Role of volatile organic compounds in residential interior air pollution: a study

Debashis Sanyal*

Department of Architecture, Engineering College Raipur, Chattisgarh 492010, India

ABSTRACT

The indoor environment is dynamic in nature, in particular, because of various emission sources contributing with volatile organic compounds (VOCs). Indoor air pollution is a consequence of increased use of synthetics as building materials, cleaning and renovation of building process, constructing airtight buildings to reduce energy costs and inadequate ventilation efficiency. VOCs are ubiquitous in indoor air and by far the largest group of pollutants. Studies reveal that interior painting, carpets, use of detergents and personal hygiene products contribute maximum amount of VOCs in the household interiors. Changes of ventilation and airflow patterns are responsible for variations of indoor concentrations of VOCs as a function of time and space. The major health effects are eczema, hyper-reactivity, dermatitis and irritation of the mucous membrane. This research aims at highlighting various impacts of VOCs for architects, due to usage of various building materials and household objects in urban housing, on indoor environment.

INDEX TERMS

VOC; Residential; Air pollution

INTRODUCTION

Today's urban growth is easily characterized by growing pollution due to several malpractices. Many architects of the present era are ignorantly using various artificial building materials. This increasing usage of several synthetics including PVC, toxic and preservative chemicals in house construction and interior finishing are raising indoor pollution. Many of indoor pollutants are added by food preparation, fuel burning, tobacco smoking, hair sprays, cleaning products, paints and pesticide spray residues. Carpeting, plywood and chemicals from air-conditioning coolants also produce contaminators. This phenomenon is creating problems of indoor air quality. To properly understand the possible impact of volatile organic compounds (VOCs) on the indoor air quality in residential buildings, coordinated research is the need of the hour. The process should initially include developing methodologies of sampling and analysing indoor air pollutants. Investigative research is necessary about knowledge of their sources and emission characteristics, with determining methods of field investigations, besides climatic chamber studies. Finally, development of appropriate methodologies will lead to proper evaluation and experimentation. This will quantify the negative impacts of various emissions from indoor pollutant sources, which affects the residential inhabitants. The aim of this research is to find about the role of VOCs in combination with other indoor pollutants on indoor air quality as well as studying their impact on residential inhabitants. As early as in the 1970s, people started perceiving deteriorated indoor air quality in contemporary buildings.

They started complaining about irritation of mucous membranes of the eye, the nose and the throat, and CNS related problems, such as headache, fatigue and difficulties of concentration including stuffy air feeling and odour annoyance. These complaints gave birth to a new term 'Sick building Syndrome'. Generally, if 20% of the occupants complain about

* E-mail: debashissanyal@rediffmail.com

air quality problems and these symptoms vanish after coming out of the building then sick building syndrome can be suspected (Source: ASHRAE). Studies reveal that people spent approximately 80% of their time indoors. About 70% of the current building materials consist of involvement of around 50 000 chemicals. Some of these chemicals are already known to be carcinogens/mutagens. Many can create dizziness, headache, stress, migraine, memory loss, respiratory difficulties and allergies of all kind, disturbances in biological functions, breakdown of immune system, damage of cellular growth and genetics. It has been already established that concentrations of some of the major pollutants such as radon, formaldehyde and asbestos reach much higher levels in indoor air than outdoor air. Several hundred organic compounds have been already detected in indoor air and most of these belong to a class called VOCs. Volatile organics are a broad range of compounds with boiling points from less than 0°C to about 400°C.

Hazardous VOCs including formaldehyde are emitted from various building materials. Concentrations of organic air pollutants vary widely between indoor spaces and may also vary within a single space as a function of location and time. Thus, indoor air pollution is a combination of continuous and discontinuous emissions of different sources.

THE HOUSING INTERIORS

The present trend of using synthetic basic and finishing materials in housing interiors is imparting a number of negative impacts on the occupants. There is much chemical and microbiological pollution in the residential interiors because of these materials. They constitute about 70% of current conventional building materials (for example, concrete, plastics, steel, aluminium, chemically treated wood, synthetic floor and wall surfaces, toxic paints. insulation and furniture, etc.). A selected list of building materials and their general resultant polluting compounds is given in Table 1.

Table 1 Selected list of indoor sources and associated general resultant polluting compounds

Sources	Major Polluting Compounds Emitted
1. Building materials	
Cement	Lime
Lime	Lime
Sand	Silica
Wood/ wood based products	Suspended particulate matters, terpens, aldehydes, wood preservatives, formaldehyde
Vinyl floor	Alkanes, aromatics, glycol esters, 2-ethyl-1- hexanal
Interior painting	VOC, NOx, toxic compounds
Furniture	Vapours of preservative chemicals
Cupboard (kitchen)	Butanol, hexanal, 2-methyl-1-propanal
Lacquered beech parquet	Butyl acetate, ethyl acetate, ethylbenzene and xylenes
Carpets	VOC, SVOC, HCHO, solvents, 4-phenylcyclohexene
PVC floor (bathroom)	Toulene, methyl cyclohexene, heptane, isododecane
Door (interior)	Butyl ccetate, hexanal, butanal, butanol
Door (threshold)	α-Pinene, 3-carene, limonene, allocimene
Gypsum board	Xylenes, diacid esters, butyl acetate, isododecane, decane, 3-carene
Particle board	Alkanes, aldehydes, butanol, formaldehyde, ketones
Painted wall	3-Carene, α-pinene, texanol, hexanal
Wall paper	Hexanal, terpenes
Rubber	Acetophenone, alkyl-aromatics, styrenes
Textile/drapery	Acetone, ethyl acetate, methylfuran, thiopene, dimethyl disulfide

Insulating / fire retardant materials	Asbestos
Varnish	Alkanes, aromatics
2. Related human activities	
Shampoo	Ethylene glycol butylether
Showering	Chlorinated hydrocarbons
Gluing	Aldehydes
Painting	Aldehydes, alcohols, solvents
Personal Care products	Siloxanes, oxygenates (fragrances)
Room freshener	Alkanes, limonene, fragrances
Cleaning	Solvents, limonene
Dry cleaning	Chlorinated hydrocarbons (tetrachloroethylene)
Pest control	BHC
Insect repellents	Malathion

Source: The Danish Twin Apartment Study, National Institute of Occupational Health, Denmark, (1989); *Indoor Air*, Supplement 3/95, 18.

These resultant polluting compounds have very harmful effects on occupants due to continuous and prolonged exposures. Sometimes the composite effect of multiple pollutants can seriously affect human respiratory systems, leading to susceptibility to viral infections and asthma. Primary pollutant sources emit free (non-bound) VOCs. The primary pollutants, generally, are low molecular weight VOCs, such as solvent residues, additives and unreacted raw materials, for example, monomers. Secondary pollutants are either chemically or physically bound VOCs, but a number of VOCs are emitted or formed by several different reactions. Emission by hydrolytic decomposition is already known, other examples are oxidative degradation and re-emission of absorbed VOCs (sink effect).

INDOOR AIR POLLUTION

There are many diseases reported typical to indoor air pollution. They include asthma, hypersensitivity reactions, pneumonitides, pulmonary infections and dermatitis. Recent evidences indicate an even more ominous correlation between indoor air pollution and hypersensitivity. Exposure to irritant gases such as SO_2 and O_3 can potentate significantly the induction of allergy in animal models. A short list of health effects due to indoor air pollutants is given in Table 2.

There is an increasing awareness regarding the potential impact of indoor pollution on health and comfort, in particular, the emission of VOCs from building materials and products. Internationally, there is a need to label building materials according to their impact on the indoor air quality.

Table 2 Health effects related to indoor pollution

Pollutants	Health effects
Microbiological pollutants	
Allergens, mites, etc.	Asthma, hyper-reactivity, stuffy nose, skin irritation, sneezing, rhinitis
Chemical pollutants	
CO_2	Bronchoconstriction, headache

CO	Headache, dizziness
NO, NO_2, SO_2	Cough, bronchitis
Formaldehyde	Cough, bronchitis, anxiety, eczema
Radon	Cancer
Ozone	Asthma, hyper-reactivity
Asbestos	Chest/abdominal cancer, lung infections
VOC	Eczema, hyper-reactivity, dermatitis, damage to liver and kidney, loss of coordination, headaches, Hyper-reactivity of mucous membrane

VOCs originate from various abundant sources, such as building materials, consumer and household products, furniture, office machines, human activities and negative sources. Indoor air pollution is a combination of continuous and discontinuous emissions of different sources. It is noted that concentrations of organic air pollutants may vary widely between indoor spaces and may also vary within a single space as a function of location and time. It is being noted after experimentations that the level of VOCs may fluctuate significantly during a day because of activities and/or the number of persons present. Two types of emission sources generally produce VOCs from building materials. Primary pollutant sources emit free (non-bound) VOCs in the material. Secondary pollutant sources emit VOCs that are either chemically bound in the material matrix or formed by different reactions, for example, re-emission of absorbed VOCs (sink effect), chemical hydrolysis and oxidative degradation. The building materials start emitting a variety of VOCs during and after construction. As the time passes 'emission decay' occurs. After some time, finally they will reach a 'quasi steady' emission rate for VOCs and SVOCs in new buildings, within weeks to months or even a year. The emission decay varies greatly for different material types, but it may, for some materials, continue for more than a year, for example, waterborne paints. After the initial equilibrium time usually other phenomena such as oxidative degradation and adsorption and desorption takes over. The timescale of emission from these sources is in the range from weeks to continuous. The levels of VOCs (which are building materials related) noted in interiors are generally higher in the vacant apartment though occupancy may introduce other set of VOCs due to human activities. Seasonal variations are also being noted in them. The increase in VOC emission rate is being noted with the reduced air exchange rates (this happens when indoor and outdoor temperature is the same). Major details regarding the construction of building, its history, materials used, temperature, humidity, air exchange, the occupants' activity pattern and many other indoor parameters are required to arrive at conclusions about the VOCs concentration levels. It is being recommended that pollutants originating mostly indoors such as radon, formaldehyde, certain pesticides and some heavy metals be controlled drastically (Sanyal, 1994).

LIST OF MAJOR POLLUTING COMPOUNDS OF INDOOR SOURCES AND THEIR RELATED HAZARDS

Polluting Compounds	Hazards	Exposure Limits
1. Lime	Burns of skin/eyes Chronic skin disease	CaO- 2 mg/m^3 (8 h TWA)
2. Silica	Silicosis, cough, Sputum, death	SiO_2 - 6mg/m^3 (Inhalable dust) (8 h TWA)
3. NOx	Fatal lung damage	NO_2 - long 3 ppm, short 5 ppm
4. HCHO	Eye/lungs irritant, thickening of skin, dermatitis	Long 2 ppm Short 2 ppm
5. Turpentine	Skin burn, vomiting, irritation, coma.	Long 100 ppm Short 150 ppm

6. Acetone (CH_3COCH_3)	Irritation of eyes, nose chest, headache, dry cracking of skin	Long 1000 ppm Short 1250 ppm
7. Asbestos	Lung cancer, mesoth-elioma, asbestosis	0.2 fibres/ml of air averaged over 4 h
8. Barium	Vomiting, diarrhoea	Long 0.5 mg/m^3
9. Benzene	Narcotic, nausea	10 ppm (8 h TWA)
10. Polyurethanes [$C_6H_3CH_3(NCO)_2$]	Cough, asthma, bronchitis	Long 0.02 mg/m^3 Short 0.07 mg/m^3

Note: mg/m^3—milligrams per cubic metre; TWA—time weighted average; ppm—parts per million.

REMEDIAL MEASURES

Pre-auditing

As building materials used indoors have a direct impact on the health of occupants most of the time, there is a need to check them beforehand. This will ascertain the use of these materials for a safe and healthy interior. This is termed as pre-environmental auditing. This will help establish a list of safe materials. Before introduction of any new materials they should be also pre-audited. This envisages further research and determinations of indoor household pollutions according to different situation and locality of houses. It is necessary to promote and use eco-friendly building materials for usage in mass housing and other habitable structures.

The Addition of Alternative Materials

There exist a variety of non-conventional and alternate materials that can be increasingly used for mass housing. This will effectively reduce the chances of environmental pollution due to conventional building materials. There is also a need of exploration of suitable different sources of renewable and non-conventional energy that will reduce the resultant environmental pollution. At this juncture it is necessary to outline the need of adopting good habits, human activities and recycling of materials and energy practices, which will further improve the scenario.

Gassing Off

It has been observed that some of the building materials continue to emit VOCs and formaldehyde even after 1 year. A ‘flushing period’ to obtain a steady emission from building materials appears to be approximately 100–130 days but this depends upon several factors like season, temperature, humidity, air exchange and activity patterns.

THE ARCHITECTURAL DESIGN ASPECTS

Use of solar/wind energy, active and passive solar systems, renewable energy sources/biomass/biogas, etc. Use low energy materials, clay products/fired clay products. Use recycling process. Use eco-friendly and biodegradable materials. Use energy efficient/preservation/conservation techniques. Use minimum radiation emitting gadgets.

RECOMMENDATIONS

1. The objective of development of mass housing should be to provide a healthy living environment for human conditions.
2. There should be a balanced relationship between building technology, economy and biology–ecology. Reduction/avoidance of environmental and indoor pollutions from chemicals, particles, microbes, radiations and fields (electromagnetic/ static) is necessary.

3. Housing should be developed in such a way so that it can be harmonious to nature and environment.
4. Maximum recycling/reusing of resources/wastes should be aimed at. Before starting development of any kind, life-cycle analysis study should be done considering long-term/global effects.
5. Energy preservation/conservation and use of eco-friendly energy sources should be maximized. Eco city, ecological parks and other sustainable developments should be promoted.

THE NEW CONCEPTS

Bio-harmonic Architecture

It promotes healthy, harmonious and ecologically sound buildings, which are ‘breathing third skin’ of humankind. It uses such building materials that can breathe and protect people, insulate, regulate, absorb, evaporate and enhance indoor living quality. Some of the indoor plants can improve indoor air quality (Sanyal, 1997).

Self-sufficient Housing

The concept of ‘self sufficient housing’ (Sanyal, 1995) is to minimize the pressure on cities in terms of space, energy, traffic, population, etc. This housing will be in a self-contained commune with a building unit designed to cater the needs of approximately 15–20 families. They will produce their own energy for domestic use also grow their own agricultural produces for food and their visit to urban areas will be limited to only such task and products that are not feasible in this commune. They will be situated in rural areas.

REFERENCES

Sanyal, D. (1994). Development of mass housing: a study of environmental impacts. *Proceedings of National Seminar on Development & Environment*, Bhopal, pp. 77–80.

Sanyal, D. (1995). Self sufficient housing: searching of parameters. *Architects India* Bombay, **7**(6), 26–27.

Sanyal, D. (1997). Environmental impacts of conventional building materials: a study of housing interiors. *Proceedings of Second International Conference on Non-Conventional Construction Materials*, pp. 134–144, Bhubaneshwar.