Chapter 5
Volatile Organic Compounds Emission from Building Sector and Its Adverse Effects on Human Health

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Abstract The volatile organic compounds (VOCs) from building sector include aliphatic hydrocarbons, halo-hydrocarbons, and aromatic hydrocarbons. The recent research findings conducted in the non-residential indoor environments have demonstrated that the concentration of indoor VOC often exceeds the outdoor concentrations. The recent evidence insinuates that the significant amount of VOCs can clearly have both acute and chronic adverse effects on human well-being including cardiovascular and nervous system, increased mortality, etc., and may even cause cancer. Furthermore, VOCs have a significant effect in "sick building syndrome" reported by the WHO. Volatile organic compounds generally occur as liquids or as vapours at normal room temperature but may also exist in solid form such as bathroom deodorants, dichlorobenzene, naphthalene, and para-mothballs. Due to the presence of plenty of VOCs it is not practicable to handle all the compounds and their toxicity. It is evident that while hundreds of VOCs may exist in any type of environment, the substantial health effects of the exposure of VOCs are yet to be identified. Thus to improve the air quality of the indoor building environment it is mandatory to expertise the better understanding of the mechanism and basic characteristics of VOC generation from the building sectors and construction materials.

Keywords Benzene · Building sector · Carcinogenic · Formaldehyde · Indoor environment · VOCs

5.1 Introduction

Despite the fact that humans are becoming more opulent and developing towards modern life, we spent an estimate of 80% of our time in the indoor air environment (Poljansek et al. 2017). Whereas, in environmental equity dialogue the indoor environment has been scarcely mentioned (Adamkiewicz et al. 2011). There has been a constant increase in the tendency of constructing the structures that are more

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focussed on the extravagance and consolation of the inhabitant as well as towards the energy conservation leading to the construction of buildings which are more airtight and have a lesser number of operable windows and meagre airflow (Chang and Gershwin 2004). As per the documentation of EPA, the concentrations of the VOCs are comparatively 2–5 times more than the concentrations present outdoors and occasionally much higher (EPA 2016). Selectively, the newly constructed buildings occupy the topmost level so far as VOC off-gassing in the indoor environment is concerned, which tends to the increased number of new substances producing VOC particles collectively within a short space of time (Wang et al. 2007). In the course of certain activities, the concentrations of VOCs in the indoor environments can achieve 1,000 folds than the outside environment. Meanwhile, various studies have depicted that when VOCs are considered separately in the indoor environment the emissions are not very high. Moreover, the total VOC (TVOC) concentrations in an indoor air may be comparatively as much as five times higher than the concentration of VOCs present outside. Apart from new buildings, various consumer products are responsible for the emission of VOCs thus elevating the inside concentrations (Wang et al. 2007; Jones 1999).

The regularly found VOCs within the indoor environment were aliphatic aldehydes, alkanes, benzenes, substantial chlorinated aliphatic hydrocarbons, and terpenes. Though there are significant sources of VOCs present indoor, thus the concentrations of VOCs are considerably greater than that of the outdoor environment (Meciarova et al. 2017). This insinuates that the inhabitant maybe intermittently exposed to miscellaneous VOCs at the higher level concentration in a short span period, moreover depending upon the duration of exposure, occupant activity location, and type of the VOC present (Tsai 2019). In connection with the winter season, the extent of VOCs in indoor air is about three to four times greater as compared to concentrations of the summer season (Barro et al. 2009). The quality of air within the building sector is not so clean and safe particularly in buildings that involve the utilisation of hazardous chemicals or wherein processes of combustion take place. The indoor air pollution generally depicts the production and transportation of pollutants in the inner side of different indoor environments where people reside and carry out their work, like workplaces of industries, hospitals, schools, apartments, and homes of the private sector (Heinsohn and Cimbala 2003). The indoor air quality (IAQ), or indoor environmental quality (IEQ), in broader terms, has received significant awareness from the common public along with practitioners including the researchers (Lai et al. 2009). The organic compounds having boiling points less than 250 °C at (101.325 kPa) atmospheric pressure are generally referred as “volatile organic compounds” (Huang et al. 2020). VOCs are referred as the wide range of compounds with an organic origin to which people are exposed on regular intervals. Materials from the buildings such as furniture, cleaning products, paint, and cosmetics are the predominant VOC sources. These regular products cause emissions of VOCs in the form of gases that are ultimately inhaled by the people (Lim et al. 2014).

There are various causes responsible for the potential sources of indoor pollution in school buildings as in case utilization of materials having high emission for the construction and furnishing of buildings, restricted landscaping with an inadequate drainage system, the pattern of air conditioning, heating and ventilation, the absence of preventative measures, cramped conditions and products of cleaning which are responsible for releasing chemicals into the air (Godwin et al. 2007; Moriske et al. 2008). The pollutants present in indoor environments expose the occupants of the building to the adverse health threats (Chan et al. 2015). The VOCs have constantly been placed among five leading environmental public health risks (EPA 2015). Though the children have comparably higher sensitivity to pollutants than that of the adults, yet they spend more time in the school indoor environment where they are easily exposed to an unspecified amount of building pollutants (De Gennaro et al. 2013). The enormous amount of released VOCs comprises of alcohols, aldehydes, alkanes, alkynes, aromatics, alkenes, esters, halocarbons, sulphur/nitrogen containing VOCs, and ketones, while as the environmental impression of these compounds is characteristically reliant on the effectiveness of the particular VOC. Assume that hundreds of VOCs may exist in all forms of environment; the precise effects of VOCs exposure on humans are still unidentified. The prominent levels of VOCs are contributed by the minimal pace of air exchange system in between the indoor air environment and the outdoor as consequences of tightly-shut windows and continuous increase in the utilisation of humidification devices (Schlink et al. 2004). Commonly utilized products that carry the VOCs are glues (ethyl benzene, toluene, n-hexane, xylene, vinyl chloride) inks paints, and varnishes, products used to remove stains (for example carbon tetrachloride, trichloroethylene, trichloroethane, tetrachloroethylene), propellants for aerosol (dichloromethane, dichlorodifluoromethane), cosmetics (acetone, ethyl acetate, propylene glycol, phenolic compounds), household products commonly used for cleaning (acetone, chloroform, phenol, dimethyl ammonium chloride, ethanol), wood preservation products (p-dichlorobenzene, pentachlorophenol) (Maji and Ashok 2003; Wille and Lambert 2004). As documented by WHO, VOC plays a significant role in SBS (Ten Brinke et al. 1998). While considering the objective to estimate potential health effects correlated with the exposure of VOCs, it is obligatory to understand and estimate both the core sources of pollution as well as pollutant concentration with an appropriate indoor monitoring.

5.2 Sources of VOCs in Building Sectors

VOCs, a significant group of compounds could be important as these compounds are considerably available in construction materials and that way can be ceaselessly released in a slow manner over an extended period of time that can pose a considerable threat to human wellbeing and health when there is a notable exposure towards them (Rumchev et al. 2007). Considering VOCs that are present in the building environment, the significant sources may incorporate building occupants who spend an extended amount of time in the buildings, microbial sources, emissions from automobiles and new construction as well as renovations (Brown 1999) (Table 5.1).

Table 5.1 Commonly known volatile organic compounds and their potential sources

Chemicals	Major sources of exposure
Acetone	Cosmetics
Alcohols (isopropanol, ethanol)	Cleansers, spirits
Aromatic hydrocarbons (xylenes, ethyl benzene, trimethyl benzenes, toluene)	Adhesives, combustion sources, gasoline, paint
Aliphatic hydrocarbons (decane, undecane, octane)	Paints, combustion sources, gasoline, adhesives
Benzene	Smoking, pumping gas, driving, passive smoking, auto exhaust
Carbon tetrachloride	Global background, fungicides
Chloroform	Dishes, washing clothes, showering (10 min average)
p-Dichlorobenzene	Moth cakes, room deodorizers
Formaldehyde	Pressed wood products
Methylene chloride	Solvent use, paint stripping
Styrene	Smoking
Tetrachloroethylene	Visiting dry cleaners, storing or wearing dry-cleaned clothes
I, I, I-Trichloroethane	Aerosol sprays, storing or wearing dry-cleaned clothes
Trichloroethylene	Unknown (correction fluid, cosmetics, electronic parts)
Terpenes (limonene, ex-pinene)	Scented deodorizers, fabrics, food, fabric softeners, cigarettes, polishes, beverages

Adapted after: Burn et al. (1993)

Wood being a biological and natural material, when burned, emits various profiles of organic chemical substances majorly being formaldehyde, very volatile organic compounds (VVOCs), and volatile organic compounds (VOCs). The concentrations of these compounds vary in comparison to the emissions that occur within indoor spaces of buildings, thus making huge concentrations of VOCs indoors comparatively to that of outdoors (Skulberg et al. 2019). The indoor variety of VOCs is extensive and includes personal products, products utilised in the household, and building materials (Rumchev et al. 2016). Any sort of material within a building can emit a notable amount of organic chemicals into the air. There are a wide variety of sources through which VOCs are emitted among commercial and residential buildings that include a wide range of construction material, and indoor samples of air may thus carry hundreds of VOCs (Rumchev et al. 2007). Mainly, the sources VOCs in building air quality include anthropogenic activities, products for personal care, smoking, products utilised for house cleaning, building products, and pollution from outside (Sarigiannis et al. 2011). Bartzis et al. (2015) also considered the emissions of NMVOC occurring due to plug-in air fresheners, personal care products and kitchen cleaning agents. Outdoor sources mainly include petrol stations, traffic sources and various chemical industries that include those dealing with oil, coal, chemicals, and paints (Godish et al. 2015). Other uses of VOCs in the building sectors as demonstrated by WHO (2010) include:

- Do-It-Yourself (DIY) items such as wallpapers, adhesives, paints, glues, lacquers and varnishes,
- Household agents for cleaning for example detergents, disinfectants, shoe products, carpet cleaners and softeners,
- Cosmetics including shampoos, liquid soap, nail hardeners and varnishes,
- Electronic equipment, such as photocopiers and computers,
- Miscellaneous consumer items such as paper products as well as insecticides.

These selected VOCs that are widely available in the air of building sectors can be classified into several subgroups that include aromatic hydrocarbons, aliphatic, oxygenated and chlorinated hydrocarbons. Many hundred diverse VOCs have been determined in the air of building sectors by government organizations and academic researchers (Wolkoff and Nielsen 2001). Ketones and alcohols are usually used in manufacturing of cosmetics and products used for personal care such as colognes, hair spray, nail paints, rubbing alcohol, nail paint removers, and perfumes. Ketones are also consumed in paint thinners, aerosols, adhesives, and varnishes, window cleaners. Alcohol based VOCs comprises benzyl alcohol, ethyl alcohol, isopropyl alcohol while ketone based VOCs include acetone, ethyl acetate, methacrylates (methyl or ethyl) and methyl ethyl ketone.

5.3 General Classification of VOCs

The categories and the overall concentration of VOCs in the air environment have been reviewed (Brown 1999). Generally, VOCs include acetone, benzene, ethanol, ethylbenzene, dichloroethylene, n-decane, xylenes, ethyl acetate, n-nonane, nonanal, methyl ethyl ketone, tetrachloroethylene, 1, 2, 4-trimethylbenzene, p-dichlorobenzene, 1, 2- *n*-hexane, 1, 1, 1-trichloroethane, dichloromethane, limonene, and toluene. These VOCs have been further divided into four categories: aldehydes (i.e. HCHO), chlorinated aromatic compounds (such as 1, 4-dichlorobenzene and 1, 2-dichlorobenzene), non-chlorinated aromatic compounds (that is, benzene, ethylbenzene, styrene, toluene and xylenes), chlorinated aliphatic compounds (for example carbon tetrachloride, tetrachloroethylene, dichloromethane, chloroform, and trichloroethylene) (Tsai 2019). Furthermore discussions on the four mentioned categories of VOC are summarized as under.

5.3.1 Formaldehyde (H-CHO)

H-CHO is a colourless, gaseous compound having a different, foul odour. It is a highly volatile and very reactive compound because it rapidly reacts with hydroxyl radicals to form formic acid at a normal room temperature (Wolkoff 2013). Perhaps, HCHO might be most significant VOC pollutant in the air environment of building sectors because its key sources are the materials that are used in building and furnishings for an instance carpet, medium-density fibreboard, particleboard, and plywood (Godish et al. 2015). Among all, the aldehydes are one of the significant pollutants in building sectors, which are commonly emitted from materials which are utilised for decoration and are caged in airtight and compact buildings (Klett et al. 2014; Mitsui et al. 2008). Aldehydes such as formaldehyde are emitted from various industrial products, such as adhesives, cleaning agents, cigarette smoke, cosmetics, carpeting, plywood, construction materials, disinfectants, treated wood resins, medium-density fibreboard, plastic particleboard, and fabrics (Li et al. 2014b). The exposure of humans to low concentration of aldehyde may cause irritation in eyes, throat irritation, breathlessness, and chest tightness (Zhu and Wu 2015). Whereas, the constant exposure to considerably high concentration of aldehyde intensifies risk of acute poisoning, whereas prolonged exposure can mark negative impacts on human comfort and health that eventually can result in chronic toxicity (Main and Hogan 1983; Andersen et al. 2008; Liotta 2010; Zhu and Wu 2015). Long-term exposure of formaldehyde can also give rise to the nasal tumours and irritation of few sensory organs such as mucous membranes of eyes, skin, and also in respiratory system (Collins et al. 2001; Yu and Crump 1998). As reported, formaldehyde may cause sensory irritation under certain occupational and environmental conditions (Wolkoff 2013).

5.3.2 Chlorinated Aromatic Compounds

The group of chlorinated volatile compounds include 1, 4-dichlorobenzene (p-dichlorobenzene), and 1, 2-dichlorobenzene (o-dichlorobenzene). These chlorinated VOCs are broadly utilised in industries and in commonly used products like chemical dye stuffs, odour-masking agents, and pesticides (Godish et al. 2015). 1, 4-Dichlorobenzene, which is the most significant volatile compound out of three dichlorobenzenes, generally is colorless to white solid compound at the normal conditions having a strong pungent odour. Moreover, it is poorly soluble in water and comparatively has high volatility. As consequence, it is chiefly applied as a deodorant in indoor spaces of residential and office areas such as urinal deodorizers, room/restroom deodorizers, and also as an insecticide fumigant for the moth control and toilet bowl blocks (WHO 2010).

5.3.3 Non-chlorinated Aromatic Compounds

The non-chlorinated VOCs arise usually from outdoor air environment and petroleum-related products that are utilised in the indoor, including adhesives, coatings, paints, enamels, household cleaners, fuels, varnishes, glues, lacquers, gasoline, lubricants, and building materials like wallpaper and carpets (Rosch et al. 2014). Aromatic non-chlorinated compounds are not only toxic but also carcinogenic (Kim and Shim 2010). Compounds such as ethyl benzene, benzene, and toluene are used in several formulations and products such as paint, petrochemicals, detergents, and medicine (Özçelik et al. 2009). Materials that are consumed in construction, decorating and remodelling contributes enormously to the concentrations of benzene in the indoor environment. Benzene is also available in caulking, paints, flooring adhesives, particleboard furniture, fiberglass, wood panelling, plywood, and paint remover (WHO 2010).

5.3.4 Chlorinated Aliphatic Compounds

Generally, chlorinated VOCs include chloroform, trichloroethylene, carbon tetrachloride, tetrachloroethylene (also referred as perchloroethylene), and dichloromethane, are primarily applied as solvents, that are commonly used ingredients of oil and fat degreasers, water repellents, shoe polishes, paint remover, epoxy paint sprays, and dry cleaners in laundries (WHO 2010). Other halogenated VOCs consist of dichloroethane, chlorobenzene, tetrachloroethane, trichloroethane, tetrachloroethylene, and trichloroethylene (Giraudon et al. 2008). In general, such chemical compounds are applied in processing of paints, adhesives, and chemical extracting agents, polymer syntheses, manufacturing of drugs, as cleaning agents, and as solvents in chemical reactions (Aranzabal et al. 2014). Through the drinking water humans can be susceptible to chlorinated aliphatic VOCs by, inhalation, drinking water and adsorption during swimming (Huang et al. 2014).

5.4 Nature and Types of VOCs

By nature, VOCs are a general category of those organic compounds having over 10.3 Pa of Reid vapor pressure at normal temperature (293.15 K) and pressure (101.325 kPa). Thus VOCs consist of a wide array of chemicals that contain carbon and can easily evaporate at room temperature (Olsen and Nielsen 2001; Li et al. 2009; Ojala et al. 2011).

The VOCs are the most common pollutants that are present in the air of building sectors and are generally defined as the organic compounds having a boiling point that possibly ranges from 50 to 260 °C (Sarigiannis et al. 2011). The moderately low

Table 5.2 WHO classification system for organic indoor pollutants

Group	Boiling point (°C)	Example compounds
VVOC	<0 to 50–100	Propane, Butane, methyl chloride,
VOC	50–100 to 240–260	Formaldehyde, ethanol (ethyl alcohol), acetone, hexanal, toluene, d-Limonene, 2-propanol (isopropyl alcohol)
SVOC	240–260 to 380–400	Plasticizers (phthalates), pesticides (DDT, chlordane, fire retardants (PCBs, PBB))

Adapted after: WHO (1989)

boiling point of VOCs allows evaporation or sublimation from the solid phase into the gaseous form. This peculiarity of VOCs is at times described as 'off-gassing'. The variety of VOCs that are identified in the air environment of building sectors is usually greater than that of outdoor air (Rumchev et al. 2016). VOCs in certain instances are classified by the ease of their emission (EPA 2017). For example, WHO categorizes indoor organic pollutants as:

- Very volatile organic compounds (VVOCs)
- Volatile organic compounds (VOCs)
- Semi-volatile organic compounds (SVOCs).

The documented organic pollutants are categorised into subgroups in several ways. Whereas, WHO classified the organic pollutants of indoor environments (Table 5.2) on the basis of their respective boiling points.

Typically the nature and type of VOCs in the indoor of building sectors is based on source of emission. Some examples of VOCs are aromatics, alkanes, alcohols, aldehydes, olefins, ketones, esters, ethers, paraffins, halogenated hydrocarbons, nitrogen and sulfur containing compounds (Khan and Ghoshal 2000; Carpentier et al. 2002; Miranda-Trevino and Coles 2003; Ozturk and Yilmaz 2006; Soylu et al. 2010; Doggali et al. 2012; Yosefi et al. 2015).

5.5 Health Effects

Undoubtedly, the sprays containing aerosols that are utilized frequently in the building sectors contain an appreciable amount of VOCs that are chemicals of organic origin that can vaporize readily at room temperature and have significant contribution to air pollution in indoor air. Furthermore, they can have an immediate health effect on humans as they spend enormous time indoors and thereby shorten the expectation of life as consequences of cardiovascular and respiratory ailments and from weak functions of lung (Dales et al. 2008; Pharmacy Magazine 2019) (Table 5.3). The Indoor air contamination resulting from VOC might affect well-being of human at the domestic level, in open areas and also in the commercial buildings (Rumchev et al. 2007).

Table 5.3 Threshold limit values (TLV) of indoor regulated VOCs and their TLV basis (ACGIH 2017)

Designated indoor VOCs	TLV (ppm)	TLV basis
Carbon tetrachloride	5	Liver damage
Dichloromethane	50	COHb; CNS impairment
Ethyl benzene	20	URT irritation; cochlear damage; kidney damage (nephropathy)
Styrene	20	CNS impairment; peripheral neuropathy; URT irritation
Chloroform	10	CNS impairment; liver and embryo/foetal damage;
1,2-Dichlorobenzene	25	Eye irritation; liver and URT damage
1,4-Dichlorobenzene	10	Kidney damage; eye irritation
Benzene	0.5	Leukaemia
Toluene	20	Visual impairment; pregnancy loss; female reproductive
H-CHO	0.1	Eye and URT irritation; URT cancer
Xylenes	100	CNS impairment; URT and eye irritation
Tetrachloroethylene	25	CNS impairment
Trichloroethylene	10	Cognitive decrements; CNS impairment; renal toxicity

CNS Central Nervous System; *H-CHO* Formaldehyde; *URT* Upper Respiratory Tract; *COHb* carboxyhemoglobin

According to the documentation of the US EPA, other health effects comprise irritation in the eyes, throat, and nose; serious harm to kidneys, CNS, and liver; loss of coordination, headache, and nausea. Whereas, some identified Volatile organic compounds can cause cancers; also some of the VOCs are alleged or assumed to cause cancer in humans. Generally, the principal symptoms or initial indications correlated with the vulnerability of VOCs may include irritation in the conjunctiva, skin allergies, throat and nose discomfort, skin allergic reaction, shortness of breath or dyspnea, dizziness, nausea, emesis or vomiting, epistaxis or nose bleeding, and decline in levels of cholinesterase serum (Kim et al. 2010; EPA 2019). The capability of organic chemicals to trigger adverse impacts on health differs substantially from the ones that are considerably toxic, to those with unknown health impacts (EPA 2019). Environment that is substantially built in the building air plays an essential part in general safety since of both the sum of time we spend inside and capacity of buildings to emphatically or contrarily affect our wellbeing (Allen et al. 2016).

VOCs categorically represent one of the most important categories of harmful pollutants, which influence quality of air and also human well-being and health in building environments. The VOCs depicted as one of the foremost critical groups of pollutants, impacting the standard conditions of air and health of humans and well-being in the indoor situations. Nevertheless, recent shreds of evidence propose that a considerable amount of given VOCs can lead to unfavourable impacts on human health and even can cause cancer (Rumchev et al. 2007). Wolkoff et al. (1997) and Weschler (2004) conducted various research studies and documented that the VOCs respond to oxidants for example ozone to generate compounds that are reactive and can likely cause unfavourable sensory effects.

VOCs can be absorbed through lungs and are then transferred through bloodstream to every organ of the body and hence have the potential to influence various other organs and tissues as either parent compound or bioactivated metabolite (Boeglin et al. 2006). A few VOCs, for instance limonene and styrene, can readily react with ozone or with oxides of nitrogen to generate secondary aerosols and new oxidation products, which can cause complaints regarding sensory irritation (Wolkoff et al. 2006).

Formaldehyde is labelled as one of the foremost common VOCs known and is additionally demonstrated as a very familiar respiratory irritant. It gets absorbed and deposited in the upper respiratory tract while reacting with the biological macromolecules (Maroni et al. 1995). In addition to the sensory and respiratory irritation caused by the chemicals present in the building sectors, exposure to volatile compounds can also influence the nervous system, which results in a lack of focus and concentration. Numerous mechanisms of the pathways could be involved in human health impacts, a few of which are the immune system's response, sensitization, impacts on the heart rate, irritation in the sensory organs, and also psychological and social stress reactions. Even though there are no visible threat for leukemia and/or lymphoma at standard concentrations of VOCs such as benzene, and HCHO in the indoor air environment (WHO 2010), these are widely presumed or known to be carcinogenic and/or of toxic quality for kidney, upper respiratory tract liver, and CNS (Tsai et al. 2018).

In general terms, the adverse health impacts incited by groups of VOCs can be categorised as carcinogenic or non-carcinogenic.

5.5.1 Carcinogenic Effects

Primarily, the carcinogenic impacts of VOCs are on the lung, liver, blood (leukemia and non-Hodgkin lymphoma), kidney, and biliary tract cancer. As an illustration, the International Agency for Research on Cancer (IARC) has specifically classified benzene as a carcinogen for humans under group 1, whereas other VOCs such as tetrachloroethylene and ethylbenzene are reviewed likely to be carcinogens for humans and are labelled under Group 2A or 2B (De Gennaro et al. 2013). Several identified VOCs are also presumed to act as carcinogens for humans such as vinyl chloride. Other groups of VOCs are considered as carcinogens for animals and may also function as human carcinogens such as methylene chloride, chloroform, trichloroethylene, dichlorobenzene, tetrachloroethylene. Another group of VOCs are mutagens for example a-pinene and are also called carcinogens for weak animals such as limonene (Burn et al. 1993).

5.5.2 Non-carcinogenic Effects

In the buildings, health-related issues usually result from the complaints of odour. Most VOCs with unpleasant and smelly properties have odour limits just below the levels that are considered toxic (Loftness et al. 2007). Nonetheless, it is mandatory to prioritize protection from odours for a better quality of life, and efficiency reasons, whereas, several VOCs particularly with respect to styrene and formaldehyde, have authenticated guidelines which are based on the odour (WHO 2000). The recent examinations for VOCs levels that were measured in residential areas and workplaces have demonstrated that average levels of VOCs are unlikely to surpass the odour thresholds (Hodgson and Levin 2003; Rumchev et al. 2007).

5.6 Sick Building Syndrome (SBS)

The ailments that have been ascribed to the habitation of building sectors have been demonstrated since the 1970s (Lyles et al. 1991). In the mid-1980s, the SBS was first observed and documented by the researchers (Finnegan et al. 1984; Hicks 1984) and came to attention after it was sensationalized by the media (Carey et al. 1985). Several VOCs may be related to the diversity of chronic health effects and symptoms such as reactions caused by allergies and asthma. These symptoms are frequently observed in newly constructed buildings or in buildings that are under construction or renovations (Berglund et al. 1984). Moreover, numerous VOC based research on office employees have clearly reported a sound relationship between illnesses like irritation in the mucous layer and CNS symptoms, and overall exposure of humans to VOCs. These noticeable symptoms and signs are very familiar to symptoms that are associated with the SBS (Mølhave et al. 1986; Hodgson et al. 1991).

5.7 Exposure of VOCs to Humans

Most often, the constant exposure of humans to VOCs in the air environment of building sectors is in turn because of the inhalation of VOCs floating in the air. The standard of the air that we breathe can exhibit considerable effect on human sense of comfort and health (Loftness et al. 2007). Subsequently, the discharge levels of VOCs from the building materials have relevance in the connection to their adverse health impacts, whereas various European nations have established nationwide prohibitions for VOC discharge levels of VOCs from several materials of buildings (ECA 2013). Besides, these pollutants can be emitted and absorbed by the walls of the building environment. The commonly used compounds to which occupants regularly get in touch also include VOCs, a few of which are regarded as perilous for human well-being. The time duration of the exposure represents an essential factor despite the fact that the pollutant concentration is moderately low (Edwards et al. 2001).

Standards have been set for the estimation of emissions or discharge from building materials within indoor air (CEN 2017). Other estimations reported that the occupants with smokers have considerably greater degree of VOCs that includes toluene, ethylbenzene, styrene, and benzene that are related to environmental smoke of tobacco (Wallace and Pellizzari 1987; Hajimiragha et al. 1989).

According to the EPA, "among the immediate symptoms that some people have experienced soon after exposure to some organics include":

- Respiratory tract, eye irritation
- Headaches
- Dizziness
- Memory impairment and visual disorders.

The aromatic group of VOCs can result in confusion, weakness, nausea, in-appetence and loss of memory, tiredness, and loss of vision even at low-level exposure. At high level exposure inhalation of volatile compounds can result in dizziness, unconsciousness, and even death (Kim and Hong 2002; Suib 2013).

5.7.1 Steps to Reduce Exposure by EPA (2017)

- To increase proper ventilation when using products that emits VOCs.
- Meet or exceed any label precautions.
- Do not store opened containers of unused paints and similar materials within the school.
- Formaldehyde, one of the best known VOC, is one of the few IAPs that can be readily measured.
- Identify, and remove the source, if possible.
- If not possible to remove, reduce exposure by using a sealant on all exposed surfaces of panelling and other furnishings.
- Use integrated pest management techniques to reduce the need for pesticides.
- Use household products according to manufacturer's directions.
- Provide plenty of fresh air when using these products.
- Throw away little-used or unused containers safely; buy in quantities that you will use soon.
- Keep out of reach of pets and children.
- Never mix products used for household care unless directed on the label.

5.8 Indoor Exposure Guidelines

The United Nations' Sustainable Development Goals (UN SDGs) have brought up again specific focus on environmental issues such as pollutant emissions and climate change (EPA 2015). For an instance, SDG number 12 that focus on responsible production and consumption, and targets significant decline in emission of various chemicals to air, water, and soil in order to reduce or decline their detrimental effects on environment and human health (EPA 2015; Le Blanc 2015). A number of countries have established the labelling and guideline scheme for the construction and building products that targets the emission control from such sources (Loftness et al. 2007). In 2002, Canada established "Guidelines for Volatile Organic Compounds in Consumer Products" that targets VOC content limits specifically for 23 consumer product categories. Other indoor environment related scheme, for example Indoor Climate Labelling Scheme in Denmark, were originally introduced to reduce the emissions from the building material and are built not on the legislation but on market forces. Various countries have now building rules and regulations at minimum requirements for ventilation that can eventually minimize the exposure to a variety of IAs, including VOCs (Witterseh 2002). It is easily understood, inhalation is the primary passage of hazardous VOC exposure in the building air environment, and on the contrary absorption through the skin and intake from consuming water, beverages, and food are noticeable. As in IAQ guidelines and standards, about 13 VOCs were designated as IAPs (Tsai 2019).

According to the, 7th Environmental Action Programme (EAP) for EU, "Inventorying chemicals emissions and characterising their impacts can help measure progress towards the objectives for environmental quality and public health as well as towards a non-toxic environment" (EU 2013; Persson et al. 2019). U.S. Green Building Council (USBGA) have credited numerous designs that not only aims to have better environmental performance and energy efficiency but also includes the rules and guidelines for improving filtration and, ventilation, controlling chemical and pollutant sources, to utilise materials with low emissions, improving lighting and thermal conditions, and to provide daylight sights to inhabitants of the building (USGBC 2014).

As a consequences of the health impact of VOCs, the international organizations like World Health Organisation (WHO), administrative agencies such as the Word related Security and Wellbeing Organization within the Joined together States; and cosmopolitan association of scientists and professionals in particular the American Industrial Hygiene Association have prescribed instructions that aims to regulate the limiting values of human exposure to specific airborne pollutants that are present within the building. For an instance, the Ministry of Health, Labor and Welfare (MHLW) in Japan has chosen eight targets VOCs which includes HCHO, acetaldehyde, ethylbenzene, p-dichlorobenzene, styrene, toluene, tetradecane, and xylenes as the components of IAQ guidelines (Noguchi et al. 2016). According to the IAQ guidelines and standards systematic compilation, there has been no documented or recorded census given by several official organizations based on the IAQ guidelines, the components of IAPs, and their suggested and the restricting values (Abdul-Wahab et al. 2015; Luengas et al. 2015).

It can be assumed from the fact that various guidelines and standards solely focus on the reduction and prevention of irritations that are caused by several IAPs whereas other guidelines are solely based on health related concerns (Luengas et al. 2015). Generally, the guidelines provided by WHO is considered as valid and authorized (WHO 2010). The non-governmental organization (NGO), and scientific organization such as ACGIH that is committed to promoting health and safety within offices and other workplaces. According to ACGIH, the TLV limits are based on health and thus are not designed to be utilized as guidelines, because the standards have to be set by reviewing the authorized literature from numerous disciplines of science, including epidemiology, including occupational medicine, industrial hygiene, and toxicology (ACGIH 2017).

5.9 Conclusion and Solution

Taking IAQ into consideration, all those organic compounds that have the property to evaporate under normal temperature and pressure are referred to as VOCs and it is mandatory to assess the potential effect of IAQ on human well-being. Though IAQ has been persuading the environment related issues from past two decades, a wide gap of knowledge still exists with respect to unfavourable and antagonistic impacts on human health for various known indoor air components. Though it is commonly known that the main route of exposure to VOC is inhalation, in addition to this, the intake of food, water and the beverage consumption is readily noticeable. When utilizing the products that emit VOCs, the ventilation in the residential areas or within the office should be enhanced and the opened containers of unutilised paints should be discarded and other materials that emit VOCs. Formaldehyde is one of widely known VOC pollutants, present in the indoor environments of building sector that can be readily measured. If it is the potential pollutant indoors, the identification and removal of the source is essential. Formaldehyde which is also consumed in the permanent mattress ticking and press fabric has adverse effects on human health; the sensitive individuals must avoid using such products.

Any sort of activity in declining the emission of aerosols in the indoor sector can have a rapid impact on IAQ and also on human well-being since the majority of the aerosol sprays are used in the indoor building sectors. Therefore, to prevent human health and well-being, it is mandatory to estimate the average concentrations of VOCs from the building environment to which people are exposed. Subsequently, the appropriate and reliable standards have been difficult to set up, whereas the indoor air regulation and building materials have been agitated with inaccurate information and confusions. It is an essential goal to reduce the concentrations of VOCs inside as well as outside environmental and health. Howsoever, it is compulsory to take note that some VOCs of concern are present indoors as well as outdoors that don't have an impact on photochemical oxidation and thus are not governed by EPA. It is mandatory to create an appropriate distinction and understand the strategies while using it in improvement of IAQ.

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