Ground Water Monitoring&Remediation

Portable GC/MS Methods to Evaluate Sources of cVOC Contamination in Indoor Air

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Abstract

A portable gas chromatograph-mass spectrometer (GC/MS) was used to investigate sources of chlorinated volatile organic compound (cVOC) contamination in indoor air at 46 residences around Hill AFB, Utah, that were potentially affected by vapor intrusion. Analytical methods were developed to allow sample turnaround times of less than 10 min and method detection limits (MDLs) generally less than 1 μg/m^3 for a selected list of cVOCs. Area-by-area sampling was used to identify the likely vapor source locations. In many cases, individual container/enclosure sampling and subsequent field emission rate measurements from isolated consumer products were used to determine if identified products were likely to be the primary source of vapors in the residence. The portable GC/MS was also used to characterize vapor intrusion in two residences. In one of these two residences, building pressure control was used to enhance vapor entry in order to facilitate the investigation resulting in confirmation of vapor intrusion and identification of a primary route of vapor entry. cVOCs were identified in 42 of the 46 homes investigated, subsurface vapor intrusion was identified in two homes, and two homes had inconclusive results.

Introduction

Hill AFB, located north of Salt Lake City, Utah, has been operated as a military facility since 1934. Historic waste management practices resulted in a number of chlorinated volatile organic compound (cVOC) plumes in groundwater that have migrated off site into residential neighborhoods north, west, and south of the base. Trichloroethene (TCE) is the predominant groundwater contaminant in these off-site plumes while 1,2-dichloroethane (1,2-DCA), 1,1-dichloroethene (1,1-DCE), *cis*-1,2-dichloroethene (*cis*-DCE), and tetrachloroethene (PCE) are also present in some areas. In 2003, Hill AFB began a formal program to evaluate the potential for migration of vapors from dissolved plumes into overlying residences (vapor intrusion).

Hill AFB selected a vapor intrusion characterization and monitoring approach that relies on analysis of indoor air samples as the initial step for evaluation of potential vapor intrusion at residences overlying affected groundwater. The primary reasons for this approach were (1) indoor air measurements provide a direct measure of exposure point concentration and (2) an assumption that residents would have more confidence in direct measurements as opposed to estimates of indoor concentration based on empirical or modeled relationships with subsurface samples. To date, more than 7000 indoor air samples have been collected from 1800 residences and analyzed for a targeted list of cVOCs found in underlying groundwater. Indoor air samples for vapor intrusion characterization are typically collected over 24 h in 6-L Summa® canisters and analyzed by commercial laboratories by EPA Method TO 15. Although this type of sampling provides concentration measurements for cVOCs of concern, the approach is incapable of distinguishing between interior and subsurface sources. A vapor intrusion characterization approach based on sampling indoor air presents a significant challenge because interior sources of cVOCs are present in many consumer products. Interior sources of the same VOCs suspected in vapor intrusion are sometimes referred to as "background sources" (Dawson and McAlary 2009). Household products containing cVOCs are ubiquitous (Stolwijk 1990; Sack et al. 1992; Samfield 1992; Brown et al. 1994; Holcomb and Seabrook 1995; Shah and Singh 1998; USEPA 1998; Dawson and McAlary 2009; Odabasi 2009) and can often result in VOC concentrations above regulatory screening levels. For example, Dawson and McAlary (2009) report background concentrations of PCE and TCE in indoor air ranging from 0.9 to 7.4 μg/m^3 and 0.3 to 1.6 μg/m^3 (50th to 95th percentile values) compared to the current US EPA Regional Screening Levels of 0.41 and 1.2 μg/m^3, respectively for the 10−6 cancer risk level (USEPA 2011).

Identifying and minimizing interference from indoor sources is a critical component of vapor intrusion characterization and monitoring efforts. At Hill AFB, an approach based on interviewing residents, along with chemical inspection and

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inventory, has resulted in the identification of nearly 200 potential indoor sources in homes (Dettenmaier and Gorder 2011). However, because some residents were reluctant to cooperate or simply did not know that they had products containing cVOCs of interest, the chemical inspection approach could not identify all indoor sources in many homes. Prior to 2008, the best indicator of a possible indoor source was the lack of effect of operation of a sub-slab depressurization (SSD) system on indoor concentrations. For example, in 2007, the ineffectiveness of SSD systems to reduce 1,2-DCA concentrations in one area around Hill AFB prompted further investigation to determine if interior sources could be identified (Doucette et al. 2010; McHugh and Gorder 2010). Using an area-by-area sorbent tube sampling approach combined with off-site gas chromatography-mass spectrometry (GC/MS) analysis, Doucette et al. (2010) determined that molded plastic decorations were emitting 1,2-DCA at levels of concern. The main disadvantage of this approach was that it required multiple sampling and analysis events before the source could be isolated and positively identified and finding convenient times for repeat sampling was often difficult because of the varied schedules of the residents. Based on the successful identification of several specific indoor sources using the area-by-area sampling approach with off-site analysis, it was suspected that indoor source investigations could be optimized by using rapid on-site analysis. The overall objective of the project was to develop and demonstrate procedures to further optimize indoor source investigations and vapor intrusion characterization using a portable GC/MS. Specific objectives included reducing sample analysis turnaround time so that the majority of investigations could be conducted in a few hours to minimize the effects of temporal variability while maintaining the ability to quantify the low concentrations of cVOCs expected.

Methods

The overall concept for vapor source characterization was to combine the rapid sample collection and analysis capabilities of the portable GC/MS with on-site decision making to track higher contaminant concentrations to the source. Investigations started with area-by-area sampling and followed the highest measured concentration through progressively smaller areas until a specific vapor source could be identified. For cases where consumer products were identified as a primary vapor source, a method was developed to determine the cVOC emission rate from the products. In one residence, building pressure control was used to enhance vapor intrusion to facilitate investigation and characterization.

Portable GC/MS

Sampling and analysis was conducted using the HAPSITE® field portable GC/MS (Inficon, Syracuse, NY, USA). A customized analytical method was developed for the HAPSITE that enabled both a rapid sample turnaround time and low detection limits for the target cVOCs (Table 1). Samples of room air (100 mL) were drawn through the handheld, heated probe and onto an internal "Tri-Bed" sorbent trap for sample concentration after a pre-sample collection purge of 100 mL. The cVOCs were subsequently thermally desorbed from the trap into the GC/MS operated in Selected Ion Monitoring (SIM) mode. The GC column temperature was held at 55 °C for 80 s, and then increased at 30 °C/min to a maximum temperature of 110 °C. The total time required for sample collection and analysis was approximately 6 min. Detection limits of less than 1 μg/m^3 were achieved for the target analytes (Table 1). Calibration and quality control procedures followed documented protocols (i.e., EPA Method TO-17; USEPA 1999).

Table 1
Target List of VOCs and Associated Method Detection Limits

Compound	Method Detection Limit (μg/m^3)	SIM *m/z* (Quant)
Trichloroethene	0.4	95, (130), 132
Tetrachloroethene	0.7	131, (164), 166
cis-1,2-Dichloroethene	0.5	(61), 63, 96
trans-1,2-Dichloroethene	0.5	(61), 63, 96
Carbon tetrachloride	0.3	(117), 119
1,2-Dichloroethane	0.7	61, (62), 63
1,1-Dichloroethene	0.3	(61), 63, 96
1,1-Dichloroethane	0.3	61, (63), 83

Real-Time Screening

The "survey mode" of the HAPSITE was used to provide real-time results for rapid screening of potential sources. In survey mode, a continuously collected sample bypassed the concentrator and column and was introduced directly to the MS. Relative concentrations and tentative identification of target cVOCs were achieved by operating the MS in SIM mode with mass to charge ratios (*m/z*) listed in Table 1. The survey mode provided a rapid screening capability that was particularly useful for screening storage containers or individual products that were identified using the sampling methodologies discussed in the following sections. Once suspect containers or products were identified, the GC/MS method was used to positively identify cVOCs.

Area-by-Area Sampling

In each residence, an area-by-area sampling method was used to identify a particular area, then a particular room with the highest concentration of the target cVOC. Results from the area-by-area sampling were used to focus the collection of additional samples in rooms in the highest concentration area. The short turnaround time between samples allowed subsequent sampling to be rapidly focused on the specific portion of the building that exhibited the highest cVOC concentration.

To maximize the concentration differences within the residence, on the day of the investigation residents were asked to: (1) discontinue the use of heating, ventilation, and air conditioning systems; (2) close windows and internal doors; and (3) keep doors closed on attached garages.

If this was not done prior to arrival of the sampling team, these steps were taken just prior to the beginning of sample collection. The results indicated that implementing these measures even for a short time prior to sampling resulted in measurable concentration differences between areas.

Initially, samples were collected from common areas on all levels of the residence and from the attached garage, if present. If the results from one level of the home, or the attached garage, showed an elevated concentration of the target cVOC compared to other areas, then the investigation was focused on that area. Generally, a concentration was considered elevated in an area if it was two times higher than other areas in the residence. However, in some cases relatively small (10% to 20%) differences in observed cVOC concentrations between areas/rooms were used to identify sources. If an elevated concentration was observed on a given level within the home, room-by-room sampling of that level was conducted in an attempt to further isolate the room containing the source of the contaminants. Room-by-room samples were collected either by entering the room for sample collection or via a 4.8-mm Teflon® tube inserted into the room under the closed door. Once a specific area or room was identified, the focus of the investigation changed to sampling of individual storage containers and consumer products.

Enclosure/Container Sampling

Storage containers or other enclosed spaces (e.g., drawers, cabinets) were opened as little as possible to allow air samples to be collected, typically with a short length of 4.8-mm Teflon tubing attached to the HAPSITE probe. These samples were analyzed using either the full GC/MS method or the MS-only survey mode depending on expected concentrations. If sampling results indicated the potential presence of a cVOC in one or more containers, then containers were opened to examine the contents and perform further source identification, if required.

Vapor Source Isolation

The area-by-area procedure described above frequently resulted in the identification of a consumer product labeled as containing the cVOC of interest. However, when specific products could not be identified or when other suspect products were observed, individual products were isolated in a sealed glass jar or polyethylene bag (for bulk or odd-size objects) filled with outdoor air for further screening and analysis after a 2-min equilibration time. Samples were also collected from the containers containing only outdoor air to verify that the containers were not the source of cVOC emissions.

Emission Rate Estimation

Once one or more products containing the target cVOC were identified, emission rates were measured if possible and a simple box model was used to calculate the expected concentration inside the home (Equation 1). The goal of the emission rate measurement was to determine if the product identified had the potential to be the primary source of the cVOC measured in the home. Calculated concentrations similar to historic concentrations suggested that the isolated product(s) was a primary source of contamination in the home, whereas calculated concentrations considerably less than historically measured concentrations suggested that other, stronger sources were potentially present.

$$C_{\text{air}} = \frac{E}{IV} \tag{1}$$

where C_{air} is the indoor air concentration (μg/m^3); E, the emission rate (μg cVOC/d) measured; I, the air exchange rate (1/d); and V is the indoor air volume (m^3).

Field emission rate measurements were conducted using a 10-L glass jar with a tight-fitting metal cap. The metal cap included two stainless steel bulkhead fittings that were used to attach a Tedlar® bag (SKC, Eighty Four, Pennsylvania) and 1-L syringe to the emission chamber. A Teflon (Fisher Scientific, Pittsburgh, Pennsylvania) tube extended from the bottom of one bulkhead fitting to the bottom of the chamber to facilitate mixing during the test. The 1-L syringe was used to cycle (every 15 to 20 s) air through the jar and 1-L Tedlar bag to provide mixing over the 2-min test duration (Figure 1). After mixing, the Tedlar bag was removed and analyzed for the cVOC of interest. The emission rate was then calculated using Equation 2.

$$E = \frac{CV_{\text{t}}}{t} \tag{2}$$

where E is the field emission rate (μg cVOC/min); C, the cVOC concentration after emission test (μg/m^3); V_{t}, the volume of emission test system (m^3); and t is the emission test duration (min).

Investigation Procedures for Vapor Intrusion

The approach used to investigate potential vapor intrusion relied on first using the methodology described above to rule out an interior source. If detections in samples from the lowest level of the residence were elevated with respect to upper levels, or if area-by-area sampling did not result in the identification of a specific area with elevated concentration, then vapor intrusion was considered a potential source of the indoor air contamination. In some buildings, preferential entry points such as dry wells, utility penetrations, or

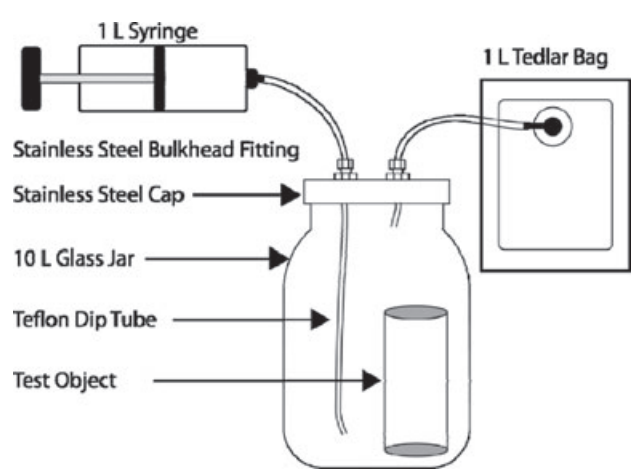

Figure 1. Field emission rate testing materials.

large cracks in the building structure or foundation can serve as sources of vapor intrusion. For these buildings, the survey mode and/or focused sampling of potential entry points was used to investigate vapor intrusion. In other buildings, vapors may enter through multiple openings at a low rate. In these cases, selected openings (e.g., smaller cracks in the foundation slab) were isolated, sampled multiple times over 10 to 30 min, and analyzed using the GC/MS to determine if vapor intrusion was occurring. Detection of target cVOCs in an isolated entry point does not provide definitive evidence of vapor intrusion because interior sources can contaminate subsurface air (McHugh et al. 2006). However, the observation of increasing concentrations over time in an isolated entry point in structures where interior sources have been ruled out does provide good evidence of a subsurface vapor source.

Building Pressure Control

In one residence where historic sampling had identified cVOCs of concern, follow-up sampling with the portable GC/MS resulted in cVOC concentrations below MDLs. However, by manipulating the building pressure detectable cVOC concentrations were induced allowing the investigation to continue. Inducing a negative building pressure (relative to the subsurface) during an investigation enhances the flow from the subsurface into the building resulting in observable increases in indoor contaminant concentration if a subsurface source of vapor is present (McHugh 2008; McHugh and Gorder 2010). For this study, negative building pressure was induced by installation of a standard box fan in a window and directing flow outward.

Results

Various combinations of the methods described above were used to investigate 46 homes near Hill AFB. Most commonly, homes were investigated at the request of the residents in homes with previous detections of one or more cVOC of concern. Residents with detections during periodic monitoring were typically contacted by telephone to discuss options including: (1) more frequent monitoring, (2) SSD system installation, and/or (3) portable GC/MS characterization. Interior sources were located in 42 of the homes as summarized in Table 2. A primary route of vapor intrusion was identified in two of the homes, and two homes did not have detectable concentrations on the day of investigation or were inconclusive. To illustrate the investigation process, the following sections present detailed results from four homes.

Residence 12

Residence 12 was a split-level home with three levels and an attached garage. Historic PCE concentrations ranging from 1.2 to 12 μg/m^3 (the most recent result was 2.9 μg/m^3) in 24-h Summa canister samples prompted a source investigation. Area-by-area sampling results suggested a PCE source

Table 2
Summary Results from Characterization of 44 Homes

Residence	Target VOC	Identified VOC Source	Residence	Target VOC	Identified VOC Source
1–9	1,2-DCA	Molded plastic decoration	31	PCE	Shoe glue
10[1]	CTCL	General cleaner[2]	24[1]	PCE	Shoe glue
11	CTCL	Tile cleaner[2]	32[1]	PCE	Spray dry cleaner
12[1]	CTCL	Toilet and general cleaner[2]	30[1]	TCE	Bug and tar remover
13, 14	PCE	Brake cleaner	33, 34	TCE	Degreaser
15	PCE	Contacts cleaner	35	TCE	Penetrating lubricant
16–19	PCE	Dry cleaning	36	TCE	Pepper spray
20	PCE	General purpose adhesive	32[1]	TCE	Spray dry cleaner
21–23	PCE	Hobby adhesive	37[1]	TCE	Tire repair adhesive
12[1]	PCE	Hobby adhesive	38	TCE	Gun cleaner
24[1]	PCE	Hobby adhesive	39	TCE	Vapor intrusion
10[1]	PCE	Hobby adhesive	40	TCE	Vapor intrusion
25	PCE	Hobby spray glitter	41	*trans*-DCE	Foam wall insulation
26, 27	PCE	Penetrating lubricant	42	*trans*-DCE	Taxidermy mold (Deer)
28	PCE	Roof sealant	37[1]	*trans*-DCE	Taxidermy mold (Deer)
29	PCE	RV sealant	43	*trans*-DCE	Taxidermy mold (unused)
30[1]	PCE	Shoe Glue	44	1,1-DCE	Tile cleaner[2]

Note: Two homes where PCE and TCE, respectively, were not detected on the day of investigation are not included.
CTCL = carbon tetrachloride.
[1]Residences where more than one VOC source was identified.
[2]All cleaners identified contained sodium hypochlorite and detergent/surfactant.

on the top floor (Figure 2). Subsequent room-by-room sampling suggested a source in the northeast bedroom (Figure 2). The survey mode of the portable GC/MS was used to investigate several drawers in a desk in the northeast bedroom, and suggested a possible PCE source in the middle desk drawer. Upon opening the middle desk drawer, a tube of hobby adhesive with PCE listed on the label was identified.

Adhesives similar to that found in Residence 12 have been found in 9 of the 22 homes with PCE contamination investigated to date. These adhesive products include hobby glues and shoe glues and have been clearly labeled as containing PCE. The emission rate for a previously used but capped tube of the adhesive was measured to be 9 μg/min. Based on the emission rate and an estimated home volume of 465 m^3 with 10 air changes per day, Equation 1 was used to calculate an expected indoor PCE concentration of 3 $\mu g/m^3$. Considering the spatial distribution of PCE within the home, the investigation results suggested that the adhesive was a primary source of PCE observed in the residence and it was suggested that the resident remove the adhesive from inside the home. The resident has not responded to several requests to conduct routine air sampling since the investigation.

Residence 32

Residence 32 was a two-level home with a detached garage, and a history of TCE and PCE concentrations ranging from 1.6 to 3.1 $\mu g/m^3$ and 0.9 to 2.9 $\mu g/m^3$, respectively. Area-by-area sampling suggested an upstairs source for both TCE and PCE (Table 3). Subsequent room-by-room sampling did not identify a source in any of the upstairs rooms. However, because of the slightly elevated TCE concentration, items in the upstairs closet were inspected and determined not to be a source of contamination. Because the closet and kitchen share a common wall, it was suspected that the source could be in one of the kitchen cabinets. The survey mode of the portable GC/MS was used to investigate all of the kitchen cabinets, resulting in identification of a potential source of TCE under the kitchen sink. Analysis of a sample collected from inside the sink cabinet resulted in

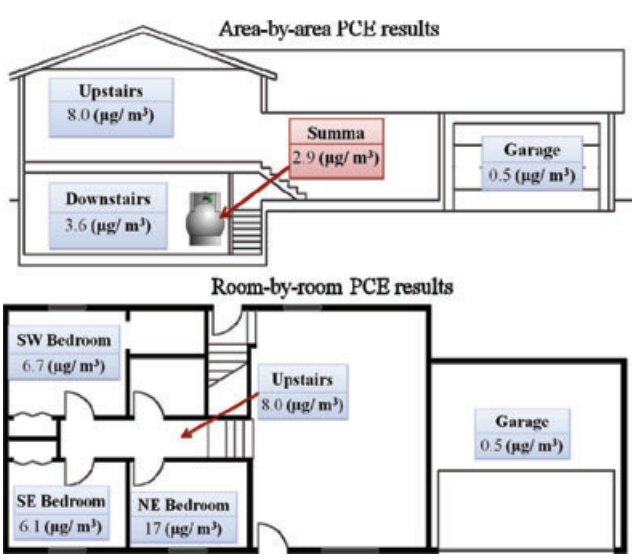

Figure 2. Characterization results from Residence 12.

Table 3
Investigation Results from Residence 32

Description	TCE ($\mu g/m^3$)	PCE ($\mu g/m^3$)
Basement	1.9	1.1
Upstairs hall	2.3	1.3
Upstairs closet	2.5	1.3
Upstairs SW room	2.3	1.4
Upstairs N room	2.0	1.3
Upstairs E room	2.2	1.1
Kitchen cabinet	190	65

TCE and PCE concentrations of 190 and 65 $\mu g/m^3$, respectively. Visual inspection of the sink cabinet identified dozens of cleaning products including an aerosol can of "Dry Cleaner," labeled as containing TCE and PCE. No additional products containing TCE or PCE were identified either by label or additional GC/MS screening. Although time constraints did not allow for an emission test on the identified product, given the results from the room-by-room sampling it is suspected that this cleaner was a primary source of TCE and PCE observed in Residence 32. After removing the product, follow-up Summa canister sampling approximately 10 months later resulted in no detectable concentrations of PCE and TCE in the indoor air, confirming that product was the only significant source of PCE and TCE.

Residence 21

Residence 21 was a two-level home with an attached garage. One previous 24-h Summa canister sample identified PCE at a concentration of 5.8 $\mu g/m^3$. Area-by-area sampling conducted upstairs, downstairs, and in the garage resulted in PCE concentrations of 1.1, 2.3, and 8.7 $\mu g/m^3$, respectively, suggesting a PCE source in the garage. Visual inspection of items stored in the garage, along with use of the HAPSITE in survey mode, initially identified a spray carburetor cleaner as a source of PCE. The carburetor cleaner was placed in the field emission chamber and an emission rate of 0.02 μg/min was estimated for PCE. Based on the emission rate and an estimated home volume of 350 m^3 with 10 air changes per day, Equation 1 calculated a potential indoor PCE concentration of 0.01 $\mu g/m^3$. The calculated indoor PCE concentration clearly suggested that the carburetor cleaner was not the primary source of PCE.

Further inspection of items in the garage using the survey mode was conducted, resulting in discovery of a tube of previously used adhesive. The emission rate for the tube of adhesive was estimated to be 9 μg/min, resulting in a calculated indoor concentration of 4 $\mu g/m^3$.

The results of this investigation showed that the tube of adhesive was likely a primary source of the PCE observed in the indoor air, and a follow-up Summa canister sampling approximately 11 months later resulted in no detectable concentrations of PCE in the indoor air. This investigation highlights the utility of field emission testing for determining the primary source of contamination when multiple indoor sources are identified.

Residence 40

Residence 40 was a split-level home with an attached garage that was purchased by Arizona State University (ASU) for vapor intrusion research. Although this home has a history of elevated cVOC levels, monitoring at the time of this study showed concentrations of the main cVOCs (TCE; 1,1-DCE; and PCE) below detection limits under "normal" (no pressure manipulation) conditions. The cVOCs of concern were less than their MDLs in initial samples collected upstairs, downstairs, and in the garage at the beginning of the investigation (Table 4). Following the initial sampling, all internal doors in the home were closed and a box fan was installed to blow air out of the window of the upstairs southeast bedroom in the home. Periodic sampling then continued in the upstairs and downstairs hall locations for approximately 2 h until concentrations of TCE and 1,1-DCE were relatively stable (Figure 3).

Following the apparent stabilization of concentrations about 140 min after inducing negative indoor pressure, and based on results showing higher concentrations of target cVOCs in the upstairs hall sample relative to the downstairs hall and garage samples, upstairs room-by-room sampling was conducted. Because the concentration of target cVOCs was less than their respective MDLs in all upstairs room samples, room-by-room sampling continued downstairs, resulting in relatively high concentrations of target cVOCs. Specifically, target cVOC concentrations in a storage area under the stairs resulted in concentrations about five times higher than any other room in the home (Table 4). The survey mode was then used to identify an approximately 1- to 3-mm wide crack between the basement slab and foundation wall as a primary route of vapor entry.

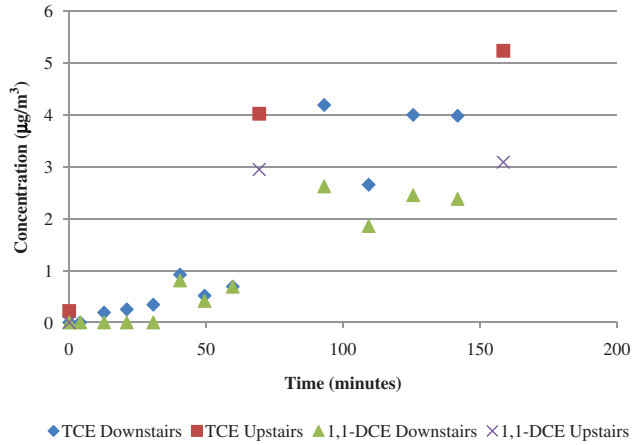

Figure 3. TCE and 1,1-DCE concentration during depressurization of Residence 40.

Additional sampling under a baseboard located in the center of the stair landing directly above the storage room revealed a direct pathway to the second floor. The presence of this direct pathway is believed to be the explanation for the higher results upstairs vs. downstairs in post-depressurization samples collected at 159 and 141 min, respectively (Table 4). A final sample from the crack in the storage room confirmed that target VOCs were present with estimated concentrations of 670, 620, and 170 µg/m³ for TCE, 1,1-DCE, and PCE, respectively.

Overall, the combination of building pressure control and portable GC/MS analysis was successful in determining that vapor intrusion occurs in this residence even though initial samples without pressure manipulation showed concentrations less than MDLs. The investigation also resulted in identification of a primary route of vapor entry into the home.

Table 4
Investigation Results from Residence 40
(All Units µg/m³)

Description	Time (min)	TCE	1,1-DCE	PCE
Upstairs hall	0	<0.4	<0.3	<0.7
Downstairs hall	0	<0.4	<0.3	<0.7
Garage	0	<0.4	<0.3	<0.7
Downstairs hall	141	4.0	2.4	1.0
Upstairs hall	159	5.2	3.1	1.3
Garage	167	<0.4	<0.3	<0.7
Upstairs SW bedroom	176	<0.4	<0.3	<0.7
Upstairs NW bedroom	184	<0.4	<0.3	<0.7
Upstairs bathroom	192	<0.4	<0.3	<0.7
Downstairs living room	201	29	19	6.6
Downstairs bathroom	210	15	10	3.3
Downstairs storage area	218	150	87	37
Under center landing baseboard	239	96.4	56.0	23.0
Crack in downstairs storage area	248	668[1]	623[1]	168

[1]Result above method calibration range.

Discussion

A HAPSITE portable GC/MS system has been successfully used to identify and quantify sources of previously detected indoor air chemicals. Analytical methods were developed to provide rapid sample turnaround times and low MDLs. A sampling and analysis approach progressing from large areas of low concentration to small areas of high concentration allowed for the rapid and efficient determination of cVOC sources. The investigation method has been proven effective in identifying the location of interior sources in more than 40 residences, generally in less than 2 h. In these 40 residents, interviews, chemical inventories and 24-h Summa canister samples failed to identify interior sources. Product isolation methods and field emission rate testing have been effective for positive identification of chemicals of concern in consumer products, and for determining whether an identified product is likely to be the primary source of the observed cVOC(s). The portable GC/MS was also successful in characterizing buildings where

the primary source of cVOCs was vapor intrusion. One investigation conducted using building pressure manipulation resulted in the successful identification of vapor intrusion along with the primary entry points of vapors into the building, even though chemical concentrations were below MDLs upon initiation of the investigation.

Because of the success with source characterization, Hill AFB now recommends a portable GC/MS investigation to residents prior to installation of SSD systems when a target cVOC concentration is measured above the action level. This revised approach has minimized the possibility of installing unnecessary SSD systems and resulted in substantial cost savings. The revised approach has been well received by affected residents, mainly because vapor sources are definitely identified and intrusive mitigation is avoided unless vapor intrusion is the confirmed source of the target cVOC in the home.

Although a specific portable GC/MS was used for this project, similar characterization work could be accomplished using different approaches to on-site analysis. For example, the USEPA "TAGA" unit and mobile laboratories could be used along with the sampling approaches described to provide similar results.

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