Indoor volatile organic compounds at an Australian university

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Abstract

This study investigates volatile organic compounds (VOCs) at a large Australian university, within locations of campus services, restrooms, renovated offices, a green building, meeting areas, and classrooms. Analysis of 41 VOCs across 20 locations reveals indoor concentrations higher than outdoor concentrations for 97% of all VOC measurements (493 unique comparisons). Hazardous air pollutants (formaldehyde, benzene, toluene, and xylenes) were up to an order of magnitude higher indoors than outdoors, and at the highest combined geometric mean concentrations in classrooms (51.6 $\mu g/m^3$), renovated offices (42.8 $\mu g/m^3$), and a green building (23.0 $\mu g/m^3$). Further, d-limonene, ethanol, hexaldehyde, β-pinene, and isobutane were up to two orders of magnitude higher indoors than outdoors. The most prevalent VOCs (e.g., ethanol, d-limonene, and formaldehyde) have links with building materials, furnishings, and fragranced consumer products such as air fresheners and cleaning supplies. Highest indoor to outdoor concentration (I/O) ratios of formaldehyde (27), toluene (9), p-xylene (12), and m-xylene (11) were in a green building; highest of benzene (6) in renovated offices; and highest of o-xylene (9) in meeting areas. Results from this study are consistent with findings from similar international studies and suggest that university indoor environments may be important sources of pollutants.

Key Words: volatile organic compounds, indoor air quality, formaldehyde, BTEX, university, indoor environments.

Introduction

Volatile organic compounds (VOCs) are prevalent indoor air pollutants, with primary sources typically consumer products and building materials (Ott et al., 2006; Brown, 2002; Wallace et al., 1987). Consumer products, such as air fresheners, cleaning supplies, and personal care products, can emit numerous VOCs, such as limonene, alpha-pinene, beta-pinene, acetaldehyde, acetone, and ethanol (Steinemann, 2015). Fragrance terpenes (e.g., limonene) in these products can react with ozone to generate secondary pollutants such as formaldehyde (Nazaroff and Weschler, 2004). Building materials, such as engineered wood products, coatings, and floorings, can also emit numerous VOCs, including formaldehyde, toluene, and benzene (Guo et al., 2004; Brown 2002; Brown et al., 1994). Even green consumer products and building materials can emit potentially hazardous VOCs, and green buildings with reduced ventilation can concentrate pollutants indoors (Steinemann et al., 2017).

In Australia, regulations do not currently exist for acceptable VOC concentrations within indoor environments. In contrast, for outdoor air, the "hazardous air pollutants" of formaldehyde, toluene, benzene, xylenes, and polycyclic aromatic hydrocarbons are monitored in accordance with the National Environmental Protection Measure (NEPM, 2004). Although the Australian National Health and Medical Research Council recommended national indoor air quality guidelines in 1992, they were rescinded in 2002 (NHMRC, 2016). (Table 1 provides a summary of air quality guidelines.)

Internationally, a number of studies have investigated the type and concentration of VOCs in educational facilities such as primary and secondary schools (Zhang et al., 2006; Godwin and Batterman, 2007; Rumchev et al., 2007; Sofuoglu et al., 2011; Madureira et al., 2015; Mishra et al., 2015; Verriele et al., 2015). However, relatively few studies have evaluated the type and concentration of VOCs across a range of indoor environments within a university. The only Australian investigation took place over 14 years ago (Rumchev et al., 2003), with a focus on BTEX and chlorobenzene levels in laboratories. International studies examined VOCs within classrooms, canteens, workshops, laboratories, offices, and a library (Chan et al., 2007); and offices, laboratories, classrooms, hallways, storage areas, and a coffee room (Yurdakul et al., 2017). One study evaluated formaldehyde and other carbonyls, but not other VOCs, within 15 different categories of indoor environments, including university offices, lecture theatres, a laboratory, a library, stores, dining facilities, services, and housing (Ho et al., 2014). Other studies examined VOCs including formaldehyde, but with a focus on specific environments such as libraries (Allou et al., 2008; Kang et al., 2017), refurbished offices (Kolarik et al., 2015), dormitories and teaching buildings (Kang et al., 2017), and a departmental building (e.g., Solomon et al., 2008; Akal et al., 2015). Thus, few if any studies investigated (i) a broad suite of VOCs including carbonyls and (ii) a range of different indoor environments in universities, and both are contributions of this present study.

As a mini-city, the university provides diverse indoor locations that accommodate tens of thousands of students, staff, and visitors. This study investigates VOCs, including carbonyls, within a variety of indoor environments at a large Australian university. The objectives of the study are to determine the concentrations and prevalence of pollutants indoors, compare indoor to outdoor concentrations, and assess the potential implications of the results. Through the analysis and evaluation of 41 pollutants, with a focus on NEPM hazardous air pollutants (i.e. formaldehyde, benzene, toluene, and o, m, p-xylene), the study contributes information and insights on university indoor environments.

Methods

The study was performed at the University of Melbourne, an Australian public research and teaching institution with over 52,000 students and 10,000 staff (AEN, 2016). The Parkville campus is located 3 kilometres north of Melbourne's central business district. On the University campus, the following categories of indoor environments were investigated: campus services (supermarket, hairdresser), restrooms, renovated offices (less than 2 years old), a green building (less than 2 years old), meeting areas, and classrooms. The green building received the highest Green Star rating (6 Star) from the Green Building Council of Australia (GBCA, 2017). Green Star is a voluntary rating scheme that assesses the sustainable design, construction, and operation of buildings across a range of categories including indoor environmental quality, materials, and energy (GBCA, 2017). Data on building type, age, occupancy rate, room dimensions, floor area, ceiling height, distinguishing features, materials, and ventilation characteristics are included as supplementary material (Table S1). The study received ethics approval from the University of Melbourne (Application number: 1545481.1).

Sampling approach

Indoor air samples were collected and analysed in accordance with USEPA compendium methods TO–17 and TO–11A (US EPA, 1999a, 1999b). In all cases, outdoor air samples were collected within close proximity to, and simultaneously with, indoor air samples. Further details of all indoor and outdoor locations are provided as supplementary material (Table S1). All samples were collected during normal working hours, between 8:30 am and 6:30 pm, in February and March, 2016.

For VOCs (other than carbonyl compounds), two multi-adsorbent tubes in series (Markes Carbograph 1TD/Carbopack X) were connected to a SKC Pocket Pump 210-1002 (Eighty Four PA, USA) at a flow rate of approximately 35 mL per minute for 2.5 hours (5 L). For carbonyl compounds, a single low pressure drop dinitrophenylhydrazine LpDNPH S10 cartridge (Supelco Cat No 21014) was connected to TSI Incorporated SidePak SP730 (Shoreview, MN, USA) at a flow rate of approximately 1200 mL per minute for 7 hours (500 L). An ozone scrubber (Supelco Cat No 505285) was placed in front of the S10 cartridge to prevent ozone interference with the carbonyls. According to established methods 10% of samples were reserved as blanks (Wallace et al., 1991). Temperature and relative humidity were measured using a portable weather station (Holman, WS5052B), and data are provided as supplementary material (Table S1).

A total of 47 VOC tubes and 35 carbonyl cartridges (indoor and outdoor) were analysed. Analysis of VOCs used a PerkinElmer TurboMatrix™ 650 automated thermal desorber (ATD)–and a Hewlett Packard 6890A gas chromatography (GC)/mass spectrometry (MS)/flame ionization detector (FID) in accordance with US EPA method TO–17. An Agilent (DB5-MS) capillary column (60 m x 0.32 mm x 1 µm) was used for compound separation. Certified gas standards were used for calibration, these included a benzene, toluene, ethylbenzene and xylenes (BTEX) standard (Air Liquide–Scott Specialty Gases, Longmont, CO, SA), and a BTEX plus isoprene standard (National Physical Laboratory, Middlesex, UK). Where a gas standard was not available, quantification of VOCs was done using the FID response factor of toluene. Only VOCs with concentrations greater than the method detection limit (MDL) of the analytical instrument were reported. For VOCs, the MDL was between 0.01–0.04 µg/m^3, determined as the 95th percentile of the response from 7 field blanks. Analysis of carbonyls used ultra-high performance liquid chromatography (UHPLC) consisting of a Thermo Scientific Dionex Ultimate 3000 RS system with diode array detector (DAD) and mass spectrometry (MS) detector in accordance with US EPA Method TO–11A. A rapid separation liquid chromatography (RSLC) Acclaim™ (No. 077973) carbonyl column (150 mm x 2.1 mm, particle size: 2.2 μm) was used for compound separation. The chromatographic conditions included a flow rate of 0.4 mL/min and an injection volume of 3.0 µL. The DAD was operated in the 220–520 nm wavelength range with 360 nm used for mono-carbonyl quantification. The peaks were separated by gradient elution with an initial mobile phase of 52% acetonitrile and 48% deionized water (18.2 ΩM cm, Millipore Milli-Q Advantage) for 8.3 minutes, followed by a linear gradient to 100% acetonitrile for 8 minutes, with a column temperature of 30 °C. A certified liquid standard (Supelco Carb Method 1004 DNPH mix 2 C/N 47651-U) containing 30 µg/mL of each derivatised carbonyl was diluted 1:25 in a volumetric flask. This prepared standard was then used to perform a four-point calibration (0.15, 0.30, 0.6, and 1.2 µg/mL). For carbonyl compounds, the MDL was between 0.01–0.07 µg/m^3, determined as the 95th percentile of the response from 8 field blanks. All original concentrations were blank corrected. For data reported in this article, the term VOCs will include carbonyl compounds.

Data analysis

The concentration range, geometric mean (GM), and geometric standard deviation (GSD) of all compounds measured in all indoor and outdoor environments are presented in Table 2. As VOC data are predominantly log-normally distributed (Brown et al., 1994), the geometric mean is the main statistical parameter used to present data. Method detection limits (MDL) and additional descriptive statistics such as the median, mean, and standard deviations are presented as supplementary material (Tables S2–S7).

The relationship between indoor and outdoor VOCs was investigated using indoor to outdoor (I/O) concentration ratios. The median I/O ratio for each compound was calculated for each location using individual I/O ratios for each sample at each location (Tables S2–S7). For calculation of I/O ratios, only compounds that had concentrations greater than the MDL in more than 50% of the locations (indoors and outdoors) were reported. The GM concentrations of the hazardous air pollutants were summed (i.e., ΣFBTX = [formaldehyde] + [benzene] + [toluene] + [xylenes]) as a metric to enable further comparisons (Table S8).

Results

Concentration of compounds

Among the 41 compounds analyzed, 17 were detected in all indoor and outdoor locations (i.e., 100% of measurements were above MDL). These compounds were isobutane, n-butane, ethanol, 2-methylbutane, benzene, toluene, ethylbenzene, o, m, p-xylene, α-pinene, d-limonene, formaldehyde, acetaldehyde, acetone, methyl glyoxal, and hexaldehyde (Table 2). Notably, the hazardous air pollutants formaldehyde, benzene, toluene and o, m, p-xylene were detected in all indoor and outdoor locations (Table 2). In addition to these 17 compounds, five compounds (i.e., styrene, β-pinene, eucalyptol, naphthalene, and glyoxal) were detected in all indoor locations, and in up to 75% of outdoor locations. Benzothiazole was the only compound present in all indoor locations, but not at all outdoors (Table 1).

Among all VOC concentrations at all locations, the highest was ethanol (>628 µg/m^3) in a restroom. The highest GM concentrations of ethanol were in renovated offices (>127 µg/m^3), restrooms (>101 µg/m^3), and campus services (>61.3 µg/m^3) (Table 2).

Formaldehyde had the highest GM concentration in classrooms (16.9 µg/m^3), renovated offices (14.2 µg/m^3), and a green building (13.6 µg/m^3), with a range in other locations from 4.5 to 7.2 µg/m^3. Benzene had the highest GM concentration in renovated offices (2.2 µg/m^3), with a range in other locations from 0.2 µg/m^3 to 0.9 µg/m^3. Toluene had the highest GM concentration in classrooms (25.5 µg/m^3), with a range in other locations from 1.7 µg/m^3 to 13.9 µg/m^3. Ethylbenzene had the highest GM concentrations in renovated offices (2.2 µg/m^3), with a range in other locations from 0.3 µg/m^3 to 1.8 µg/m^3. Xylene(s) had the highest GM concentrations in renovated offices: p-xylene (7.2 µg/m^3), m-xylene (2.2 µg/m^3), and o-xylene (3.1 µg/m^3).

Acetone had the highest GM concentration within classrooms (48.6 µg/m^3), and a green building (24.7 µg/m^3), with a range in other locations from 2.7 µg/m^3 to 12.5 µg/m^3. d-Limonene had the highest GM concentration in restrooms (35.5 µg/m^3).

Prevalence of compounds

Table 3 shows the twelve most prevalent compounds in each category of indoor environment, ranked by concentration. Across all environments, the most prevalent compounds at the highest GM concentrations were ethanol, formaldehyde, acetaldehyde, acetone, toluene, n-butane, 2-methylbutane, p-xylene, and d-limonene. Based on the combined GM concentration of hazardous air pollutants (ΣFBTX) (Table S8), the highest concentrations were reported in classrooms, renovated offices, a green building, followed by restrooms, campus services and meeting areas.

Indoor to outdoor concentration ratios

Table 2 provides the ratios of indoor concentrations to corresponding outdoor concentrations (I/O ratios). Indoor concentrations were higher than outdoor concentrations for nearly all VOCs measured (above MDL) at all locations (i.e., 97% of 493 unique comparisons).

Among all environments, the highest I/O ratios (greater than 100) were d-limonene, ethanol, hexaldehyde, β-pinene, and isobutane. Within each environment, the compounds with the highest I/O ratios were as follows: d-limonene (331) and ethanol (168) in campus services; ethanol (290) and d-limonene (123) in restrooms; ethanol (155) and β-pinene (127) in renovated offices; ethanol (71) and acetaldehyde (51) in a green building; ethanol (40) and d-limonene (34) in meeting areas; and hexaldehyde (214) and styrene (84) in classrooms.

Hazardous air pollutants were up to an order of magnitude higher indoors than outdoors. For formaldehyde, toluene, p-xylene, and m-xylene, I/O ratios were higher in a green building than in any other indoor environment (Figure 1). For alkanes and alcohols, the I/O ratios of ethanol and isobutane were highest overall, both measured in restrooms (Figure 2). For terpenes and terpenoids, the highest I/O ratios were for d-limonene, measured in campus services and restrooms, and for α-pinene and β-pinene, measured in renovated offices and classrooms (Figure 3). For carbonyl compounds, the highest I/O ratio was for hexaldehyde, measured in classrooms (Table 2). For individual compounds, the range of I/O ratios measured in the different locations are as follows: formaldehyde 3–27; benzene 2–6; toluene 3–9; ethylbenzene 2–9; xylenes 2–12; d-limonene 25–331; and ethanol 8–290.

Discussion

Explanations for higher levels indoors can be explored using the distinguishing features of each indoor environment. Descriptions of the characteristics and distinguishing features for each category of indoor environment are detailed in Table S1, and discussed below.

In campus services, ethanol, d-limonene, n-butane, acetone, 2-methylbutane, and formaldehyde were among the most prevalent compounds at the highest concentrations. Many of the compounds identified in campus services have been associated with consumer products and cleaning supplies in previous studies (Steinemann, 2015; Nazaroff and Weschler, 2004).

In restrooms, ethanol, isobutane, d-limonene, acetone, and formaldehyde were among the most prevalent compounds at the highest concentrations. These compounds are frequently detected in studies of air freshener emissions and cleaning products (Steinemann, 2015; Kim et al., 2015; Uhde and Schultz, 2015). Yurdakul et al. (2017) identified cleaning agents and air fresheners as sources of VOCs in university offices. In another study, regular morning peaks in the concentration of monoterpenes (range 5 to 17 ppb) were associated with cleaning activities (Solomon et al., 2008). By comparison the highest combined concentration of monoterpenes (i.e., d-limonene, α-pinene, and β-pinene) in this study was 60.2 $\mu g/m^3$ (10.81 ppb) measured in classrooms.

In renovated offices, ethanol, n-butane, isobutane, formaldehyde, and toluene were among the most prevalent compounds at the highest concentrations. These compounds were also found in prior studies of building materials (Guo, 2011; Missia et al., 2010; Brown, 1999, 2001, 2002), furnishings and floorings (Lee and Kim, 2012; Guo et al., 2002; Wolkoff, 1995), and fragranced consumer products (Steinemann, 2015). The offices in this study were renovated in 2014. Other studies have shown that higher VOC levels typically occur post-renovation or in the first few years post-construction (e.g., Park and Ikeda, 2006; Brown, 2001). Ho et al. (2014) measured formaldehyde levels in university offices, lecture theatres, and grocery stores in the range of 8.6 to 57 ppbv (10.5 to 70 $\mu g/m^3$), compared to a range of 3.8 to 26 $\mu g/m^3$ in this study. A study of a university building in Turkey measured indoor benzene and toluene concentrations of 3.2 $\mu g/m^3$ and 37 $\mu g/m^3$ respectively (Yurdakul et al., 2017), similar to the levels in the offices in this study (Table 2). A study of an Australian office building reported concentrations for benzene (range: 1–5 $\mu g/m^3$), toluene (range: 4–14 $\mu g/m^3$), and xylenes (range: 6–19 $\mu g/m^3$) (Brown et al., 2006).

In the green building, the construction and finishing materials were selected based on performance and environmental parameters, including structural and acoustic properties, embodied energy, carbon footprint, and VOC emissions (UOM, 2017). However, the highest formaldehyde I/O ratios, as well as the highest acetaldehyde, acetone, m-xylene, and p-xylene I/O ratios, occurred in this green building (Figure 1 and Table 2). Many of these compounds are associated with compressed wood products, wood finishing compounds, adhesives, and occupant density (Brown, 1999; Jiang et al., 2017; Cheng et al., 2016). In a prior study in Australia, Brown et al. (2007) also found that green buildings can have higher levels of hazardous air pollutants indoors than outdoors. For example, a GM formaldehyde concentration of 8.3 µg/m^3 and I/O concentration ratio of 1.5 were reported in Brown et al. (2007), compared to 13.6 µg/m^3 and 27 reported in this study.

In meeting areas, ethanol, formaldehyde, n-butane, acetone, and toluene were among the most prevalent compounds at the highest concentrations. Similarly, in classrooms, acetone, ethanol, toluene, formaldehyde, and α-pinene were among the most prevalent compounds at the highest concentrations. At a new university campus (less than a year old) located in Tianjin, China, the average formaldehyde concentration in teaching buildings was 46 µg/m^3 (Kang et al. 2017). The average formaldehyde concentration for similar spaces in this study was 17.8 µg/m^3. Higher levels in the Chinese study may be partly attributed to the recent construction of the university (i.e., less than one year old) and differing sampling conditions.

Comparisons of data in this study to international indoor air quality guidelines (e.g., WHO, 2010) are limited due to differing sampling periods. Benzene is an exception as the WHO guideline of "no safe limit" was exceeded in all indoor and outdoor locations sampled (Table 1). For instance, the highest benzene levels were measured in renovated offices (i.e., GM=2.2µg/m^3). Although indoor concentrations of hazardous pollutants are higher than outdoors, the indoor concentrations of formaldehyde, toluene, and xylenes and in this study are nonetheless lower than the investigation levels in the NEPM and WHO guidelines (Table 1). The concentrations of hazardous air pollutants measured in this study are similar to those observed in other university air quality studies.

The study had several limitations. First, the durations for sampling (e.g., 2.5 hours, 7 hours), required to collect sufficient volume to meet MDLs, differed from the durations for health-based guidelines (e.g., 30 minutes), thus preventing direct comparisons. Second, in some instances, higher I/O concentration ratios are due to low ambient VOC levels rather than high indoor levels. Third, ethanol concentrations are semi-quantitative due to possible sample breakthrough of multisorbent tubes. Finally, sampling was conducted during summer and autumn, which may not represent VOC levels during all seasons.

The study also revealed several paradoxes. First, as previously noted, the hazardous air pollutants were consistently higher indoors than outdoors, however, they are only monitored outdoors. Second, the highest I/O ratios of the hazardous air pollutants formaldehyde, toluene, p-xylene, and m-xylene were in the green building, which had received the highest green building rating in Australia. Third, air fresheners can contribute to indoor levels of alcohols, alkanes, terpenes, and aldehydes, and thus may impair rather than improve air quality. Fourth, university efforts to create more favourable indoor environments through activities such as renovation and green certification may not necessarily result in improved air quality within these indoor environments, at least not in the years soon after construction and renovation.

Strategies to improve IAQ at a university can be relatively straightforward in some cases (e.g., where the primary sources are consumer products such as air fresheners and cleaning supplies), but more difficult in others (e.g., where the primary sources are construction materials and the building is built). In the former case, the university has successfully implemented a fragrance-free cleaning policy, largely upon the initiative of staff, in one building. Air fresheners are removed from restrooms, and fragranced cleaning products are used sparingly, if at all. An interesting extension of this study would be the comparison of indoor air quality levels before and after the implementation of fragrance-free policies, or a comparison of similar university environments with and without fragrance-free policies. In the latter case, regarding construction materials, inert and low-emitting materials and furnishings (e.g., metal, glass, concrete, brick, and ceramic tiles) can be selected, with the caveat that some green or low-emitting products may lack substantiation regarding their effects on IAQ (Steinemann et al., 2017).

As this study suggests, green and renovated buildings may not necessarily guarantee improvements for indoor air quality. In Australia, the Green Star certification scheme allocates 6 points (out of 100 possible points) to indoor air quality and indoor pollutants (GBCA, 2017). Thus, a building can achieve the highest level of green certification (75 points out of 100) without attention to IAQ (GBCA, 2017; Steinemann et al., 2017). Further, air quality monitoring of green buildings is not required to attain or maintain certification.

Conclusion

University indoor environments can be important sources of pollutants. This study found hazardous air pollutants consistently higher in all indoor environments than outdoors. Building on these results, future work can examine the effectiveness of strategies to reduce pollutants, such as through fragrance-free policies, selection of low-emitting construction materials and furnishings, evaluation of the green building certification scheme, and ongoing monitoring and assessment of indoor environments.

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Indoor volatile organic compounds at an Australian university (Tables)

Table 1. Air quality guidelines for organic pollutants (source: Goodman et al., 2017)

Pollutant	**Pollutant guideline (exposure period)**		
	NHMRC 1992	NEPM 2004	WHO 2000/2010
Formaldehyde	120 µg/m^3 (ceiling)	50 µg/m^3 (1 day)	100 µg/m^3 (0.5 hour)
TVOC	500 µg/m^3 (1 hour)	n/a	n/a
Benzene	50% TVOC[a]	10µg/m^3 (1 year)	No safe limit[b]
Toluene	50% TVOC[a]	3770 µg/m^3 (1 day), 377 µg/m^3 (1 year)	260 µg/m^3 (7 day)[c]
Xylenes	50% TVOC[a]	1085 µg/m^3 (1 day), 870 µg/m^3 (1 year)	n/a
Dichloromethane	50% TVOC[a]	n/a	450 µg/m^3 (7 day)[c]
Styrene	50% TVOC[a]	n/a	260 µg/m^3 (7 day)[c]
Tetrachloroethylene	50% TVOC[a]	n/a	250 µg/m^3 (1 year)
Trichloroethylene	50% TVOC[a]	n/a	250 µg/m^3 (1 year)

[a] NHMRC specified that no VOC should exceed 50% of a TVOC mixture. [b] Geometric mean concentration estimated for lifetime cancer risk of 1/100,000 is 1.7 µg/m^3 (1 year). [c] Goals provided by WHO (2000) but considered to have insufficient evidence by WHO (2010).

Table 2. Concentration range (minimum–maximum), geometric mean (GM), geometric standard deviation (GSD), and median indoor to outdoor concentration ratios for VOCs measured in all indoor environments.

Compound	Method Detection Limit (MDL)*	Indoors % Below MDL	Outdoors % Below MDL	Campus Services (n=4)				Restrooms (n=2)				Renovated Offices (n=2)				Green Building (n=3)				Meeting Areas (n=2)				Classrooms (n=3)				Outdoors (n=8)		
				(μg/m³)				(μg/m³)				(μg/m³)				(μg/m³)				(μg/m³)				(μg/m³)				(μg/m³)		
	(μg/m³)	%	%	Range	GM	GSD	I/O	Range	GM	GSD	I/O	Range	GM	GSD	I/O	Range	GM	GSD	I/O	Range	GM	GSD	I/O	Range	GM	GSD	I/O	Range	GM	GSD
Isobutane	0.03	0	0	1.7–11.6	4.8	2.0	5	5.2–312	40.4	7.7	100	9.5–118	33.6	3.5	29	0.9–1.5	1.2	1.2	4	1.3–1.5	1.4	1.0	3	2.6–3	2.9	1.1	3	0.2–2.3	0.9	2.0
n-Butane	0.04	0	0	3.4–17	8.2	1.8	5	4.4–170	27.5	6.2	33	15.9–239	61.7	3.9	38	1.9–3.6	2.9	1.3	7	3.3–3.8	3.6	1.1	4	5–7.8	5.9	1.2	3	0.5–3.4	1.5	1.9
*Ethanol***	0.03	0	0	9.8–462	61.3	5.4	168	16.3–628	101	6.2	290	56.2–287	127	2.3	155	15–125	49.6	2.4	71	20.2–24	22.0	1.1	40	25.5–50.7	34.1	1.3	8	0.5–3.8	1.0	1.9
2-Methylbutane	0.03	0	0	3.1–23	7.5	2.2	5	1.9–6.5	3.6	1.8	4	12–13.5	12.8	1.1	4	1.7–4.8	2.8	1.5	9	0.8–0.9	0.9	1.0	2	4.7–6.1	5.2	1.1	3	0.3–2.9	1.1	2.3
Benzene	0.02	0	0	0.2–1	0.5	1.8	3	0.4–0.5	0.4	1.0	2	2.2–2.3	2.2	1.1	6	0.1–0.3	0.2	1.1	4	0.2–0.3	0.2	1.0	2	0.7–1	0.9	1.1	3	MDL–0.5	0.17	2.1
Trichloroethene	0.03	25	50	MDL–0.4	0.2	1.7	-	0.1–0.3	0.2	1.2	1	1.3–1.4	1.4	1.1	6	MDL–0.1	0.03	1.0	-	MDL	-	-	-	1.6–1.8	1.7	1.1	13	MDL–0.3	0.07	2.4
Methyl methacrylate	0.03	93.75	100	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL–4.6	0.2	10.7	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-
Toluene	0.02	0	0	1.4–7.3	2.8	2.0	3	5.1–5.7	5.4	1.0	4	13.3–14.5	13.9	1.1	5	2.7–35.1	6.5	3.3	9	1.6–1.7	1.7	1.0	3	13.1–81.9	25.5	2.3	6	0.3–2.9	1.1	2.3
Tetrachloroethene	0.03	6.25	12.5	MDL–0.7	0.2	3.6	3	0.1–0.2	0.2	1.2	3	0.4–0.5	0.5	1.1	4	MDL–0.1	0.07	1.2	-	0.1–0.2	0.2	1.0	2	0.2–0.3	0.2	1.1	1	MDL–0.2	0.07	1.7
Ethylbenzene	0.01	0	0	0.3–1.3	0.6	1.6	4	0.5–0.7	0.6	1.1	2	1.9–2.5	2.2	1.1	4	0.3–1.5	0.7	1.8	9	0.2–0.3	0.3	1.4	4	1.3–2.8	1.8	1.3	3	MDL–0.7	0.19	2.6
p-Xylene	0.02	0	0	0.6–2.4	1.2	1.6	3	1.1–1.3	1.2	1.1	3	5.1–10	7.2	1.4	5	0.7–3.1	1.5	1.8	12	0.5–0.6	0.7	1.3	4	3.2–5.5	4.1	1.2	4	0.1–1.5	0.43	2.6
m-Xylene	0.01	0	0	0.2–1	0.5	1.8	3	0.3–0.5	0.42	1.1	2	1.8–2.6	2.2	1.2	4	0.2–1.1	0.5	1.8	11	0.2–0.3	0.3	1.3	4	1–1.9	1.3	1.2	3	MDL–0.6	0.17	2.7
Styrene	0.03	0	50	0.1–1.6	0.4	2.3	-	2.1–3.8	2.9	1.3	-	0.7–1	0.83	1.2	12	0.3–21.8	1.5	6.7	-	0.1–0.6	0.3	2.4	-	4–9.9	5.9	1.5	84	MDL–0.2	0.04	1.8
o-Xylene	0.04	0	0	0.4–1.6	0.8	1.6	5	0.5–0.8	0.7	1.1	-	2.7–3.4	3.1	1.2	4	0.3–1.2	0.7	1.6	8	0.6–0.7	0.7	1.1	9	2.5–3.5	2.9	1.1	5	MDL–0.8	0.24	2.5
R(-)3,7-Dimethyl-1,6-octadiene	0.03	62.5	100	0.1–2.3	0.61	3.3	-	MDL–25.0	0.9	28.7	-	MDL	-	-	-	MDL–0.3	0.06	2.6	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-
a-Pinene	0.03	0	0	0.5–1.7	1.0	1.5	18	0.6–2	1.0	1.8	30	12.6–13.8	13.2	1.1	86	1.7–4.3	2.8	1.5	44	0.2–0.5	0.3	1.5	5	10.4–35.8	17.3	1.7	53	MDL–0.3	0.08	1.8
β-Pinene	0.03	0	75	0.2–1.3	0.5	1.8	-	0.5–1.7	0.9	1.8	-	10.2–11.6	10.9	1.1	127	0.5–2.2	1.4	1.8	-	0.1–0.2	0.2	1.0	-	6.8–9.5	7.8	1.2	52	MDL–0.2	0.04	1.9
d-Limonene	0.03	0	0	5.7–30.6	12.6	1.9	331	30.6–41.1	35.5	1.2	123	5.9–7	6.4	1.1	53	0.6–1.6	1.0	1.4	25	1–1.1	1.1	1.1	34	4.8–14.9	7.4	1.6	53	MDL–0.3	0.07	2.2
Eucalyptol	0.03	0	37.5	0.4–1.9	1.1	1.7	18	2.8–5.1	3.8	1.3	-	1–1.7	1.3	1.3	16	0.1–0.5	0.3	1.4	-	0.1–0.2	0.2	1.1	-	0.6–1.2	0.8	1.3	16	MDL–0.2	0.05	1.7
2-Methyl-6-methylene-2-octanol	0.03	68.75	100	MDL–3.6	0.2	7.5	-	MDL–56.5	1.3	43.4	-	0.2–0.4	0.3	1.1	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-
Phenylethyl alcohol	0.03	93.75	100	MDL	-	-	-	MDL–17.7	0.7	24.3	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-
Phenylmethyl acetate	0.03	43.75	100	MDL–0.5	0.2	2.2	-	0.2–10.0	1.7	6.0	-	0.1–0.2	0.2	1.2	-	MDL–0.06	0.04	1.4	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-
a-Methylbenzyl acetate	0.03	87.5	100	MDL–0.1	0.03	1.0	-	1.8–15.8	5.5	2.9	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-
Naphthalene	0.03	0	75	0.1–0.3	0.2	1.2	-	0.1–0.3	0.2	1.3	-	0.3–0.4	0.4	1.1	-	MDL–0.3	0.2	1.6	-	MDL–0.2	0.1	1.3	-	1–1.5	1.3	1.2	35	MDL–0.04	0.03	1.1
Benzothiazole	0.03	0	100	0.1–0.6	0.3	1.7	-	0.5–0.8	0.7	1.2	-	0.3–0.5	0.4	1.2	-	0.04–0.3	0.2	2.5	-	MDL–0.1	0.1	1.2	-	3.3–5.8	4.4	1.2	-	MDL	-	-
4-tert-Butylcyclohexyl acetate	0.03	87.5	100	MDL–3.2	0.2	8.3	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-
Formaldehyde	0.03	0	0	3.9–18.9	7.2	1.9	3	3.8–9.9	6.2	1.6	4	13.5–15	14.2	1.1	13	12.4–14.8	13.6	1.1	27	4.1–4.8	4.5	1.1	6	13.5–26	16.9	1.4	12	0.5–2.4	1.1	1.7
Acetaldehyde	0.04	0	0	1.7–9.2	3.2	1.9	4	2.7–3.8	3.2	1.2	5	3.4–4.6	4.0	1.2	6	3.4–10	6.1	1.5	51	1–1.6	1.3	1.2	6	6.5–18.9	9.4	1.6	11	0.1–0.8	0.44	1.9
Acetone	0.07	0	0	6.1–10.7	8.1	1.2	3	6.7–10.8	8.5	1.3	5	11.4–13.6	12.5	1.1	9	12.6–38.4	24.7	1.6	35	2.3–2.4	2.7	1.2	3	36.4–86.3	48.6	1.5	22	0.5–3.8	1.4	1.8
Acrolein	0.01	100	100	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-
Propionaldehyde	0.02	25	100	MDL–2.2	0.14	8.9	-	0.3–0.7	0.5	1.4	-	0.3–0.5	0.4	1.1	-	0.3–2.4	0.9	2.2	-	MDL	-	-	-	1.1–7.8	2.3	2.4	-	MDL	-	-
Crotonaldehyde	0.02	100	100	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-
MEK	0.10	12.5	62.5	0.3–0.9	0.54	1.6	-	0.5–1.1	0.8	1.4	4	2.1–2.4	2.3	1.1	-	0.4–1.8	0.9	1.7	-	MDL	-	-	-	2.2–3.7	2.7	1.24	16	0.1–0.6	0.14	1.9
Methacrolein	0.02	68.75	100	MDL–0.4	0.03	3.7	-	MDL	-	-	-	MDL	-	-	-	MDL–0.3	0.1	3.3	-	MDL	-	-	-	MDL –0.5	0.1	3.9	-	MDL	-	-
Butyraldehyde	0.02	25	100	MDL–1.5	0.2	4.9	-	0.2–0.4	0.3	1.1	5	0.5–0.7	0.6	1.1	-	0.4–1.5	0.8	1.6	-	MDL	-	-	-	1–2.6	1.4	1.5	-	MDL–0.06	0.02	1.5
Benzaldehyde	0.04	12.5	87.5	MDL–1	0.3	3.4	-	0.4–0.7	0.5	1.3	-	0.2–0.3	0.3	1.1	-	0.5–1	0.6	1.4	-	MDL	-	-	-	1.6–2.6	1.9	1.2	38	MDL–0.04	0.04	1.4
Valeraldehyde	0.03	25	100	MDL–1.3	0.1	5.5	-	0.1–0.3	0.2	1.3	-	0.7–0.8	0.7	1.1	-	1–2.1	1.3	1.4	-	MDL	-	-	-	2.2–7.5	3.4	1.7	-	MDL	-	-
Glyoxal	0.01	0	12.5	0.1–0.5	0.3	1.7	-	MDL–0.2	0.1	1.6	-	0.1–0.3	0.2	1.1	-	0.2–0.4	0.3	1.3	9	0.1–0.2	0.1	1.3	3	0.1–0.3	0.2	1.1	2	MDL–0.5	0.09	3.6
m-Tolualdehyde	0.03	93.75	100	MDL	-	-	-	MDL	-	-	-	MDL	-	-	-	MDL–0.2	0.04	2.1	-	MDL	-	-	-	MDL	-	-	-	MDL	-	-
Methyl glyoxal	0.02	0	0	1.8–4.8	2.4	1.5	1	0.3–0.6	0.4	1.3	1	1.7–2.1	1.9	1.1	3	1.1–1.8	1.5	1.2	12	0.8–0.9	0.9	1.1	4	0.8–1.4	1.1	1.2	2	0.1–1.7	0.45	2.5
Hexaldehyde	0.04	0	0	0.1–4.6	0.8	4.1	-	0.4–1	0.6	1.5	-	3.2–4	3.6	1.1	-	4.3–6.4	5.6	1.2	-	MDL–0.1	0.1	1.4	-	8.9–27.6	13.2	1.7	214	MDL–0.2	0.05	1.6

[*] Compounds reported are all above MDL in >50% of locations with corresponding ambient levels above MDL.
[**] Ethanol concentrations are semi-quantitative due to possible sample breakthrough of multisorbent tubes.

Table 3. The twelve most prevalent compounds in each environment, based on geometric mean concentration.

Campus Services	
Compound	**(μg/m³)**
Ethanol	61.3
d-Limonene	12.6
n-Butane	8.2
Acetone	8.1
2-Methylbutane	7.5
Formaldehyde	7.2
Isobutane	4.8
Acetaldehyde	3.2
Toluene	2.8
Methyl glyoxal	2.4
p-Xylene	1.2
Eucalyptol	1.1

Restrooms	
Compound	**(μg/m³)**
Ethanol	101
Isobutane	40.4
d-Limonene	35.5
n-Butane	27.5
Acetone	8.5
Formaldehyde	6.2
α-MBA[*]	5.5
Toluene	5.4
Eucalyptol	3.8
2-Methylbutane	3.6
Acetaldehyde	3.2
Styrene	2.9

Renovated Offices	
Compound	**(μg/m³)**
Ethanol	127
n-Butane	61.7
Isobutane	33.6
Formaldehyde	14.2
Toluene	13.9
α-Pinene	13.2
2-Methylbutane	12.8
Acetone	12.5
β-Pinene	10.9
p-Xylene	7.2
d-Limonene	6.4
Acetaldehyde	4.0

Green Building	
Compound	**(μg/m³)**
Ethanol	49.6
Acetone	24.7
Formaldehyde	13.6
Toluene	6.5
Acetaldehyde	6.1
Hexaldehyde	5.6
n-Butane	2.9
α-Pinene	2.8
2-Methylbutane	2.8
Styrene	1.5
p-Xylene	1.5
Methyl glyoxal	1.5

Meeting Areas	
Compound	**(μg/m³)**
Ethanol	22.0
Formaldehyde	4.5
n-Butane	3.6
Acetone	2.7
Toluene	1.7
Isobutane	1.4
Acetaldehyde	1.3
d-Limonene	1.1
Methyl glyoxal	0.9
2-Methylbutane	0.9
o-Xylene	0.7
p-Xylene	0.7

Classrooms	
Compound	**(μg/m³)**
Acetone	48.6
Ethanol	34.1
Toluene	25.5
α-Pinene	17.3
Formaldehyde	16.9
Hexaldehyde	13.2
Acetaldehyde	9.4
β-Pinene	7.8
d-Limonene	7.4
n-Butane	5.9
Styrene	5.9
2-Methylbutane	5.2

Ambient	
Compound	**(μg/m³)**
n-Butane	1.5
Acetone	1.4
Formaldehyde	1.1
Toluene	1.1
2-Methylbutane	1.1
Ethanol	1.0
Isobutane	0.90
Methyl glyoxal	0.45
Acetaldehyde	0.44
p-Xylene	0.43
o-Xylene	0.24
Ethylbenzene	0.19

[*] *α-Methylbenzyl acetate*

Indoor volatile organic compounds at an Australian university (Figures)

Figure 1. Indoor to outdoor concentration ratios for hazardous air pollutants (FBTX) and ethylbenzene.

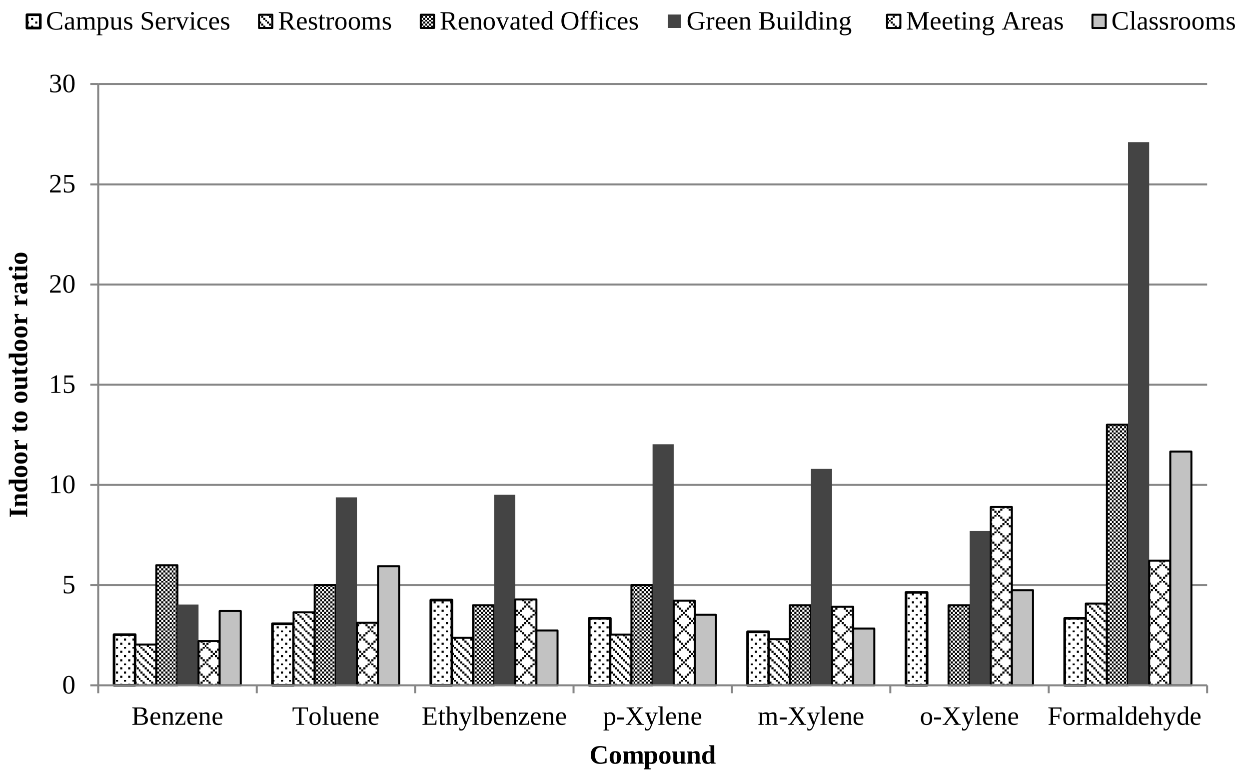


Figure 2. Indoor to outdoor concentration ratios for alkanes and ethanol.

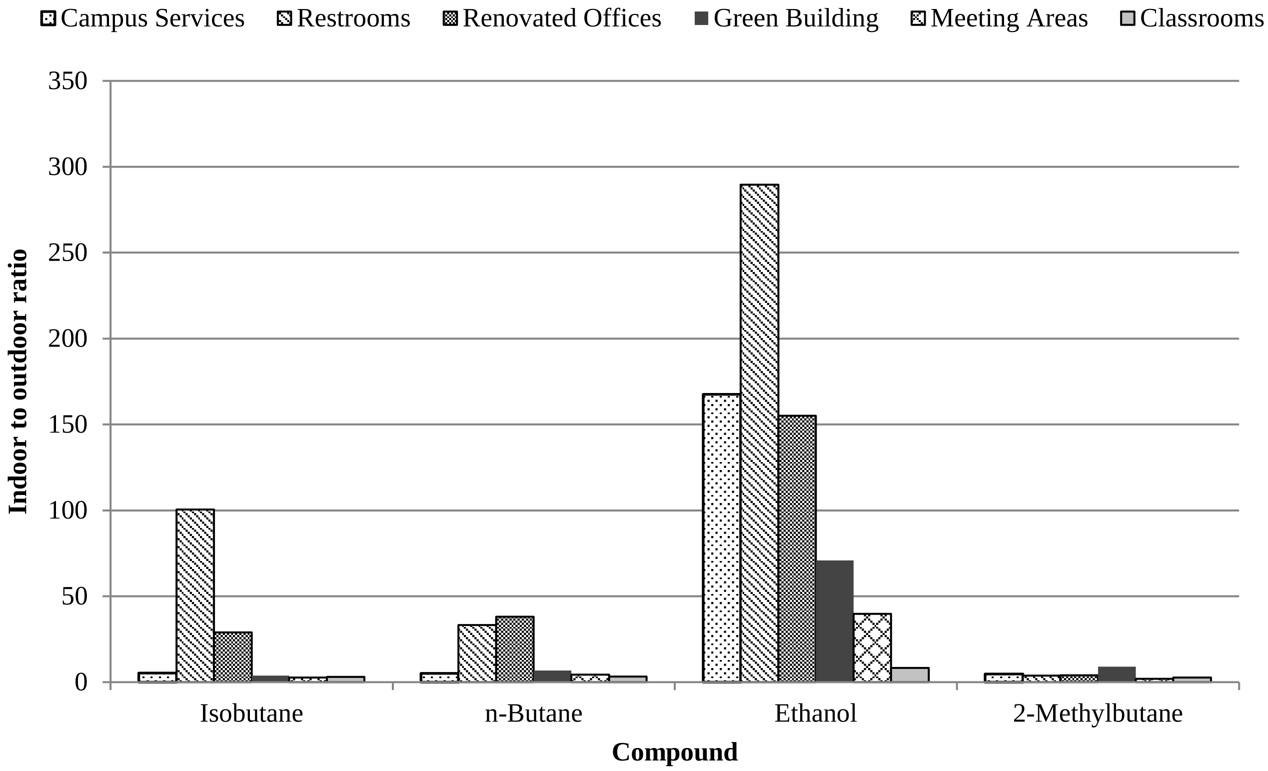
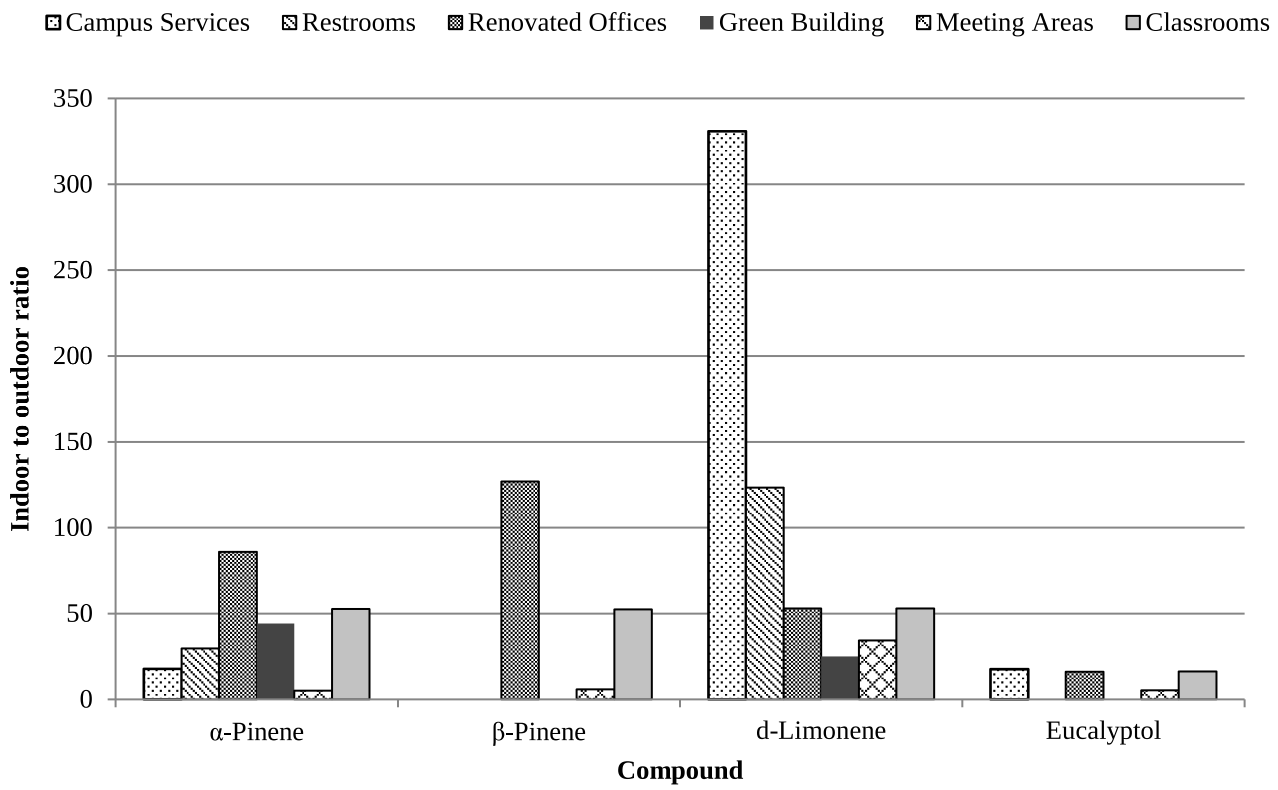


Figure 3. Indoor to outdoor concentration ratios for terpenes and terpenoids.



Indoor volatile organic compounds at an Australian university (Supplementary Material)

Table S1. Description of each indoor and outdoor sampling location, room dimensions, temperature and relative humidity measurements during sampling.

Location	**Description of indoor and outdoor sampling locations**	**Temp (°C)**	**RH (%)**	**Floor Area (m^2)**	**Ceiling Height (m)**	**Volume (m^3)**
Campus Services	This location is the campus supermarket. The space consists of three ailes containing fresh and packaged food, stationary, cleaning supplies, and personal care products. The main odours are of groceries and cleaning products. The space is mechanically ventilated and air conditioned. The approximate occupancy rate was 25 persons per hour. The space was last renovated in 1994.	23.2–25.5	34–55	109	2.5	276
Campus services	This location is the campus hairdressers. The space is furnished with a large reception counter (1.2 m x 1.5 m x 0.6 m), three large vinyl covered chairs, and three mirrored dressing tables made from painted medium-density fibreboard (MDF) and glass. The main odours are of shampoo and hair products. The space is mechanically ventilated and air conditioned. There were approximately 5 customers per hour. The space was last renovated in 1994.	22.1–22.9	34–54	31.7	2.96	94
Campus services ambient	This location is an external fire escape (concrete) on the eastern side of a nearby building (third floor), approximately 15 m from a road. Duplicate samples for campus services were collected using the same paired ambient location as the green building (see below).	22.5–26.9	33–50	-	-	-
Restrooms	This male restroom contains a toilet cubical, a urinal, and two wash basins each with a scented hand soap dispenser. Materials in the room include ceramic wall and floor tiles, masonry walls, painted timber doors, and a ceiling made from painted plaster board or plywood. An automatic air freshener, active every few minutes, provides the dominant odour. The space is mechanically ventilated. The approximate occupancy rate was 5 people per hour. The space was last renovated in 1973.	23.0–24.1	50–53	9.59	2.44	23.4
Restrooms	This female restroom contains a toilet cubical and single wash basin with scented hand soap dispenser. Materials in the room include ceramic floor tiles, and a laminex coated bench and cubical partitions made from compressed timber. The walls are painted masonry and the ceiling is painted plaster board or plywood. The space is mechanically ventilated. Additional ventilation is provided by a single window mounted fan. An automatic air freshener, active every few minutes, provides the dominant odour. The approximate occupancy rate was 7 people per hour. The space was last renovated during the 1980's.	23.3–25.5	52–55	9.28	2.73	25.4
Restrooms ambient	This location is the rooftop of the building (level 5). Materials include concrete and galvanized metal. The location is partially enclosed by a metal shelter.	24.2–25.1	46–50	-	-	-
Renovated offices	This is a large open plan office. Its furnishing and materials include Laminex coated MDF desks and bookcases, small metal filing cabinets, chairs, computers, printers. The floor is made from sealed concrete. Walls are glass, concrete or fabric (covered plywood), and the ceiling is sealed concrete. There was a noticeable smell of new materials in this space. The space is mechanically ventilated and air conditioned. The space was occupied by 5-10 people during sampling. The space was last renovated in 2014.	22.8–23.2	45–52	234	10.2	2390
Renovated offices	This space is a linkage corridor from the main office area to staff showers and restrooms. The walls are glass, concrete or painted plywood, and the ceiling is made from sealed concrete. There was a noticeable smell of new materials and fragrances from cleaning products and air fresheners in this location. The space is mechanically ventilated and air conditioned. The occupancy rate was 2 to 5 people per hour. The space was last renovated in 2014.	23.0–26.5	40–53	32.36	3.69	119
Renovated offices ambient	This location is the rooftop of the building (level 3), and included a staff recreational area accessible by an elevator. Sampling took place approximately 15 m away from the entrance to the elevator, and outdoor furniture.	26	42	-	-	-
Green building	This location is a studio. The space is primarily constructed from timber (solid and veneered), including the floor and all walls. The room is dominated by a large timber conference table (~4 m x 2 m). The room has a strong timber/sealant smell. The space is mechanically ventilated and air conditioned. The room was unoccupied during sampling. The space was constructed in 2014.	23.2–23.6	44–54	36.52	8.2	299
Green building	This location is a studio. The space has solid timber floors, and walls made from painted plasterboard and timber (solid and veneered). It also contains cabinets made from MDF, eight tables made from coated MDF, and twenty fabric covered chairs. The room has a strong timber/sealant smell. The space is mechanically ventilated and air conditioned. There were up to 13 people in the room during sampling. The space was constructed in 2014.	22.8–23.2	50–55	40.03	2.88	115
Green building	This location is a classroom. The space has linoleum floors and soft finish walls (felt) on the north, east and south walls. There are 15 desks (laminex/MDF) and 32 chairs. The ceiling is finished with unpainted, sprayed concrete. There was a subtle odour of new materials. The space is mechanically ventilated and centralised air conditioning was active at the time of sampling. Automatic operable windows were closed. The space was unoccupied during sampling. The space was constructed in 2014.	22.5–23.1	47–50	74.57	3.7	275
Green building ambient	This location is a large (14 m x 7 m) western balcony (level 6) that included concrete paving, plants, and garden material. Sampling took place approximately 5 m from the nearest seating area (unoccupied), and within 1.5 m of vegetation.	20.1–23.9	43–44	-	-	-
Meeting areas	This location is meeting area at the centre of a building. The area has two large vinyl couches/chairs face onto a central coffee table. Walls are made from glass, or painted plasterboard, and floors are carpeted. There are some subtle material aromas and a strong odour of cleaning fluids/fragrances. The space is mechanically ventilated and air conditioned. The space was constructed in 2000.	21.4–23.0	44–50	61.13	3.46	211
Meeting areas	This location is a waiting area and corridor providing access to classrooms and offices. Materials include painted plasterboard, carpeted pin boards, and painted medium density fibreboard (MDF) cabinetry. The floor is polished vinyl/linoleum. There is a musty damp smell throughout the space as well as a strong odour of cleaning fluids/fragrances. The space is mechanically ventilated and air conditioned. The space was last renovated in 2000.	21.0–22.3	44–49	63.36	3.67	232
Meeting areas ambient	This location is at ground level approximately three metres from the western wall of the building, with large trees, shrubs, and grasses nearby (within 10 metres). The sample point was approximately 30 m from the nearest seating area (unoccupied).	22.4	45	-	-	-
Classroom	This classroom has 5 large benches (5 m x 1 m) that have computers and smaller electronic devices (e.g., oscilloscopes, lock in amplifiers) on them. Each bench is covered with an electrically safe elastomer/rubber matt. There are several large (~2 m x 5 m) timber cupboards (MDF-lacquered). The floor is linoleum or vinyl and the ceiling of the room is made from suspended foam tiles. There is an odour of new materials. The space is mechanically ventilated and air conditioned. The space was occupied by 1 person during sampling. The space was last renovated in 2014.	21.1–22.0	48–52	115	3.68	426
Classroom	This is a large classroom filled with 7 timber (lacquered MDF) benches (1 m x 2 m). One quarter of the space is separated by a clear plastic wall to provide space for an instrumental test rig. The door between the space and the main room was open on the day of sampling. The floor is linoleum or vinyl and the ceiling of the room is made from suspended foam tiles. There is an odour of new materials. The space is mechanically ventilated and air conditioned. The space was occupied by 2 people during sampling. The space was last renovated in 2014.	22.5–21.7	49–54	82.82	3.36	278
Classrooms ambient	This location is an external metal stairwell near the rooftop of the building (level 4).	21.1–21.3	52–53	-	-	-

Table S2. Statistical analysis of VOCs for campus services. Median I/O ratios for campus services for selected compounds.

Compound	MDL (μg/m³)	Min (μg/m³)	Max (μg/m³)	Mean (μg/m³)	σ	MED (μg/m³)	GM (μg/m³)	GSD	Outdoor (median)	MED I/O ratio
isobutane	0.03	1.7	11.58	5.97	3.6	5.3	4.8	2.0	1.13	5
n-Butane	0.04	3.4	16.95	9.56	4.9	8.9	8.2	1.8	1.77	5
Ethanol	0.03	9.9	461.98	179.15	186	122	61.3	5.4	0.99	168
2-Methylbutane	0.03	3.2	22.98	10.13	7.9	7.2	7.5	2.2	1.59	5
Benzene	0.02	0.24	0.99	0.53	0.31	0.45	0.5	1.8	0.26	3
Trichloroethene	0.03	0.09	0.34	0.21	0.10	0.20	0.2	1.7	MDL	-
Methyl methacrylate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Toluene	0.02	1.5	7.2	3.5	2.4	2.8	2.8	2.0	1.06	3
Tetrachloroethene	0.03	MDL	0.64	0.29	0.25	0.24	0.2	3.6	0.08	3
Ethylbenzene	0.01	0.32	1.2	0.70	0.34	0.62	0.6	1.6	0.20	4
p-Xylene	0.02	0.63	2.3	1.3	0.64	1.1	1.2	1.6	0.50	3
m-Xylene	0.01	0.20	0.99	0.59	0.28	0.58	0.5	1.8	0.25	3
Styrene	0.03	0.14	1.5	0.59	0.56	0.34	0.4	2.3	0.09	-
o-Xylene	0.04	0.50	1.5	0.85	0.42	0.68	0.8	1.6	0.29	5
R(-)3,7-Dimethyl-1,6-octadiene	0.03	0.13	2.3	1.1	0.91	0.98	0.61	3.3	MDL	-
α-Pinene	0.03	0.54	1.7	1.1	0.42	1.1	1.0	1.5	0.06	18
β-Pinene	0.03	0.29	1.2	0.64	0.38	0.52	0.5	1.8	MDL	-
d-Limonene	0.03	5.7	30.5	15.3	9.54	12.5	12.6	1.9	0.05	331
Eucalyptol	0.03	0.45	1.8	1.2	0.49	1.2	1.1	1.7	0.06	18
2-Methyl-6-methylene-2-octanol	0.03	MDL	3.6	1.0	1.5	0.26	0.2	7.5	MDL	-
Phenylethyl alcohol	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Phenylmethyl acetate	0.03	0.05	0.42	0.20	0.14	0.17	0.2	2.2	MDL	-
a-Methylbenzyl acetate	0.03	MDL	-	-	-	-	0.03	1.0	MDL	-
Naphthalene	0.03	0.13	0.21	0.16	0.03	0.16	0.2	1.2	MDL	-
Benzothiazole	0.03	0.16	0.51	0.30	0.15	0.27	0.3	1.7	MDL	-
4-tert-Butylcyclohexyl acetate	0.03	MDL	3.1	1.1	1.27	0.62	0.2	8.3	MDL	-
Formaldehyde	0.03	4.0	18.8	8.8	6.0	6.3	7.2	1.9	2.10	3
Acetaldehyde	0.04	1.7	9.2	4.1	3.0	2.7	3.2	1.9	0.71	4
Acetone	0.07	6.1	10.7	8.3	1.7	8.2	8.1	1.2	2.86	3
Acrolein	0.01	MDL	MDL	-	-	-	-	-	MDL	-
Propionaldehyde	0.02	MDL	2.1	0.7	0.87	0.32	0.14	8.9	MDL	-
Crotonaldehyde	0.02	MDL	-	-	-	-	-	-	MDL	-
MEK	0.10	0.33	0.86	0.60	0.25	0.60	0.54	1.6	MDL	-
Methacrolein	0.02	MDL	0.33	0.09	0.14	0.02	0.03	3.7	MDL	-
Butyraldehyde	0.02	MDL	1.4	0.51	0.55	0.31	0.2	4.9	MDL	-
Benzaldehyde	0.04	MDL	0.99	0.43	0.36	0.35	0.3	3.4	MDL	-
Valeraldehyde	0.03	MDL	1.2	0.43	0.49	0.24	0.1	5.5	MDL	-
Glyoxal	0.01	0.11	0.44	0.28	0.13	0.28	0.3	1.7	0.45	-
m-Tolualdehyde	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Methyl glyoxal	0.02	1.8	4.7	2.6	1.2	1.9	2.4	1.5	1.44	1
Hexaldehyde	0.04	0.13	4.6	1.8	1.8	1.1	0.8	4.1	0.10	-

Table S3. Statistical analysis of VOCs for university restrooms. Median I/O ratios for university restrooms for selected compounds.

Compound	MDL (μg/m^3)	Min (μg/m^3)	Max (μg/m^3)	Mean (μg/m^3)	σ	MED (μg/m^3)	GM (μg/m^3)	GSD	Outdoor	MED I/O Ratio
isobutane	0.03	5.2	311	158	153	158	40.4	7.7	1.6	100
n-Butane	0.04	4.5	169	87.08	82	87.0	27.5	6.2	2.6	33
Ethanol	0.03	16.3	627	322	305	322	101	6.2	1.1	290
2-Methylbutane	0.03	1.9	6.46	4.22	2.2	4.2	3.6	1.8	1.1	4
Benzene	0.02	0.41	0.45	0.43	0.02	0.43	0.4	1.0	0.21	2
Trichloroethene	0.03	0.16	0.22	0.19	0.03	0.19	0.2	1.2	0.13	1
Methyl methacrylate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Toluene	0.02	5.2	5.6	5.4	0.23	5.4	5.4	1.0	1.5	4
Tetrachloroethene	0.03	0.14	0.19	0.16	0.03	0.16	0.2	1.2	0.05	3
Ethylbenzene	0.01	0.55	0.64	0.60	0.04	0.60	0.6	1.1	0.25	2
p-Xylene	0.02	1.1	1.3	1.2	0.09	1.2	1.2	1.1	0.47	3
m-Xylene	0.01	0.39	0.45	0.42	0.03	0.42	0.42	1.1	0.18	2
Styrene	0.03	2.2	3.8	2.9	0.79	2.9	2.9	1.3	MDL	-
o-Xylene	0.04	0.59	0.75	0.67	0.08	0.67	0.7	1.1	0.23	-
R(-)3,7-Dimethyl-1,6-octadiene	0.03	MDL	24.8	12.4	12.4	12.4	0.9	28.7	MDL	-
α-Pinene	0.03	0.60	1.9	1.3	0.66	1.3	1.0	1.8	0.04	30
β-Pinene	0.03	0.50	1.7	1.1	0.59	1.1	0.9	1.8	MDL	-
d-Limonene	0.03	30.7	41.1	35.9	5.2	35.9	35.5	1.2	0.29	123
Eucalyptol	0.03	2.8	5.03	3.9	1.1	3.9	3.8	1.3	MDL	-
2-Methyl-6-methylene-2-octanol	0.03	MDL	56.4	28.2	28.2	28.2	1.3	43.4	MDL	-
Phenylethyl alcohol	0.03	MDL	17.7	8.9	8.8	8.9	0.7	24.3	MDL	-
Phenylmethyl acetate	0.03	0.28	9.9	5.1	4.9	5.1	1.7	6.0	MDL	-
a-Methylbenzyl acetate	0.03	1.9	15.8	8.8	6.9	8.8	5.5	2.9	MDL	-
Naphthalene	0.03	0.14	0.25	0.2	0.05	0.19	0.2	1.3	MDL	-
Benzothiazole	0.03	0.55	0.8	0.67	0.11	0.67	0.7	1.2	MDL	-
4-tert-Butylcyclohexyl acetate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Formaldehyde	0.03	3.9	9.8	6.9	2.9	6.9	6.2	1.6	1.7	4
Acetaldehyde	0.04	2.7	3.7	3.2	0.52	3.2	3.2	1.2	0.63	5
Acetone	0.07	6.7	10.7	8.7	2.0	8.7	8.5	1.3	1.6	5
Acrolein	0.01	MDL	MDL	-	-	-	-	-	MDL	-
Propionaldehyde	0.02	0.32	0.65	0.48	0.17	0.48	0.5	1.4	MDL	-
Crotonaldehyde	0.02	MDL	MDL	-	-	-	-	-	MDL	-
MEK	0.10	0.58	1.1	0.82	0.24	0.82	0.8	1.4	0.20	4
Methacrolein	0.02	MDL	MDL	-	-	-	-	-	MDL	-
Butyraldehyde	0.02	0.27	0.33	0.30	0.03	0.30	0.3	1.1	0.06	5
Benzaldehyde	0.04	0.43	0.67	0.55	0.12	0.55	0.5	1.3	MDL	-
Valeraldehyde	0.03	0.17	0.27	0.22	0.05	0.22	0.2	1.3	MDL	-
Glyoxal	0.01	0.04	0.11	0.08	0.03	0.08	0.1	1.6	0.05	-
m-Tolualdehyde	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Methyl glyoxal	0.02	0.34	0.55	0.45	0.11	0.45	0.4	1.3	0.40	1
Hexaldehyde	0.04	0.42	0.92	0.67	0.25	0.67	0.6	1.5	MDL	-

Table S4. Statistical analysis of VOCs for renovated offices. Median I/O ratios for renovated offices for selected compounds.

Compound	**MDL (µg/m³)**	**Min (µg/m³)**	**Max (µg/m³)**	**Mean (µg/m³)**	**σ**	**MED (µg/m³)**	**GM (µg/m³)**	**GSD**	**Outdoor**	**MED I/O ratio**
isobutane	0.03	9.5	118	64	54.5	64	33.6	3.5	2.2	29
n-Butane	0.04	15.9	239	127	111	127.5	61.7	3.9	3.3	38
Ethanol	0.03	56.3	287	171	115	171.7	127	2.3	1.1	155
2-Methylbutane	0.03	12.0	13.5	12.7	0.72	12.7	12.8	1.1	2.9	4
Benzene	0.02	2.2	2.2	2.23	0.01	2.2	2.2	1.1	0.35	6
Trichloroethene	0.03	1.3	1.4	1.34	0.01	1.3	1.4	1.1	0.21	6
Methyl methacrylate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Toluene	0.02	13.4	14.4	13.8	0.54	13.9	13.9	1.1	2.9	5
Tetrachloroethene	0.03	0.44	0.47	0.46	0.01	0.46	0.5	1.1	0.11	4
Ethylbenzene	0.01	1.9	2.4	2.2	0.22	2.2	2.2	1.1	0.59	4
p-Xylene	0.02	5.2	9.9	7.6	2.4	7.6	7.2	1.4	1.5	5
m-Xylene	0.01	1.8	2.5	2.2	0.35	2.2	2.2	1.2	0.57	4
Styrene	0.03	0.7	0.93	0.83	0.10	0.83	0.83	1.2	0.07	12
o-Xylene	0.04	2.7	3.3	3.0	0.31	3.0	3.1	1.2	0.76	4
R(-)3,7-Dimethyl-1,6-octadiene	0.03	MDL	MDL	-	-	-	-	-	MDL	-
α-Pinene	0.03	12.6	13.8	13.2	0.58	13.2	13.2	1.1	0.15	86
β-Pinene	0.03	10.3	11.5	10.9	0.65	10.9	10.9	1.1	0.09	127
d-Limonene	0.03	5.9	6.9	6.4	0.54	6.4	6.4	1.1	0.12	53
Eucalyptol	0.03	1.0	1.6	1.32	0.30	1.32	1.3	1.3	0.08	16
2-Methyl-6-methylene-2-octanol	0.03	0.30	0.33	0.32	0.02	0.32	0.3	1.1	MDL	-
Phenylethyl alcohol	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Phenylmethyl acetate	0.03	0.12	0.18	0.15	0.03	0.15	0.2	1.2	MDL	-
a-Methylbenzyl acetate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Naphthalene	0.03	0.34	0.37	0.35	0.02	0.35	0.4	1.1	MDL	-
Benzothiazole	0.03	0.31	0.40	0.35	0.05	0.35	0.4	1.2	MDL	-
4-tert-Butylcyclohexyl acetate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Formaldehyde	0.03	13.6	14.9	14.3	0.66	14.3	14.2	1.1	1.1	13
Acetaldehyde	0.04	3.5	4.5	4.0	0.53	4.0	4.0	1.2	0.71	6
Acetone	0.07	11.5	13.6	12.5	1.0	12.5	12.5	1.1	1.4	9
Acrolein	0.01	MDL	MDL	-	-	-	-	-	MDL	-
Propionaldehyde	0.02	0.39	0.42	0.41	0.02	0.41	0.4	1.1	MDL	-
Crotonaldehyde	0.02	MDL	MDL	-	-	-	-	-	MDL	-
MEK	0.10	2.2	2.4	2.3	0.11	2.3	2.3	1.1	MDL	-
Methacrolein	0.02	MDL	MDL	-	-	-	-	-	MDL	-
Butyraldehyde	0.02	0.58	0.69	0.63	0.06	0.63	0.6	1.1	MDL	-
Benzaldehyde	0.04	0.28	0.28	0.28	0.00	0.28	0.3	1.1	MDL	-
Valeraldehyde	0.03	0.71	0.74	0.73	0.01	0.73	0.7	1.1	MDL	-
Glyoxal	0.01	0.19	0.23	0.21	0.02	0.21	0.2	1.1	0.23	-
m-Tolualdehyde	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Methyl glyoxal	0.02	1.8	2.1	1.9	0.15	1.9	1.9	1.1	0.69	3
Hexaldehyde	0.04	3.2	3.9	3.6	0.35	3.6	3.6	1.1	MDL	-

Table S5. Statistical analysis of VOCs for a green building. Median I/O ratios for a green building for selected compounds.

Compound	MDL (μg/m³)	Min (μg/m³)	Max (μg/m³)	Mean (μg/m³)	σ	MED (μg/m³)	GM (μg/m³)	GSD	Outdoor	MED I/O ratio
isobutane	0.03	0.95	1.5	1.2	0.21	1.1	1.2	1.2	0.29	4
n-Butane	0.04	1.9	3.6	2.9	0.73	3.4	2.9	1.3	0.50	7
Ethanol	0.03	15.1	125	68.4	45.0	65.0	49.6	2.4	0.92	71
2-Methylbutane	0.03	1.7	4.7	3.1	1.23	2.8	2.8	1.5	0.31	9
Benzene	0.02	0.17	0.21	0.20	0.02	0.2	0.2	1.1	0.05	4
Trichloroethene	0.03	MDL	MDL	-	-	-	0.03	1.0	MDL	-
Methyl methacrylate	0.03	MDL	4.6	1.54	2.13	0.03	0.2	10.7	MDL	-
Toluene	0.02	2.8	35.1	13.6	15.2	2.9	6.5	3.3	0.31	9
Tetrachloroethene	0.03	0.05	0.09	0.07	0.01	0.07	0.07	1.2	0.07	-
Ethylbenzene	0.01	0.37	1.4	0.77	0.46	0.53	0.7	1.8	0.06	9
p-Xylene	0.02	0.76	3.0	1.7	0.98	1.4	1.5	1.8	0.11	12
m-Xylene	0.01	0.26	1.0	0.59	0.34	0.46	0.5	1.8	0.04	11
Styrene	0.03	0.31	21.8	7.5	10.1	0.51	1.5	6.7	MDL	-
o-Xylene	0.04	0.37	1.2	0.78	0.32	0.82	0.7	1.6	0.11	8
R(-)3,7-Dimethyl-1,6-octadiene	0.03	MDL	0.23	0.10	0.10	0.03	0.06	2.6	MDL	-
α-Pinene	0.03	1.8	4.3	3.0	1.02	3.03	2.8	1.5	0.07	44
β-Pinene	0.03	0.58	2.12	1.6	0.70	2.02	1.4	1.8	MDL	-
d-Limonene	0.03	0.66	1.6	1.0	0.37	0.95	1.0	1.4	0.04	25
Eucalyptol	0.03	0.18	0.44	0.31	0.11	0.30	0.3	1.4	MDL	-
2-Methyl-6-methylene-2-octanol	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Phenylethyl alcohol	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Phenylmethyl acetate	0.03	MDL	0.06	0.04	0.02	0.03	0.04	1.4	MDL	-
a-Methylbenzyl acetate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Naphthalene	0.03	0.08	0.25	0.18	0.07	0.20	0.2	1.6	MDL	-
Benzothiazole	0.03	0.04	0.29	0.18	0.11	0.23	0.2	2.5	MDL	-
4-tert-Butylcyclohexyl acetate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Formaldehyde	0.03	12.4	14.7	13.6	0.95	13.8	13.6	1.1	0.51	27
Acetaldehyde	0.04	3.5	9.9	6.6	2.6	6.5	6.1	1.5	0.13	51
Acetone	0.07	12.7	38.3	27.3	10.8	30.8	24.7	1.6	0.87	35
Acrolein	0.01	MDL	MDL	-	-	-	-	-	MDL	-
Propionaldehyde	0.02	0.34	2.3	1.18	0.83	0.89	0.9	2.2	MDL	-
Crotonaldehyde	0.02	MDL	MDL	-	-	-	-	-	MDL	-
MEK	0.10	0.48	1.7	1.0	0.53	0.82	0.9	1.7	MDL	-
Methacrolein	0.02	MDL	0.22	0.14	0.09	0.17	0.1	3.3	MDL	-
Butyraldehyde	0.02	0.43	1.4	0.86	0.42	0.71	0.8	1.6	MDL	-
Benzaldehyde	0.04	0.50	0.97	0.7	0.22	0.52	0.6	1.4	MDL	-
Valeraldehyde	0.03	1.0	2.0	1.4	0.48	1.1	1.3	1.4	MDL	-
Glyoxal	0.01	0.22	0.39	0.29	0.07	0.26	0.3	1.3	0.03	9
m-Tolualdehyde	0.03	MDL	0.12	0.06	0.04	0.03	0.04	2.1	MDL	-
Methyl glyoxal	0.02	1.1	1.8	1.5	0.27	1.5	1.5	1.2	0.12	12
Hexaldehyde	0.04	4.4	6.3	5.6	0.90	6.2	5.6	1.2	MDL	-

Table S6. Statistical analysis of VOCs for meeting areas. Median I/O ratios for meeting areas for selected compounds.

Compound	**MDL (μg/m³)**	**Min (μg/m³)**	**Max (μg/m³)**	**Mean (μg/m³)**	**σ**	**MED (μg/m³)**	**GM (μg/m³)**	**GSD**	**Outdoor**	**MED I/O ratio**
Isobutane	0.03	1.4	1.5	1.4	0.04	1.4	1.4	1.0	0.52	3
n-Butane	0.04	3.4	3.7	3.6	0.21	3.6	3.6	1.1	0.82	4
Ethanol	0.03	20.3	23.9	22.0	1.82	22.0	22.0	1.1	0.55	40
2-Methylbutane	0.03	0.85	0.85	0.85	0.00	0.9	0.9	1.0	0.43	2
Benzene	0.02	0.22	0.22	0.22	0.00	0.22	0.2	1.0	0.10	2
Trichloroethene	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Methyl methacrylate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Toluene	0.02	1.7	1.7	1.7	0.01	1.7	1.7	1.0	0.54	3
Tetrachloroethene	0.03	0.13	0.13	0.13	0.00	0.13	0.2	1.0	0.08	2
Ethylbenzene	0.01	0.21	0.21	0.32	0.11	0.32	0.3	1.4	0.08	4
p-Xylene	0.02	0.54	0.54	0.75	0.21	0.75	0.7	1.3	0.18	4
m-Xylene	0.01	0.20	0.20	0.27	0.07	0.27	0.3	1.3	0.07	4
Styrene	0.03	0.11	0.59	0.35	0.24	0.35	0.3	2.4	MDL	-
o-Xylene	0.04	0.70	0.70	0.73	0.03	0.73	0.7	1.1	0.08	9
R(-)3,7-Dimethyl-1,6-octadiene	0.03	MDL	-	-	-	-	-	-	MDL	-
α-Pinene	0.03	0.20	0.47	0.34	0.14	0.34	0.3	1.5	0.07	5
β-Pinene	0.03	0.17	0.17	0.17	0.00	0.17	0.2	1.0	MDL	-
d-Limonene	0.03	1.0	1.0	1.1	0.07	1.1	1.1	1.1	0.032	34
Eucalyptol	0.03	0.15	0.17	0.16	0.01	0.16	0.2	1.1	MDL	-
2-Methyl-6-methylene-2-octanol	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Phenylethyl alcohol	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Phenylmethyl acetate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
a-Methylbenzyl acetate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Naphthalene	0.03	0.08	0.14	0.11	0.03	0.11	0.1	1.3	MDL	-
Benzothiazole	0.03	0.09	0.09	0.10	0.02	0.10	0.1	1.2	MDL	-
4-tert-Butylcyclohexyl acetate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Formaldehyde	0.03	4.2	4.8	4.5	0.29	4.5	4.5	1.1	0.72	6
Acetaldehyde	0.04	1.1	1.5	1.3	0.21	1.3	1.3	1.2	0.22	6
Acetone	0.07	2.3	2.3	2.7	0.41	2.7	2.7	1.2	1.07	3
Acrolein	0.01	MDL	MDL	-	-	-	-	-	MDL	-
Propionaldehyde	0.02	MDL	MDL	-	-	-	-	-	MDL	-
Crotonaldehyde	0.02	MDL	MDL	-	-	-	-	-	MDL	-
MEK	0.10	MDL	MDL	-	-	-	-	-	MDL	-
Methacrolein	0.02	MDL	MDL	-	-	-	-	-	MDL	-
Butyraldehyde	0.02	MDL	MDL	-	-	-	-	-	MDL	-
Benzaldehyde	0.04	MDL	MDL	-	-	-	-	-	MDL	-
Valeraldehyde	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Glyoxal	0.01	0.10	0.16	0.13	0.03	0.13	0.1	1.3	0.04	3
m-Tolualdehyde	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Methyl glyoxal	0.02	0.90	0.90	0.94	0.04	0.94	0.9	1.1	0.23	4
Hexaldehyde	0.04	0.08	0.08	0.12	0.04	0.12	0.1	1.4	MDL	-

Table S7. Statistical analysis of VOCs for classrooms. Median I/O ratios for classrooms for selected compounds.

Compound	**MDL (μg/m³)**	**Min (μg/m³)**	**Max (μg/m³)**	**Mean (μg/m³)**	**σ**	**MED (μg/m³)**	**GM (μg/m³)**	**GSD**	**Outdoor**	**MED I/O ratio**
isobutane	0.03	2.67	2.99	2.9	0.13	2.9	2.9	1.1	0.92	3
n-Butane	0.04	5.04	7.77	6.0	1.22	5.3	5.9	1.2	1.7	3
Ethanol	0.03	25.52	50.62	35.6	10.9	30.7	34.1	1.3	3.8	8
2-Methylbutane	0.03	4.72	6.05	5.2	0.61	4.8	5.2	1.1	1.8	3
Benzene	0.02	0.77	0.97	0.87	0.08	0.88	0.9	1.1	0.24	3
Trichloroethene	0.03	1.64	1.79	1.7	0.06	1.8	1.7	1.1	0.14	13
Methyl methacrylate	0.03	MDL	MDL	-	-	-	-	-	MDL	-
Toluene	0.02	13.19	81.8	36.8	31.9	15.4	25.5	2.3	2.6	6
Tetrachloroethene	0.03	0.20	0.23	0.21	0.01	0.21	0.2	1.1	0.17	1
Ethylbenzene	0.01	1.4	2.7	1.9	0.58	1.7	1.8	1.3	0.60	3
p-Xylene	0.02	3.25	5.5	4.2	0.94	3.8	4.1	1.2	1.1	4
m-Xylene	0.01	1.1	1.8	1.4	0.31	1.2	1.3	1.2	0.43	3
Styrene	0.03	4.0	9.9	6.3	2.5	5.2	5.9	1.5	0.06	84
o-Xylene	0.04	2.5	3.5	2.9	0.38	2.9	2.9	1.1	0.62	5
R(-)3,7-Dimethyl-1,6-octadiene	0.03	MDL	MDL	-	-	-	-	-	MDL	-
α-Pinene	0.03	10.5	35.7	19.9	11.2	13.8	17.3	1.7	0.26	53
β-Pinene	0.03	6.9	9.5	7.9	1.1	7.4	7.8	1.2	0.14	52
d-Limonene	0.03	4.8	14.8	8.5	4.5	5.8	7.4	1.6	0.11	53
Eucalyptol	0.03	0.60	1.1	0.86	0.20	0.87	0.8	1.3	0.05	16
2-Methyl-6-methylene-2-octanol	0.03	MDL	-	-	-	-	-	-	MDL	-
Phenylethyl alcohol	0.03	MDL	-	-	-	-	-	-	MDL	-
Phenylmethyl acetate	0.03	MDL	-	-	-	-	-	-	MDL	-
a-Methylbenzyl acetate	0.03	MDL	-	-	-	-	-	-	MDL	-
Naphthalene	0.03	1.0	1.5	1.3	0.18	1.4	1.3	1.2	0.04	35
Benzothiazole	0.03	3.4	5.7	4.5	0.97	4.4	4.4	1.2	MDL	-
4-tert-Butylcyclohexyl acetate	0.03	MDL	-	-	-	-	-	-	MDL	-
Formaldehyde	0.03	13.5	25.9	17.8	5.8	13.8	16.9	1.4	1.2	12
Acetaldehyde	0.04	6.6	18.8	10.7	5.7	6.7	9.4	1.6	0.62	11
Acetone	0.07	36.4	86.2	53.0	23.5	36.5	48.6	1.5	1.6	22
Acrolein	0.01	MDL	-	-	-	-	-	-	MDL	-
Propionaldehyde	0.02	1.2	7.8	3.4	3.1	1.3	2.3	2.4	MDL	-
Crotonaldehyde	0.02	MDL	-	-	-	-	-	-	MDL	-
MEK	0.10	2.3	3.7	2.8	0.63	2.4	2.7	1.24	0.14	16
Methacrolein	0.02	MDL	0.41	0.19	0.16	0.15	0.1	3.9	MDL	-
Butyraldehyde	0.02	1.0	2.5	1.5	0.71	1.0	1.4	1.5	MDL	-
Benzaldehyde	0.04	1.6	2.5	1.9	0.42	1.6	1.9	1.2	0.043	38
Valeraldehyde	0.03	2.3	7.5	4.0	2.4	2.4	3.4	1.7	MDL	-
Glyoxal	0.01	0.18	0.23	0.20	0.02	0.19	0.2	1.1	0.08	2
m-Tolualdehyde	0.03	MDL	-	-	-	-	-	-	MDL	-
Methyl glyoxal	0.02	0.84	1.4	1.1	0.22	1.0	1.1	1.2	0.6	2
Hexaldehyde	0.04	8.9	27.6	15.3	8.7	9.4	13.2	1.7	0.043	214

Table S8. The geometric mean concentrations, and sum of GM concentrations (i.e., ΣFBTX) of hazardous air pollutants.

Compound	**Campus Services (μg/m^3)**	**Restrooms (μg/m^3)**	**Renovated Offices (μg/m^3)**	**Green building rooms (μg/m^3)**	**Meeting Areas (μg/m^3)**	**Classrooms (μg/m^3)**	**Outdoors (μg/m^3)**
Formaldehyde	7.2	6.2	14.2	13.6	4.5	16.9	1.1
Benzene	0.5	0.4	2.2	0.2	0.2	0.9	0.17
Toluene	2.8	5.4	13.9	6.5	1.7	25.5	1.1
p-Xylene	1.2	1.2	7.2	1.5	0.7	4.1	0.43
m-Xylene	0.5	0.4	2.2	0.5	0.3	1.3	0.17
o-Xylene	0.8	0.7	3.1	0.7	0.7	2.9	0.24
ΣFBTX	13.0	14.3	42.8	23.0	8.1	51.6	3.2