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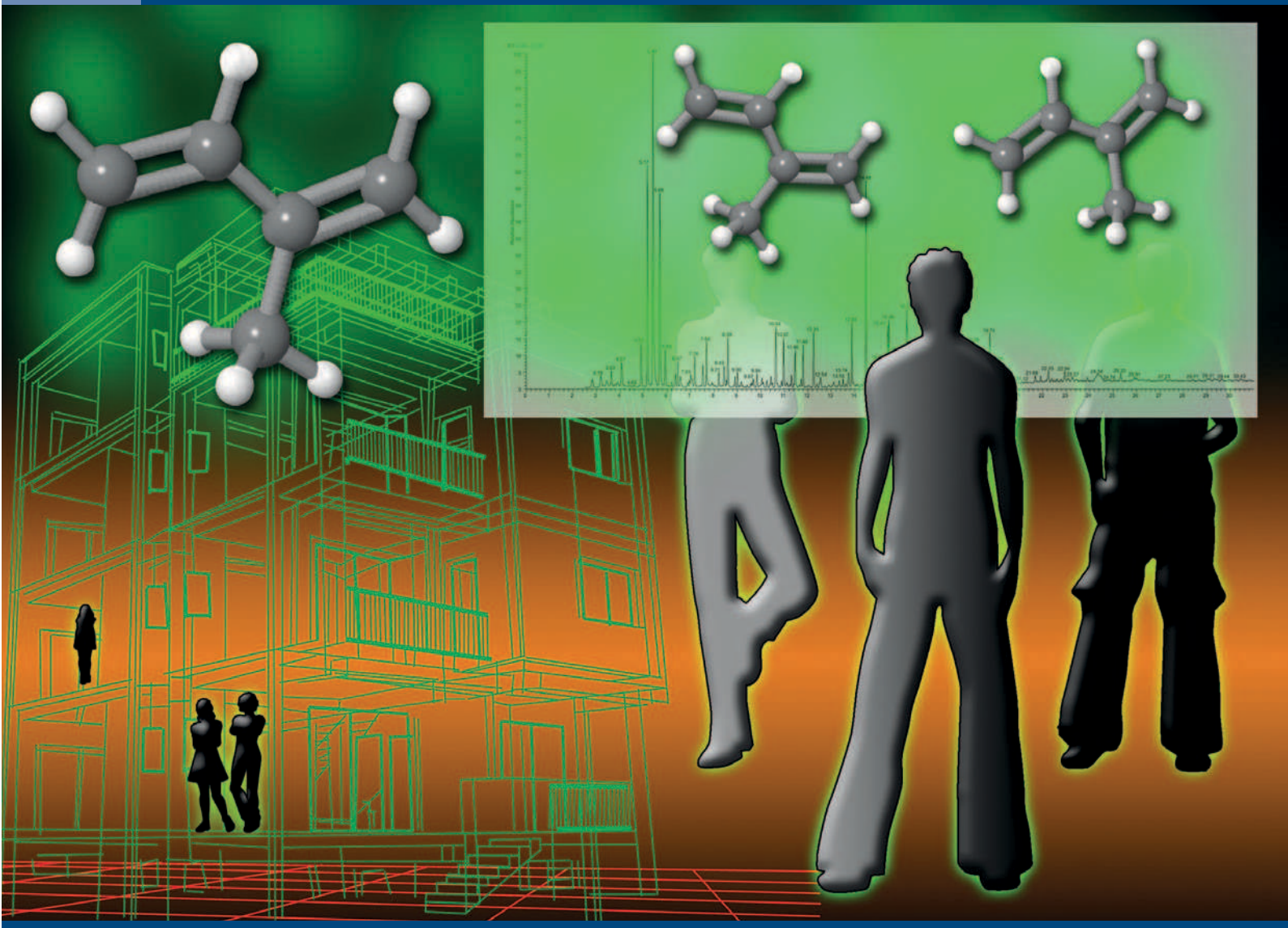

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Research Article

Detection of volatile organic compounds indicative of human presence in the air

Volatile organic compounds were collected and analyzed from a variety of indoor and outdoor air samples to test whether human-derived compounds can be readily detected in the air and if they can be associated with human occupancy or presence. Compounds were captured with thermal desorption tubes and then analyzed by gas chromatography with mass spectrometry. Isoprene, a major volatile organic compound in exhaled breath, was shown to be the best indicator of human presence. Acetone, another major breath-borne compound, was higher in unoccupied or minimally occupied areas than in human-occupied areas, indicating that its majority may be derived from exogenous sources. The association of endogenous skin-derived compounds with human occupancy was not significant. In contrast, numerous compounds that are found in foods and consumer products were detected at elevated levels in the occupied areas. Our results revealed that isoprene and many exogenous volatile organic compounds consumed by humans are emitted at levels sufficient for detection in the air, which may be indicative of human presence.

Keywords: Gas chromatography with mass spectrometry / Human emission / Isoprene / Volatile organic compounds
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1 Introduction

Detection of human scent, while currently performed in most cases by canines due to their extraordinary sense of smell, has frequently been used in various security applications, criminal investigations, and rescue operations to locate criminals, missing persons, disaster victims, and/or cadaver recovery (reviewed in [1]). Although the use of working dogs for tracking human scent is valuable, it is laborious and costly. Dogs can easily become stressed under various environmental conditions and their effective operational time is physically limited. Additionally, working dogs are often tasked with operating in high-risk situations in performance of their duties to help locate persons affected by natural and man-made disasters. Still, the chemical nature and identities of the human odor cues perceived by dogs remain unknown. There may be markers indicative of human presence that could be detected at lower levels using alternative detection paradigms. Therefore, gaining a better understanding of the unique signatures produced by human occupancy could potentially lead to versatile technologies which do not experience the same limitations as animal-based detection.

Previous studies have identified numerous volatile organic compounds (VOCs) released from different parts of the human body, many of which are odorous compounds. De Lacy Costello et al. [2] compiled a list of VOCs detected in exhaled breath, saliva, blood, milk, skin secretions, urine, and feces from various studies that have sought to profile the volatile fraction of human body fluids. For example, a total of 872 and 532 VOCs have been detected from the expired breath and skin, respectively. Since most of these studies have captured VOCs from body fluid samples in a closed container (or bag), from skin surfaces, or employed extractions with organic solvents before analysis, many of the VOCs reported are likely not detected in the ambient air due to dilution.

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Abbreviations: 6-MHO, 6-methyl-5-hepten-2-one; **FDR**, false discovery rate; **LASSO**, least absolute shrinkage and selection operator; **MeDDL**, metabolite differentiation and discovery lab; **TD**, thermal desorption; **TIC**, total ion chromatogram; **VOC**, volatile organic compound

However, some have been found to be emitted from human bodies at levels sufficient enough to be detected in the air, and these may be indicative of human occupancy or presence. The major VOCs detected in exhaled breath include isoprene, acetone, and ethanol [3] and their presence in occupied buildings has been previously reported [4]. De Blas et al. [5] reported that the indoor isoprene concentration was higher compared to the outdoor concentration. It was determined that the highest levels were observed on weekdays when the building was occupied, suggesting that the major source of isoprene detected was likely from the air exhaled by the occupants. Straight-chain aldehydes and 6-methyl-5-hepten-2-one (6-MHO), reaction products of skin lipids with ozone [6,7], were detected in a simulated aircraft environment [8] as well as inside commercial flights during operation at ppb levels [9]. The ozone level determined in the aircrafts was strongly associated with the concentrations of 6-MHO, octanal, nonanal, and decanal and occupancy was significantly correlated with the 6-MHO level.

Exogenous VOCs derived from consumers products which people often apply to their skin, nails, or hair have been detected in the ambient air. Shields et al. [10] measured VOCs from the indoors and outdoors of 70 different buildings, and compared the concentrations in sparsely vs. densely occupied buildings to determine the influence of human occupancy on indoor VOCs. Siloxanes (octamethylcyclotetrasiloxane and decamethylcyclopentasiloxane; derived most likely from deodorants and antiperspirants), *n*-alkanes (C_{12}–C_{16}: petrolatum widely used in skin care products), limonene (a common scent material for soaps, shampoo, etc.), and, to a lesser degree, tetrachloroethylene (derived from dry cleaned clothing) were present in higher levels in the buildings with more occupants. Hodgson et al. [4] analyzed VOCs inside and outside a call center office building over multiple days, and reported that decamethylcyclopentasiloxane, 2-ethyl-1-hexanol (derived from plastic materials), 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate (derived from nail care products), and formaldehyde (derived from nail care products, lotions, shampoos, etc. [11, 12]) were associated with human occupancy.

The detection of human-derived VOCs from outdoor environments has been demonstrated as well. Veres et al. [13] measured carbon dioxide, ozone, and VOCs in a stadium during a football game where more than 30 000 people attended. Carbon dioxide increased upon arrival of the attendees and then decreased as they left, indicating that CO_2 was directly associated with the respiration of the attendees. Ozone started to decrease whereas 6-MHO and decanal (reaction products of skin lipids with ozone mentioned above) increased as the attendees entered the stadium. Upon their departure, this pattern was reversed. This result indicated that ozone was consumed by the attendees and reacted with skin lipids, producing the oxidation products. In addition, increased levels of isoprene, acetone, ethanol, acetonitrile, and diacetyl were observed during the game. The increase of acetone and isoprene was largely due to the respiration of the attendees. Veres et al. [13] suggested that the ethanol increase was mainly due to the exhalation of alcoholic beverages consumed by humans at the stadium. Acetonitrile and diacetyl were considered as VOCs derived from cigarette smoke [14, 15].

While the studies mentioned above focused on the impact of VOCs associated with human presence and activity on indoor or outdoor air qualities, several studies determined gases and VOCs supposedly released from human(s) confined in a chamber to test whether these compounds could be used to detect human presence. Statheropoulos et al. [16] suggested use of VOCs detected from the exhaled breath, blood, and urine in search of human presence. However, their later studies focused heavily on the use of urine-derived VOCs for detecting human presence (reviewed in [17]). The use of urinary VOCs for this purpose is limited since the VOCs are not directly emitted from humans unless they urinated. Rather, the use of VOCs emitted from breath, skin, and hair is a more practical approach for detecting human presence. Huo et al. [18] analyzed gases and VOCs released from subjects (total of eight participants) who lay in a chamber for 6 h, and reported that carbon dioxide, ammonia, and acetone were indicators of human presence. While CO_2 is an important indicator of human presence due to respiration [4, 19], its use for searching for human presence may be limited since it is altered in the presence of plants and other animals or derived from sources such as combustion, fires, etc. Vautz et al. [20] later reanalyzed the data generated by Huo et al. [18], and identified seven VOCs (2-ethyl-1-hexanol, acetophenone, benzaldehyde, decanal, limonene, octanal, and nonanal) whose concentrations were correlated with the concentration of CO_2 emitted from the subjects, suggesting that these compounds might be considered as signs of life. However, these VOCs are typical VOCs detected in the air and may not be specific to humans. The detection of human-derived VOCs such as isoprene, 6-MHO, and geranyl acetone [3, 7] was not demonstrated, which is likely due to the minimal sample collection volume (33–50 mL) and/or the detection sensitivity of the analytical instrumentation. This might also reflect low ozone level and thus lack of a catalyst for the oxidative reactions. Giannoukos et al. [21] monitored compounds in a room where subjects (two in total) were confined for 6 h, and reported that the levels of water vapor, four inorganic gases (NH_3, CO, CO_2, and O_2), and 17 VOCs increased compared to levels determined before the subject entered the room. Notably, acetone, isoprene, propionic acid, and lactic acid were the major VOCs that were considered to be released from the human subjects.

As discussed above, only a handful of studies have determined human-derived VOCs in the air. Moreover, each of the previous studies monitored a small set of human-derived VOCs (either endogenous or exogenous, or an indistinguishable mixture of both) and consequently only a few compounds (e.g. isoprene and acetone derived most likely from the exhaled breath) have consistently been demonstrated throughout the studies. To the best of our knowledge, no comprehensive investigation for human-derived VOCs in the air is available. In this study, examining a variety of indoor and outdoor air samples, we determined a subset of human-derived VOCs previously reported as well

as a set of newly discovered VOCs which were demonstrated to be associated with human presence or occupancy.

2 Materials and methods

2.1 Air sampling sites

Air sampling was performed at Wright-Patterson AFB, OH, USA. Seven locations were chosen for the sampling. Three sampling sites were office areas with human occupancy, whereas other sampling areas had no or minimum occupancy. A summary of the information for the sampling sites is located in Table 1. The outside temperatures on April 24 and May 13 in 2014 were 14 and 28°C, respectively. The relative humidity was 60% on both sampling dates. The indoor temperature at the sampling sites was maintained at 21°C with approximately 40% relative humidity. The air change rate in each sampling area was approximately two per hour.

2.2 Thermal desorption sorbent tubes

Tenax® TA stainless-steel thermal desorption (TD) tubes were purchased from Markes International (Llantrisant, UK) for this study. All tubes were conditioned before use based on the manufacturer's instruction.

2.3 Air sampling

Three GilAir Plus pumps purchased from Sensidyne (St. Petersburg, FL, USA) were used for sampling air from each location. A Tenax sorbent tube was connected to each pump and an air sample was collected for 5 min at 200 mL/min. The volume of air per tube collected was 1 L. A total of three tubes were collected from each sampling site. The pumps were calibrated with a Bios Defender 510 primary flow calibrator (Brandt Instruments, Prairieville, LA, USA) before use.

2.4 Analysis of volatile organic compounds from sorbent tubes

Each sorbent tube was analyzed by a TD-100 thermal desorber (Markes International, South Wales, UK) coupled to a Trace GC Ultra-ISQ single quadrupole GC–MS (Thermo Scientific, Waltham, MA, USA). The TD-100 parameters are as follows: tube desorption temp: 310°C; tube desorption time: 10 min; flow path temp: 160°C; trap flow: 50 mL/min; pre-trap fire purge time: 1 min; trap low temp: 25°C; trap high temp: 315°C for 5 min; trap heating rate: 40°C/s (MAX). The entire VOCs in the sorbent tube was transferred to the cold trap, and then split and delivered to GC (outlet split; at 3.5:1). A 0.8 L cylinder containing gaseous internal standards (bromochloromethane, 1,4-difluorobenzene, chlorobenzene-d_5, and 4-bromofluorobenzene; 1 ppm each; Linde Gas North America, Stewartsville, NJ, USA) was connected to the TD-100 and 1 μL of the standards were applied to the sampling end of a sorbent tube before the desorption of the tube. An Rxi® -624Sil MS column (60 m x 0.32 mm Id x 1.80 μm df; Restek, Bellefonte, PA, USA) was used for GC separations. The GC temperature program started at 40°C for 1 min, and increased at 10°C/min to 240°C where the final temperature was held for 20 min. The total GC analysis time was 41 min. Helium carrier gas was used at a constant flow of 2 mL/min. The mass spectrometer was operated in the electron impact ionization mode at 70 eV. The transfer line temperature was 230°C and the ion source temperature was 275°C. The mass scan range was 35–300 m/z with a scan time of 0.154 s.

2.5 Data analysis

A total of 20 total ion chromatograms (TICs) were obtained: 3 Main Fl (Bldg A), 3 Basement (Bldg A), 3 Second Fl (Bldg A), 3 Outside (Bldg A), 3 Office A (Bldg B), 3 Office B (Bldg B), and 2 Hallway (Bldg B). The resulting chromatograms and mass spectra were then analyzed by using the Metabolite Differentiation and Discovery Lab (MeDDL [22]; http://meddl.cs.wright.edu/doku.php), a novel metabolite profiling software solution adapted for GC–MS data. Peaks (each peak is defined here as a single ion or measured mass/charge (m/z) at a given retention time) were registered and aligned in both time and mass. The registered and aligned peaks were then time-binned to select a representative peak (ion) for each compound since a single compound is generally composed of multiple peaks in GC–MS data (see Ref. [23] for details). It should be noted that following the time-binning, some compounds were filtered out.

The total intensity distribution was observed to vary across samples. Consequently, the data were normalized to a common intensity scale since this variance was likely related to sampling methodology or other unknown collection factors. In this application, the matched peak set intensity was normalized to a common scale using average sample quantiles, which is commonly referred to as quantile normalization in gene-expression microarray studies [24]. An unpaired t-test assuming unequal population variance was applied to all peaks. Rather than comparing our observed statistic to a theoretical null distribution, we performed 10 000 permutations of sample randomization to measure type-I error. The Benjamini–Hochberg linear step up procedure was then applied to permutation derived p-value to estimate a false discovery rate (FDR) for each time-binned peak.

Additionally, isoprene was used as a target variable to identify other VOCs indicative of human presence. Isoprene has previously been observed to be correlated with human presence as described above, and was the most differentiated peak in our study. Since human presence abundance is likely correlated with VOC concentrations, isoprene was used as an auxiliary human presence indicator so that more subtle VOC patterns could be elucidated. The least absolute

Table 1. Air sampling sites and descriptions

Sampling site	Site description	Sampling date	# of air samples collected
Outside (Bldg A)	Outside	April 24, 2014	3
Basement (Bldg A)	No human occupancy	April 24, 2014	3
Main Fl (Bldg A)	Hallway and conference rooms	April 24, 2014	3
Second Fl (Bldg A)	Office	April 24, 2014	3
Office A (Bldg B)	Office	May 13, 2014	3
Office B (Bldg B)	Office	May 13, 2014	3
Hallway (Bldg B)	Hallway	May 13, 2014	2

shrinkage and selection operator (LASSO) regression, a technique commonly applied in machine learning domain to down-select features [25], was applied to screen for isoprene predictors that we argue are candidate human presence markers. The LASSO parameterization (i.e. regularization penalty) with lowest error, as estimated by tenfold cross validation, was taken to be the most appropriate model given available data, and hence, identified a parsimonious isoprene correlate set with highest predictive strength.

Matlab© Bioinformatics toolbox was used to normalize data, perform permutation based *t*-test, and calculate FDR, while Matlab Statistics Toolbox provided LASSO software implementation.

2.6 Compound identification

The endogenous compounds detected in the air samples (listed in Table 2) and phenylethyl alcohol, menthol, methyl salicylate, isopropanol, propylene glycol, ethanol, and linalool were identified by comparison with standard samples purchased from Sigma–Aldrich (St. Louis, MO, USA) for the retention times and mass spectra. Texanol was identified with the standard sample supplied by the Eastman Chemical Company (Kingsport, TN, USA). Hydroxycitronellol, 1-methoxy-2-propanol, 1-methylbutyl acetate, isocetane, butyl acetate, 1-(1-methoxypropan-2-yloxy)propan-2-yl acetate, and 1-(2-butoxylethoxy)ethanol were tentatively identified using the NIST11 mass spectral library.

3 Results and discussion

The air samples collected on Tenax TD tubes were analyzed by a TD-100 thermal desorber coupled to a Trace GC Ultra-ISQ single quadrupole GC–MS, and a total of 20 data files were obtained. Representative overlaid chromatograms obtained from an occupied sampling site and an unoccupied area are shown in Supporting Information Fig. S1, and the compounds identified are listed in Supporting Information Table S1. The GC–MS files were subsequently analyzed with MeDDL. A total of 10 454 peaks were registered and aligned. Following the application of the time-binning filter (see Section 2 for details), a minimum of 602 discrete chromatographic peaks were obtained. Their intensity values were then quantile normalized and log2 transformed. Normalization was performed to remove any experimentally induced variation and the log2 transformation was applied to induce Gaussian distribution behavior in the data (see Ref. [26] for details). Then, a permutation based unpaired *t*-test was performed with the intensities of the 602 peaks between sampling sites with occupancy (Second Fl [Bldg A], Office A [Bldg B], Office B [Bldg B]) and those with no or minimum occupancy (Outside [Bldg A], Main Fl [Bldg A], Basement [Bldg A], and Hallway [Bldg B]).

Eleven endogenous VOCs that have been reported to be derived from exhaled breath and/or skin [3, 7, 27] were detected in the air samples collected. Isoprene, a major VOC found in exhaled breath, differed quantitatively the most between the occupied areas and the unoccupied or minimally occupied areas among the endogenous VOCs with the highest statistical significance (Table 2). Isoprene in exhaled breath has been reported to increase with physical exercise, suggesting that it is upregulated with muscle use ([28] and references therein). Our finding that higher level of isoprene was detected in the occupied areas is consistent with the previous studies mentioned above [5, 28]. Acetone, another major breath-borne VOC, was detected higher in unoccupied or minimally occupied areas than in human-occupied areas, indicating that its majority may be derived from exogenous sources. Acetone is a common solvent and used in the chemical industry. Sources of acetone in indoor air include consumer products, adhesives, building materials, etc. [29–31]. The association of endogenous skin-derived VOCs (e.g. propionic acid, dimethyl sulfone, benzothiazole, nonanal, decanal, 6-MHO, and geranylacetone) with human occupancy was not significant (Table 2). Acetol (= hydroxyacetone or 1-hydroxy-2-propanone), a skin lipid oxidation product [7], exhibited a quantitative difference between locations with different occupancies (FDR = 0.0006; Table 2 and Fig. 1). However, it is also a known flavor component in coffee [32]. Based on the fact that acetol is not a major volatile constituent in human skin [27], its elevated level observed in the occupied areas was likely due to the consumption of coffee, although it is not clear whether the increase was due to the direct evaporation of acetol from coffee or the exhalation of the consumed acetol by humans.

Veres et al. [13] observed that carbon dioxide, a major breath component, was directly associated with the

Table 2. Endogenous volatile organic compounds derived from exhaled breath and/or skin that were detected in the air samples collected, and their association with human occupancy

Compound ID	RT[g] (min)	Quant ion[h]	*p*-value	FDR	log2_foldChange
Isoprene[a)]	5.23	67	0.000003	0.0003	−1.69
Acetone[b)]	5.46	43	0.000004	0.0003	1.12
Acetic acid[c)]	7.77	43	0.049413	0.1438	−0.94
Propionic acid[d)]	9.75	74	0.015095	0.0663	−0.41
Acetol (= 1-hydroxy-2-propanone)[e)]	13.51	43	0.000017	0.0006	−0.52
6-Methyl-5-hepten-2-one[f)]	15.07	43	0.156630	0.2956	−0.72
Dimethyl sulfone[d)]	15.43	79	0.108130	0.2420	−0.59
Nonanal[f)]	17.12	57	0.433370	0.5956	−0.31
Decanal[f)]	18.77	43	0.167240	0.3060	−0.55
Benzothiazole[d)]	19.86	135	0.113880	0.2474	−0.43
Geranylacetone[f)]	22.51	43	0.089048	0.2127	−0.71

a) Derived from exhaled breath.
b) Derived from exhaled breath; skin lipid oxidation product; also a common solvent.
c) Derived from exhaled breath and skin as well as from diets.
d) Derived from skin.
e) Skin lipid oxidation product; flavor component in coffee.
f) Skin lipid oxidation products.
g) Retention time.
h) *m/z* used for relative quantification.

Table 3. Volatile organic compounds correlated highly with isoprene

Compound ID	RT[a)] (min)	Quantion[b)]	Pearson r	LASSO Weights	log2_fold Change
Isoprene	5.23	67	NaN[c)]	NaN	−1.69
Hydroxycitronellol	16.52	59	0.8982	0.0000	−2.94
1-Methoxy-2-propanol	8.82	45	0.8885	0.0235	−2.10
Phenylethyl alcohol	17.96	91	0.8757	0.1897	−1.07
1-Methylbutyl acetate	12.01	43	0.8539	0.0535	−1.71
Menthol	18.61	71	0.8448	0.1174	−2.10
Isocetane	20.21	57	0.8227	0.0000	−1.64
1-(1-Methoxypropan-2-yloxy)propan-2-yl acetate	18.05	59	0.7958	0.0000	−2.33
Texanol	25.20	71	0.7953	0.0000	−1.37
Methyl salicylate	19.05	120	0.7844	0.0000	−3.04
Isopropanol	5.53	45	0.7833	0.0000	−3.08
1-(2-Butoxylethoxy)ethanol	18.66	57	0.7766	0.0000	−1.15
Propylene glycol	11.11	45	0.7550	0.0000	−3.29
A terpene	15.96	93	0.7447	0.0000	−1.46
A siloxane	16.71	73	0.7371	0.0000	−0.91
Butyl acetate	11.35	43	0.7255	0.0000	−1.65
Acetol (= 1-hydroxy-2-propanone)	13.51	43	0.7203	0.0000	−0.52
Ethanol	4.96	45	0.7027	0.0000	−2.33
Linalool	16.99	43	0.7013	0.0000	−0.58

All compounds listed in the table have $p < 0.005$, FDR < 0.05 and Pearson FDR < 0.05.
a) Retention time.
b) *m/z* used for relative quantification.
c) Not a number; isoprene is used as a reference in this case.

respiration of the attendees in a football stadium, and assessed the relationship between CO_2 and VOCs detected in the stadium. The levels of ethanol, acetone, and isoprene detected in the stadium were well correlated with that of carbon dioxide, suggesting that the source of these VOCs was exhaled breath [13]. In this study, however, we did not monitor CO_2 mainly because some sampling areas were close to biochemical laboratories where dry ice has often been used. Instead, we determined the correlation between the breath-borne isoprene and the remaining compounds to identify additional VOCs for human presence. First, Pearson correlation coefficients (*r*) were calculated. 182 out of the 601 time-binned

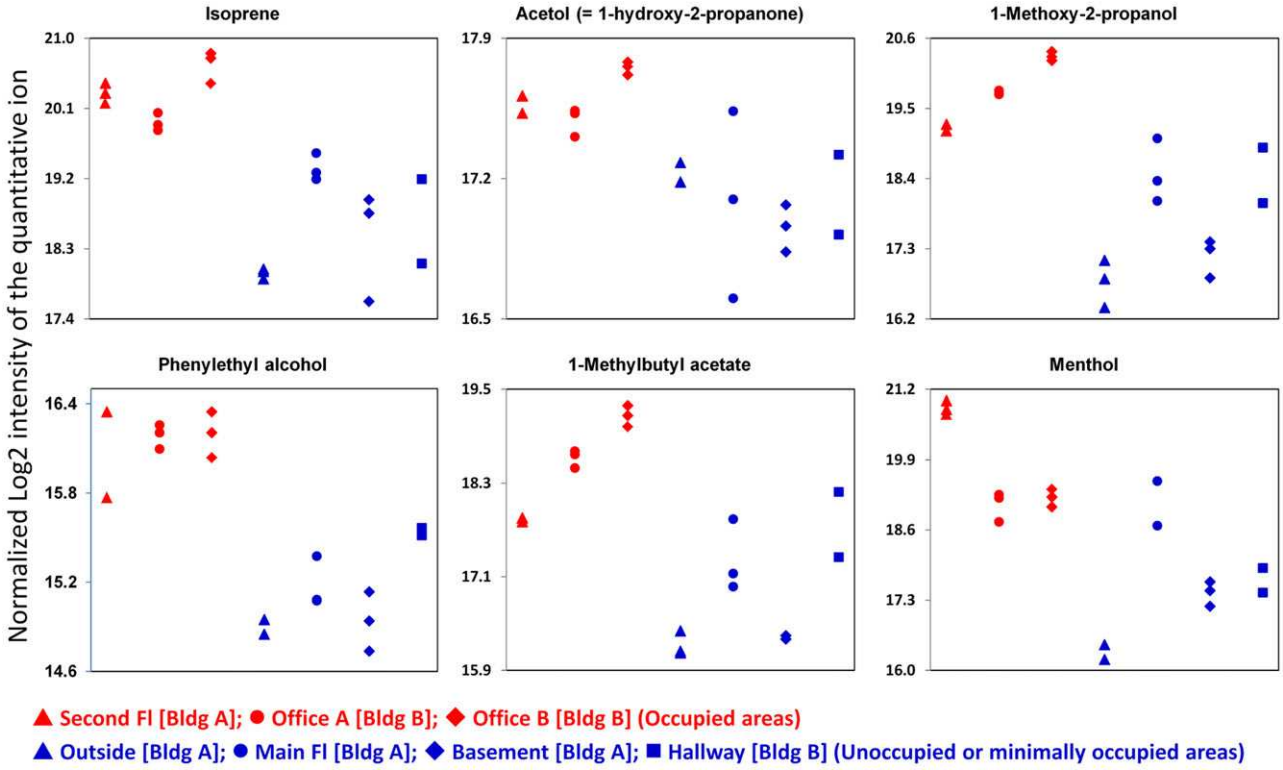

Figure 1. Selected volatile organic compounds that were detected at elevated levels in the air samples collected from human-occupied areas.

peaks were positively correlated with isoprene and 21 peaks had $r = 0.7$ or higher. The identified VOCs with $r > 0.7$ are listed in Table 3 (three peaks were filtered out: two were unidentified and one (*p*-cymene) had *p*-values > 0.05 in the permutation test and FDR). In addition, LASSO linear regression analysis was performed. Four compounds (1-methoxy-2-propanol, phenylethyl alcohol, 1-methylbutyl acetate, and menthol) were best fit for isoprene, and hence, had the most robust and parsimonious linear relationship with isoprene (Fig. 1 and Table 3). As listed in Table S2, the compounds correlated with isoprene are common ingredients used or found in foods, fragrances, and consumer products. These compounds are likely released during respiration or evaporate from skin or clothes. Additional exogenous VOCs that were correlated with isoprene but filtered out after the time-binning process were identified and listed in Table S3. The distributions in the levels of some representative VOCs over different sampling areas with different occupancies are illustrated in Fig. 1. Their concentrations are estimated to be in the low ppbv or high pptv range. This result is consistent with the previous study [27] that revealed a large contribution of exogenous VOCs to human skin volatile profiles.

While a small number of samples were analyzed in this study, we were able to identify statistically significant VOCs between occupied and non-occupied areas after correcting for multiple hypothesis testing. It is worth noting that the various occupied or unoccupied areas were pooled for comparison. Furthermore, the isoprene correlates were searched irrespective of condition tested. The association of isoprene with human occupancy or presence is not likely to be changed with additional sampling since it is an endogenous VOC derived from exhaled breath. On the other hand, the list of exogenous human-derived VOCs will be changed depending on human consumption of foods and consumer products. Therefore, monitoring both human-derived endogenous and exogenous VOCs as well as determination of their association is recommended for further studies with large sample size. Further studies would also be needed to determine exogenous VOCs commonly shared in human populations and those specific to certain populations with different diets, personal habits, cultures, religions, etc. We suggest that these exogenous VOCs may be used for detecting and tracing certain individuals or human populations.

In summary, our result showed that the breath-borne isoprene was the best indicator for human presence among other endogenous VOCs. Notably, none of the endogenous skin-derived VOCs detected were significantly correlated with human occupancy, which is likely due to their lower emission compared to that of isoprene. Instead, a number of exogenous VOCs found in foods or cosmetic and other consumer products were well correlated with human occupancy, indicating that the concentrations or emission rates of exogenous VOCs releases from skin may be higher than those of endogenous VOCs. We suggest that monitoring these exogenous VOCs in conjunction with isoprene would be useful for detecting human presence.

4 Conclusion

To test whether human-derived VOCs can be readily detected in the air and they can be associated with human occupancy or presence, VOCs were collected and analyzed from a variety of indoor and outdoor air samples. Isoprene, a major VOC found in the exhaled breath, was the best indicator of human presence among other endogenous VOCs. The association of endogenous skin-derived VOCs with human occupancy was not significant. In contrast, numerous compounds that are found in foods and consumer products were detected at elevated levels in the occupied areas. Our results revealed that isoprene and many exogenous VOCs consumed by humans are emitted at levels sufficient for detection in the air, which may be indicative of human occupancy or presence. Our study may lead to development of technologies for sensing the presence of humans by analyzing human-derived VOCs in the air.

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The authors have declared no conflict of interest.

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