Atmospheric Environment xxx (2014) 1–7

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Volatile Organic Compounds: Characteristics, distribution and sources in urban schools

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HIGHLIGHTS

- VOCs represent a major group of indoor and outdoor air pollutants.
- Indoor and outdoor VOCs in 25 primary schools in Brisbane were quantified.
- PCA- APCS technique used to identify sources of VOCs and their contributions.
- Risks of exposure associated with indoor sources including cleaning products.

ARTICLE INFO

Article history:
Received 7 August 2014
Received in revised form
30 September 2014
Accepted 30 October 2014
Available online xxx

Keywords:
Volatile Organic Compounds
Ambient concentrations
Personal exposure
Schools
Children

ABSTRACT

Long term exposure to organic pollutants, both inside and outside school buildings may affect children's health and influence their learning performance. Since children spend significant amount of time in school, air quality, especially in classrooms plays a key role in determining the health risks associated with exposure at schools. Within this context, the present study investigated the ambient concentrations of Volatile Organic Compounds (VOCs) in 25 primary schools in Brisbane with the aim to quantify the indoor and outdoor VOCs concentrations, identify VOCs sources and their contribution, and based on these; propose mitigation measures to reduce VOCs exposure in schools. One of the most important findings is the occurrence of indoor sources, indicated by the I/O ratio >1 in 19 schools. Principal Component Analysis with Varimax rotation was used to identify common sources of VOCs and source contribution was calculated using an Absolute Principal Component Scores technique. The result showed that outdoor 47% of VOCs were contributed by petrol vehicle exhaust but the overall cleaning products had the highest contribution of 41% indoors followed by air fresheners and art and craft activities. These findings point to the need for a range of basic precautions during the selection, use and storage of cleaning products and materials to reduce the risk from these sources.

1. Introduction

Volatile Organic Compounds (VOCs) are released into the environment via natural and anthropogenic processes. They represent a major group of indoor and outdoor air pollutants; they are ubiquitous and associated with increased long term health risks. Vehicular and industrial emissions are the major sources of VOCs in outdoor air, while the indoor sources are tobacco smoke, cooking fumes, cleaning products, heating, varnishing and painting, computers, photocopiers and printers (Destaillats et al., 2008; Jia et al., 2008; Wu et al., 2011). Urban air consists of different types of VOCs, many of which are classified as group 1 carcinogen (e.g. benzene), potential carcinogens (e.g. toluene and xylenes) while some, including formaldehyde are classified as known carcinogens (IARC, 2006) to humans.

Children are exposed at schools to pollutants from different emission sources operating both inside and outside the classroom. Indoor air quality may even be of more concern in classrooms than in other types of buildings due to a number of factors, including higher occupant density (i.e. volume of classroom and number of children), activities conducted inside the classrooms and

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http://dx.doi.org/10.1016/j.atmosenv.2014.10.052
1352-2310/

insufficient ventilation, aggravated by the poor construction and/or maintenance of many school buildings. VOC concentration tends to be lower in the spacious and well ventilated classrooms with a low occupancy ratio (Pegas et al., 2011b). Accumulation of pollutants is possible when doors and windows remain closed for long periods of time in order to maintain thermal comfort, especially in winter. In addition to this, children are involved in different types of art and craft activities, with the use of glue and paints that may increase the level of VOCs in the classroom as reported by Zhang et al. (2006) and Pegas et al. (2011b). Besides these, the use of cleaning and other consumer products inside the classroom are also possible sources of VOCs. If the school is located in an urban environment, the air quality can be affected by many other factors, such as the amount and type of passing traffic, distance from the road and the location of drop off and pick up areas, together with some meteorological factors, like wind direction and speed.

The pollutants most commonly monitored in elementary school studies are carbon dioxide, carbon monoxide, nitrogen dioxide, particulate matter (PM_{10}, $PM_{2.5}$) and inorganic components, as well as biological agents including airborne fungi and bacteria (Meklin et al., 2002; Godoi et al., 2009; Sohn et al., 2009). There have been several studies performed worldwide to assess students' exposure to indoor particles, but very few aimed at characterizing their chemical composition, and those that did mainly focused on elemental content (e.g. Molnar et al., 2007; Stranger et al., 2008; Almeida et al., 2011; Oeder et al., 2012).

Due to the long term health risks associated with organic pollutants, there is increased concern about their presence in the air of schools. A study conducted by (Godwin and Batterman, 2007) in 64 classrooms in Michigan, USA reported that benzene, ethylbenzene, toluene, xylene and limonere were the prevalent VOCs. Sofuoglu et al. (2011) measured the concentrations of VOCs in classrooms, kindergartens and outdoor playgrounds of three primary schools in Turkey in different seasons and found the concentrations were higher indoors than outdoors. Ten VOCs were identified in the study conducted in three primary schools in Western Australia (Zhang et al., 2006), of which the highest concentration was measured in the visual art classroom. Pegas et al., 2011a, Pegas et al., 2012 investigated the pollutant (organic and inorganic) concentrations inside and outside school buildings and found the important contribution from indoor sources. In general, literature reports higher VOC concentrations indoors than outdoors. None of the above studies investigated on the sources of VOCs and their contributions. Therefore, the identification and of outdoor and indoor sources of VOCs particularly in school environment is still lacking.

To address this gap in knowledge, the following aims were established for this study: 1) to conduct comprehensive measurements of VOCs in indoor and outdoor air of representative number of urban primary schools; 2) to quantify the relationship between indoor and outdoor VOCs concentrations; 3) to identify the VOCs sources and activities contributing to these sources in urban schools and 4) to identify the optimal scenarios for reduction of VOCs exposure to children at schools. This study is a part of larger project called "The Effect of Ultrafine Particles from Traffic Emissions on Children's Health (UPTECH)," which seeks to determine the effect of exposure to traffic generated ultrafine particles and organic pollutants in schools. The complete study design is available online (http://www.ilaqh.qut.edu.au/Misc/UPTECH%20Home.htm).

2. Experimental section/material and methods

2.1. Study location

Brisbane, the capital city of the State of Queensland, is located along the South-East coast of the state and is the third most populated city in Australia, with population more than 2 million (ABS, 2011). Although the city lies on either side of the Brisbane River, on a low lying flood plain, it is surrounded by hills, some of which reach 300 m in height. The major air pollution sources in Brisbane include, vehicle emissions, controlled and uncontrolled biomass burning in the vicinity of the city and a limited number of industrial activities, such as a power station, oil refineries, the airport, port and a brewery (Morawska et al., 2002). Brisbane has a subtropical climate, with a hot and humid summer (mean temperature 25 °C) and a dry, moderately warm winter (mean temperature 15 °C), with an average diurnal temperature variation around 9–10 °C.

2.2. Study design

2.2.1. School selection and location

The 25 state schools selected for this study, coded as S01 to S25, were from a range of different suburbs in the Brisbane Metropolitan Area. The schools were randomly selected but they need to meet several selection criteria, which were: (i) no major pollution sources near the schools other than traffic; (ii) not close to any large infrastructure project, such as a major road, tunnel or building construction; and (iii) naturally ventilated classrooms used by 8–11 year old children. The general characteristics of each school are described in the Supplementary Table S1.

2.2.2. Sampling period and sites

The field measurements were conducted throughout the year, from October 2010 until August 2012, except on school holidays. There were two sampling sites for VOCs at each school - one outdoor and one indoor. The outdoor site was chosen in a central location within the school grounds, which was assumed to represent the air quality within the school as best as possible. The indoor site was a classroom used by 8–11 year old children. All of the classrooms were naturally ventilated via doors and windows, with an occasional use of a fan or local air conditioning systems, which were not operated during the measurements. Doors and windows were usually closed while doing indoor measurements. Children were involved in different activities inside the classroom, including painting, art and craft.

2.3. Sample collection and analytical methods

VOCs samples were collected using active sampling procedure by a portable VOC pump. The flow rate was set to 150 mL/min. The measurements were taken at the height of 1.5 m from the ground. Stainless steel desorption tubes filled with Tenax TA ((20/35 and 60/80 mesh; 300 mg) were used indoors to prevent terpenes and aldehydes from analytical losses. To avoid artefacts (due to reactive gases like ozone or NO_x) tubes were filled with carbotrap (20/40 mesh; 300 mg) for outdoor measurements. Air samples were collected between 7 am and 5 pm, each day (outdoor: 9:00 am, 9:45am, 1:10 pm, 1:55 pm; indoor: 7:00 am, 7:45 am, 3:00 pm, 3:45 pm; volume: 6 L) in each school. Several sampling periods, including before the start of class, during school and after school hours was chosen. There were no students and teachers inside the classroom during the indoor measurements. Once the sampling was completed, the tubes were made air tight using screw caps, placed in a ziplock plastic bag and sent to Fraunhofer WKI, Braunschweig, Germany for analysis.

Laboratory analysis of all sorbent tubes was performed via thermal desorption/gas chromatography, coupled with mass spectrometry (TD-GC/MS), according to DIN ISO 16000-6. An Agilent 7890/5975 GC/MS system equipped with a Markes TD 100 thermal desorber was used and the compounds were separated on

Please cite this article in press as: Mishra, N., et al., Volatile Organic Compounds: Characteristics, distribution and sources in urban schools, Atmospheric Environment (2014), http://dx.doi.org/10.1016/j.atmosenv.2014.10.052