Sci. Technol. **35**, 997, **2000.**
19. KIM Y.M., HARRAD S., HARRISON R. Concentrations and Sources of VOCs in Urban Domestic and Public Microenvironments Indoor Built. Environ. **10** (3-4), 147, **2001.**
20. KOHLER M., ZENNEGG M., WAEBER R. Coplanar polychlorinated biphenyls (PCB) in indoor air. Eviron. Sci. Technol. **36**, 4735, **2002**.
21. LEE S.C., CHANG M., CHAN K.Y. Indoor and outdoor air quality investigation at 14 public places in Hong Kong. Environ. Intern. **25**, 443, **1999.**
22. LEE S.C., CHAN K.Y., CHIU M.Y. Indoor and outdoor air quality investigation at six residential buildings in Hong Kong. Environ. Intern. **25**, 489, **1999**.
23. WANNER H.U. Sources of pollutants in indoor air. In: Seifert, B. (Ed). Environmental carcinogens - methods of analysis. International Agency for Research on Cancer, Lyon, pp.19-30, **1993.**
24. HIPPELEIN M. Background concentrations of individual and total volatile organic compounds in residential indoor air of Schleswig-Holstein, Germany. J. Environ. Monit. **6** (9), 745, **2004**.
25. BAYA M.P., BAKEAS E. B., SISKOS P.A. Volatile Organic Compounds in the air of 25 Greek homes. Indoor and Built Environment **13** (1), 53, **2004**.
26. COLT J.S., ZAHM S.H., CAMANN D.E., HARTGE P. Comparison of pesticides and other compounds in carpet dust samples collected from used vacuum cleaner bags and from a high-volume surface sampler. Environ. Health Perspectives **106**, 721, **1998.**
27. COX M.L., STURROCK G.A., FRASER P.J., SIEMS S.T, KRUMMEL P.B., O'DOHERTY S. Regional sources of methyl chloride, chloroform and dichloromethane identified from AGAGE observations at Cape Grim, Tasmania, 1998-2000. J. Atmos. Chem. **45**, 79, **2003.**
28. CRUMP D.R., SQURE R.W., YU CH. Sources and concentrations of formaldehyde and other volatile organic compounds in the indoor air of four newly built unoccupied test houses. Indoor Build Environ. **6**, 45,**1997**.
29. HOLCOMB L.C. Indoor air quality and environmental Tobacco Smoke: concentration and exposure. Environ. Intern. **19**, 9, **1993.**
30. NORBACK D. WIESLANDER G., EDLING C. Occupational exposure to volatile organic compounds (VOCs), and other air pollutants from the indoor application of water based paints. Ann. Occup. Hyg. **39**, (6) 783, **1995**.
31. OTSON R., FELLIN Ph. Volatile organics in the indoor environment: sources and occurrence. In: Nriagu JO (Ed). Gaseous pollutants: Characterization and cycling. John Wiley & Sons, Inc. New York, pp.335–421, **1992.**
32. LEWIS Ch.W. Sources of air pollutants indoors: VOC and fine particulate species. J. Exposure Anal. Environ. Epidemiol. **1** (1) 31, **1991**.
33. ROULET C.A. Indoor environment quality in buildings and its impact on outdoor environment. Energy and Buildings **33**, 183, **2001.**
34. FOARDE K. K., Van OSDELL D. W., Chang J.S. Evaluation of fungal growth on fiberglass duct materials for various moisture, soil, use, and temperature conditions. Indoor Air **6**, 83, **1998**.
35. MENETREZ M.Y., FOARDE K.K. Microbial Volatile Organic Compound emission rates and exposure model. Indoor Built Environ. **11,** 208, **2002**.
36. YU CH.,CRUMP D. A review of the emission of VOCs from polymeric materials used in buildings. Build and Environ. **33** (6) 357, 1998.
37. ECA. Evaluation of VOC Emissions from Building Products (Solid Flooring Materials), Report No 18, **EUR 17334 EN. Luxembourg, 1999**.
38. BROWN S.K. Volatile organic pollutants in new and established buildings in Melbourne, Australia. Indoor Air **12**, 55, **2002.**
39. WOLKOFF P. How to measure and evaluate volatile organic compound emissions from building products. A prospective. Sci. Total. Environ. **227**, 197,**1999.**
40. SAARELA K., JÄRNSTRÖM H**.** Indoor Air quality in new residential buildings and behaviour of materials in structures. Indoor Built Environ. **12**, (4), 243, **2003**.
41. WON D., CORSI R.L., RYNES M. Sorptive interactions between VOCs and indoor materials, Indoor Air **11** (4), 246, **2001.**
42. GUO Z., CHANG C.S., SPARKS L.E., FORTMANN R.C. Estimation of the rate of VOC emissions from solvent-based indoor coating materials based on product formulation. Atmos. Environ. **33**, 1205, **1999.**
43. JORGENSEN R.B., BJORSETH O. Sorption behavior of volatile organic compounds on material surfaces – the influence of combinations of compounds and materials compared to sorption of single compounds on single materials. Environ. Intern. **25**, 17, **1999.**
44. JORGENSEN R.B., BJORSETH O., MALVIK B. Chamber testing of adsorption of volatile organic compounds (VOCs) on material surfaces. Indoor Air **9**, 2, **1999.**
45. MEININGHAUS R., GUNNARSEN L., KNUDSEN N. Diffusion and sorption of volatile organic compounds in building materials-impact on indoor air quality. Environ. Sci. Technol. **34**, 3101, **2000**.
46. JENSEN L. K., LARSEN A., MOLHAVE L., HANSEN M. KNUDSEN, B. Health evaluation of volatile organic compound (VOC) emissions from wood and wood-based materials. Arch Environ Health, **56**, (5):419, **2001**
47. NISHIOKA M. G., BUKHOLDER H.M., BRINKMAN M.C., GORDON S.M. Measuring transport of lawn-applied herbicide acids from Tuft to home: Correlation of dislodgeable 2,4-D Turf residues with carpet dust and carpet surface residues. Environ. Sci. Technol. **30**, 3313, **1996**.
48. van LOY M.D., RILEY W.J., DAISEY J.M., NAZAROFF W.W. Dynamic behavior of semivolatile organic compounds in indoor air. 2. Nicotine and phenanthrene with carpet and wallboard. Environ. Sci. Technol. **35**, 560, **2001.**

49. van LOY M.D., LEE V.C., GUNDEL L.A., DAISEY J.M., SEXTRO R.G., NAZAROFF W.W. Dynamic behavior of SVOC in indoor air. 1. Nicotine in a stainless steel chamber. Environ. Sci. Technol. **31**, 2524, **1997**.
50. ZHU J., ZHANG J., SHAW C.Y. Chemical composition analysis and its application of VOC emission rates from hydrocarbon solvent-based indoor materials. Chemosphere **39**, 2535, **1999**.
51. BARTONOVA A., CLENCH-AAS J., GRAM F., GRØNSKEI K.E., GUERREIRO C., LARSSEN S., TØNNESEN D.A., WALKER S.E. Air pollution exposure monitoring and estimation. part V. Traffic exposure in adults. J. Environ. Monit., **1** (4), 337, **1999**.
52. CLENCH-AAS J., BARTONOVA A., GRØNSKEI K., E., HAGEN L.O., BRAATHEN O., WALKER S.E. Air pollution exposure monitoring and estimation. Part VI. Ambient exposure of adults in an industrial region. J. Environ. Monit. **1** (4), 341,. **1999.**
53. HELLEN H., HAKOLA H., LAURILA T., HILTUNEN V., KOSKENTALO T. Aromatic hydrocarbons and methyl tert-butyl ether measurements in ambient air of Helsinki (Finland) using diffusive samplers. Sci. Total Environ. **298**, 55, **2002.**
54. ILGEN E., LEVSEN K., ANGERER J., SCHNEIDER P., HEINRICH J., WICHMANN H.E. Aromatic hydrocarbons in the atmospheric environment: Part II. Univariate and multivariate analysis and case studies of indoor concentrations. Atmos. Environ. **35**, 1253, **2001**.
55. DUFFY B.L., NELSON P.F. Exposure to emissions of 1,3-butadiene and benzene in the cabins of moving motor vehicles and buses in Sydney, Australia. Atmos. Environ. **23**, 3877, **1997.**
56. SCHNEIDER P., GEBEFÜGI I., RICHTER K., WÖLKE G., SCHNELLE J., WICHMANN H.E. Indoor and outdoor BTX levels in German cities. Sci. Total Environ. **267**, 41, **2001**.
57. ELKE K., JERMANN E., BEGEROW J., DUNEMANN L. Determination of benzene, toluene, ethylbenzene, xylenes in indoor air at environmental levels using diffusive samplers in combination with head space solid-phase microextraction and high resolution gas chromatography -flame–ionization detection. J. Chromatogr. A, **826**, 191, **1998**.
57. OLANSANDAN A. T., MATSUSHITA H. A passive sampler–GC/ECD method for analyzing 18 volatile organohalogen compounds in indoor and outdoor air and its application to a survey on indoor pollution in Shizuoka, Japan. Talanta **50** (4), 851, **1999**.
59. MOYA J., HOWARD-REED C., CORSI R.L. Volatilization of chemicals from tap water to indoor air from contaminated water used for showering Environ. Sci. Technol. **33** (14), 2321, **1999**.
60. HOWARD-REED C., CORSI R.L., MOYA J. Mass transfer of volatile organic compounds from drinking water to indoor air: The role of residential dishwashers. Environ. Sci. Technol. **33** (13), 2266, **1999**.
61. SHEPHERD J.L., CORSI R.L., KEMP J. Chloroform in indoor air and wastewater: The role of residential washing machines. J. Air Waste Manage. **46** (7), 631, **1996**.
62. FENSKE J.D., PAULSON S.E. Human breathe emissions of VOCs J. Air Waste Manage. **49** (5), 594, **1999**.
63. GROTE C., PAWLISZYN J. Solid-phase microextraction for the analysis of human breathe. Anal. Chem. **69** (4), 587, **1997**.
64. SANCHEZ J., M., SACKS R.D. GC analysis of human breath with a series-coupled column ensemble and a multibed sorption trap. Anal. Chem. **75** (10), 2231, **2003**.
65. ZHANG J., SMITH K.R. Emissions of carbonyl compounds from various cookstoves in China. Environ. Sci. Technol. **33** (14), 2311, **1999**.
66. KOECK M., PICHLER-SEMMELROCK F.P., SCHLACHER R. Formaldehyde–study on indoor air pollution in Austria. Centr. Eur. J. Publ. Health **3**, 127, **1997**.
67. GAVIN M., CRUMP D.R., BROWN V.M. Appropriate Sampling strategies for the measurement of formaldehyde in indoor air. Environ. Technol. **16**, 579, **1995**.
68. FANTUZZI G., AGGAZZOTTI G., RIGHI E., CAVAZZUTI L., PREDIERI G., FRANCESCHELLI A. Indoor air quality in the university libraries of Modena (Italy). Sci Total Environ. **193**, 49, **1996**.
69. PEDERSEN E.K., BJORSETH O., SYVERSEN T., MATHIESEN M. Emission from heated indoor dust. Environ. Intern. **27**, 579, **2002**.
70. SINGER B.C., HODGSON A.T. Gas-phase organics in Environmental Tobacco Smoke. 1. effects of smoking rate, ventilation, and furnishing level on emission factors. Environ., Sci. Technol. **36**, 846, **2002**.
71. HEUDORF U., ANGERER J. Internal exposure PAHs of children and adults living in homes with parquet flooring containing high levels of PAHs in the parquet glue. Int. Arch. Occup. Environ. Health **74**, 91, **2001**.
72. PANDIT G.G., SRIVASTAVA P.K., MOHAN RAO A.M. Monitoring of indoor volatile organic compounds and polycyclic aromatic hydrocarbons arising from kerosene cooking fuel. Sci. Total Environ. **279**, 159, **2001**.
73. WINKLE M.,R., SCHEFF P.,A. Volatile organic compounds, Polycyclic aromatic Hydrocarbons and elements in the air of ten urban Homes. Indoor Air **11** (1), 49, **2001**.
74. CRIADO M.R., PEREIRO I.R., TORRIJOS R.C. Determination of polychlorinated biphenyl compounds in indoor air samples. J. Chromatogr. **936**, 65, **2002**.
75. LEIDY R.B., WRIGHT C.G., DUPREE JR. H.E. Exposure levels to indoor pesticides. In: Racke KD, Leslie AR (Eds). Pesticides in urban environments. Fate and significance. American Chemical Society, Washington, DC, chapter **24**, pp. 282-296. **1993**.
76. NISHIOKA M.G., BURKHOLDER H.M., BRINKMAN MC. Distribution of 2,4-dichloro-phenoxyacetic acid in floor dust throughout homes following homeowner and commercial lawn applications: quantitative effects of children, pets and shoes. Environ. Sci. Technol. **33**, 1359, **1999**.
77. SCHNELLE-KREIS J., SCHERB H., GEBEFUGI I., KETTRUP A. Pentachlorophenol in indoor environments. Does a single measurement of air and dust concentrations represent the contamination? J. Eviron. Monit. **1**, 353, **1999**.
78. SCHNELLE-KREIS J., SCHERB H., GEBEFUGI I., KETTRUP A., WEIGELT E. Pentachlorophenol in indoor environments. Correlation of PCP concentrations in air and settled dust from floors. Sci. Total. Environ. **256**, 125, **2000**.

79. KUO H.W, LEE H.M. Volatility of propoxur from different surface materials commonly found in homes. Chemosphere **38**, 2695, **1999**.
80. MAHANAMA K.R.R., DAISEY J.M. Volatile N-Nitrosoamines in Environmental Tobacco Smoke: Sampling, analysis, emission factors, and indoor air exposure. Environ. Sci. Technol. **30**, 1477, **1996**.
81. ROTHBERG M., HELOMA A., SVINHUFVUD J., KAHKONEN E., REIJULA K. Measurement and analysis of nicotine and other VOCs in indoor air as an indicator of passive smoking. Ann. Occup. Hyg. **42**, 129, **1998**.
82. CRUMP D. Strategies and protocols for indoor air monitoring of pollutants. Indoor Built Environ. **10**, 125, **2001**.
83. BROWN S.K., SIM M.R., ABRAMSON M.J., GRAY C.N. Concentrations of volatile organic compounds in indoor air – a review. Indoor Air **4**, 123, **1994**.
84. ECA (European Collaborative Action "Indoor Air Quality and its Impact on Man"). "Total Volatile Organic Compounds (TVOC) in Indoor Air Quality Investigations", Report No 19, EUR 17675 EN. Luxembourg,**1997**.
85. ISO/DIS 16000-6 Indoor air – Part 6: Determination of volatile organic compounds in indoor and chamber air by active sampling on Tenax TA, thermal desorption and gas-chromatography MSD/FID.
86. BROWN R.H., Monitoring volatile organic compounds in air—the development of ISO standards and a critical appraisal of the methods. J. Environ. Monit. **4** (6), 4, **2002**
87. MOLHAVE L., NIELSEN G.D. Interpretation and Limitations of the Concept "Total Volatile Organic Compounds" (TVOC) as an Indicator of Human Responses to Exposures of Volatile Organic Compounds (VOC) in Indoor Air. Indoor Air, **2**, 65, **1992**.
88. SEIFERT B. Regulating Indoor Air. Proceeding of the 5th International Conference Indoor Air Quality and Climate - Indoor Air '90, Vol. **5**, pp. 35-49 **1990**.
89. SEIFERT B. Guidelines for indoor air quality: The evaluation of indoor air quality by means of the sum of volatile organic compounds (TVOC value). Bundesgesundheitsblatt. **42**, 270, **1999**.
90. NHMRC, National Indoor Air Quality Goal for Total Volatile Organic Compounds. A Discussion Paper, National Health & Medical Research Council, Canberra. **1992**.
91. PHILLIPS K., MCKENNA A.M., HOWARD D.A., BENTLEY M.C., COOK J.N. Volatile organic compounds (VOCs): their concentration inside and outside the homes of the residents of six European cities. In: Proc. Volatile Organic Compounds in the Environment. Risk Assessment and Neurotoxicity. Pavia, Italy, October. **1997**.
92. ILGEN E., KARFICH N., LEVSEN K., ANGERER J., SCHNEIDER P., HEINRICH J., WICHMANN,H.E., DUNEMANN L., BEGEROW J. Aromatic hydrocarbons in the atmospheric environment: Part I. Indoor versus outdoor sources, the influence of traffic. Atmos. Environ. **35**, 1235, **2001**.
93. ILGEN E., LEVSEN K., ANGERER J., SCHNEIDER P., HEINRICH J., WICHMANN H.E. Aromatic hydrocarbons in the atmospheric environment: Part III. Personal monitoring. Atmos. Environ. **35**, 1265, **2001**.
94. LEE S.C., CHANG M. Indoor and outdoor air quality investigation at schools in Hong Kong. Chemosphere **1-2**, 109, **2000**.
95. LEE S.C., L. WAI-MING, CHAN L.Y. Indoor air quality at restaurants with different styles of cooking in metropolitan Hong Kong. Sci. Total Environ. **279**, 181, **2001**.
96. CHAO CH.Y.H. Comparison between indoor and outdoor air contaminant levels in residential buildings from passive sampler study. Building and Environ. **36**, 999, **2001**.
97. EDWARDS R.D., JURVELIN J, SAARELA K, JANTUNEN M. VOC concentrations measured in personal samples and residential indoor, outdoor and workplace microenvironments in EXPOLIS-Helsinki, Finland. Atmos. Environ. **35**, 4531, **2001**.
98. BRICKUS L.S.R., CARDOSO J.N., De AQUINO NETO F.R. Distributions of indoor and outdoor air pollutants in Rio de Janeiro, Brazil: Implications air quality in bayside offices. Environ., Sci. Technol. **32** 3485, **1998**.
99. KHODER M.I., SHAKOUR A.A., FARAG S.A., HAMEED A. Indoor and outdoor formaldehyde concentrations in homes in residential areas in Greater Cairo J. Environ. Monit. **2**, 123, **2000**.
100. LIU Y., ZHU L., SHEN X. Polycyclic Aromatic Hydrocarbons (PAHs) in Indoor and Outdoor Air of Hangzhou, China. Environ Sci. Technol. **35**, 840, **2001**.
101. PALMIOTTO G., PIERACCINI G., MONETI G., DOLARA P. Determination of the levels of aromatic amines in indoor and outdoor air in Italy. Chemosphere **43**, 355, **2001**.
102. WAAGMAN N., STRANBERG B., TYSKLIND M. Passive sampling of PCBs from in and outdoor air with semipermeable membrane devices (SPMDs). Organochalogen Compounds **35**, 209, **1998**.
103. ELKILANI A., BOUHAMRA W. Estimation of optimum requirements for indoor air quality and energy consumption in some residences in Kuwait. Environ. Intern, **27**, (6), 443, **2001**.