



Review article

The micro-environmental impact of volatile organic compound emissions from large-scale assemblies of people in a confined space



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ABSTRACT

Large-scale assemblies of people in a confined space can exert significant impacts on the local air chemistry due to human emissions of volatile organics. Variations of air-quality in such small scale can be studied by quantifying fingerprint volatile organic compounds (VOCs) such as acetone, toluene, and isoprene produced during concerts, movie screenings, and sport events (like the Olympics and the World Cup). This review summarizes the extent of VOC accumulation resulting from a large population in a confined area or in a small open area during sporting and other recreational activities. Apart from VOCs emitted directly from human bodies (e.g., perspiration and exhaled breath), those released indirectly from other related sources (e.g., smoking, waste disposal, discharge of food-waste, and use of personal-care products) are also discussed. Although direct and indirect emissions of VOCs from human may constitute < 1% of the global atmospheric VOCs budget, unique spatiotemporal variations in VOCs species within a confined space can have unforeseen impacts on the local atmosphere to lead to acute human exposure to harmful pollutants.

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1. Introduction

Large human gatherings on small spatiotemporal scales are becoming increasingly common; examples include religious,

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athletic, and recreational events such as public concerts, team sports, and festivals. The Fédération Internationale de Football Association (FIFA) World Cup 2014 in Brazil reported an average attendance in excess of 50,000 per game with a total attendance of more than 3.4 million people. Such large gatherings are not restricted to Olympics and World Cups but are also common on local/regional scales. Crowds of 25–45,000 frequent league football games on a regular basis (where nearly twelve to thirteen hundred matches are played each season) across Europe, Asia, USA, and Canada (The Economist, 5th June 2014). Smaller recreational activities, e.g., concerts, demonstrations, public plays, film broadcasts, fairs and festivals can also contribute to “spikes” of VOCs emission originating from breathing, sweating, smoking, cooking, waste discharge, cleaning activities, etc. (Schmidt, 2006; Veres et al., 2013; Williams et al., 2016).

Air pollutants can be classified into the following categories based on their volatility: hydrocarbons, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and non-volatile organic compounds (NVOCs). VOCs and oxygenated volatile organic compounds (OVOCs) are known to actively participate in the photochemical interactions with small radicals (e.g., OH and NO₂) leading to tropospheric ozone formation (CMA, 1998; USEPA, 2011; Ni et al., 2012; Mellouki et al., 2015; EPA, 2016). Ozone plays a pivotal role in atmospheric chemistry as it is an important greenhouse gas with large contributions toward the total anthropogenic radiative forcing (IPCC, 2013). The U.S. Environmental Protection Agency (EPA) defines VOCs as “organic chemical compounds whose composition makes it possible for them to evaporate under normal indoor atmospheric conditions of temperature and pressure” (USEPA, 2011). Exposures to certain VOCs can have serious human health implications, e.g., isoprene, acetone, toluene, benzene, and acetonitrile (Jung et al., 2016; Tong et al., 2013). These pollutants can be generated during short-term mass turnouts due to direct emissions from human, e.g., breath and ozonolysis of skin oils (de Lacy Costello et al., 2014; Veres et al., 2013; Williams et al., 2016) and indirect emissions from cigarette smoking, cooking, disposal of food waste, and personal care products (Agapiou et al., 2016; Faber et al., 2013; Steinemann et al., 2011).

The mixing ratios of VOCs and aerosols, when measured inside a football stadium in Mainz, Germany, were seen to be substantially higher than the background (Faber et al., 2013; Veres et al., 2013). These authors accounted for the cause of the enhanced VOC levels as human occupant density, degree of atmospheric isolation (i.e., indoor versus outdoors), and socializing activities like tobacco smoking. de Lacy Costello et al. (2014) reported that as many as 1404 VOCs emanated from a healthy individual human (i.e., breath (872) and skin secretions (532)). de Lacy Costello et al. (2014) provided a list of different classes of volatiles in human breath, namely, hydrocarbons, acids, esters, alcohols, aldehydes, ketones, furans, ethers, chloro biphenyls, sulphur, nitrogen, and halogen-containing compounds. The reported levels of major VOCs in exhaled breath were acetone (985 ppb), ethanol (770 ppb), methanol (330 ppb), isoprene (210 ppb), and isopropanol (150 ppb) (Fenske and Paulson, 1999). Recently, it was found that the human-induced chemical emissions are susceptible to various audiovisual stimuli such as ‘suspense’ or ‘comedy’ scenes of a film (Williams et al., 2016). Other direct emission sources such as biomass burning, a known source of VOCs (Holzinger et al., 1999; Lobert et al., 1990), during large bonfire events on St. Joseph’s eve, called ‘fogheracce’ (when bonfires are lit throughout the area as a ritual to welcome spring) have also been reported (Vassura et al., 2014). Although fairly large fluxes of human-induced VOCs have been observed during large assemblies, their health effects or global impacts are still poorly elucidated (Veres et al., 2013). Lelieveld et al. (2015) estimated that around

3.3 million premature deaths occur globally due to outdoor air pollution, in this case, due mainly to fine particulate matter with a diameter smaller than 2.5 μm (PM_{2.5}). It is noteworthy that these authors acknowledged the complexities of computing global impacts of air pollution, particularly in the regions where such effects are not monitored. Such lack of records is fairly common in the case of human-generated VOCs, especially when people gather en masse in a relatively confined space for different activities. However, reports are available in comparatively large number on human-induced VOCs in various indoor and outdoor environments. For instance, Hodgson et al. (2003) examined the effect of outside air ventilation rate on VOC concentrations in a call center with 217–273 personnel. Accordingly, the major VOCs in the indoor air consisted of ethanol (38 ppb), isopropanol (44 ppb), acetone (14 ppb), formaldehyde (11.9 ppb), acetaldehyde (3.0 ppb), and toluene (1.2 ppb). In contrast, the concentrations of these VOCs in outdoor air were generally much smaller.

Global atmospheric budgets of VOCs are generally made up of various components, and the common anthropogenic sources include vehicle emissions, fuel combustion, domestic solvent usage, industrial activity, and deforestation (Bo et al., 2008; Piccot et al., 1992). On the other hand, VOC emissions from direct and indirect sources during large-scale mass gatherings within a confined area may constitute a small fraction (less than 1%) of the global VOC budget (Veres et al., 2013). Nonetheless in a small-scale, such emissions can cause large spatiotemporal variations of local air chemistry. Most indoor air quality studies in the past have concentrated on a relatively small number of people in buildings and/or emissions from building materials (Shah and Singh, 1988; Zuraïmi and Tham, 2008; Kim et al., 2001). Likewise, a large number of research data exist on the impacts of human occupants on air chemistry in indoor and outdoor environments like classrooms, aircraft cabin, etc. (Weisel et al., 2013; Weschler, 2016). For instance, Gao et al. (2015) and Wisthaler and Weschler (2010) studied VOCs derived from ozonolysis (e.g., ozone/squalene reaction) of organic compounds associated with human skin in aircraft cabins. In contrast, only a limited number of studies have so far focused on the human-induced environmental emissions that occurred during large gatherings. Given the increasing number of major sporting and other recreational events occurring in urban settings globally, physicochemical properties, exposure limits, and fates of specific air pollutants must be identified. The goal of this review is to point out the suspected magnitude and consequences of the localized spikes of VOCs emissions generated from large human congregations within a small spatiotemporal scale and to suggest a few pre-emptive remedial measures for mitigating their impacts.

2. Sources of VOCs during mass human gatherings

The observed sources of VOCs during mass gatherings have been categorized into three groups: (1) human respiration/breath, (2) secondary oxidation of human skin oil via ozonolysis, and (3) cigarette smoke/combustion and diet (Veres et al., 2013; Weschler et al., 2016; Williams et al., 2016). The use of personal care products such as shampoos, perfumes, and colognes might be an additional source (Steinemann et al., 2011; Bartzis et al., 2015). Other sources of VOCs include activities such as cooking and waste disposal of food waste (Agapiou et al., 2016; Faber et al., 2013). Among the three above-mentioned broad categories, some VOCs appear to have a single emission source, while others have multiple emission sources.

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