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Wearable environmental monitor to quantify personal ambient volatile organic compound exposures

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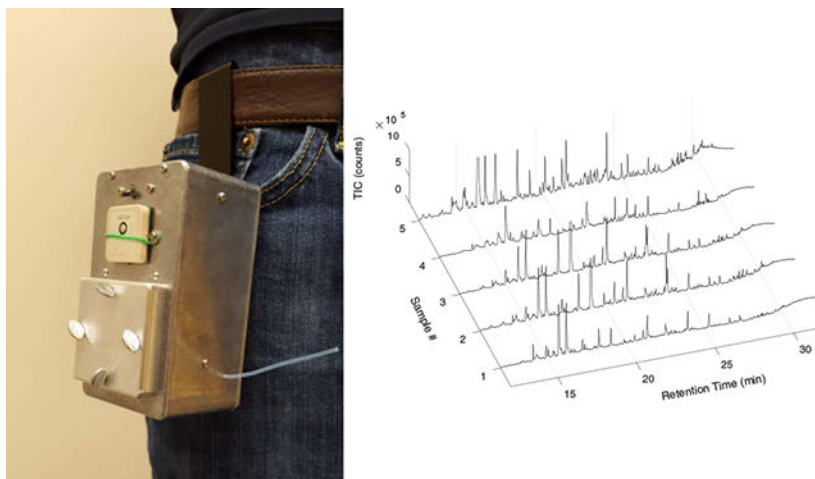
Abstract

Air pollution can cause acute and chronic health problems. It has many components, and one component of interest is volatile organic compounds (VOCs). While the outdoor environment may have regulations regarding exposure limits, the indoor environment is often unregulated and VOCs often appear in greater concentrations in the indoor environment. Therefore, it is equally critical to monitor both the indoor and outdoor environments for ambient chemical levels that an individual person is exposed to. While a number of different chemical detectors exist, most lack the ability to provide portable monitoring. We have developed a portable and wearable sampler that collects environmental VOCs in a person's immediate "exposure envelope" onto custom micro preconcentrator chips for later benchtop analysis. The system also records ambient temperature and humidity and the GPS location during sampling, and the chip cartridges can be used in sequence over time to complete a profile of individual chemical exposure over the course of hours/days/weeks/months. The system can be programmed to accumulate sample for various times with varying periodicity. We first tested our sampler in the laboratory by completing calibration curves and testing saturation times for various common chemicals. The sampler was also tested in the field by collecting both indoor and outdoor personal exposure samples. Additionally under IRB approval, a teenaged volunteer wore the sampler for 5 days during which it sampled periodically throughout a 12 hour period each day and the volunteer replaced the micro preconcentrator chip each day.

Graphical Abstract

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Keywords

wearable sensor; environmental monitor; environmental sampler; volatile organic compounds (VOCs); asthma

Air pollution can cause a number of both acute and chronic health problems¹. Air pollution has many components which vary from particulate matter (PM), heavy metals, persistent organic pollutants, and gaseous pollutants (eg various oxides, semi volatile and volatile organic compounds (VOCs) among others)¹⁻³. It is important to monitor these levels to identify when they pose a risk to human health and when action must be taken. Government agencies such as the American Environmental Protection Agency (EPA) and the European Directorate-General for Environment (DG ENV) regulate outdoor standards for some macro components of air such as ozone, sulfur dioxide, and nitrogen dioxide. However, they do not regulate the indoor environment where people now spend at least 80% of their time^{3, 4}. Indoor environments can have high levels of air pollution from sources such as cooking, smoking, air cleaning devices, building materials, biological air pollutants from pets and even radioactive pollutants such as radon from granite/gneiss flooring and decorations³. VOCs represent a form of air pollution that warrants further study as they are typically in greater concentrations in indoor environments⁵ where there often are no regulations regarding exposure limits. Additionally, high levels of VOCs are associated with health problems such as asthma^{6, 7} and other negative respiratory effects^{8, 9}. Monitoring the trace levels of VOCs in air is essential due to the possible risks they can cause towards humans health.

Several trace chemical detection techniques have emerged in the past decades to address this concern. The manufacturers of these chemical sensors have targeted lowering the production cost, miniaturizing sensors for portability and increasing detection capabilities¹⁰. Commercially available gas phase chemical sensors are usually either electrochemical, metal oxide semiconductor (MOS), light detecting such as infrared (IR), or photo ionization based detectors^{11, 12}. However each of these devices has pros and cons, and each has a narrow range of chemicals that can be detected. Compared to advanced analytical techniques, these

limitations have dampened the applicability of these detectors for personal VOC exposure monitoring. Traditional analytical techniques such as gas chromatography (GC) and mass spectrometry (MS) provide superior detection limits, chemical specificity and a wider range of chemicals detected over those other sensors. However, the high manufacturing and operating costs as well as the large size and weight of GC-MS systems are major obstacles for mobile air quality monitoring applications.

Regardless of chemical sensor type, the low levels of VOCs present in air make it challenging to detect air pollutant VOCs without the use of proper sampling techniques. Often, chemical analysis includes a preconcentration step, in which a device traps (collects) and concentrates VOCs from air samples over a desired duration to achieve improved limits of detection (LOD)^{13, 14}. Custom fabricated preconcentrator chips are versatile, as they can be married to microelectromechanical (MEMS)-based chemical sensors for a completely mobile detection system, or preconcentrators can be returned to the laboratory for benchtop analysis, such as GC-MS. Such preconcentrators have been tested for different applications in the past^{15–17}. However, no study has been conducted to use a gas preconcentrator in a handheld or wearable device to trap VOCs directly in the personal user environment.

In this work, we report a portable and wearable custom-built environmental sampler that contains a preconcentrator chip. Design emphasis was placed on a lightweight, wearable sampler to collect the VOCs exposed to the wearing user. The sampler is programmable, allowing adjustments to sampling time and flow rate. To collect VOC samples, the device uses our previously described micro preconcentrator (μ PC) chips, which can easily be replaced by users to collect multiple samples in a single exposure time period¹⁸. Samples in our study were returned to the laboratory for GC-MS analysis, but the sampler could be married to mobile chemical sensing platforms for real-time analysis in the future.

Material and Methods

Microfabricated preconcentrator chip (μ PC)

We used a previously published microfabricated sorbent chip¹⁸ in our newly described wearable system. Briefly, a chip is created using traditional photolithography and etching into a glass substrate. Resistive heaters are patterned onto the back side of the device allowing for rapid heating and desorption of VOCs. Tenax TA sorbent (Sigma-Aldrich, St. Louis, MO) is packed into the chip, which allows for broad spectrum sampling and quantification of many VOCs of interest. The chip can be tailored with other sorbents if specific chemical sampling is desired, which was outside the scope of this current work.

Sampler engineering design and specifications

We designed an environmental sampler light enough to be worn with micro gas preconcentrator chips that can be easily swapped for multiple sample collections and be programmed for varying sample durations and flow rates.

The sampler is housed in a modified aluminum case (Part CN-5704, BUD Industries, Willoughby, Ohio) (Figure 1). A custom aluminum-fixture houses the microfabricated chip. The fixture consists of top and bottom halves that are held together with 4× 6–32

thumbscrews that enable easy and rapid opening and closing. The top half has a 2.54 cm (1") cutout to align the microfabricated chip that rests on 2× 006 PTFE O-rings (Part 9559K11, McMaster-Carr Supply Company, Elmhurst, IL). The bottom half attaches to the system housing and has two spring-loaded custom PTFE transfer lines that make contact with the microfabricated chip via 006 Viton® O-rings (Part 1284N106, McMaster-Carr Supply Company, Elmhurst, IL). The spring-loaded nature of the transfer lines allows them to adjust to the microfabricated chip, which creates an airtight seal on the inlet and outlet of the chip while also prevent excessive pressure on the chip that could shatter it. Both transfer lines connect to 1.59 mm (1/16") OD PTFE tubing via 1.59 mm (1/16") NPT to 1.59 mm (1/16") compression fitting adapters (Part 5182K834, McMaster-Carr Supply Company, Elmhurst IL). While the inlet line is directly exposed to the environmental air, the outlet line connects to a 10 micron filter (Part CEF1F, Valco Instruments Co. Inc, Houston, TX) to remove any potential particulate that might clog the sampling pump (Part number NMP03 B3, KNF Neuberger, Inc, Trenton, NJ). The end of the filter connects to the sampling pump via 238 mm (3/32") ID silicone tubing through use of a 10–32 O-ring lined tubing adapter (Part 4406T12, McMaster-Carr Supply Company, Elmhurst IL).

The system is controlled by an Adafruit Feather microcontroller with built in microSD card slot (Part 328, Adafruit Industries, LLC, New York, NY) and is powered by a 3.7 V, 2500 mAH rechargeable lithium ion polymer battery (Part 328, Adafruit Industries, LLC, New York, NY). GPS data is collected via a GPS antenna (Part AP.25F.07.0078A, Taoglass, Enniscorthy, Ireland) and the Adafruit Ultimate GPS FeatherWing (Part 3133, Adafruit Industries, LLC, New York, NY). Additionally, there is a custom PCB that connects the microcontroller to the sampling pump motor driver (which came with the pump) and temperature and humidity sensor (Part HIH8121–021-001, Honeywell, Morris Plains, NJ) to collect ambient conditions. A belt clip is attached to the housing to allow for the device to be worn during operation.

The microcontroller records the data to the SD card, communicates with the GPS and temperature and humidity sensor and controls the sampling pump. With the sampling pump operating at a 50% duty cycle, the system consumes ~64 mA of current and reduces to ~48 mA when the sampling pump is off. With the current battery, the device is estimated operate between 39 and 52 h per charge. The Adafruit feather has built in battery charging circuitry so the battery can be charged via any USB connection such as with a computer or wall outlet.

Device operation

The environmental sampler can be programmed to operate in a variety of different modes. For this study the sampler updates the GPS, temperature and humidity readings every 10 sec and only saves this data to the SD card during sampling. The sampling flow rate is set by the duty cycle of the pulse width modulation (PWM) signal sent to the motor driver board, which was set to a 50% duty cycle for a sampling flow of ~80 mL/min, verified using an electronic flow meter (ProFLOW 6000, Restek Corporation, Bellefonte, PA)

The device sampling time and rate are easily adjusted in the code and can be set to either sample periodically throughout the day or for a single duration. The sampler can be

programmed in the Arduino IDE which enables quick and easy reprogramming of the device.

Laboratory-based assessment

To verify the sampler performance, a series of tests was first conducted inside the laboratory. The sampling inlet of the environmental sampler was connected to 3 L Tedlar® bags (Part 30291-U, Sigma Aldrich, St. Louis, MO). The Tedlar® sampling bags were prepared with varying concentrations of chemical standards, obtained from typical commercial vendors, diluted in air. With a volume of 3 L, multiple samples could be taken from the same bag, reducing error from sample preparation. Sampling times, sample concentrations and VOCs varied by test (see Results and Discussion).

Environmental sampling

The sampler was used by laboratory researchers in settings to mimic expected use, including samples taken around the UC Davis campus and in researchers' homes. Sampling time varied, including tests of letting the sampler run for 1 h nonstop, or for several minutes each hour over the course of 8–12 h.

Under IRB approval by the University of California, Davis campus (IRB# 1048328), the sampler was given to a 17 year old high school student volunteer. The student was given instructions on how to change the preconcentrator chips in the sampler and was asked to change the chip once a day for 5 d. A total of 5 samples were collected from this participant. During each sample, the sampler engaged for 10 min each hour for 12 h during the day (no sample collected overnight).

Desorption and GC-MS Analysis

After sample collection, the μ PCs were removed from the environmental sampler and loaded onto a custom built test fixture connected to the mass spectrometer, previously described¹⁸. Briefly, an aluminum fixture was fabricated to hold and heat the chip to 260 °C for a total desorption time of 15 min. A flow of 25 mL/min of helium carried desorbed VOCs from the μ PC through a borosilicate transfer line and into the inlet of a GC-MS (Varian 3800 GC with 4000 ion trap MS). The inlet was set to splitless mode at 235 °C. After desorption, the column (a VF-5ms 30 m x 0.25 mm x 0.25 μ m, Agilent Technologies Inc., Santa Clara, CA), initially at 40 °C, heated at 10 °C/min to 170 °C, then heated at 30 °C/min to 250 °C, holding for 6 min. Helium flow was set to constant flow (1 mL/min). The mass spectrometer scanned from 35 to 249 m/z. Data files were deconvoluted using AMDIS (Version 2.71, NIST.gov) and aligned using Agilent's Genespring (Version B.14.9). Putative identification of compounds was made by comparison of extracted mass spectra to the NIST '14 MS database. Calibration curves were built to quantify the grams of VOCs retained onto the μ PC chip during sampling. Curves contained triplicates at four concentration levels. Liquid solutions were prepared of the target analytes dissolved in methanol with 0.6 μ L injected directly into the GC-MS. Pure standards were of ACS Reagent grade and obtained from Sigma-Aldrich.

Results and Discussion

Fabrication of the sampler

Components and photographs of the wearable sampler are presented (Figure 1). Examples of GPS, temperature and humidity data are shown (Figure 2). Although the GPS is programmed to acquire a signal every 10 sec, this time occasionally varies. This has a minor effect for the timing of sample collection and increases the power usage slightly. Furthermore, while the sampler is designed for use in indoor and outdoor environments, the GPS signal is too poor for indoor location updates. However, the system stores the last updated location and will record it until the GPS updates again. The system also records whether or not the sampler is receiving a GPS signal.

We found that the sampler could be machined and constructed in less than 16 h with a material cost around \$400 USD. Almost half of the material cost came from the pump. Per the manufacturer, the pump produces less than 40 dB of noise, meaning it could be heard in a quiet room but would not be a loud disruption. In the sampler, the pump is encased in the aluminum fixture, muffling any noise. We found that the pump was very quiet and could barely be heard in typical use. The device weighed just under 400 g and could fit comfortably attached to the belt of a user. Ways to further reduce the weight include: custom PCBs in place of the commercial microcontroller and GPS; using a custom plastic outer case.

Laboratory-based benchmarking

Benchmarking of the micro preconcentrator chips has been previously described.¹⁸ The work herein focuses on performance of the wearable environmental sampler.

We first present evidence that the sampler successfully and reproducibly enables the μ PC chip to collect a VOC sample. The sampler was set a sample time of 10 min and a calibration curve was produced of four chemicals (hexane, heptane, 2-pentanone and 2-hexanone) ranging from 300 ppb to 5 ppm (Figure 3, A). As expected, the sampler showed a linear increase of signal with an increase in chemical concentration. R^2 values ranged from 0.958–0.999. Two samples were collected per concentration and the relative standard deviation ranged from 7–11%.

We continued to collect samples of increasing concentration to profile the limit of linearity for this particular sampling protocol and sorbent. This is not a limitation of the environmental sampler but instead represents saturation of the sorbent within the μ PC, where an increase in sample concentration would no longer lead to an increase in signal response. We sampled up to 100 ppm (Figure 3, B). Above 10 ppm, these four chemicals showed evidence of sorbent saturation for 10 min of sample time: signal increases no longer maintained a linear relationship to increases in sampling concentration. Based on this data, 10 min of sampling time might be best used in environments where VOCs are present in less than 10 ppm. This is largely contingent on the VOCs of interest, which is further discussed below.

In addition to varying concentration, we also varied sampling time (Figure 4). There was a steady increase of signal response with longer sampling times from 10 to 60 min for hexane, 2-pentanone and 2-hexanone, and a steady increase from 10 to 90 min for heptane. After these ranges, signals decreased in intensity, suggesting saturation of the preconcentrator sorbent trap inside the sampler. Based on this experiment, a sampling time of less than 60 min might be appropriate in an environment with VOCs around a concentration of 100 ppb.

We intended to build a sampler that would be worn by a person for hours at a time and provide a snapshot that was as complete as possible of their integrated VOC exposure. A variety of factors influence such detection goals. Within the sampler, VOC extraction is influenced by sampling time, flow rate and the preconcentrator chip (sorbent type and volume)¹⁹. Furthermore, without advanced knowledge of environmental conditions, it is even more challenging to define an optimized sampling protocol for general use. For instance, the sampler could be optimized to detect VOCs in the parts-per-billion range. If it is then used in situations with high concentrations, the preconcentrator chip would quickly saturate, reducing the quality of any quantitative assessment. The reverse could also occur. Additionally, the μ PC chip could be exchanged at a greater frequency which would improve the temporal and spatial resolution of exposure; however, this would put greater requirements on the user and could result in relatively clean samples in unpolluted environments. Finally, it is impossible to create a single method that is optimized to detect every known VOC, as parameter changes have varying effects on classes of compounds (higher flows might help preconcentrate some chemicals but impede collection of others¹⁸).

The above tests helped us establish initial sampling guidelines for untargeted analyses in unpredictable environments. Furthermore, we designed the sampler so that parameters can be easily changed or tailored for specific applications. The USB port on the sampler allows users to change these settings via the Adafruit Feather microcontroller. Should a researcher seek targeted analysis, such as user's exposure to benzene or toluene, sampler parameters such as sampling time, sampling flow rate and sorbent type can be tested, optimized and applied.

Environmental sampling

The environmental sampler was tested outside the lab environment as a handheld device initially by researchers in our group. Different sampling durations, sampling locations, and preconcentrator chips were used for qualitative assessments of the performance the sampler. Figure 5 shows three deployments of the samplers for a continuous sampling duration of one hour for each run. Samples were collected in a kitchen when the user was cooking (Figure 5, A), in an institutional hallway when the floors were being stripped and waxed (Figure 5, B), and in a room where a cat litter box was kept (Figure 5, C). Table 1 shows putative peak identities of sixteen example compounds, although more were detected.

Many of the putatively identified compounds are unsurprising given the context of the samples. The sample taken while the user was cooking included detection of limonene (a major constituent of citrus oils), ocimene (another common plant VOC) and cuminal (found in cumin). A sample taken in a hallway during a floor stripping/waxing yielded high abundances of benzyl alcohol (a common solvent for waxes) and ethylene glycol monohexyl

ether (found in safety data sheets of Butyl CELLOSOLVE™ Solvent, produced by the Dow Chemical Company²⁰). The cat litter box emitted common fragrance VOCs, such as limonene, eucalyptol and nerol, which can help mask odor.

To further test our sampler, we let a representative person of the general public (e.g. an unskilled naïve user) use the device for a week. Under IRB approval, a 17 year old high school student volunteered to test our sampler. The student carried the sampler for 12 h during the day and the sampler automatically collected a 10 min sample every 1 h. The student repeated this for 5 d. This test aided to monitor the experimental performance and get feedback of the user friendliness of the sampler during a lengthy test. The sampler did not interrupt any daily activities of the user, noise due to the sampling pump was negligible, and the student was able to carry the sampler and exchange the preconcentrator chips easily.

Raw GC-MS chromatograms of samples collected by the volunteer are shown (Figure 6). Table 2 summarizes the number of VOCs deconvoluted from each chromatogram and also the number of unique VOCs detected in a sample. The user did vary their location during the five days of sampler use, with some overlap in location between days, and varied the time spent in each location (GPS data withheld). It is thus expected that the number of captured VOCs reflected the similarities and differences of the user's environment.

Putative identifications of compounds were performed by comparison of obtained mass spectra to the NIST '14 database, providing a list of potential VOCs that the user was exposed to during their day to day activities, as collected by the environmental sampler. A number of naturally occurring VOCs were detected, such as benzeneacetaldehyde, β -myrcene and camphor. Other compounds were potentially artificial in origin, such as lilial and galaxolide, two synthetic fragrances that smell floral and musky, respectively, and likely originated from a scented cosmetic product. As captured by the sampler, the user was potentially exposed to hazardous VOCs, such as ethylbenzene, toluene, phenol and benzoyl chloride.

To demonstrate the quantitative capabilities of the sampler, we chose four VOCs that were present in all five of the participant's samples (limonene, menthol, decanal, 2-butyl-1-octanol). Limonene, menthol and decanal are all common fragrance compounds while 2-butyl-1-octanol is a known humectant. As these compounds appeared in each of this volunteer's samples, we suspect they may have derived from a personal product that was applied daily. We did not speculate further to the origins of these VOCs as the purpose of this was only to present quantification of chemicals.

A calibration curve was constructed to quantify the amount of each chemical retained onto the μ PC chip during deployment (Table 3). Limonene is seen as the most variable, with values ranging from 3.4 to 71.5 ng. Decanal was the most stable with a relative standard deviation of 34% across all five samples. Menthol was found in the lowest abundance (with a mean of 6.7 ng).

In future work, we hope to deploy these samplers in environments that potentially contain hazardous levels of certain VOCs. Locations would be areas such as California's Central Valley, which contains multiple sources of air pollution from industry, agriculture and

benzene treatment plants. Areas like Paradise, California could also benefit from VOC samplers, since the area is currently recovering from a massive wildfire that has the potential to expose residents to unsafe compounds as they rebuild their community. At these sites, samplers could be used to target dangerous compounds, such as benzene or toluene, and quantify exposure concentrations.

Conclusions

A portable and wearable environmental sampler was developed to collect VOCs of personal exposure onto a micro preconcentrator for benchtop analysis. The sample can be worn on a belt and records temperature, humidity, and GPS location during sampling. The system can be programmed using the Arduino IDE and can be set to sample once or periodically throughout the day. The system was assessed in the laboratory, in the field, and by a teenaged volunteer over 5 days under IRB approval.

The portability and programmable nature of the sampler provides an easy to use collection system that could find widespread use for personal exposure and environmental monitoring. The ease of exchanging micro preconcentrators enables individuals with no technical background to operate the sampler. We believe this device can be useful to collect personal exposure data for epidemiology studies, and may be especially relevant for asthma studies involving VOC triggers. Together with time-logged symptom diaries, our wearable exposure monitoring system can enable large scale studies in pediatric and teenage asthma populations (our target demographic). Future work could involve decreasing the sampler size and weight.

Associated Content

Software and device design information—The software code and PCB design specifications for our wearable environmental sampling device are available on GitHub. Please refer to Professor Cristina Davis' webpage for more information. This material is available as open source for research and personal use under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International Public License (<https://creativecommons.org/licenses/by-nc-nd/4.0/>). Commercial licensing may be available, and a license fee may be required. The Regents of the University of California own the copyrights to the software and PCB designs. Future published scientific manuscripts or reports using this software and/or hardware designs must cite this original publication (DOI: xxxx-xxx-xxxx-x).

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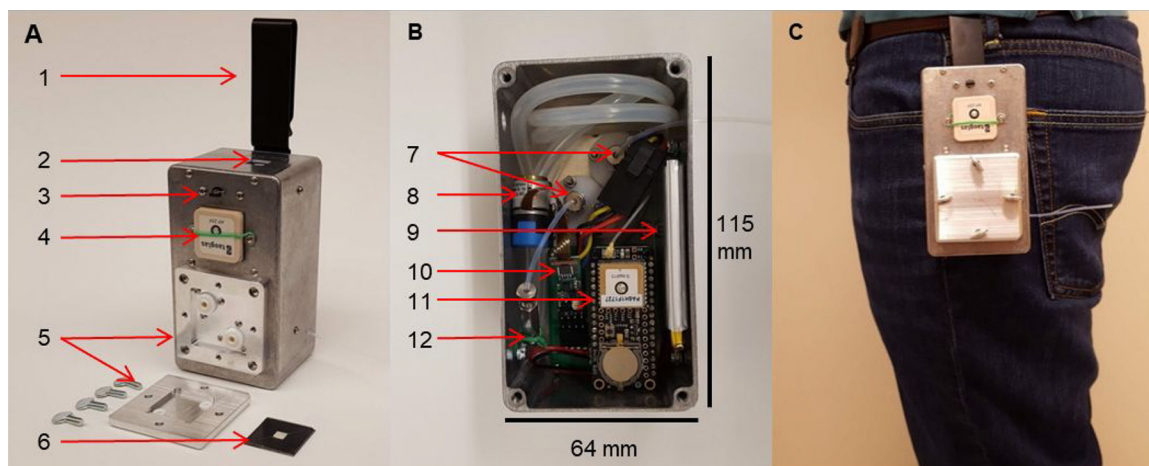


Figure 1:

The environmental sampler **A**: Device with micro gas preconcentrator (μ PC) housing open with components shown 1) belt clip, 2) USB port, 3) temperature and humidity sensor, 4) GPS antenna, 5) μ PC housing, 6) μ PC; **B**: Internal components 7) μ PC sample inlet/outlet, 8) sampling pump, 9) battery, 10) sample pump motor driver PCB, 11) GPS and microcontroller stacked PCBs, 12) filter; **C**: Sampler worn on a belt

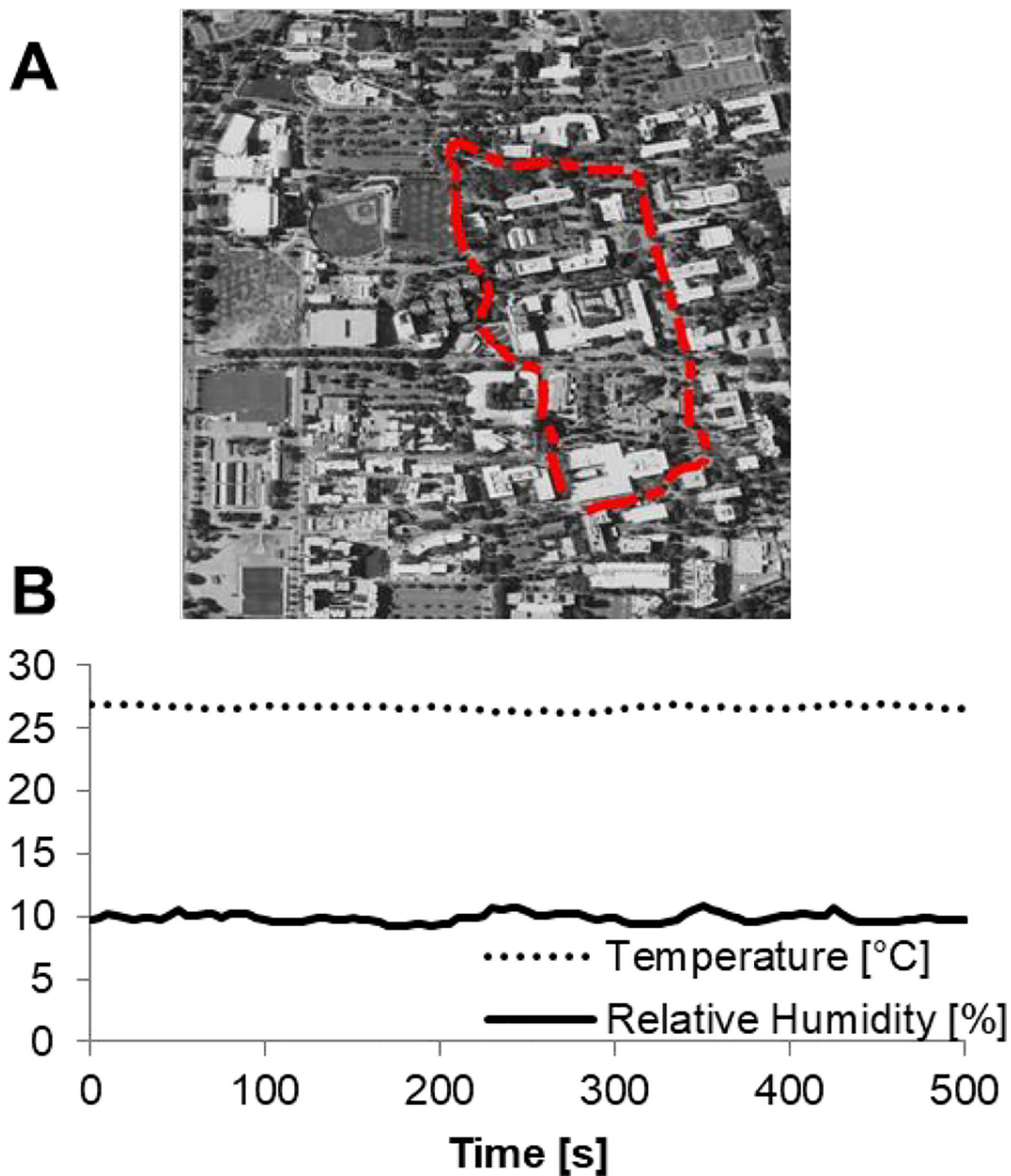


Figure 2. Example of A) GPS location data. The base image is attributed to the USDA Farm Production and Conservation – Business Center. B) Temperature and humidity data collected with the environmental sampler. These provide additional information about the environment the user was exposed to during VOC sample collection. This data was collected while riding a bicycle.

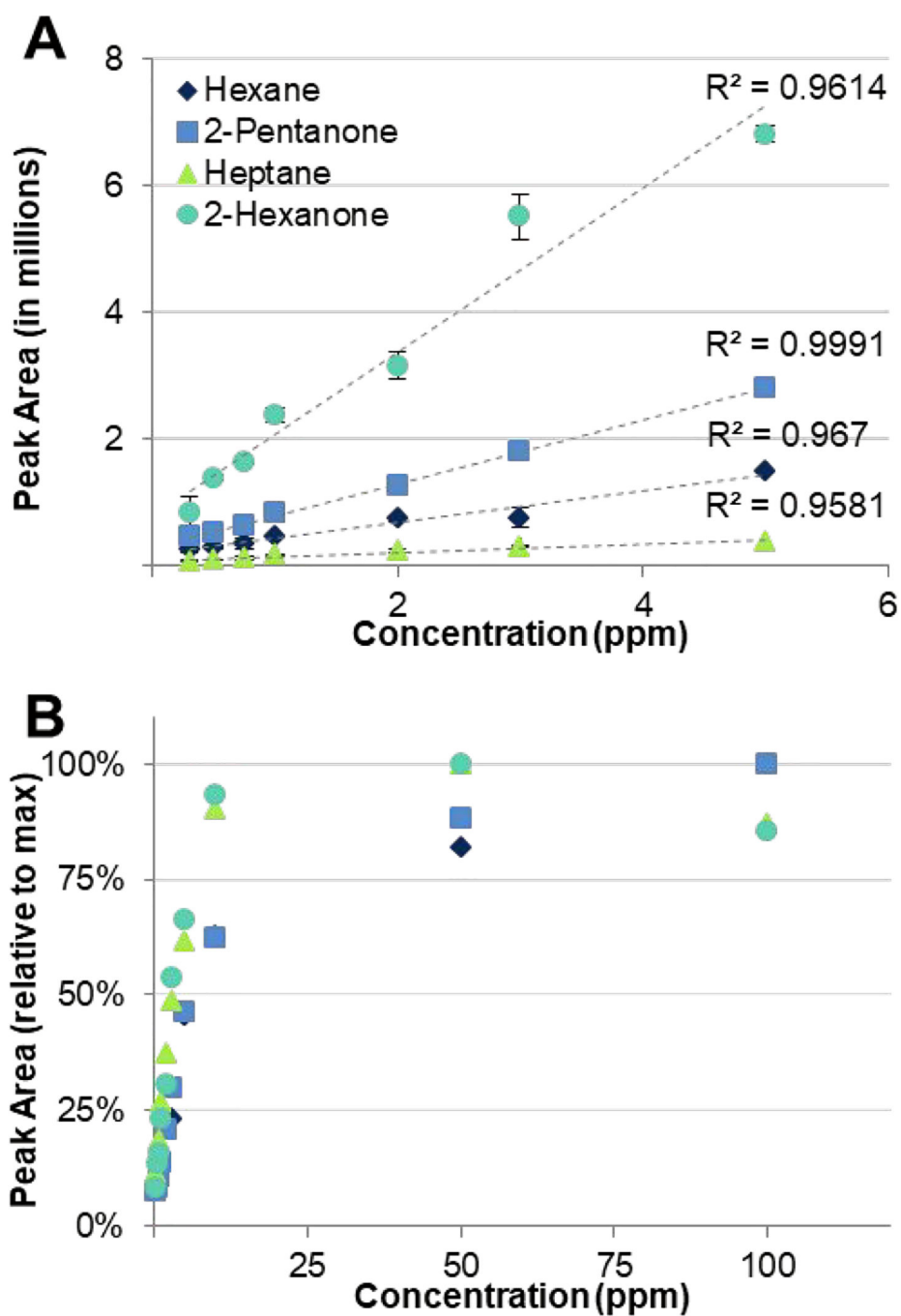


Figure 3. Calibration curves of four chemicals using the environmental sampler with a 10 min sampling time. **A:** Within a range from 300 ppb – 5 ppm, there was a linear increase of signal response with concentration increase. **B:** Evidence of saturation occurred at samples >10 ppm; peak areas are presented as relative to the maximum intensity of the corresponding compound.

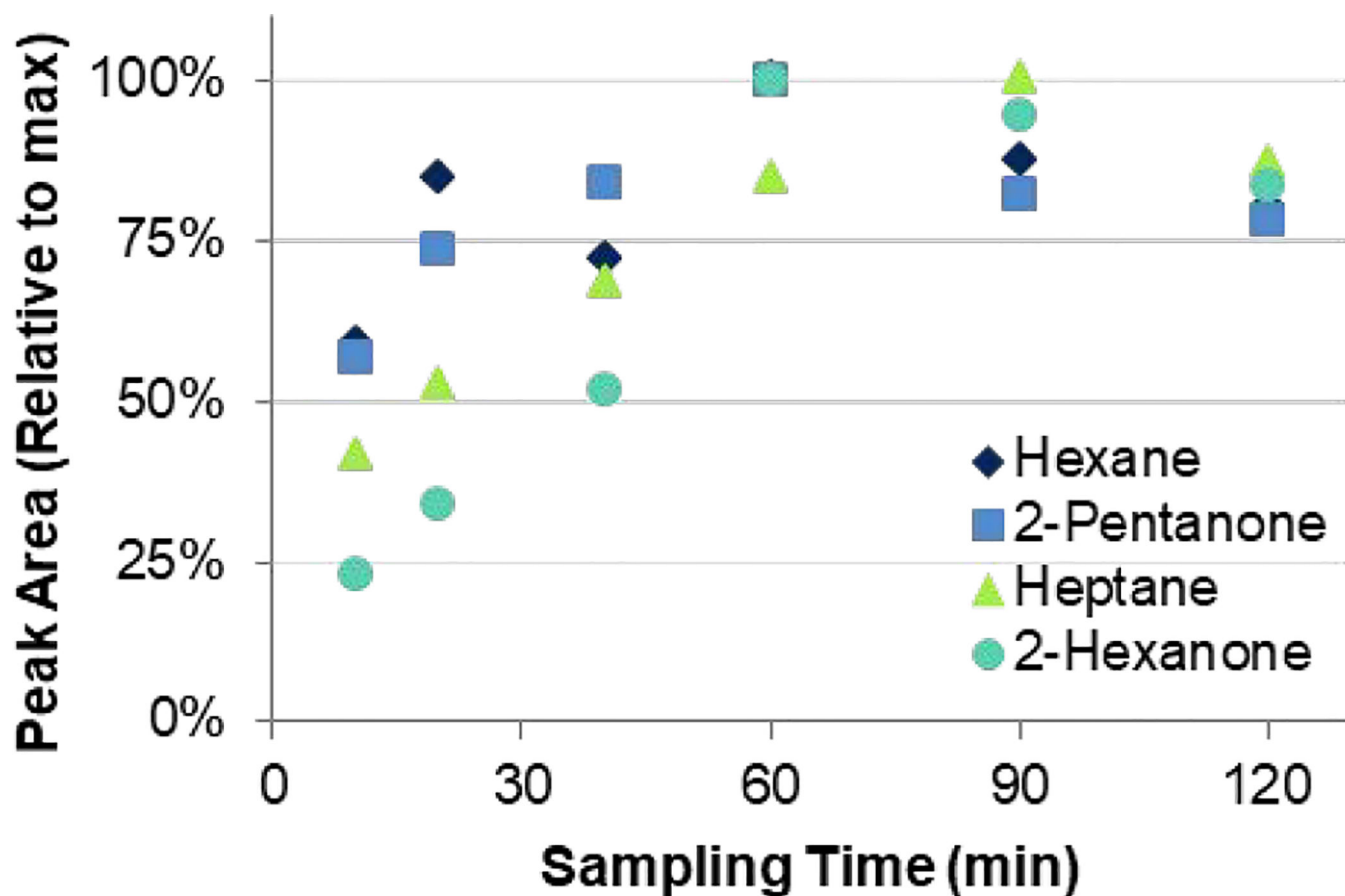


Figure 4. Effect of increased sampling times on chemical signal. Chemicals were present at 100 ppb. Peak areas are presented as relative to the maximum intensity of the corresponding compound. The preconcentrator chips generally saturated around 60 min of sampling time for these various chemicals.

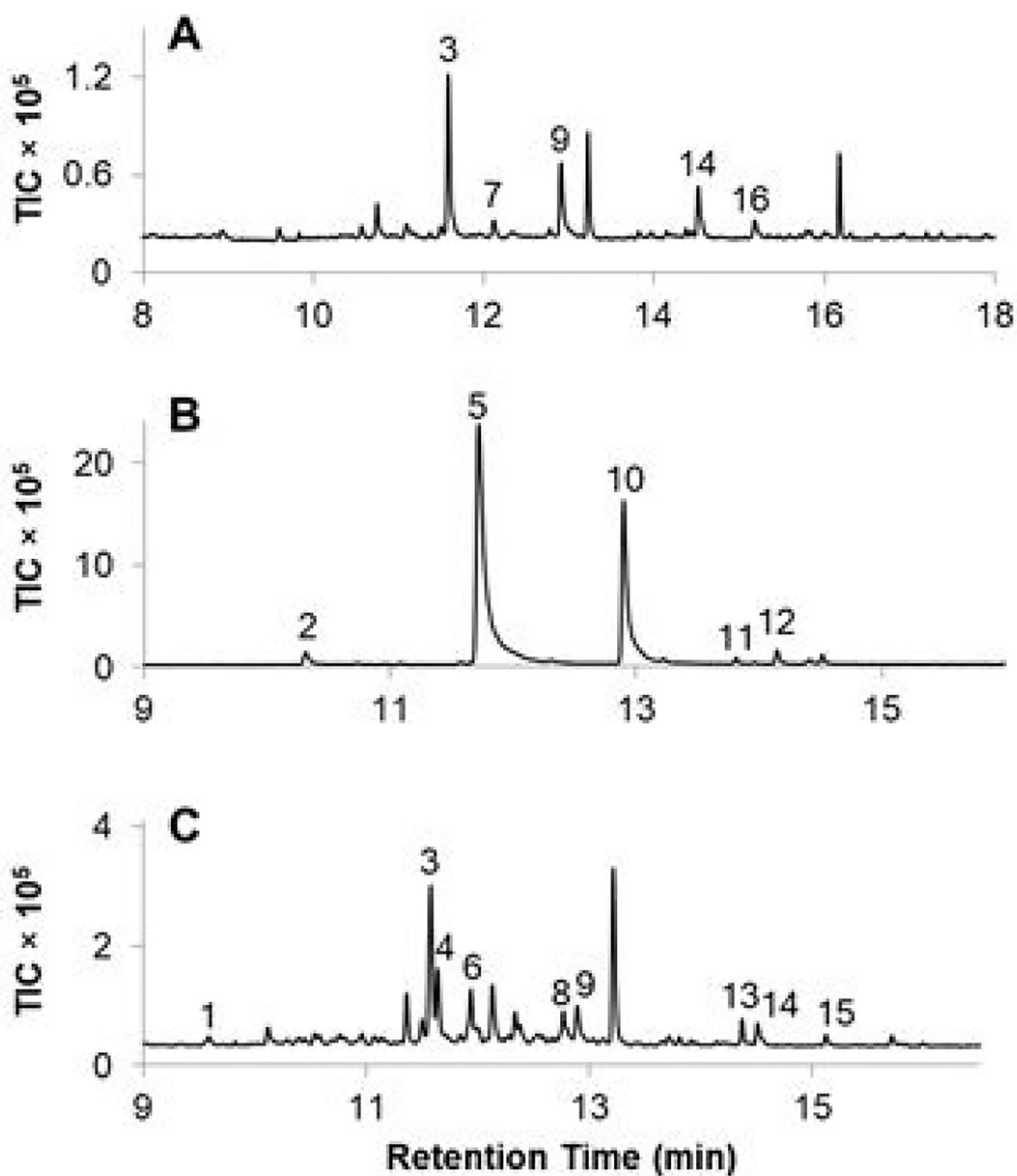


Figure 5. GC-MS chromatograms of three samples collected with the environmental sampler, taken **A:** in a kitchen during cooking, **B:** in a commercial hallway while floors were stripped and waxed, and **C:** next to an indoor cat litter box. Numbered peaks are putatively identified in Table 1. TIC: total ion count.

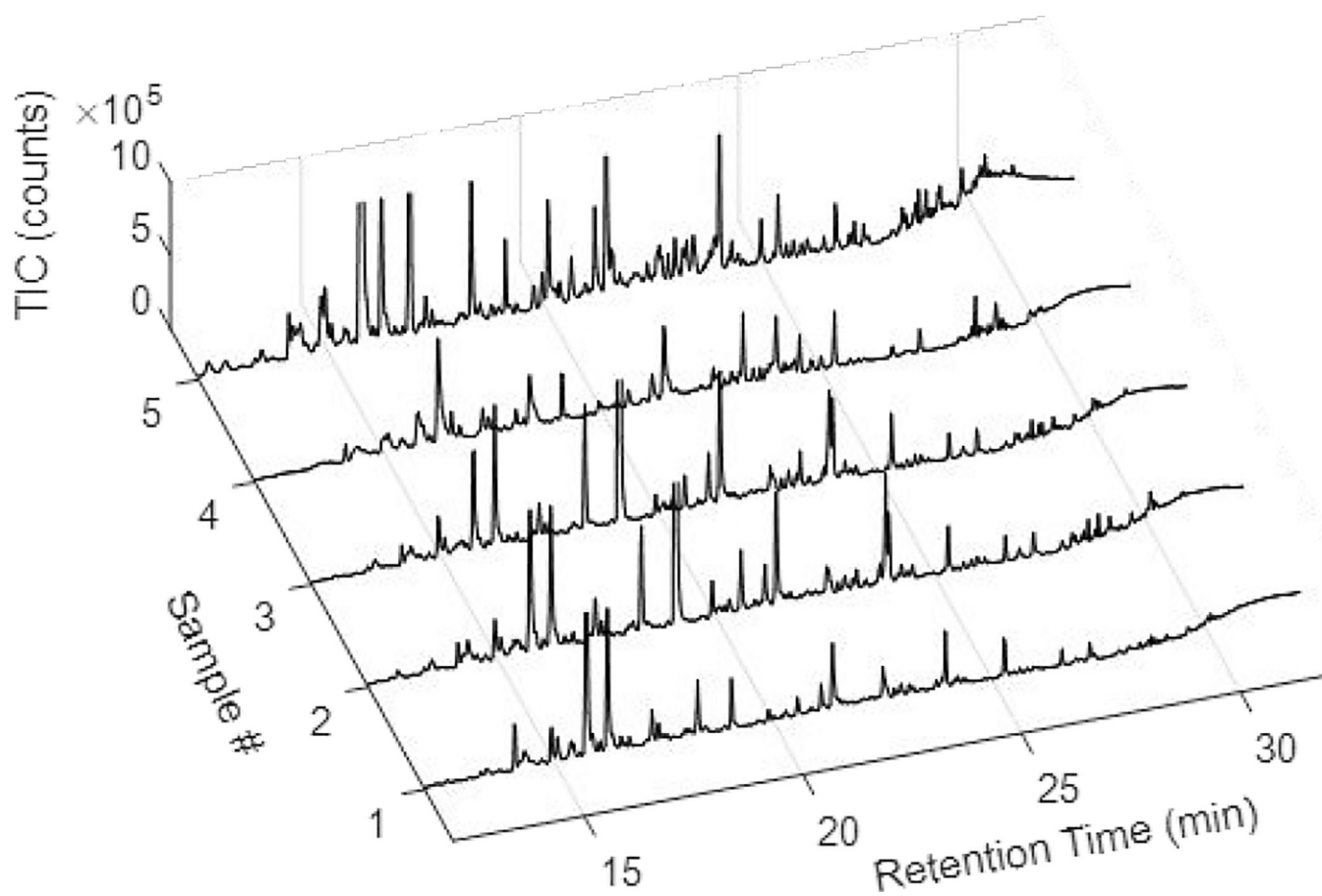


Figure 6:
Chromatograms from 5 samples collected by a 17 year old high school student volunteer. The volunteer used the sampler for 5 consecutive days, replacing the preconcentrator chip each day. TIC: total ion count.

Table 1:

List of putatively identified VOCs taken with the environmental sampler in Figure 4. RT: retention time; KI (Lit): Kovats Index from the literature; R.Match: Mass spectrum score compared to a NIST database.

#	Compound	CAS ID	RT (min)	KI (Lit)	R.Match
1	fenchene	471-84-1	9.591	939	764
2	benzaldehyde	100-52-7	10.331	982	881
3	limonene	5989-27-5	11.604	1010	879
4	eucalyptol	470-82-6	11.643	1033	821
5	benzyl alcohol	100-51-6	11.741	1032	876
6	2-methyldecane	6975-98-0	11.938	1062	694
7	ocimene	29714-87-2	12.122	1023	722
8	undecane	1120-21-4	12.768	1100	746
9	nonanal	124-19-6	12.907	1103	826
10	ethylene glycol monohexyl ether	112-25-4	12.921	1135	730
11	menthone	89-80-5	13.816	1176	874
12	menthol	1490-04-6	14.149	1171	879
13	dodecane	112-95-8	14.374	1200	722
14	decanal	112-31-2	14.513	1207	807
15	nerol	106-25-2	15.122	1237	773
16	cuminal	122-03-2	15.180	1246	789

Table 2:

Description of the number of VOCs detected from 5 samples collected by a 17 year old volunteer using the environmental sampler (Figure 5).

Sample #	Total # Compounds detected	# Compounds unique to sample	# Compounds Overlapping with other samples
1	66	12	54
2	72	11	61
3	70	5	65
4	58	11	47
5	100	39	61

Table 3:

Example of quantification of VOCs collected onto the μ PC chip during deployment. For this demonstration, selected were four VOCs found in all 5 samples collected by a 17 year old volunteer using the environmental sampler.

Analyte	Amount retained (ng)				
	Day 1	Day 2	Day 3	Day 4	Day 5
Limonene	71.5	46.7	25.4	16.4	3.4
Menthol	2.4	11.0	5.3	3.4	11.3
Decanal	20.0	43.8	53.9	36.9	53.7
2-Butyl-1-octanol	7.3	13.3	12.3	13.6	26.3