FINAL REPORT

The VI Diagnosis Toolkit for Assessing Vapor Intrusion Pathways and Impacts in Neighborhoods Overlying Dissolved Chlorinated Solvent Plumes

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The objective of this project was to demonstrate and validate a suite of tools that can improve our ability to more accurately, cost-effectively, and confidently assess vapor intrusion (VI) impacts and, if necessary, select appropriate remedies in neighborhoods and industrial buildings overlying dilute chlorinated solvent plumes. The project focused on advancing the *VI Diagnosis Toolkit*, which includes: external VI source screening for at-risk building identification; building-specific controlled pressurization method (CPM) testing to quickly measure worst-case VI indoor air impacts in at-risk buildings; indoor vapor source identification through use of portable analytical tools; passive samplers for longer-term (week to month duration), time-weighted indoor air concentration measurement; and use of the data from all tools to select appropriate mitigation strategies, if needed. Protocols and guidance for use of these tools were developed, demonstrated and validated in residential and industrial buildings as part of this work.

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FINAL REPORT
Project: ER-201501

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

Page

LIST OF FIGURES

LIST OF FIGURES

Page

LIST OF FIGURES

LIST OF FIGURES

Page

LIST OF TABLES

LIST OF TABLES

Page

ACRONYMS AND ABBREVIATIONS

1,1-DCA	1,1-dichloroethane
1,2-DCA	1,2-dichloroethane
1,1-DCE	1,1- dichloroethene
AFB	Air Force Base
ASU	Arizona State University
BS	below slab
CFM	cubic feet per minute
cis-DCE	cis-1,2-dichloroethene
CHC	chlorinated hydrocarbon
CPM	controlled pressure method
cVOC	chlorinated volatile organic contaminant
DELCD	dry electrolytic conductivity detector
DNAPL	dense non-aqueous phase liquid
DoD	Department of Defense
ECD	electron capture detector
ft	feet
GC	gas chromatograph(y)
GW	groundwater
hr	hour
HVAC	heating, ventilation and air conditioning
km	kilometer
m	meter
MDL	method detection limit
min	minute
MLE	multiple-lines-of-evidence
MS	mass spectroscopy
NAPL	non-aqueous phase liquid
PCE	tetrachloroethylene
PDD	pulsed discharge detector
ppb_v	parts per billion in volume
QA	quality assurance

QAPP	Quality Assurance Project Plan
QC	quality control
RBCs	risk-based concentrations
ROD	Record of Decision
SF_6	sulfur hexafluoride
SIM	selective-ion monitoring
SS	sub-slab
SSD	sub-slab depressurization
1,1,1-TCA	1,1,1-trichloroethane
1,1,2-TCA	1,1,2-trichloroethane
TCE	trichloroethylene
trans-DCE	trans-1,2-dichloroethene
USEPA	United States Environmental Protection Agency
VI	vapor intrusion
VOA	volatile organic analysis
VRS	vapor recovery system

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- To Kyle Gorder for his support of the project with background information regarding VIand residential impacts within OU-8.

Finally, we would like to thank the many individuals who we forgot to name that made this project a success.

ABSTRACT

The objective of this project was to demonstrate and validate a suite of tools that can improve our ability to more accurately, cost-effectively, and confidently assess vapor intrusion (VI) impacts and, if necessary, select appropriate remedies in neighborhoods and industrial buildings overlying dilute chlorinated solvent plumes.

The project focused on advancing the acceptance and use of a suite of tools referred to as the *VI Diagnosis Toolkit*, which includes:

- External VI source screening for at-risk building identification (e.g., use of groundwater, soil gas, and subsurface piping vapor concentration data).
- Building-specific controlled pressurization method (CPM) testing to quickly measure worst-case VI indoor air impacts in at-risk buildings.
- Indoor vapor source identification through use of portable analytical tools.
- Passive samplers for longer-term (week to month duration), time-weighted indoor air concentration measurement.
- Use of the data from all tools to construct comprehensive VI pathway conceptual models that can be used to select appropriate mitigation strategies, if needed.

Relative to current regulatory approaches for VI pathway assessment – which incorporate some, but not all of its components - use of the VI toolkit components offers the potential for greater confidence, speed, and cost-efficiency in pathway assessment and decision-making. In particular, this project focused on advancing the following tools as their use for VI pathway assessment is relatively new: vapor sampling in subsurface piping (e.g., sewers and land drains), building-specific controlled pressure method testing, use of passive samplers for longer-term monitoring and validation, and use of data to identify likely VI pathways and appropriate mitigation strategies. Protocols and guidance for use of these tools were developed, demonstrated and validated in residential and industrial buildings as part of this work.

EXECUTIVE SUMMARY

INTRODUCTION

Regulatory guidance for assessing the vapor intrusion (VI) pathway emphasizes multiple-lines-of-evidence (MLE) approaches that involve point-in-time indoor air, sub-slab soil gas, deeper soil gas, groundwater, and soil sampling plus screening-level extrapolation or modeling.

However, the temporal variabilities in indoor air volatile organic compounds (VOCs) and increasing evidence of alternative VI pathways (e.g., sewer and land drain utilities) have brought new challenges to the current VI investigation paradigm. More comprehensive approaches are necessary to more fully address VI impacts.

The objective of ESTCP ER-201501, *The VI Diagnosis Toolkit for Assessing Vapor Intrusion Impacts and Selecting Remedies in Neighborhoods and Industrial Buildings overlying Dissolved Chlorinated Solvent Plumes*, was to develop, demonstrate and validate, and advance the use of a suite of tools that can improve our ability to more accurately, quickly, cost-effectively, and confidently assess VI impacts. The VI Diagnosis Toolkit includes:

- External VI source screening for at-risk building identification (e.g., use of groundwater, soil gas, and subsurface piping vapor concentration data).
- Building-specific controlled pressurization method (CPM) testing to quickly measure worst-case VI indoor air impacts in at-risk buildings.
- Indoor vapor source identification through use of portable analytical tools.
- Passive samplers for longer-term (week to month duration), time-weighted indoor air concentration measurement.
- Use of the data from all tools to construct comprehensive VI pathway conceptual models that can be used to select appropriate mitigation strategies, if needed.

The Final Report presents results of the overall validation process.

OBJECTIVES

The objective of the project was to advance a set of tools to more effectively assess VI impacts in residential or industrial buildings on the neighborhood scale. Tasks associated with the project are as follows:

- <u>Task 1: External source and flux screening.</u> Using groundwater data, soil gas data, vapor concentration data from utilities, and if advantageous, videos of utility corridors to narrow the scope of detailed building specific investigations necessary during VI assessments in large neighborhoods. This task included a determination of how to best sample vapors in sewers and land drains, the utility of video surveys, and a demonstration of the use of external source strength data to identify at-risk neighborhood sub-areas and homes with potential for VI impact.

- Task 2: Controlled pressurization method (CPM) protocol validation and demonstration. This task focused on the development of a practicable CPM protocol that can be used to assess VI impacts, providing data that can be used to determine if mitigation is necessary, and if so, what type of mitigation system might be appropriate. This task included rigorous testing of numerous CPM test design factors, including blower equipment placement, operable pressure differences, test duration (and building air exchanges), and sampling techniques.
- Task 3: Use of passive samplers under time-varying indoor air conditions. The focus of Task 3 was to validate that passive samplers can provide accurate time-averaged results under conditions of large temporal variability over multi-week periods of time. This task involved a comparison of passive sampler results to active sampling results over the same period.
- Task 4: VI Mitigation system performance under conditions with alternate vapor intrusion pathways. The focus of Task 4 was to assess if conventional VI mitigation systems are effective or inadvertently create adverse impacts under conditions with pipe flow VI. Testing was performed to determine if a new energy efficiency-focused mitigation system approach (e.g., reduced blower flow) produced protective designs.
- Task 5: Comparison of VI Toolkit and conventional MLE approaches to VI pathway assessment. The focus of Task 4 was to put VI Toolkit components in context relative to conventional regulatory approaches to VI pathway assessment, particularly with respectto VI pathway assessment in neighborhoods overlying dilute dissolved chlorinated solvent groundwater plumes.

TECHNOLOGY DESCRIPTION

Table ES-1 summarizes the primary components of the VI Diagnosis Toolkit, their purpose, and the key demonstration and validation questions associated with each and indicates how knowledge gained from other SERDP and ESTCP-sponsored studies isintegrated.

PERFORMANCE ASSESSMENT

Overall, this project met the performance objectives as listed above. CPM protocol (Task 2) and the use of passive samplers (Task 3) were validated and demonstrated in both residential and industrial scale buildings. The effectiveness of a sub-slab depressurization (SSD) system (Task4) was evaluated in a study house with a known pipe-flow VI pathway through the land drain system.

Table ES-1. Primary Components of the *VI Diagnosis Toolkit*.

Component	Purpose	Key Demonstration and Validation Questions
1. External VI source strength screening (e.g., groundwater, soil gas, sewer and landdrain vapor concentrations)	Identify buildings and neighborhood sub-areas most likely to be impacted by VI and needing building- specific testing	How can external VI source strength screening beused to identify buildings and neighborhood areasneeding building-specific testing? How best to characterize vapor concentrations in subsurface piping?
2. Indoor air source screening	Identify and remove indoor air sources prior to indoor air testing under natural or controlled pressurization conditions.	How long must one wait after removing indoor air sources to conduct building-specific tests?
3. Controlled pressurization method (CPM) testing	Measure the maximum indoor air impact under natural conditions caused by VI; identify the VI pathway most responsible for VI impacts to indoor air	What protocol should be followed when conductinga controlled pressurization method tests (e.g., flowrate, pressure differential, duration, sequence of events)? How should the data be analyzed?
4. Passive samplers	Longer-term confirmation monitoringand validation of mitigation system performance.	Do passive samplers provide accurate time- weighted concentrations under field conditions withsignificantly time-varying concentrations?
5. ComprehensiveVI conceptual model	Used as framework to interpret data collectedfrom the components above.	Can improper conceptualization lead to misinterpretation of assessment results, andinstallation of mitigation systems that are ineffective or even amplifiers of VI impacts?

External VI source strength screening (Task 1). External VI source strength screening to reduce the number of buildings that would be candidates for building-specific testing was demonstrated in an approximately 1 km^2 residential area overlying a shallow dilute CVOC groundwater plume. The demonstration included 1) evaluation of the temporal and spatial distributions of trichloroethylene (TCE) vapors in land drain and sewer piping networks; 2) the use of external vapor source data (groundwater, soil gas and utility survey results); and 3) videos from neighborhood land-drains. Important conclusions were:

- When conducting VOC surveys in utility corridors, multi-season synoptic events using weekly time-integrated vapor sampling should be considered to provide a greater level of confidence in characterizing vapor concentration and distribution.
- Use of vapor sampling data from subsurface utility networks is needed to identify buildings that might be affected by VI, especially outside of the extent of groundwater plumes. For this demonstration, vapor source strength screening eliminated about 50% of all neighborhood buildings from consideration for building-specific testing, as shown in Figure ES-1.

- Video surveys in utility corridors can help identify those structures that have a direct connection to utility corridors, such as land-drains and their laterals that connect sub-slab areas of homes to land drain main piping. Those without connections are not at risk from pipe-flow VI.

Controlled Pressurization Method (CPM) Testing. CPM testing protocols were developedand validated in a well-instrumented study house and then demonstrated in residential and industrial buildings. Recommended CPM procedures are summarized in Table ES-2.

CPM testing was demonstrated in three residential homes of up to 2,000 ft^2, each with a vapor sampling history at Hill AFB OU-8, and at four industrial-scale settings up to 20,500 ft^2, including Travis AFB Facility 18 and Beale AFB Buildings 2425 (theatre), 2474 (Community Activity Center), and 24176 (dorms). The demonstration results identified 1 of 3 residential homes (RB3) and 1 of 4 industrial buildings (Facility 18, Travis AFB) with potentially unacceptable VI impacts. This conclusion was consistent with historic indoor air sampling results from RB3 and long-term indoor air monitoring data from Facility 18.

Passive Sampler Validation. Passive sampler validation was performed in the well-instrumented research house for up to 10 months and during industrial-scale CPM demonstrations. Initially, in the research house, four different types of passive samplers were deployed. Early on, use of two of those samplers was discontinued due to poor performance. For the remaining two types of passive samplers (a tube type and vial type), a total of 13 deployments were conducted during the 10-month period with deployments ranging from 7 days to over 7 weeks. For each deployment, passive sampler results were compared to active sampling results from 24-h thermal desorption (TD) tube data for the same period.

Passive sampler validation using the vial type sampler was also conducted for 18 days at 11 different indoor locations in Beale AFB Building 2425 Community Activity Center; and for 218-day periods at 4 indoor air locations in the Travis AFB Facility 18.

Overall, the results of this study suggested that passive sampling, with validated and properly-calibrated samplers, can be a cost-effective tool for time-averaged multi-day and multi-week indoor air concentration measurement. Clear linear correlations between passive sampler and active sampling results were found for the two passive samplers that were used primarily in this work. Passive sampler results were similar to or lower than active sampling results by about 50% for most chemical/sampler combinations; for example, as shown in Figure ES-2 for TCE. The results indicate the need for standardized validation and calibration methods, particularly under time-varying conditions, to ensure that any passive sampler use will produce accurate time-averaged concentration results.

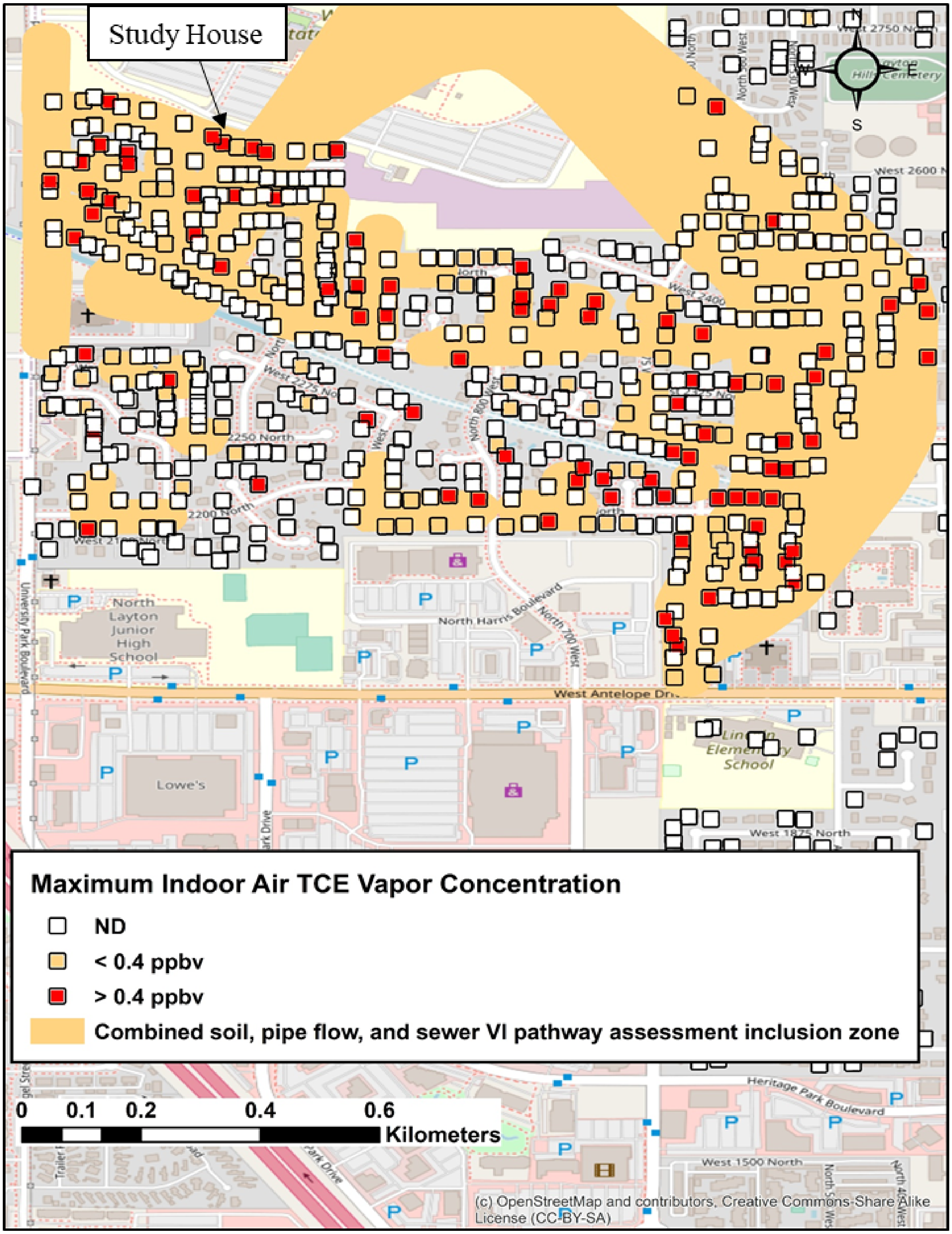


Figure ES-1. Maximum Historical TCE Indoor Air Concentrations and the Total Combined Soil, Pipe-flow, and Sewer VI Pathways Assessment Inclusion Zone.

Table ES-2. Test Design Guidelines for Negative Pressure Difference CPM Tests

Variable	Negative Pressure Difference CPM Tests	Positive Pressure Difference CPM Tests
Exhaust Fan Location	Install fan in any convenient location. Position it to exhaust air from the building fornegative pressure CPM testing and to blow ambient air into the building for positive pressure CPM testing.	
Exhaust Fan Operating Conditions	A consistent indoor – outdoor pressure difference in the range 10 Pa to 15 Pa should be maintained during the test for both negative and positive pressure difference CPM tests.	
Test Duration	At least 9 air exchanges before indoor air sampling	At least 4 air exchanges before indoor air sampling
Operating Conditions Monitoring	Indoor – outdoor pressure difference measured relative to a composite reference pointthat connects open-ended tubing running from all exterior sides of the building. Exhaust fan flowrate (flow-calibrated equipment is preferred; tracer testing is an alternative option for flowrate measures).	
Air Sample Collection	• One or more samples collected near the fan intake with active floor-fan mixing near the fan intake (essential). • One or more ambient air samples (essential). • One or more samples collected from each room with active floor-fan mixing in each room during sample collection.	• One or more ambient air samples • One or more samples collected fromeach room with active floor-fan mixing in each room during sample collection.

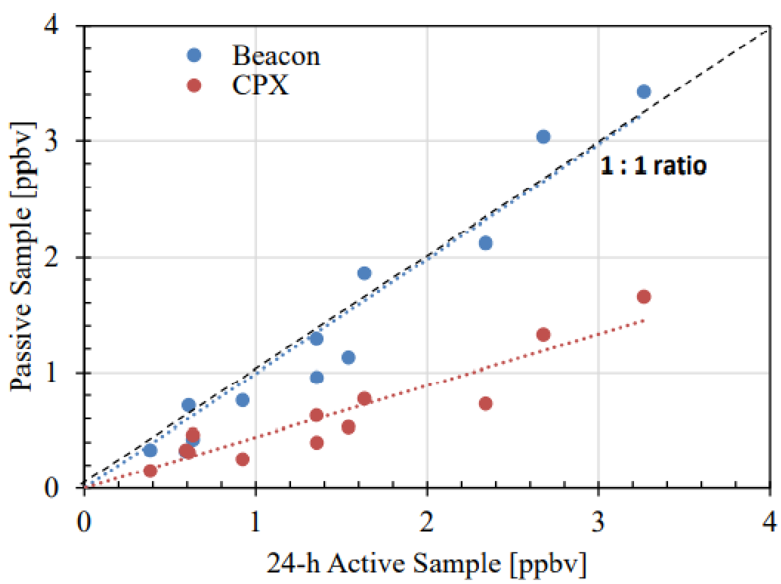


Figure ES-2. Passive Sampler Results Using Beacon Passive Sampler (Beacon) and Beacon Carbopack X Passive Sampler (CPX) vs Time-averaged 24-h TD Tube Sampling Results for Indoorair TCE Vapor Concentrations.

Sub-Slab Depressurization (SSD) System Effectiveness. This study was the first to measure the effectiveness of a VI mitigation system applied to a house with a pipe-flow VI pathway. The SSD system was operated over a range of extraction flowrates selected based on the design approach developed under ESTCP ER-201322. Results indicated that the VI mitigation system extraction flowrate necessary to protect against pipe-flow VI impacts was much greater than that calculated via the ESTCP Project ER-201322 design guidelines. In this test, the design flowrate was <24 SCFM, but an extraction flowrate of about 110 SCFM was required to ensure a sustained positive indoor-to-subsurface pressure differential across the whole foundation and no movement of land drain vapors to indoor air.

Comprehensive VI Conceptual Model. The tools provided by the VI Assessment Toolkit provide new options for VI pathway assessment in neighborhoods and industrial buildings overlying dissolved chlorinated solvent plumes. These tools addresses limitations of use of conventional multiple lines-of-evidence, including the confounding effect of indoor air vapor sources, temporal variability, and the presence of alternative VI pathways. These tools can easily be integrated into the conventional regulatory approach in the future, as they expand theoptions for the multiple lines-of-evidence that are considered in decision-making. Table ES-3 provides a comparison of the primary VI Toolkit and conventional MLE components.

COST ASSESSMENT

This ESTCP project did not involve the demonstration and cost-tracking of a specific technology. Instead, the focus was on demonstrating and validating the use of the VI Diagnosis Toolkit components to improve our ability to more accurately, cost-effectively, and confidently assess VI impacts to indoor air.

Costs for some of the VI Analysis Toolkit components are already well-understood in the industry (e.g., groundwater and soil gas sampling and analysis) and do not need to be addressed here. Four of the tools that were developed and demonstrated under this work, however, are new to vapor intrusion pathway assessment and so those are the emphasis of the cost analysis below.

The primary cost drivers for use of the VI Assessment Toolkit were as follows:

- Labor costs: Labor costs are an underlying element associated with the implementation of all aspects of the toolkit, including any/all investigations and the design of the comprehensive VI conceptual model.
- Field costs: Field costs include, but are not limited to, drilling, well installation, groundwater and/or soil gas sampling, equipment/disposables, and analytical costs.
- Equipment: For CPM testing, the primary costs beyond labor would include blower-doorequipment and sampling/analytical costs.
- Sampling and Analytical: Costs associated with passive sampler use would include passive sampler costs, labor costs associated with deployment/retrieval, and analytical.

A basic cost assessment for relevant field activities associated with the application of the VI Assessment Toolkit within a 1 km^2 (3000 ft by 4000 ft) neighborhood are shown in Table ES-4. Note that costs are approximate and based on the assumptions detailed in the report.

Table ES-3. Comparison of Primary Lines-of-evidence for the Conventional and VI DiagnosisToolkit Approaches to VI Pathway Assessment.

VI Pathway Assessment Components	Conventional Regulatory Approach (based on USEPA 2015)	VI Diagnosis Toolkit
Groundwater Concentrations	Yes	Yes
Soil Gas Concentrations	Yes	Yes
Sub-Slab Soil Gas Concentrations	Yes	Not needed
Indoor Air Concentrations	Yes (typically 24-h samples)	Yes (multi-week passive samplers)
Sewer and Other Connected Utility Vapor Concentrations	(no explicit guidance forcollection or use)	Yes
Video Surveys forSubsurface Piping Connections	No	Yes
Indoor Source Identification	Yes (through indoor air analysis)	Yes (through portable instrumentsand CPM Testing)
Risk-Based Concentration Screening Table Values	Yes	Yes
VI inclusion Zone Determination	Yes (based on groundwater and soil gas concentrations and lateral distance consideration)	Yes (based on groundwater, soilgas, and utility vapor concentrations and lateraldistance)
Mathematical Modeling	Yes (limited as a line-of-evidence)	Inclusion Zone Determination and with CPM Test Results for VI Pathway Identification
Controlled Pressure Method (CPM) Testing	No	Yes
Mitigation System Selectionand Design	Yes Sub-Slab Depressurization isthe Presumptive Remedy	Yes Sub-Slab Depressurization is a presumptive remedy only if theSoil VI pathway is the only significant route to indoor air

Table ES-4. Cost Estimates for Relevant VI Assessment Toolkit Field Activities

Activity	Scope	Cost
Manhole sampling	Assuming 270 manholes in a 1 km^2 area.	$73,550
Video survey	Assuming an approximate video run-length of 42 blocks within the 1 km^2 area.	$34,000
Constant pressurization method (CPM) test	Per residential-scale test assuming 2000 ft^2 structure.	$17,250
Passive sampler use	Per sample including deployment and retrieval	$300

IMPLEMENTATION ISSUES

The purpose of the study was to validate and demonstrate VI Diagnosis Toolkit components. These include:

- External VI Source Strength Screening
- Indoor Air Source Screening
- Controlled Pressurization Method (CPM) Testing
- Passive Samplers
- Comprehensive VI Conceptual Model

The toolkit incorporates fairly standard hardware and practices. For example, data needs for External VI Source Strength Screening involve soils and/or groundwater data and vapor data from manholes, and CPM testing utilizes readily available blower door equipment from the Heating, Ventilation, Air Conditioning (HVAC) industry. The adoption of passive samplers is growing, but standardized approaches for their validation and calibration are needed as discussed above, particular for use in time-varying concentration environments.

The VI Diagnosis Toolkit can be applied under current regulatory guidance and does not require any additional approvals, licenses, etc. beyond those normally associated with site investigations. No barriers to the collection of the necessary data are anticipated other than those presented by unique site conditions. For manhole sampling, however, it is recommended that manhole access approval is obtained from local governmental engineering departments andthose entities are aware of sampling dates to avoid any issues with local law enforcement.

1.0 INTRODUCTION

1.1 BACKGROUND

Regulatory guidance for assessing the vapor intrusion (VI) pathway varies from federal to state to local levels, but all emphasize multiple-lines-of-evidence (MLE) approaches that involve point-in-time indoor air, sub-slab soil gas, deeper soil gas, groundwater, and soil sampling plus screening-level extrapolation or modeling. Experience suggests that, of the multiple lines of evidence, indoor air data have been weighted most heavily, while detailed research studies have shown that our ability to accurately assess the VI pathway with typical indoor air data is low.

For example, data from the SERDP-funded ER-1686 multi-year study at a well-instrumented and frequently-monitored residence revealed the following limitations of the current MLE paradigm (Holton et al., 2013):

a) It can be costly and time-consuming; the MLE approach rarely leads to decisions in short time frames and might lead to errant outcomes, which is frustrating to owners, occupants, and responsible parties.

b) It is building-centric, without consideration of the practicability of dealing with hundreds of homes in neighborhoods overlying large dissolved chlorinated solvent plumes. The MLE paradigm is also not well-suited for multi-zone residence, office, and industrial buildings. All are possible scenarios with sites that DoD is responsible for.

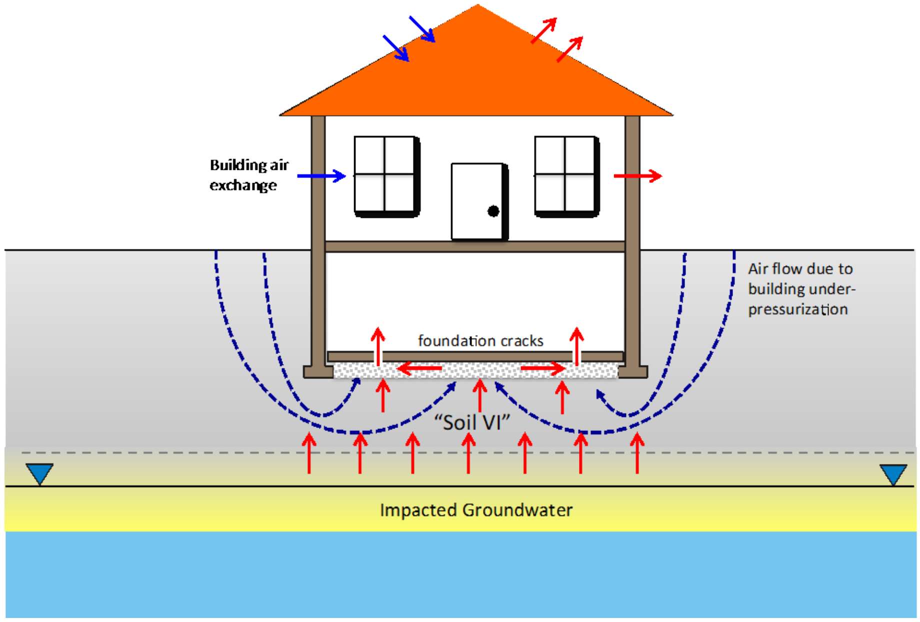
c) It requires or encourages through-the-slab sampling, which is invasive and of concern to building owners and occupants, and likely unnecessary for many buildings.

d) It does not recognize that indoor sources are not easily identified by visual inspection and inventories, and that indoor sources can create subsurface gas plumes that might not dissipate quickly after source removal.

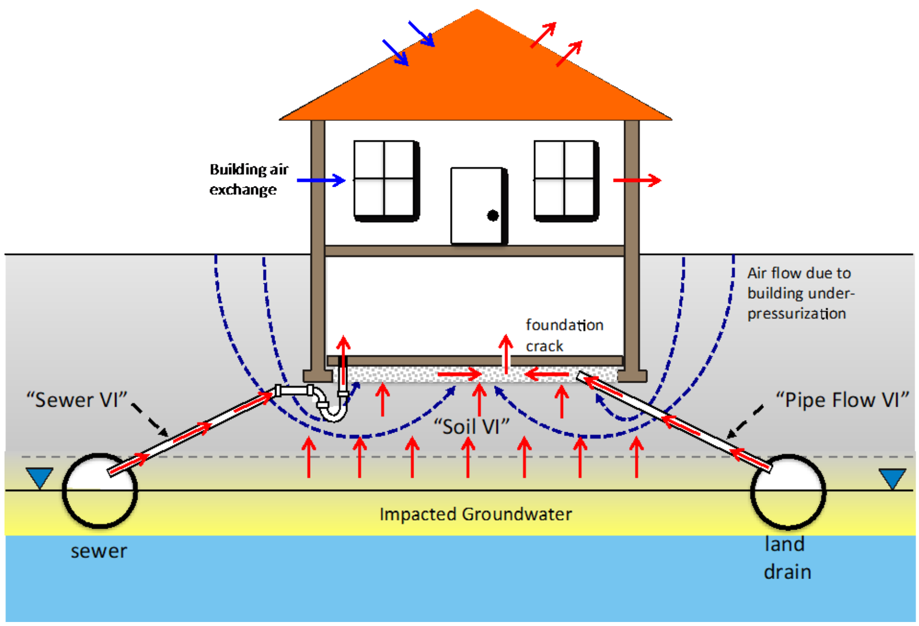
e) It does not recognize that buildings are unique and dynamic systems. Recent projects sponsored by SERDP, ESTCP, USEPA and others have shown that typical point-in-time and space sampling plans are not well matched to the temporal and spatial variability inherent with vapor intrusion processes and their indoor air impacts.

f) It does not build on lessons-learned from recent ESTCP-sponsored VI-related projects (e.g., ER-200707, ER-201119, ER-200830, and ER-1686).

Furthermore, the current MLE approach and data interpretation are founded in simple pathway conceptualizations, such as that shown in Figure 1.1a. There, vapors diffuse upward through soil and away from impacted groundwater. As they approach a foundation, they are swept into the building through foundation cracks and perforations by the advective flow induced by building under-pressurization.



a) Conventional vapor intrusion pathway conceptualization considering only the "soil VI" pathway.



b) Vapor intrusion pathway conceptualization considering "*alternate VI pathways*",including "*pipe flow VI*" and "*sewer VI*" pathways.

Figure 1.1. Vapor Intrusion Pathway Conceptualization for a) the Conventional Pathway which Considers Only the "Soil VI" Pathway, and b) the "Alternate VI Pathway" which Includes "Pipe Flow VI" and "Sever VI" Pathways.

That route to indoor air is referred to as the "soil VI" pathway in this document and is the oneaddressed by most modeling and data interpretation paradigms to date (i.e., Johnson and Ettinger, 1991; USEPA, 2002; Abreu and Johnson, 2005, 2006; Bozkurt et al., 2009).

Through the ER-1686 study and others' anecdotal experiences that we are aware of, it has become clear that additional VI pathways beyond the soil VI pathway can be key contributors. For example, vapor intrusion can result from sewers and their piping connections leading directly indoor as well as foundation drains or other conduits that connect vapor sources directly to the backfill beneath foundations. In addition to impacted aquifers serving as vapor sources, neighborhood sewer mains and land drains can contain contaminants of concern either from chemical discharge to those systems or from contaminated groundwater plumes that intersect the sewers and land drains and leak into them. These neighborhood sewers, land drains, and other major underground piping can serve as distributors of chemical-containing water beyond the footprint of the regional dissolved groundwater plume. These "*alternate VI pathways*" including"*pipe flow VI*" and "*sewer VI*" pathways are shown in Figure 1.1b.

All buildings have subsurface infrastructure and the potential for alternate VI pathways; however, the infrastructure and any natural conduits are not easily discerned via simple observation, building drawings, or traditional site characterization. The significance of it to vapor intrusion is also not assessed by the existing MLE paradigm. For example, at the highly- instrumented ER-1686 study house Sun Devil Manor (SDM), pipe flow VI due to a lateral pipingconnection to a neighborhood land drain system was only discovered and its significance confirmed after four years of study under both natural and controlled pressurization conditions. Itwould not have been discoverable using MLE paradigm data.

Understanding which VI pathways are present and which are significant will be important for mitigation system selection and design, when VI mitigation is needed. For example, under soil gas VI-only scenarios, operation of a traditional sub-slab depressurization system is likely to cause a decrease in sub-slab soil gas concentrations and be protective. When pipe flow VI is present and significant, a sub-slab depressurization system could cause increased sub-slab soil gas concentrations, which could lead to periodic high-concentration indoor air impacts when significant building depressurization transients occur. These transients could be a function of many variables such as high wind loading on the building, rapid barometric pressure swings dueto weather fronts, or use of standard building appliances including ceiling fans, gas water heaters, gas furnaces, and/or clothes driers, to name a few.

The soil gas data in Figure 1.2 from the ER-1686 study house illustrate this. After the land drainlateral piping was discovered, a valve was installed on it to isolate its effect on VI. Soil gas concentrations are plotted for three depths (sub-slab, 3 ft below-slab (BS) and 6 ft BS) and four operational conditions (natural with land drain open, controlled depressurization with land drain open (shaded area A), controlled depressurization with land drain closed (shaded area B), naturalconditions with land drain closed (shaded area C). As can be seen, the sub-slab soil gas concentrations increased by 100X to 1000X when the pressure in the sub-slab region was reduced and the land drain lateral valve was open.

Additionally, data from ER-1686 has shown that an indoor source can create a sub-foundation soil gas plume that persists for days to weeks under natural conditions after the indoor source is removed. Currently there are no guidelines in the MLE-based approaches for waiting periods following indoor source identification and removal.

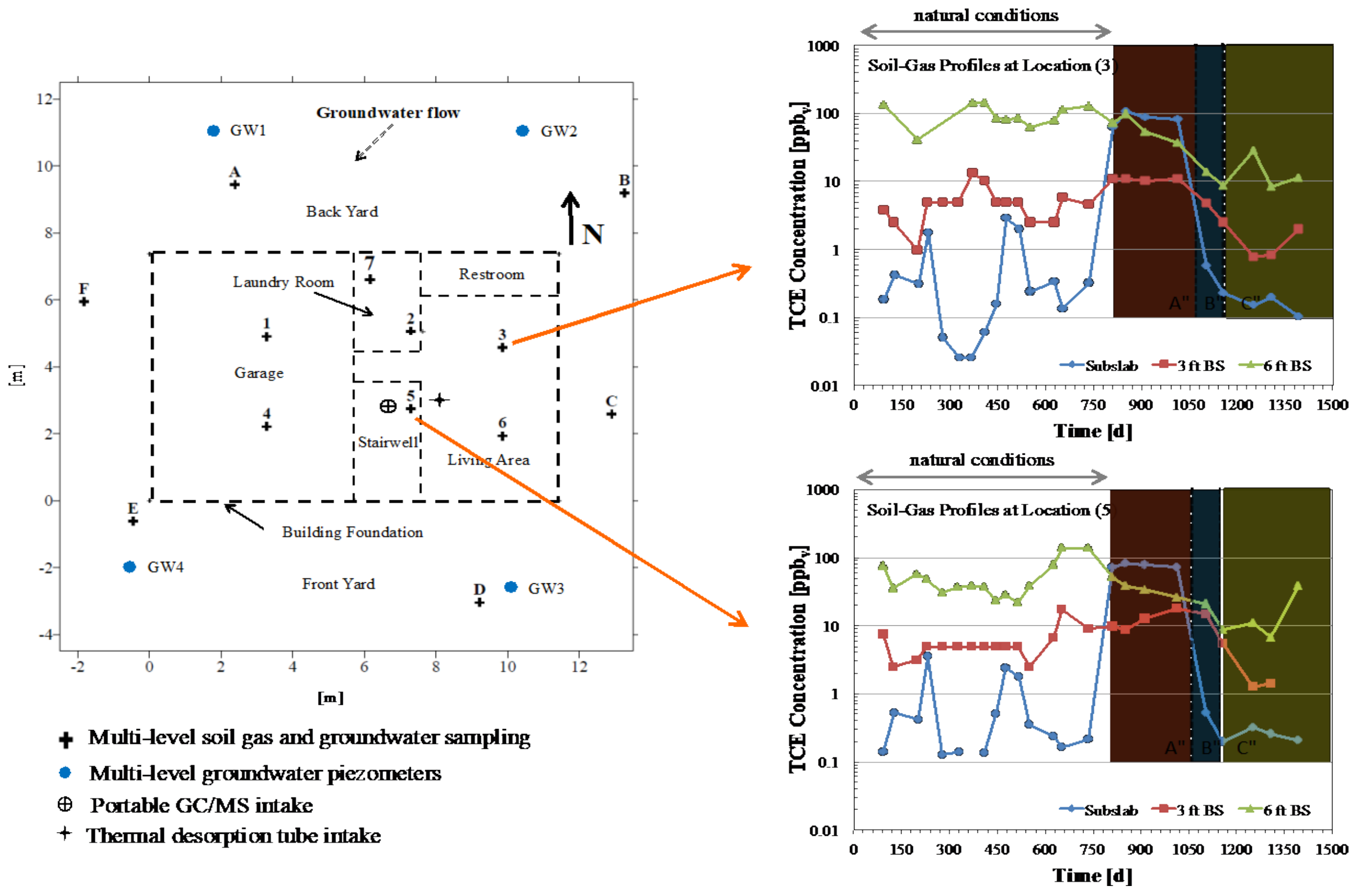


Figure 1.2. Soil Gas Concentrations at Monitoring Locations 2 and 5 Beneath the ER-1686 Study House, Showing Concentrations at Sub-slab, 3 ft Below Slab (BS) and 6 ft BS Depths During Four Operational Conditions: Natural with Land Drain Valve Open, Controlled Depressurization with Land Drain Valve Open (shaded area A), Controlled depressurization with Land Drain Closed (Shaded Area B), Natural Conditions with Land Drain Valve Closed (Shaded Area C).

In summary, the following can render conventional MLE paradigm-based pathway assessment approaches ineffective:

- Each building is a unique dynamic system, so VI impacts can be both temporally and spatially variable at both the neighborhood and individual property scale; thus, infrequent point-in-time measurements common to MLE approaches may not adequately characterize the true indoor exposures and higher-frequency sampling is impracticable.
- Multiple VI pathways may be present, including soil VI, sewer VI and pipe flow VI. This is not explicitly addressed in MLE-based approaches. If not understood and characterized, incorrect neighborhood and site VI conceptual models may be formulated. The footprint of sewer VI- and pipe flow VI-impacted homes may extend beyond the footprint of the dissolved contaminant plume.
- The impacts of alternate VI pathways (pipe flow and sewer flow) might not be addressed by conventional mitigation approaches, and could inadvertently be amplified.

- Indoor sources can create sub-foundation contaminant vapor clouds that may persist for periods of days to weeks after indoor sources are identified and removed. Investigators could remove an indoor source, wait a short period of time, collect sub-slab data in the MLE paradigm, and conclude that the potential for VI impacts is high.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this project was to develop, demonstrate and validate, and advance the use of a suite of tools that can improve our ability to more accurately, quickly, cost-effectively, and confidently assess vapor intrusion (VI) impacts and, if necessary, select appropriate remedies in neighborhoods and industrial areas overlying dilute chlorinated solvent plumes. This suite of tools is referred to as the *"VI Diagnosis Toolkit"*. This project differed from previous efforts in that it recognized that there could be multiple VI pathways, including: a) the traditional "*soil VI*" conceptualization (vapor source → through soil → through foundation to indoor air); b) "*pipe flow VI*" from vapor sources like land drains to sub-foundation regions; and c) "*sewer VI*" where vapors originate in sewers and travel directly to indoor air through sewer piping. It also recognized that VI impacts might extend beyond dissolved plume boundaries due to impacted water distribution by sewers and other subsurface infrastructure, and that the VI pathways discussed above could be present but not discernible by traditional site characterization.

In particular, this project focused on advancing the following tools as their use for VI pathway assessment is relatively new: vapor sampling in subsurface piping (e.g., sewers and land drains), building-specific controlled pressure method testing, use of passive samplers for longer-term monitoring and validation, and use of data to identify likely VI pathways and appropriate mitigation strategies. Protocols and guidance for use of these tools were developed, demonstrated and validated in residential and industrial buildings as part of this work.

1.3 REGULATORY DRIVERS

Regulatory agencies at the federal, state, and local levels generally outline criteria for VI assessment that involve single and possibly time-averaged composite sampling. These criteria invariably focus on seemingly efficient methods for assessment, but do not recognize temporal or spatial variability of contaminant concentrations nor the potential for alternative pathways. In addition, they do not recognize the complexities associated with assessing larger industrial or non-residential structures. Providing a package of tools and protocols that recognize temporal/spatial variability, the potential for alternative pathways, and that provide a common assessment protocol for both large and small structures would improve the confidence associated with VI assessment.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

This project was focused on a suite of tools referred to as the *"VI Diagnosis Toolkit,"* which is intended to be an alternative to the conventional regulatory MLE paradigm. Table 2.1 summarizes the primary components of the VI Diagnosis Toolkit and indicates how knowledge gained from other SERDP and ESTCP-sponsored studies is integrated. The table also lists the key demonstration and validation questions that needed to be addressed for each toolkit component.

2.2 TECHNOLOGY DEVELOPMENT, APPLICATION, AND PREVIOUS TESTING

The primary components of the VI Diagnosis Toolkit summarized in Table 2.1 were at different levels of technical maturity at the project onset. For example, VI pathway source screening using soil gas and groundwater data was already part of the conventional MLE approach, but vapor source strength assessment for the sewer VI and pipe flow VI pathways was not. CPM testing had been demonstrated at a few locations (e.g., McHugh et al. 2012), but validated protocols for its application had not been developed. Based on laboratory data, use of passive samplers looked promising (e.g., McAlary et al. 2014), but their use had not been validated under real time-varying conditions. Finally, conceptual models did not include alternative VI pathways and it was assumed that the presumptive VI remedy (sub-slab depressurization) would be protective under all conditions.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

A more flexible, cost-effective, time-efficient, and robust method for assessing VI impacts was and is still desired by both regulators and practitioners. The VI Diagnosis Toolkit offers a broader suite of tools for VI pathway assessment and can lead to a better understanding of the risks and routes by which VI occurs at a site. The primary limitation is the lack of practitioner experience with applying the VI Diagnosis Toolkit components, especially vapor sampling in subsurface piping, CPM tests, use of passive samplers, and use of all data to select appropriate mitigation strategies, if needed. That is why those were the focus of this demonstration project.

Table 2.1. Primary Components of the *VI Diagnosis Toolkit*.

Component	Purpose	Builds on Knowledge-Gained from previous SERDP/ESTCP Projects	Key Demonstration and Validation Questions
1. External VI source strength screening (e.g., groundwater, soilgas, sewer and land drain vapor concentrations)	Identify buildings and neighborhood sub-areas most likely to be impacted by VI and needing building-specific testing	ER-1686; the sampling of sewers and land drains and use of that data *is a new assessment component likely critical at some sites as indicated by ER-1686 results*	How can external VI source strength screening be used to identify buildings and neighborhood areas needing building-specific testing? How best to characterize vapor concentrations in subsurface piping?
2. Indoor air source screening	Identify and remove indoor air sources prior to indoor air testing under natural or controlled pressurization conditions.	ER-201119, ER-1686; *ER-201119 demonstrated value of portable detector indoor source screening; ER-1686 showed lingering memory of indoor sources.*	How long must one wait after removing indoor air sources to conduct building-specific tests?
3. Controlled pressurizatio n method (CPM) testing	Measure the maximum indoor air impact under natural conditions caused by VI; identify the VI pathway most responsible for VI impacts to indoor air	ER-200707, ER-1686; *ER-200707 demonstrated utility of depressurization; ER-1686 showed that depressurization can amplify contributions of some VI pathways over others and can lead to significant over-estimates of indoor air impacts under natural conditions; ER1686 also showed that differences in COC and radon responses might be indicators of alternate pathways.*	What protocol should be followed when conducting a controlled pressurization method tests (e.g., flowrate, pressure differential, duration,sequence of events)? How should the data be analyzed?
4. Passivesamplers	Longer-term confirmation monitoring and validation of mitigation system performance.	ER-200830; *ER-200830 validated that passive samplers can provide equivalent or better data than conventional sampling under controlled constant concentration conditions.*	Do passive samplers provide accurate time-weighted concentrations under field conditions with significantly time-varying concentrations?
5. Comprehensive VI conceptual model	Used as framework to interpret data collected from the components above.	ER-1686; *ER-1686 data indicate that improper conceptualization of VI sources and pathways can lead to misinterpretation of site data.*	Can improper conceptualization lead to misinterpretation of assessment results, and can this lead to installation of mitigation systems that are ineffective or even amplifiersof VI impacts?

3.0 PERFORMANCE OBJECTIVES

The performance objectives, as defined at the outset of the project, are shown below in Table 3.1.

Table 3.1. Performance Objectives.

Task ***[duration]***	**Performance Objective**	**Data Requirements**	**Success Criteria**
Quantitative Performance Objectives			
Task 1: External source and flux screening *[4X quarterly sampling over 12 months; concurrent with Task 2]*	Determine how best to sample vapors in sewers and land drains, and demonstrate use of external source strength data to identify at-risk neighborhood sub-areas and homes with potential for VI impact	Groundwater concentrations and vapor concentrations in land drainsand sewers in OU-8 for four seasonal events, plus historical indoor air data set	Delineation of vapor sourcestrength within 50% on a neighborhood scale for soil VI, pipe flow VI, and sewerVI pathways; >90% correlation between at-risk sub-areas and known VIimpacts
Task 2: Controlled pressurization method (CPM) protocol validationand demonstration*[24 months validation tests in Sun Devil Manor and 12 months of demonstration at other sites]*	Develop a practicable CPM protocol that leads to determining if VI mitigation is needed and what type of mitigation system is appropriate	Indoor air concentrations, building air flow rates, and differential pressures under a range of CPM conditions (e.g., over-/under-pressurizations, active pipe flow VI,pre-existing soil gas clouds caused by indoor air sources); historical Sun Devil Manor data set	Short-term CPM protocol leads to confident assessment of worst-case VI impacts within ±50% as verified by comparison to data collected from ER-1686
Task 3: Use of passive samplers under time-varying indoor air conditions *[30 months; concurrent with Tasks 2 and 4]*	Demonstrate that passive samplers provide accurate time-averaged results under conditions of large temporal variability over multi-week periods of time	Passive sampler results for 3-weeksampling durations and real-time indoor air sampling data	3-week passive sampler results are within ±50% of the known time-averaged concentration result calculated from high frequency sampling data during the passive sampler sampling period
Qualitative Performance Objectives			
Task 3: Passive samplers (cont. fromabove)			Demonstration site results are consistent with what is known about VI impacts at the test buildings
Task 4: VI Mitigation system performance under conditions with alternate vapor intrusion pathways *[12 months following CPM test validation inTask 3]*	Assess if conventional VI mitigation systems are effective or inadvertentlycreate adverse impacts under conditions with pipe flow and sewer VI	Indoor air and sub-slab soil gas concentrations, pressure differentials;building exchange rates	Performance of conventional VI mitigation system is known under conditions withand without alternate VI pathways
Task 5: Comparisonof results to conventional MLE approach *[6 months]*	Determine if Toolkit components are more practicable and lead tocorrect results	All data from Tasks 1 – 4 and historical ER-1686 data set	Similarities and differences in results of the MLE and proposed paradigm areknown

3.1 EXTERNAL SOURCE STRENGTH SCREENING: DEMONSTRATE HOW EXTERNAL SOURCE STRENGTH SCREENING CAN BE USED TO IDENTIFY AT-RISK NEIGHBORHOOD SUB-AREAS AND HOMES NEEDING BUILDING-SPECIFIC TESTING

Particularly in neighborhoods with many buildings, there is a need to identify the subset of buildings at risk from significant VI impacts and needing building-specific testing (indoor air monitoring and/or CPM testing).

3.1.1 Data Requirements

External source strength screening involves the use of groundwater, soil gas, and subsurface piping vapor concentrations.

3.1.2 Success Criteria

Collect sufficient groundwater and subsurface piping vapor concentration data to identify the subset of buildings at risk from significant vapor intrusion in the OU-8 area exterior to Hill AFB. Illustrate how the screening analysis is conducted using that data set and then compare the results with historical indoor air data in the OU-8 area.

3.2 VALIDATED CPM PROTOCOL DEVELOPMENT

Building-specific VI pathway assessment through application of CPM testing offers a quicker and more confident approach than limited indoor air grab sampling to determine if mitigation is needed. In order for its use to be accepted and to expand, a validated CPM testing protocol is needed. The goal of this task is to develop and validate a CPM testing protocol.

3.2.1 Data Requirements

CPM tests involve measurement of air flow rates, differential indoor-outdoor pressures, indoor air concentrations, indoor air volume and time. A data set of long-term VI impacts under natural conditions is also needed for at least one test building.

3.2.2 Success Criteria

The goal is to develop, validate and demonstrate use of a short-term CPM testing protocol that leads to determination of short-term maximum concentrations that agree to within ±50% of the known data from ER-1686.

3.3 DEMONSTRATE THAT PASSIVE SAMPLERS PROVIDE ACCURATE TIME-AVERAGED INDOOR AIR CONCENTRATION RESULTS UNDER SIGNIFICANTLY TIME-VARYING CONDITIONS OVER MULTI-WEEK PERIODS OF TIME

Passive samplers offer a way to accurately characterize long-term average indoor air concentrations. However, their use has not been validated under conditions for which indoor air concentrations are highly variable over time. The goal of this task is to test passive sampler use under such conditions and compare results against high-frequency grab sample results.

3.3.1 Data Requirements

Passive sampler data from extended periods of application and high-frequency grab sampling concentrations for the same time periods.

3.3.2 Success Criteria

Success will be determined by multi-week passive sampler results that are within ±50% of the known time-average result calculated from high-frequency real-time concentration data.

4.0 SITE DESCRIPTION

4.1 TEST SITE SELECTION

With the exception of the industrial building CPM tests, the ER-201501 project was conducted in the Hill AFB OU-8 groundwater plume area shown in Figure 4.1. The dilute dissolved chlorinated solvent plume extends south-southwest from Hill AFB and is beneath the "Sun Devil Manor" (SDM) ER-1686 study house. The industrial building tests were performed at Travis and Beale Air Force Bases in California. Specific components of this project and their locations include:

- External vapor source strength characterization in the sewer and land drain systems running through the neighborhood overlying the OU-8 plume.
- CPM protocol development and validation were conducted at Sun Devil Manor
- Residential house CPM protocol demonstrations were conducted in three houses adjacent to Sun Devil Manor in the OU-8 plume area
- Industrial building CPM protocol demonstrations were conducted at Bldgs. 2474, 2425, and 24176 at Beale AFB, CA and in Bldg. 18 at Travis AFB, CA.

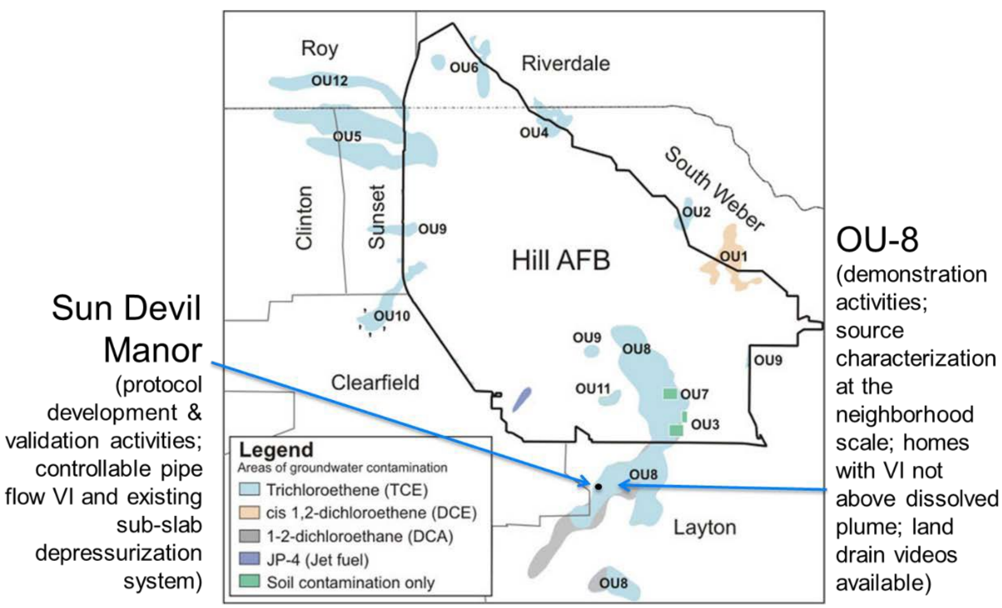


Figure 4.1. Sun Devil Manor and Hill AFB OU-8 Demonstration Sites

4.2 HILL AFB OU-8 TEST SITE HISTORY/CHARACTERISTICS

Residential neighborhoods in the vicinity of Hill AFB were selected because of the historical indoor air and groundwater data set and relationships that Hill AFB staff have with property owners. The Sun Devil Manor home shown in Figure 4.2 provided a unique opportunity for development and validation of VI diagnostic toolkit paradigm protocols because:

- It was already highly instrumented as a result of the ER-1686 SERDP project research.

- It had verified pipe flow VI, and the pipe flow VI could be turned on and off with a valve that was installed on the land drain lateral piping in our ER-1686 study.
- It had a sub-slab depressurization soil gas mitigation system that could be turned on and off.
- It was owned by ASU, so there were no logistical barriers to scheduling project activities, such as adding and removing indoor air sources, performing multiple repeats of protocol testing conditions, and duration of studies.

The Hill AFB OU-8 plume area provided a useful test area for the neighborhood-scale vapor source strength characterization protocol development and illustration of vapor source strength screening for possible at-risk home identification. The area also provided a convenient location for land drain video exploration to identify homes with direct connections to the land drain system.

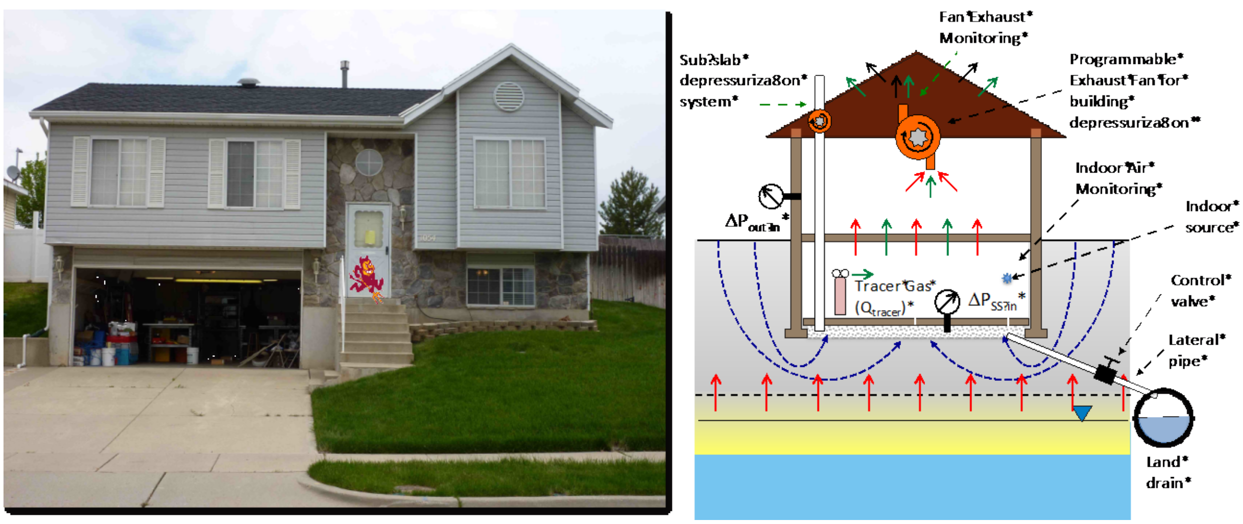


Figure 4.2. Sun Devil Manor Facility for Initial Testing and Validation of VI Diagnosis Toolkit Components, with Schematic Showing Controls for Indoor Sources, Alternate VI Pathways (Land Drain Lateral), and Temporally Variable Controlled Pressurization.

Not shown are multi-depth soil gas sampling probes beneath and surrounding the foundation installed for ER-1686.

4.3 BUILDING 18, TRAVIS AIR FORCE BASE, CALIFORNIA

Travis Air Force Base is located in northern California, midway between San Francisco and Sacramento, about three miles east of downtown Fairfield in Solano County (Figure 4.3; Travis AFB Groundwater IROD, 1997). Travis AFB is part of the Air Mobility Command (AMC) andis host to the 60th Air Mobility Wing (AMW). The primary missions of Travis AFB since its establishment have been strategic reconnaissance and airlift of freight and troops.

Building 18 lies adjacent to the active flight line (Figure 4.4; CH2MHill, 2016). It was constructed in 1960 and served as a degreasing facility through the 1990's. Degreasing operations were no longer conducted. The building was unoccupied and used as a storage facility for office equipment and other miscellaneous furniture/materials. Attributes of Bldg. 18 are shown in Table 4.1.

Table 4.1. Attributes of Travis AFB Bldg. 18

Location	Size(ft^2)	Bldg. History	Occupancy Status	Historyof VI Impact	Comment
Travis AFB Bldg. 18	6000	Aircraft engine degreasing facility	Abandoned	Yes	Building 18 is abandoned and scheduled for demolition

Building 18 is part of Environmental Restoration Program Site SS016. SS016 is a 210-acre groundwater impacted site of which TCE is the primary contaminant. Building 18 and the adjacent oil spill area have been identified as one of the sources for this dissolved groundwater plume (CH2MHill, 2016).

As part of a broader 2008-2010 vapor intrusion assessment of structures at Travis, three samples were collected from Building 18. Sample locations and associated TCE concentrations, all of which exceeded calculated risk-based concentrations (RBCs) are shown in Table 4.2 (CH2MHill, 2013). The 2008–2010 vapor intrusion assessment concluded that there was potentially significant future risk from vapor intrusion at this facility because of the presence of DNAPL in soil adjacent to the site and high TCE vapor concentrations in sub-slab soil gas samples. At the time of testing, the building was slated for demolition.

Table 4.2. TCE Concentrations Associated with Bldg. 18 Sampling.

Location		Analyte	Concentration (ppbv)
Office	Breathing zone	TCE	1.3
	Subslab		510,000
Tank Room	Breathing zone		0.26
Shower Drain	From drain		0.65

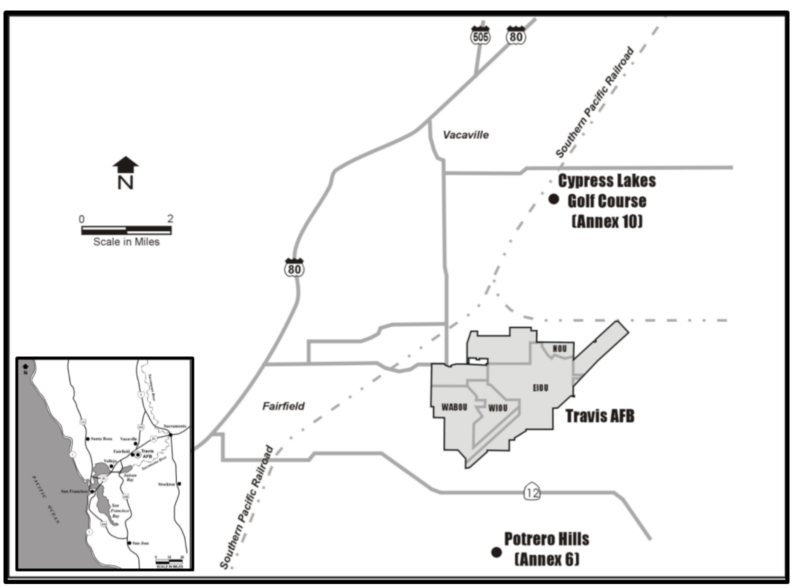


Figure 4.3. Site Location Map – Travis AFB, California

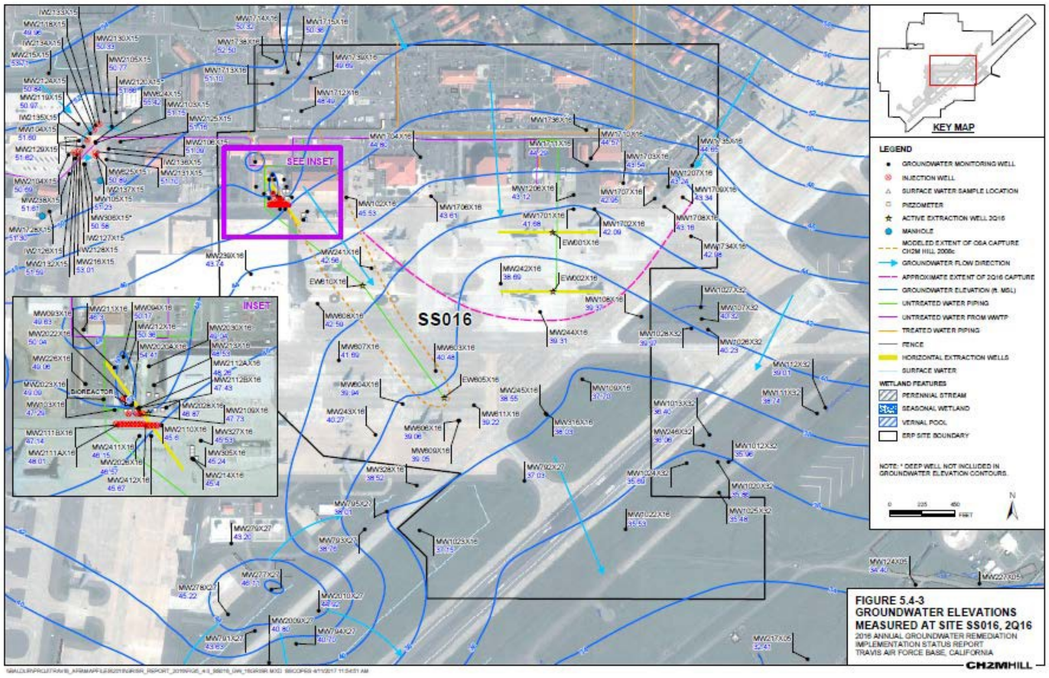


Figure 4.4. Site Location Map - Travis AFB Building 18

Building 18 was selected for demonstration use because of its history of VI, occupancy status, proximity to a chlorinated solvent plume source, and because it was conveniently accessible for CPM and indoor air testing.

4.4 BEALE AIR FORCE BASE BUILDINGS 2474, 2425, AND 24176

Beale AFB lies within Yuba County in Northern California, approximately 40 miles north of Sacramento and 13 miles east of Marysville (Figure 4.5; CH2MHill, 2016). It covers approximately 23,000 acres.

Beale AFB started as Camp Beale, an Army installation, at the onset of World War II. During World War II, the Base served as an armored division and later as infantry division training base. The Base was transferred to the Air Force in 1948 and served primarily as a training base for aviation engineers. In 1965, it became a Strategic Reconnaissance Wing and since 1981 has been the 9th Reconnaissance Wing under Air Combat Command.

The generalized geology/hydrogeology of Beale AFB consists of unconsolidated sedimentary deposits, underlain by consolidated sedimentary bedrock, which is underlain by crystalline metamorphic bedrock. Groundwater occurs primarily in the unconsolidated sedimentary deposits and flows predominantly through the unconsolidated sedimentary deposits. Depth-to-water in the CG041-039 vicinity is roughly 40 ft.

Site CG041 was established by the Air Force in 2013 to separate groundwater responses from soil responses and address base-wide groundwater as a single site. It currently consists of groundwater plumes underlying 11 soil sites. Of interest to this study was Plume GC041-039, a dilute chlorinated solvent plume that trends to the south with TCE concentrations currently ranging to approximately 110 ug/L.

As per the current Record of Decision (USAF, 2018), to address issues associated with risk assessment, an additional industrial/commercial Land Use Control addressing new buildings is to be implemented at Plume CG041-039. As such, indoor air samples were to be collected at Buildings 24176, 2425, and 2474 overlying Plume CG041-039 to directly assess risk via vapor intrusion and confirm current use of the buildings in this area is acceptable.

A map of buildings 24176, 2425, and 2474 is shown in Figure 4.6, the attributes of which are shown in Table 4.3.

Attributes that make these buildings of interest for demonstration purposes include their proximity to a dilute chlorinated solvent plume, their accessibility for CPM testing, and the ROD requirement that they be tested for VI.

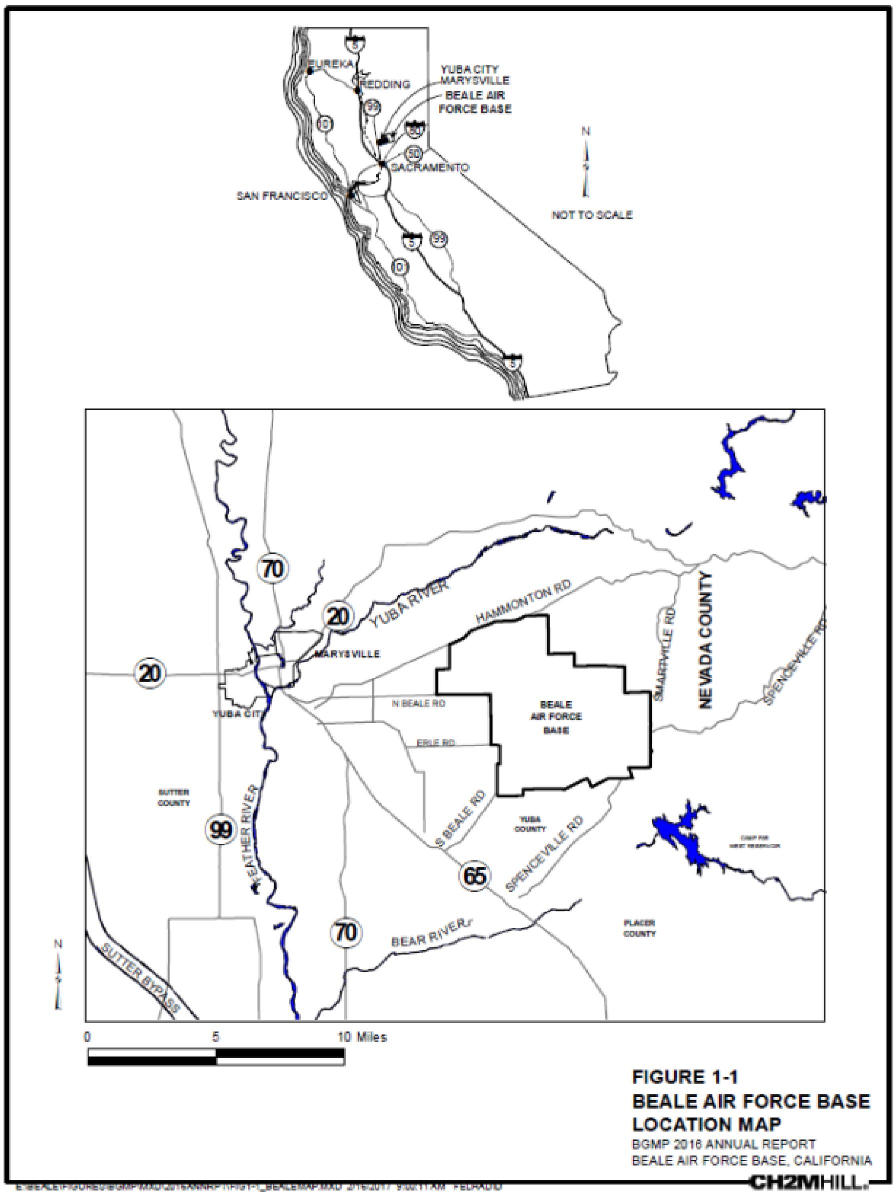


Figure 4.5. Location Map – Beale Air Force Base, California.

Table 4.3. Sites and Attributes of Industrial Scale Buildings Selected for Demonstration at Beale AFB, CA.

Beale AFB Location	Size (ft^2)	Bldg.Use	Occupancy Status	History of VI	Comment
Bldg. 2474	10,300	Theatre	Occupied	No	These buildings overlaya dilute TCE groundwater plume (5-100 ug/L)
Bldg. 2425	20,500	Community Activity Center	Occupied	No	
Bldg. 24176	13,600	Dormitory/Hotel	Occupied	No	The ROD required VI testing for these facilities

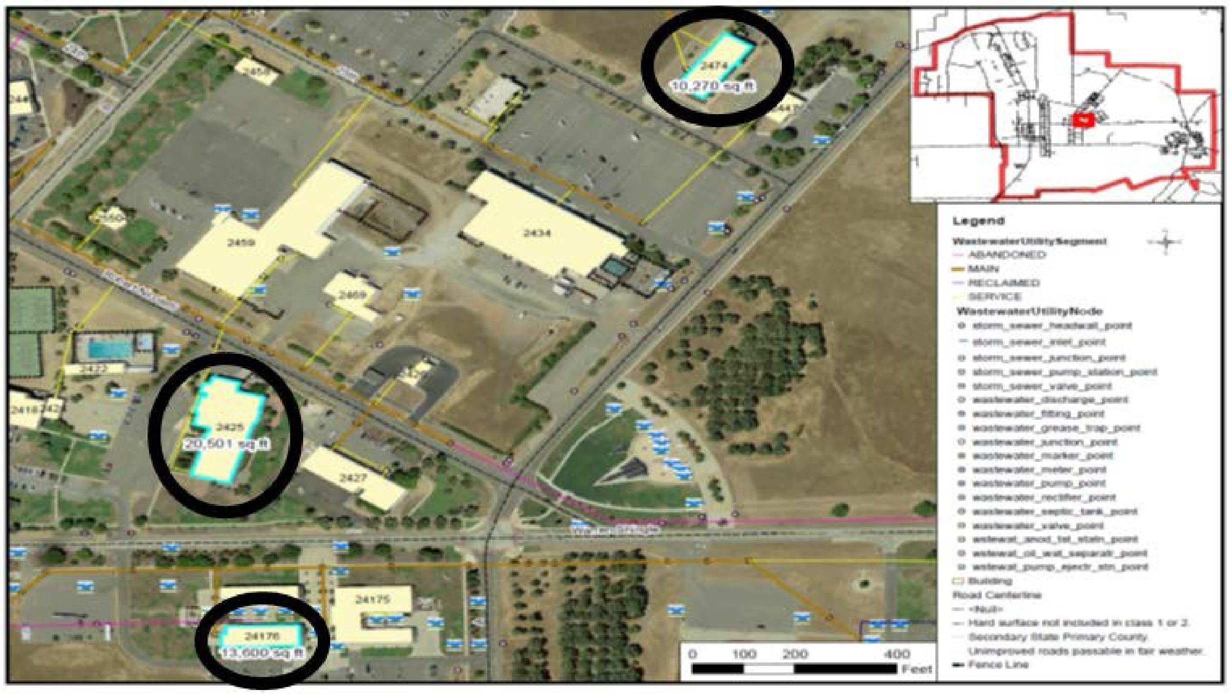


Figure 4.6. Map for Beale AFB CG041-039 Area, Showing Buildings 2474, 2425, and 24176

5.0 TEST DESIGN

5.1 OVERVIEW OF THE EXPERIMENTAL DESIGN

An overview of each task conducted under this project is discussed below.

Task 1) - External Source Strength Screening: In this task vapor samples were collected from sewer and land drain mains in neighborhoods overlying the Hill OU-8 plume area. This sampling occurred in five season-based events across a 1.25-year period.

In addition to the five area-wide season-based events, high-frequency sampling was conducted to better understand the temporal variability of vapor concentrations in the sewer and land drain main systems. This included:

- Continuous sampling for five season-based weeklong periods at 12 manholes, the selection of which was based data from on the five area-wide events; and
- Real-time sampling of two land drain manholes and one sanitary sewer for fivemonths.

Task 2) – CPM Protocol Development, Validation, and Demonstration: This effort built on lessons-learned from ER-200707. Task 2 protocol development and validation occurred primarily in Sun Devil Manor. Conditions explored are listed below in Table 5.1.

Table 5.1. Conditions to be Used During the CPM Protocol Validation Testing at Sun DevilManor.

CPM Protocol Operational Conditions	Initial Conditions	Indoor Air Source Present During Test	Pipe flow VI (controlled by landdrain lateral valve)	Other
+1, +5, -1, -5 Pa buildingunder- and over- pressurizations; 48-h duration tests with high-frequency real-time sampling and analysis	With and without initial sub-slab soil gas plume created by indoorair source	With and without indoor air source	With and without (land drain lateral valve open and closed)	Each condition was tested at least twiceto assess reproducibility of results

Following the validation phase, use of the CPM test protocol was demonstrated at thefollowing locations:

- Three additional residences within the OU-8 plume area, with the following characteristics:
  - Residence 1 – home overlying the groundwater plume, indoor air sampling history shows no VI impact/
  - Residence 2 – home outside the groundwater plume boundary, history of PCE and1,2 DCA in indoor air, a vapor recovery system (VRS) in place.

  - Residence 3 – home overlying the groundwater plume, confirmed history of TCE from VI, and a VRS system in place.

- Four industrial-scale structures:
  - Building 18, Travis AFB – unoccupied, adjacent to a TCE spill and history of VI impacts to indoor air, and presence of chemicals of interest in sub-slab soil gas.
  - Buildings 2476, 2425, and 24176, Beale AFB – all buildings occupied, all located over a dilute TCE groundwater plume, no previous indoor air sampling history, all required testing as mandated by ROD.

Task 3) - Use of Passive Samplers under Time-Varying Indoor Air Conditions: In this task, passive samplers were deployed during Tasks 2 and 4 to determine if they provide accuratetime-averaged concentrations over multi-week periods with highly-varying indoor concentrations. Results were compared against time-averages of high-frequency vapor sampling results collected during the passive sampler deployments.

Task 4) - VI Mitigation system performance under conditions with and without alternate vapor intrusion pathways: In Task 4, the sub-slab depressurization system at Sun Devil Manor was operated with the land drain lateral valve open and then with it closed. Indoor air and sub-foundation soil gas was monitored in real time to assess the performance of the conventional mitigation system under conditions with and without pipe flow VI.

In addition, the mitigation system was tested at reduced flowrates to determine the efficacyof the system when operated in more energy efficient modes, using the design approach developed in ESTCP ER#201322 (McAlary, 2018)

Task 5) - Comparison of the Conventional MLE Approach and Use of the VI Toolkit. In thistask, the tools, data, and what can be determined in both approaches are compared and contrasted.

5.2 SAMPLING PLANS

This project's sampling activities are summarized below. QA/QC for each is provided in the Quality Assurance Project Plan (Appendix B).

5.2.1 Vapor Sampling

Vapor samples were collected from indoor and outdoor air, sanitary sewers, land drains, and storm sewers. Vapor sampling locations included Sun Devil Manor, utility manholes across OU-8 (sanitary sewer, storm sewer, and land drain), and the CPM test demonstration locations.

Sampling within houses focused on the main and lower living areas, although samples throughout the houses were typically collected. Sampling within industrial buildings included all rooms in the structure as possible.

The spatial density of vapor sampling points in sewer and land drain mains was dictated by the number of access points in the neighborhood; it was the intent to sample as many of the accessible locations as possible, and the number of sampling locations increased between the initial and final sampling events.

In general, vapor sampling involved the following:

- Automated sampling for real time gas chromatography using negative pressure pumps and mass flow controllers for flow control;
- Grab sampling in Tedlar bags using a lung sampler and vacuum pump;
- Active thermal desorption tube (TD tube) sampling using an MTS-32 autosampler (Markes, Ltd., UK) for long-term, continuous 24-h sample collection, or active short term sampling with a vacuum pump with mass flow controller or flow control orifices; and
- Passive sampler deployment.

Automated GC gas sample collection followed protocols defined by the project needs. Tedlar bag grab samples were collected in new or dedicated bags that were flushed with helium, nitrogen, or zero air prior to use (and after use if dedicated to a specific sample location). Active sorbent tube (TD tube) sampling was conducted with verification of the volume of air pulled through the sampler. Passive samplers were deployed in accordance with manufacturer recommendations.

Vapor samples were analyzed for chlorinated alkenes and alkanes relevant to the chemicals present in groundwater. For all locations, those analytes included TCE, 1,1-DCA, 1,2-DCA, 1,1,1-TCA, 1,1,2-TCA, 1,1-DCE, cis 1,2-DCE, trans 1,2 DCE, and PCE as possible. Vapor samples were also analyzed for radon if circumstance permitted.

5.2.2 Soil Gas Sampling

Soil gas samples were collected beneath and adjacent to the foundation at Sun Devil Manor. Soil gas sampling involved the following:

- Use of permanently installed soil gas sampling implants. The vertical spacing of sampling points was on three-foot centers down to the groundwater surface. Spacing for all sampling locations was keyed to the sub-slab level of the house.
- Collecting soil gas in Tedlar bags using a lung sampler and a vacuum pump.

Soil gas samples were analyzed in the field for the same compounds discussed above for vaporsamples.

5.2.3 Constant Pressurization Method (CPM) Tests

CPM tests utilized a Retrotec blower door system (Wohler Retrotec, WA) for under- and over-pressurization and was operated in accordance with the manufacturer's instructions.

Following initial protocol development, CPM protocols were tested at Sun Devil Manor. In addition, protocols were also tested in two homes adjacent to Sun Devil manor and in Bldg. 11193, Vandenberg AFB, CA. While data for the two additional homes or Vandenberg AFBwill not be discussed here, these tests helped the team further refine CPM protocols for applications in both residential and industrial settings.

Subsequent to development, CPM demonstrations were performed at three additional residential locations within OU-8, one industrial building at Travis AFB, CA, and three industrial buildings at Beale AFB, CA.

5.2.4 Sample Identification and Location

Each sample was labeled with a unique sample name/number coded to identify the sampling location and date and time of sample collection. This information, along with a brief sample description, was logged. All sample locations were also mapped.

5.2.5 Demonstration Set-Up, Start-Up, and Demobilization

This project leveraged the research infrastructure put in place under SERDP ER-1686 at Sun Devil Manor, which did not need to be mobilized or demobilized.

Mobilization and demobilization from field sites other than Sun Devil Manor included the temporary placement/removal of blower doors, pressure monitoring equipment, sampling equipment, and analytical equipment as needed.

5.2.6 Amount/Treatment Rate of Material to be Treated and Residuals Handling

The only residuals generated during this project were indoor and outdoor air, land-drain, storm-drain, and sanitary sewer gas, and land-drain and storm-drain water samples. Air samples were discharged to the environment and water samples were returned to ASU for analysis and disposal as per the ASU Environmental Health and Safety Hazardous Waste Management policies.

5.3 ANALYTICAL/TESTING METHODS

Analytical methods for this project are summarized below in Table 5.2, with additional details provided below. The QA/QC for analytical/testing is provided in Appendix B, in the Quality Assurance Project Plan (QAPP).

Chemical analyses focused on the following chlorinated compounds: vinyl chloride, TCE, 1,1-DCA, 1,2-DCA, 1,1,1-TCA, 1,1,2-TCA, 1,1-DCE, cis 1,2-DCE, trans 1,2 DCE, and PCE as possible. Of these, vinyl chloride was never functionally detectable, and the GC-ECD and GC-DELCD analyses results frequently were dominated by TCE, 1,2-DCA, 1,1,1-TCA, and PCE.

Grab sample and real-time collection and analyses were performed at Sun Devil Manor. For the industrial building CPM tests, analytical equipment was deployed in the field for real-time analyses.

With few exceptions, TD tube samples were analyzed at ASU using GC-MS. Passive samplers and a select group of TD tube samples from the Beale and Travis AFB industrial facilities were shipped to and analyzed by Beacon Environmental Services, Inc. (Maryland).

5.3.1 Sorbent Tubes/Thermal Desorption Analysis

Multi-bed sorbent tubes or TD tubes (0.64 x 15.2 cm-long) packed with Tenax-GR and Carboxen-569 were used for vapor sample concentration. Sorbent tube samples were collectedin one of the following four ways:

- Active sampling onto a tube using a flow-controlled vacuum pump or flow controlorifice;
- Use of a Markes MTS-32 autosampler for continuous 24-h collections;
- Use of a customized SRI Instruments (SRI Instruments, Torrance, CA) 20-stream gas sampling valves with a vacuum pump and mass flow controller; or
- Passive sampling.

For extended active sampling periods, Markes Difflok sampling caps (Markes International, UK) were used to ensure sample stability. Active sample collection was limited to 200 mL/min to prevent damage to the sorbent packing. Sampling periods were adjusted depending on concentrations present, analytical targets, and sampling circumstances.

Passive samplers utilized screened caps and/or orifice reducers to control exposure, dependingon sampler type.

Following sample collection, sorbent tubes were capped with Swagelok caps with Teflon ferrules and were shipped to ASU for analysis.

Table 5.2. Summary of Key Site Measurements; Analytical Method, Equipment and Frequency, Sampling Location, and Data QA/QC

Key Site Measurement	Analytical Method	Equipment and Frequency	Sampling Location	Data QA/QC	Comment
Air pressure differentials	Real-time or discrete pressure transducer with data logger.	Retrotec DM32 control panels with pressure differential monitoring and logging (typically30 second to 1-minute recording intervals). User defined recording intervals for each.	Pressure differentials between indoor and sub-slab at existing sub-slab monitoring locations; indoor lowest living space and outdoor; indoor lowest living space and utilities (e.g., sewer, land drain).	Sensors are referencedto a zero differential on regular intervals	The direction/ magnitude of gas exchange between soil gas and indoor air is related to this quantity; it is a small value and varies at high frequency.
Real-time indoor air, outdoor air, andHVAC temperature	Type J thermocouple anddata logger	Type J thermocouples connected to data loggers; discrete readings on user defined intervals (usually 10 minute or less samplinginterval).	Monitored in lower living spacetargeted for indoor air and pressure differential sampling; single outdoor and HVAC locations.	Verify response in icewater and boiling water	Indoor-outdoor temperature differential was correlated with VI activity in previous study; HVAC temperature can be used to monitor HVAC operation.
Real-time and discrete indoor, outdoor and/or soil gas sampling and vapor-phase analyses of chlorinated compound concentrations (real-time and batch sampling)	SRI GC-ECD	Sample collected/analyzed using SRI 10-stream gas-sampler onto thermal desorption trap followed by desorption and analysis using on-site GC-TO-14-ECD; sampling interval as defined by project need.	Indoor air sampling in lowest living area, outdoor sampling inbackyard away from house, andselected soil gas locations.	Data from different methods were compared for internal consistency; standard QA/QC procedures are followed, including blanks, calibrations, and internal standards.	Critical measurement to which all other measurements are related and for assessing the relationship between vapor flux emissions and groundwater concentrations.
	GCMS-Thermal Desorption	Samples collected onto thermal desorption tubes using SRI data system and 20-stream gas samplers, followed by desorption and analysis by Markes Unity thermal desorber and GC-MS at ASU lab. Sampling interval as defined by project need.			
	SRI GC-ECD Or SRI GC-DELCD	Soil gas samples collected in tedlar bags using lung-sampler, then analyzed using GC-TO-14-DELCD or GC-DELCD and GC-PDD.			
	SRI GC-PDD	Real-time samples collected/analyzed usingSRI 10-stream gas-sampler and analyzed by GC-PDD; sampling interval defined byproject need.			

Table 5.2. Summary of Key Site Measurements; Analytical Method, Equipment and Frequency, Sampling Location, and Data QA/QC (Continued)

Key Site Measurement	Analytical Method	Equipment and Frequency	Sampling Location	Data QA/QC	Comment
Real-time and discrete indoor air and soil gas SF_6 sampling	SRI GC-PDD	Discrete samples collected in tedlar bags using lung-sampler, then analyzed using SRI GC-PDD.	SF_6 is released indoors continuously at 3.2 mL/min. Indoor air sampling in lowest living area, outdoor sampling in backyard away from house, and selected soil gas locations.	A reference standard was run every 10th sample run, approximately every 5 hours	SF_6 was used as a tracerfor determining air exchange rates, studyingindoor source behavior, and confirming vapor migration pathways.
Dissolved chlorinated compound concentrations in groundwaterand utilities.	SRI GC-DELCD	Groundwater samples collected and preserved with HCl in 40-mL VOA bottles and transported to ASU/CSM lab for analysis using SRI GC-DELCD. On site analysis using the same technique was utilized as needed.	All available neighborhood groundwater wells, utility access points, and existing discrete monitoring points at study site.	Results are validated using blanks, duplicates, replicates, trip blanks, and calibrations.	One initial screening lineof evidence of the footprint of potentially impacted buildings.

Sorbent tubes were analyzed using a Markes Ultra autosampler, a Markes Unity thermal desorber (Markes International, UK) and an HP5890 gas chromatograph (GC) with an HP5972 mass spectrometer (MS). The GC analytical column was a 60-m long Restek RXI-5 capillary column. GC-MS analysis of samples used the selective-ion monitoring (SIM) mode.

Prior to each use, sorbent tubes were conditioned using a Markes TC-20 tube conditioner (Markes International, UK) at ASU. Tube conditioning involves incremental heating (180°C for 10 min, 210°C for 10 min, 230°C for 10 min, and 250°C for 30min) of each tube with a simultaneous 15-20 mL/min sparge of ultra-high purity (UHP) nitrogen. Once the conditioning program was finished, tubes were allowed to cool to room temperature with a continuous sparge of nitrogen and then capped with Swagelok brass caps with Teflon ferrules

Calibration of the GC/MS was performed prior to each sample set using gas standards prepared from a customized 1 ppm_v commercial gas standard containing a suite of chlorinated and petroleum hydrocarbon compounds in nitrogen.

QA/QC included calibration prior to each batch of samples with at least three different concentrations spanning the concentration range of interest. In addition, sample blanks, trip blanks, duplicates/replicates, and internal standards were run on a regular basis.

5.3.2 GC-ECD Analysis

Depending on concentration and purpose of sampling, composite air samples were collected for analysis using a multi-bed sorbent tube trap (0.64 x 15.2 cm) packed with Tenax-GR and Carboxen-569, vacuum pump, mass flow controller (real-time sampling included an SRI gas sampling valve). Once collected, the sample was desorbed onto a Restek 60-m long MXT-5 analytical column using a 2-minute, 240°C trap heating program with helium carrier gas. The GC temperature programming will be 40°C to 220°C at 10°C/min for sample analysis by the ECD.

GC-ECD analysis was used with direct sample injection. 500-1000 uL samples were injectedon-column. Temperature programming was similar to that for composite sample analysis.

QA/QC included calibration against at least three different concentrations spanning the concentration range of interest and periodic calibration checks. In addition, sample blanks, trip blanks if applicable, sample duplicates and sample replicates, were run on a regular frequency.

5.3.3 GC-DELCD Analysis

Depending on concentration and purpose of sampling, composite air samples were collected for analysis using a multi-bed sorbent tube trap (0.64 x 15.2 cm) packed with Tenax-GR and Carboxen-569, vacuum pump, mass flow controller (real-time sampling would include an SRI gas sampling valve). Once collected, the sample was desorbed onto a Restek 60-m long MXT-5 analytical column using a 2-minute, 240°C trap heating program with helium carrier gas. The GC temperature programming will be 40°C to 220°C at 10°C/min for sample analysis by the ECD.

GC-DELCD analysis was also used for direct injection sample analysis. 500-1000 uL samples were injected on-column. Temperature programming was similar to that for composite sample analysis.

QA/QC included calibration against at least three different concentrations spanning the concentration range of interest and periodic calibration checks. In addition, sample blanks, trip blanks if applicable, sample duplicates and sample replicates, will be run on a regular frequency.

5.3.4 Analysis of Water Samples

Water samples were analyzed at ASU for dissolved CHCs by GC-DELCD with temperature programming similar to that for GC-DELCD air sample analysis. The analysis involved use of a 42°C heated-headspace technique and on-column injection of a 0.5 mL sample.

QA/QC included calibration against at least three different concentrations spanning the concentration range of interest and periodic calibration checks. In addition, sample blanks, sample duplicates, and sample replicates were included on a frequency of approximately one-in-ten samples.

5.3.5 Sulfur hexafluoride (SF_6) Analysis using GC-PDD

SF_6 was analyzed using a GC equipped with a dual mode pulse discharge detector (PDD) (Model D-2, Valco Instruments Co. Inc., Houston, TX) run in electron capture (EC) mode for SF_6 analysis. Using a vacuum pump and mass flow controller (as needed), samples were loaded into a 1-mL sample loop. Samples were then injected onto a washed, 0.6-m long (2 ft) mol sieve 5A column using a helium carrier gas purified with a heated helium purifier (Model HP2, Valco Instruments Co. Inc., Houston, TX). The calculated MDL (USEPA MDL procedure; USGS, 1999) for this instrument was 4.9 ppb_v.

QA/QC included calibration against at least three different concentrations spanning the concentration range of interest and periodic calibration checks. In addition, sample blanks, trip blanks, sample duplicates and sample replicates, were run on a regular basis.

5.3.6 Differential Pressure Measurements

Differential pressure transducers (Pace Model P300-0.4”-D, Pace Scientific Inc., Mooresville, NC) or the Retrotec DM32 (Wohler Retrotec, WA) controller were used for real-time continuous monitoring of differential pressures between soil gas and indoor air, indoor and outdoor air, and other differentials as necessary (e.g., indoor air and utilities). Both transducers were configured with high and low pressure ports. When the pressure of the high port exceeded that of the low port, a positive pressure response was recorded and vice versa. The Pace Model XR5 (Pace Scientific Inc., Mooresville, NC) was used to record Pace P300 transducer readings. Readings were collected on 2 second intervals, the average for which were averaged into user defined intervals. The DM32 incorporated its own data-logging with user defined intervals of 15 seconds or greater.

QA/QC for the Pace P300 included initial transducer calibration of the mV response for the unit and periodic “rezeroing”. Prior to use, all transducers were tested on-site against a Magnehelic differential pressure gauge (Dwyer Instruments, Inc., Michigan City, IN) using a range of pressures to generate a calibration curve for each unit. No calibration or rezeroing was necessary or possible for the Retrotec DM32, except for a confirmation of pressure reading.

5.4 DATA ANALYSIS

Table 5.3 provides a summary of sampling locations, frequencies and numbers of samples for all Tasks. No specialized statistical analysis techniques were used in this work.

Table 5.3. Sampling and Data Analysis Details.

Task	Sampling Location(s)	Sampling Frequency and/or Number of Samples	Data Reduction and/or AnalysisComments
1	Land drain and sewer main locations in OU-8	5 seasonal samples at each accessible location,with 10% replicate samples and 10%duplicate sample analyses.	Concentrations presented graphically with historical dissolvedplume data and indoor air impacts.
2 and 4	Indoor air samples collected in main living areas on each level; sub-foundation soil gas monitoring at seven locations; pressure differentials measured between indoor and outdoor air and between indoor and two sub-slab foundation areas (Sun Devil Manor only for indoor-sub slab pressure differential)	Samples collected and analyzed for chemicals of concern and tracer gas at least every 2-hours with real-time sampling; pressure differential measured and recorded every two minutes or less	Data were used to calculate the maximum, minimum, time-averaged, and 10^{th} and 90^{th} percentile concentration for each validation test condition and for each demonstration building tested;similar statistics were computed forpressure differentials
3	Passive samplers deployed in triplicate in area monitored by higher-frequency real-time analyses or MTS-32 TD tube collection.	Every three weeks for 45 weeks.	Passive sampler results were compared with time-average concentrations calculated from thehigher-frequency data collected concurrently.
	Passive samplers tested against active TD tube sampling during assessment of background vapor concentrations in Beale and Travis AFB industrial building tests.	24 samples from 4 buildings	Passive sampler results were compared active TD tube samplerresults

6.0 PERFORMANCE ASSESSMENT

6.1 TASK 1: VI PATHWAY SCREENING ASSESSMENT USING EXTERNAL VAPOR SOURCEDATA

In some cases, initiating indoor air monitoring for all buildings located above or near contaminated soils and/or groundwater is impractical or unwanted. In those cases, external vapor source data collection and analysis using screening-level theoretical and empirical calculations can be useful in identifying the subset of buildings most likely to have significant VI impacts. These data and analyses, in combination with building-specific controlled pressure method testing, can also be useful in identifying the route by which vapors are entering a building. To be clear the term “external” is used here to denote data that is collected outside of building.

External data collection will typically include groundwater and soil vapor concentrations as well as vapor concentrations in subsurface piping (e.g., land and storm drains and sanitary sewers).

Groundwater data is typically already available prior to VI pathway assessment as it is part of routine groundwater plume characterization exercises; soil gas samples and vapor samples from subsurface piping networks typically are subsequently collected specifically for vapor intrusion pathway analysis. When designing those sampling plans, it is important to note that chemical vapors have been observed in piping networks well beyond the groundwater plume footprint.

Subsurface soil gas concentrations – whether measured directly, or estimated from groundwater concentration data are used as inputs to vapor mass flux equations and mass balances to estimate potential indoor air impacts. The theory and validation of those approaches is well-established at this time (Guo et al. 2019). Vapor concentrations obtained from samples collected in subsurface piping networks are used with empirical relationships to estimate potential impacts to indoor air. The determination and validation of those empirical relationships is still the subject of study and validation and has been the focus of other ESTCP-sponsored studies (McHugh and Beckley 2018). Use of both of these approaches is illustrated below.

First, however, a study of vapor concentration distributions and in subsurface piping networks and their temporal variability in the OU-8 area are presented. This was a key task in this work as little was known about the temporal variability of vapor concentrations in subsurface piping networks prior to this study. That knowledge is critical to future design of vapor sampling plans for subsurface piping networks.

Following the presentation and analysis of those data, the use of all types of external vapor concentration data for vapor intrusion pathway screening to narrow the focus of building-specific sampling is illustrated.

6.1.1 Temporal variability of chlorinated volatile organic compound vapor concentrations in a residential sewer and land drain system overlying a dilute groundwater plume.

6.1.1.1 Background

Vapor intrusion (VI) field studies have shown that indoor air in buildings connected to sewer and land drain systems (sub-surface drainage systems that prevent water accumulation beneath building foundations) can be impacted by volatile organic chemical (VOC) vapors present in the sewers and land drains (Guo et al., 2015; T. McHugh & Beckley, 2018; T. E. McHugh et al., 2012; Pennell et al., 2013; Riis, Hansen, Nielsen, & Christensen, 2010; Roghani et al., 2018).

This often occurs when contaminated groundwater enters the sewer or land drain system, as shown in Figure 6.1. In these cases, VOC contaminants volatilize and migrate along the piping headspace and finally enter buildings via a direct connection to indoor air (sewer in Figure 6.1) and/or through the sub-foundation region and foundation cracks (land drain system in Figure 6.1). When such VI pathways exist, VI impacts can occur to buildings that are connected to the contaminated groundwater entry point, but do not overlie dilute VOC groundwater plumes(Riiset al., 2010). As a result, VI risk assessments need to consider this "pipe-flow" VI pathway in addition to the conventional "soil VI" pathway where chemical vapors migrate upward from groundwater plumes through soil and then into a building (Guo et al., 2015).

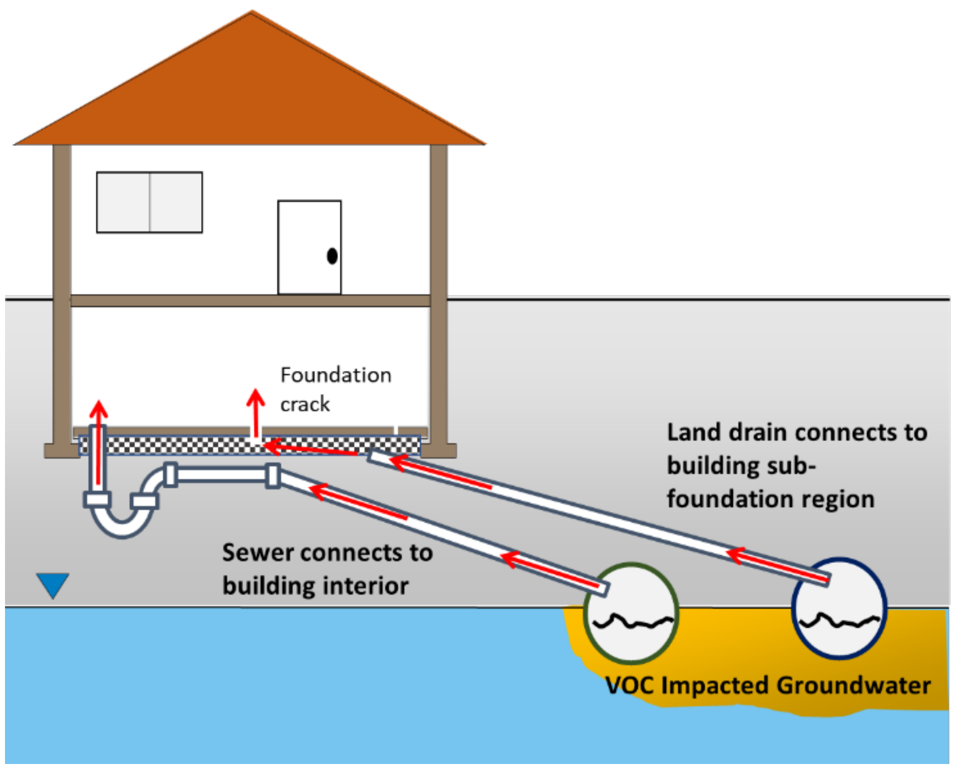


Figure 6.1. Conceptual Illustration of Sewer and Land Drain Vapor Intrusion Pathways.

Although the evaluation of alternative and preferential VI pathways is mentioned in federal and state regulatory guidance (ITRC, 2007; NJDEP, 2013; US EPA, 2015), there is little guidance on how to specifically identify or assess the VI risks associated with them.

The lack of available guidance is, in part, because these VI pathways have only recently been recognized and documented (Guo et al., 2015; T. McHugh & Beckley, 2018; T. McHugh et al., 2017; Pennell et al., 2013; Riis et al., 2010). While approaches for assessing potential indoor air impacts from VOCs in sewers and drains have yet to be developed or validated, guidance is likely to include requirements for source vapor concentration characterization and extrapolation of inhalation exposure using empirical relations or mathematical models. Thus, guidance for the characterization of VOC vapor concentrations in sewers, land drains, and other subsurface piping will be needed, including specification of sample collection and analysis methods and the time, duration, and frequency of sampling.

The presence of VOC vapors in subsurface piping networks has been reported in studies that discuss odor management in sewer networks, and most of these studies have focused on specific analytical constituents and their concentration levels (Corsi & Quigley, 1996; Corsi, Quigley, Melcer, & Bell, 1995; Huang, Chen, & Wang, 2012; Quigley & Corsi, 1995; Wang, Parcsi, et al., 2012; Wang, Sivret, Parcsi, & Stuetz, 2015; Wang, Sivret, Parcsi, Wang, & Stuetz, 2012; Yeh et al., 2011). However, the temporal variability of VOC vapor concentrations in subsurface piping networks is not well-understood. Only a limited number of studies have investigated this topic and their observations and conclusions were based on VOC vapor monitoring either from limited sampling locations or for short time period. Quigley and Corsi (1995) found weekday/weekend trends for three aromatic compounds in 17 sewer manholes during four 24-h sampling events, Sivret. et al. (C., Nhat, Bei, Xinguang, & M., 2017) observed up to 10x diurnal VOC vapor concentration changes in a pump station wet well, and Roghani et al. (2018) reported over 100x changes in trichloroethylene (TCE) concentrations in two sewer manholes adjacent to a groundwater plume over a two-year period.

The observations from past studies are informative but not sufficient to create broadly applicable guidance for characterizing VOC vapor concentrations in subsurface piping networks for use in VI pathway risk assessment. Thus, a study was undertaken to address this gap through high- and low-frequency sampling of chlorinated VOC (CVOC) vapors in land drains, storm drains, and sanitary sewers located in a neighborhood overlying a large-scale dissolved CVOC groundwater plume. Sampling was conducted over a period of about three years with the sampling efforts changing as more was learned about the levels and dynamics of vapor concentrations in the system. The sampling included multi-season synoptic collection of instantaneous grab samples from up to 277 manholes, hourly grab samples from two land drain locations and a sanitary sewer manhole, and multi-season week-long collection of 24-h duration samples from 13 land drain manholes.

6.1.1.2 Method

Study Site. Air and water sampling were conducted over an approximately 1 km^2 residential area overlying and adjacent to Hill Air Force Base, UT OU-8. This study area overlies a shallow dilute CVOC groundwater plume and throughout the area there are land drain, storm water, and sanitary sewer networks. TCE is the primary VI contaminant of concern within the study area where TCE dissolved groundwater concentrations range from approximately 5 ug/L to 100 ug/L (Hill Air Force Base, 2005). The land drain system has been previously confirmed as the source of CVOC indoor air impacts for one intensely studied residence (Guo *et al.*, 2015). The dissolved plume boundaries and 277 sampled manhole locations are presented in Figure 6.2.

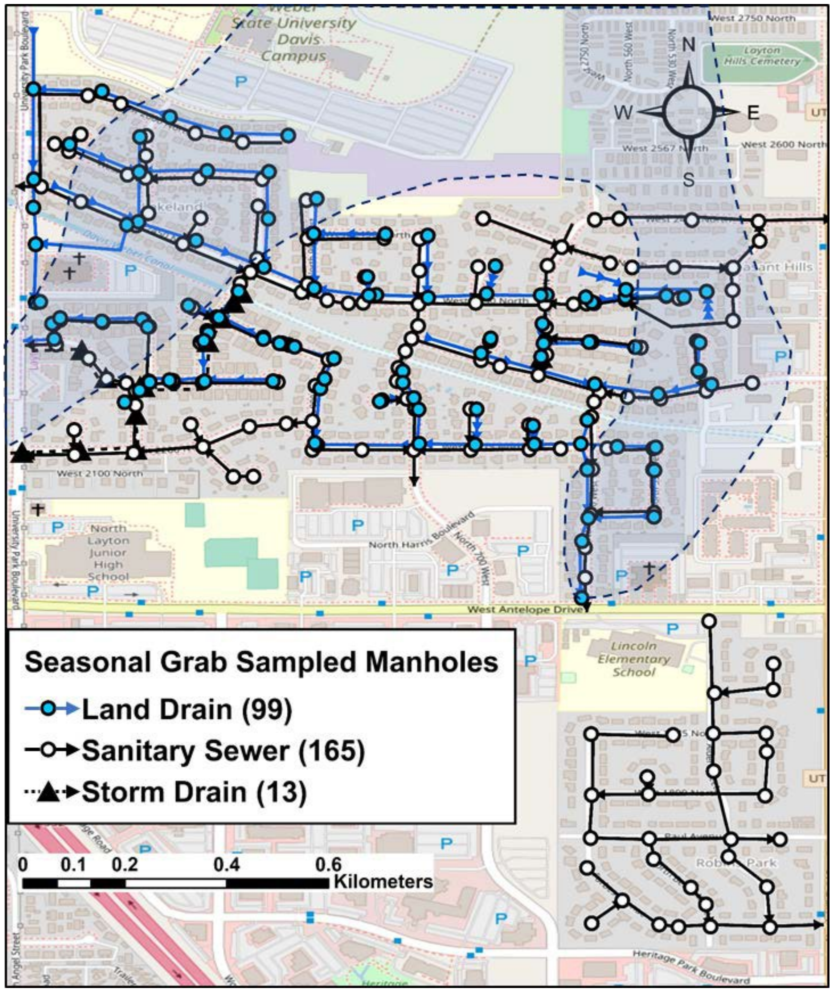


Figure 6.2. Study Area and Locations of Sampled Manholes.

The shaded area bounded by the dashed line delineates the dissolved TCE groundwater plume (2015). Arrows indicate directionof water flow in the subsurface piping networks.

<u>Sample Collection Summary</u>. Sample collection was performed from January 2016 to January 2019 and consisted of the following activities:

1) Multi-season grab sampling (January 2016 to April 2017): five synoptic grab sampling events were performed to characterize the spatial distribution of CVOC vapors in the subsurface piping networks and to assess seasonal variability. Each event included vapor sampling from up to 277 of the manholes shown in Figure 6.2 (165 sewer manholes, 99 land drain manholes, and 13 storm drain manholes). Since vapor phase VOCs in subsurface piping networks are often the result of contaminated groundwater infiltration, grab sampling of water from land and storm drain manholes was also performed along with the vapor sampling when water was present. These data are useful for assessing the value of water sampling as another line of evidence for VOC characterization in subsurface piping networks.

2) Hourly high-frequency grab sampling (September 2017 to March 2018): hourly sampling was conducted over five months in the two land drain manholes and one sanitary sewer manhole shown in Figure 6.3 to provide initial insight into shorter-term temporal variability in CVOC vapor concentrations. All three were adjacent to the residence having a confirmed pipe-flow VI alternative pathway from the land drain network.

3) Daily, high-frequency sampling (March 2018 to January 2019): A total of six, week-long, sampling events covering multiple seasons and involving the collection of daily 24-h samples were performed using the 13 manholes (9 land drain, 5 sanitary sewer, and 1 sanitary sewer/storm drain combination) shown in Figure 6.3. These locations were selected based on multi-season grab sampling results, with the intent of including locations with a range of concentrations and temporal variabilities.

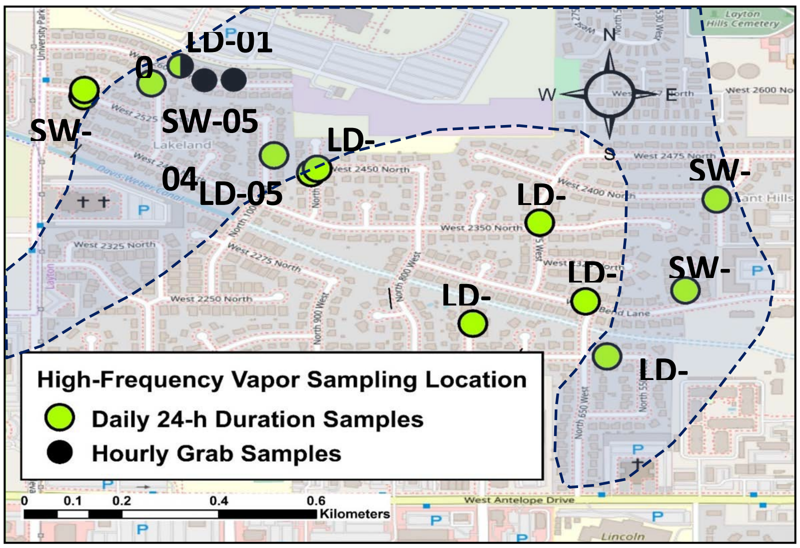


Figure 6.3. Locations Where Hourly (Black) and Daily 24-h Duration (Green) Vapor Samples Were Collected for Extended Sampling Periods.

LD = land drain manhole; SW =sanitary sewer manhole. SW03 is a sanitary sewer/storm drain combination manhole.

<u>Vapor sample collection and analysis methods</u>. *Multi-season grab samples.* Manhole vapor samples were collected using a method similar to that described in McHugh *et al.* (2017). A vacuum box sampler was used to draw vapor samples (minimum 500 mL) into a Tedlar bag via weighted nylon tubing inserted through vent holes in the manhole covers. If vent holes were not present, the cover was opened just enough to allow passage of the sampling tubing. The distal end of the weighted tubing was inserted to a depth approximately 0.3 m above the base of the manhole or manhole water level. The vapor samples were analyzed on-site using an SRI gas chromatograph equipped with a dry electron capture detector (GC/DELCD) (SRI instrument, CA) , and the minimum detection level (MDL) for TCE analysis by this method was 1.5 ppb_v. The GC/DELCD was calibrated daily prior to sample collection and calibration checks and duplicate vapor samples were analyzed every 10 sample injections for QA/QC purposes. The average relative percentage differences between duplicate samples was 26.9%.

Hourly high-frequency grab sampling. Hourly vapor grab samples were collected directly onto the GC using an external pump, autosampler, and permanent nylon and stainless-steel sampling lines extending to each manhole. Permanent sampling lines were installed to a depth 0.3 m above the manhole base or water level. Samples were analyzed real-time using an SRI GC equipped with an electron capture detector (ECD). The minimum detection limit for TCE was 1.5 ppb_v. The GC/ECD was calibrated approximately every 4 weeks during the sample collection period.

Daily 24-h duration samples. 24-h duration samples were collected daily on multi-bed sorbent tubes comprised of Tenax-GR and Carboxen-569 sorbents. The vapor samples were collected using a customized sampler which was suspended in the manhole approximately 0.3 to 0.5-m above the base of the manhole or water level. The sampler pulled vapor through each sorbent tube at a controlled flowrate (about 50 mL/min) using a Gilian LFS-113 air pump (Sensidyne, FL). The flowrate for each pump was calibrated before and after each 24-h tube sample collection using a Sensidyne Gilibrator-2 bubble flowmeter (Sensidyne, FL). Flowrate variation over a 24-h period was typically less than 5% and never exceeded 10%. Sorbent tubes were analyzed using a Markes Ultra auto-sampler and Markes Unity thermal desorber (Markes International, UK) connected to an HP5890 gas chromatograph equipped with a Restek 60 m Rxi-5 capillary column and an HP5972 mass spectrometer. Samples were analyzed using selective ion mode (SIM). The 24-h average CVOC concentration was calculated based on the CVOC mass loading for sorbent tube and the vapor sample volume. The minimum TCE detection level was 0.07 ppb_v. Duplicate samples were collected in manhole LD-02 and SW-03 and the variations in concentrations for duplicate samples and duplicate analyses were less than 30%.

Water sample collection and analysis. Water samples were collected from land drain manholes and selected storm drain manholes where possible during the area-wide seasonal grab sampling events. Samples were collected from each manhole in 40 mL volatile organic analysis (VOA) vials, which contained 0.5 mL 2% hydrochloric acid for preservation. All samples were stored at 4 °C and shipped to Arizona State University for headspace analysis within two weeks of sample collection. An SRI GC/DELCD was used for sample analysis with the minimum detection level of 0.7 μg/L for TCE. Calibration checks and duplicate vapor samples were analyzed every 10 sample injections for QA/QC purposes. The average relative percentage differences between duplicate samples was 21.6 %.

6.1.1.3 Demonstration Results

TCE vapor and water concentration spatial distribution. Five area-wide synoptic sample collection events were conducted from early 2016 to mid-2017. The first event (January 2016) included 82 manhole locations. As knowledge of the manhole system and the ability to differentiate types of manholes improved (due to differing periods of development, the neighborhood included individual land-drains, storm-drains, and sanitary sewers, or combination systems land-drain/sanitary sewer, land-drain/storm sewer, storm-sewer/sanitary sewer, and land-drain/storm-drain/sanitary sewer), all accessible manholes within the area were being sampled by August 2016.

TCE vapors were detected throughout the land drain, storm drain, and sanitary sewer network. The results of all synoptic sampling events can be found in Appendix C. Figure 6.4 provides an overview of the range of TCE vapor concentrations detected and how that changed over the five multi-season synoptic sampling events. In this figure, TCE vapor concentration distributions are presented in four concentration categories which ranges from less than 4 ppb_v to over 400 ppb_v.

To provide some context for these concentrations, published indoor air screening levels for TCE range from about 0.09 – 0.4 ppb_v (e.g., MDPH 2017, USEPA 2019), with the lower level based on a 10^{-6} risk level and the upper based on 10^{-5} risk level, with both also considering non-cancer risks. Manhole vapor concentrations were found to be 100x and 10x greater than the indoor air screening level of 0.4 ppb_v (USEPA, 2019) in approximately10 % and 40% of manhole sampling locations, respectively. For context, indoor air TCE concentrations in a study house located in this area were about 1% - 2% of the nearby land drain vapor concentrations when the house was under-pressurized (Guo et al., 2015; Holton et al., 2015). Thus, residences near the higher-level manhole TCE vapor concentrations measured in this study could be at risk of VI impact above the 0.4 ppb_v indoor air screening level, but only if there are piping conduits connecting their homes to the land drain system.

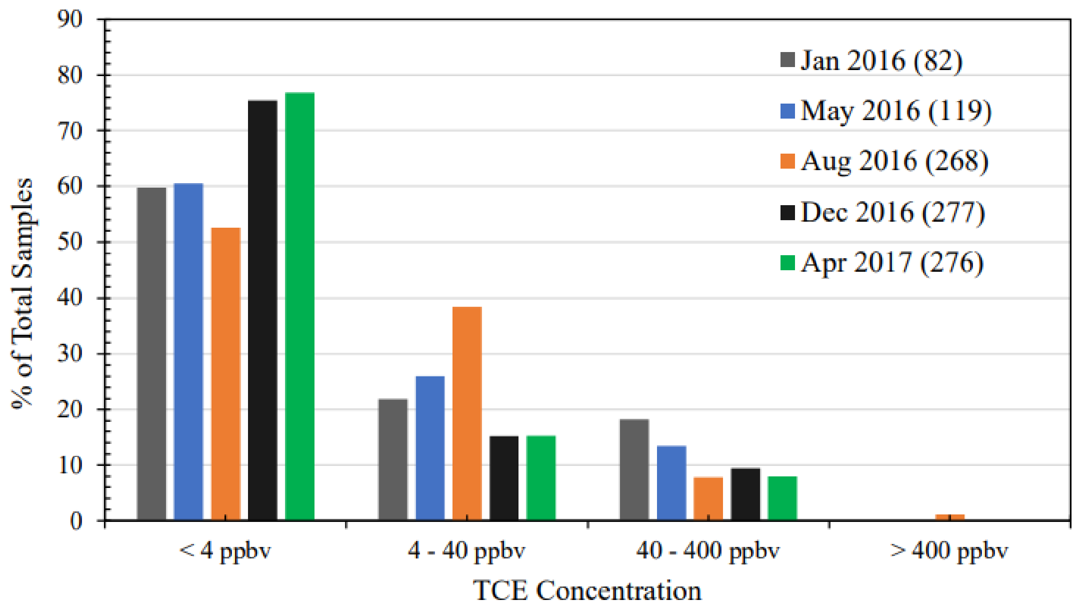


Figure 6.4. TCE Manhole Vapor Concentration Summary of Five Seasonal Synoptic Sampling Events, Categorized Relative to a 0.4 ppbv Indoor Air Screening Level.

Numbers of sampled manholes for each event are shown in brackets.

One important observation from synoptic sampling results is that the presence or concentrations of TCE in the piping networks cannot be anticipated by groundwater plume data. The poor correlation can be seen in Figures 6.5 and 6.6, which present the maximum TCE vapor and water sample concentrations from the five synoptic sampling events superimposed on a map showing the extent of the groundwater plume. About half of the locations where vapor concentrations were >40 ppb_v were located outside of the groundwater plume boundary, indicating that the piping networks were a conduit for dissolved and vapor-phase CVOC transport to areas outside the groundwater plume. Although it was difficult to identify the exact locations where groundwater entered the subsurface piping networks, TCE liquid samples were all above 0.7 µg/L in the high-TCE-vapor-concentration-level manholes that were located outside TCE groundwater plume boundary. This suggests that the migration of infiltrated groundwater along the subsurface conduit's flow pathway is the primary mechanism for VOC migration outside of the groundwater plume boundary.

Thus, it is important that any future VI pathway assessment guidance recommend sampling in subsurface piping networks beyond the boundaries of dissolved groundwater plumes, particularly, when the depth of subsurface piping networks is close to or deeper than groundwater table.

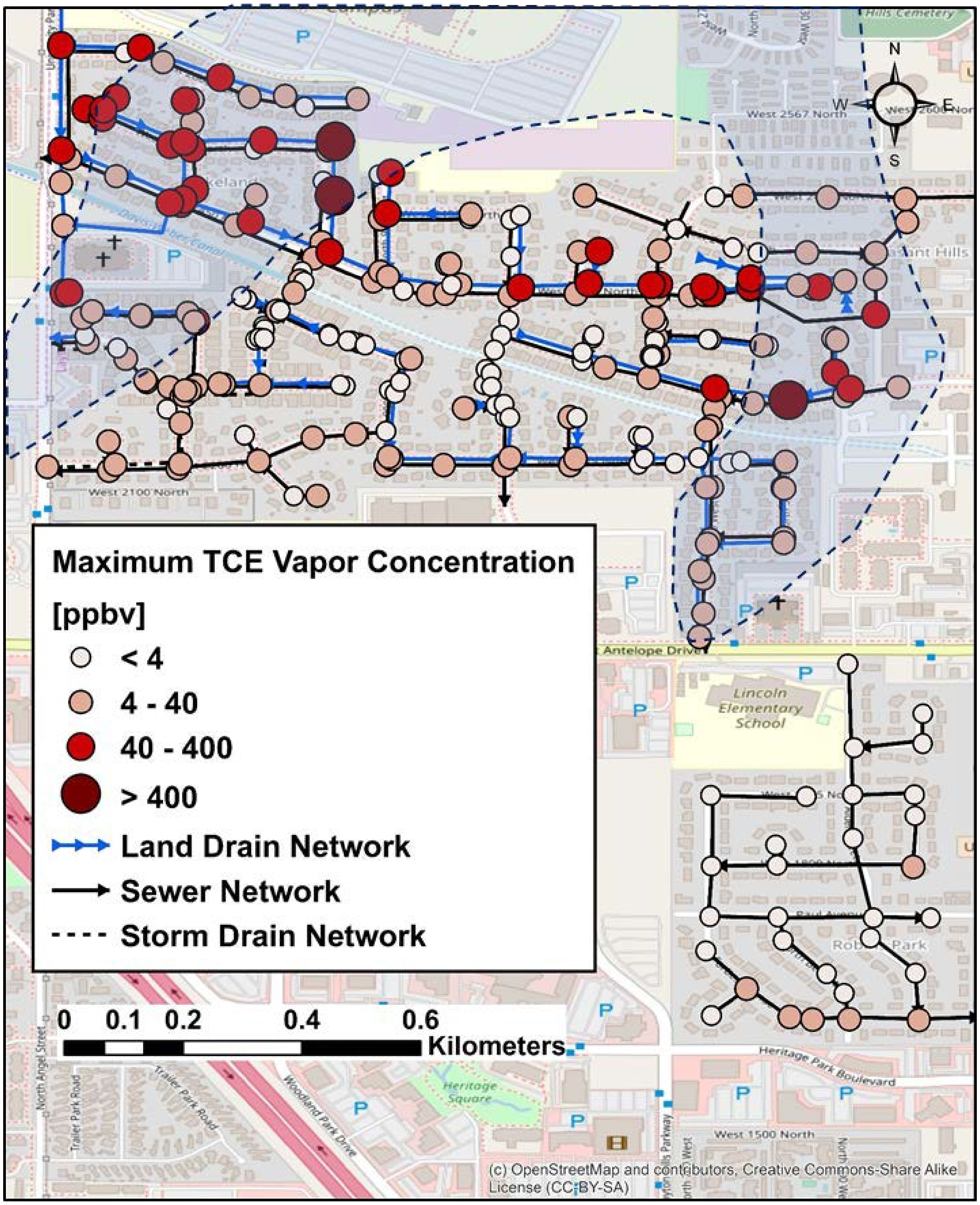


Figure 6.5. Maximum TCE Concentrations in Vapor Samples Collected from Manhole headspace sampled During the Five Quarterly Synoptic Surveys, Categorized Relative to a 0.4 ppbv Indoor Air Screening Level.

The shaded area indicates the extent of the TCE groundwater plume.

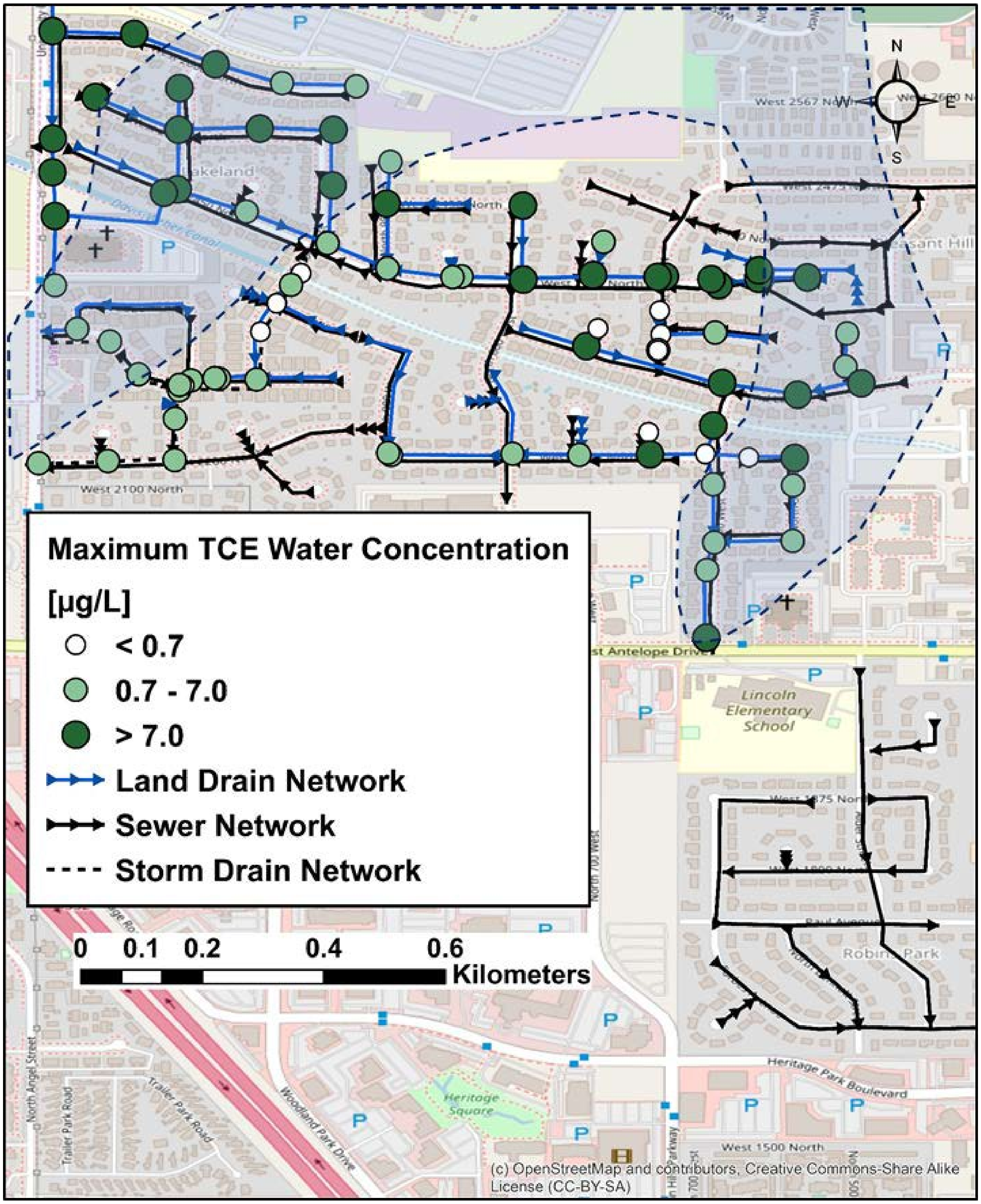


Figure 6.6. Maximum TCE Concentrations in Water Samples Collected from Land Drain Manholesduring the Five Quarterly Synoptic Surveys.

The shaded area indicates the extent of the TCE groundwater plume (2015).

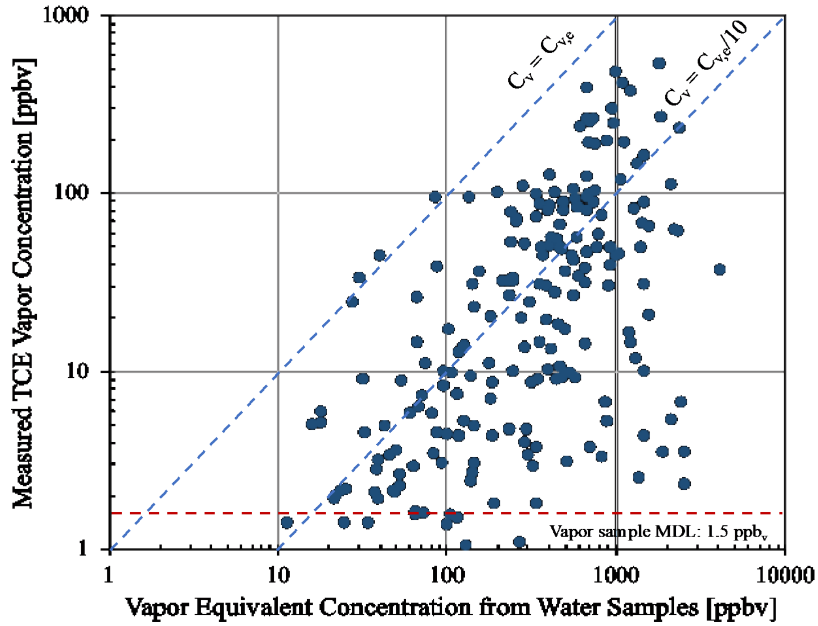


Figure 6.7. Vapor Equivalent Concentration (Cv,e) vs. Measured Vapor Concentration (Cv) For water and Vapor Samples Collected in the Same Manhole.

The Dimensionless Henry's Law Constant used in these calculations was 0.4 L-H2O/L-vapor (USEPA, 2019).

In guidance documents, from federal to state, all recognize dissolved VOC concentration in groundwater as one important line of evidence for VI risk assessment, since dissolved water concentrations can be used to predict vapor and indoor air concentrations, using the assumption of local equilibrium. Thus, we examined the correlation between TCE concentrations in water and vapor samples collected from the same manholes to evaluate the value of water sample collection in VI pathway investigation. The results are presented in Figure 6.7 where the measured headspace TCE vapor concentration (C_v) is plotted vs. the vapor equivalent concentration ($C_{v.e}$) for the water samples, calculated by multiplying the measured dissolved TCE concentration in a water sample by the dimensionless Henry's Law Constant for TCE (0.4 L-H2O/L-vapor; USEPA, 2019). A total of 256 paired water and vapor samples are plotted in Figure 6.7. As can be seen, the measured TCE vapor concentrations were less than 10% of Cv.e for 70% of the samples, suggesting that use of VOC concentrations from water samples will lead to over-prediction of VOC vapor concentrations when a simple local equilibrium assumption is applied. Corsi and Quigley (1996) identified headspace ventilation rate, water flowrates and the water flow conditions in manholes (fully submerged, partially submerged pipeline or water drops) as critical factors that affect VOC migration rate from liquid to vapor phase in piping networks. Therefore, these factors should be evaluated if VOC liquid sample concentrations were used for VI risk characterization. However, sewer ventilation rates and water flow rates in pipelines could not be easily quantified, and accurate measures of these often require intensive efforts, such as tracer releasing. As such, it is best to collect and analyze vapor samples from subsurface piping networks, rather than water samples, for VI pathway assessment.

Temporal Variability in Multi-Season Grab Sample Concentrations. The temporal changes in the multi-season grab sample results were assessed by looking at the maximum/minimum concentration ratio at each of the 268 locations where at least three sampling events occurred.

Any sample result that was non-detect was assigned a value of one-half the MDL (0.75 ppb_v) in these calculations. The results were then parsed into the three groups shown in Figure 6.8 and discussed below:

- **Group I:** Locations where TCE manhole headspace concentrations were consistently below the MDL (67 of 268 manholes). These are locations where the temporal variability could not be assessed with the data and the concentrations at these locations are unlikely to cause VI indoor air impacts above a 0.4 ppb_v TCE indoor air screening level.
- **Group II:** Locations where TCE vapor concentrations were measured above the MDL at least once, at relatively stable levels as their maximum/minimum TCE vapor concentration ratios were <10x. This group includes 120 of 268 manholes, and of those, there were 64 locations where the maximum concentration was between 10x and 100x of a 0.4 ppb_v indoor air screening level.
- **Group III:** Locations where significant changes in concentration occurred as the maximum/minimum TCE vapor concentration ratios were >10x. This set includes about 30% (81 of 268) of the sampled manholes. Most of these locations (61) had contrasting concentrations that might be judged to be both of concern (>10x a 0.4 ppb_v screening level) and not of concern (<10x a 0.4 ppb_v screening level). The largest maximum/minimum TCE vapor concentration ratio was >500x.

Overall, relatively stable vapor concentrations were observed at some locations and highly variable results were observed at others, without any way to anticipate the temporal variabilities or maximum concentration at any specific location. Of the Group III locations – those with the greatest changes between samples – the maximum concentration was measured during a winter sampling event at 21% of these manholes and the maximum concentration was measured in a summer sampling event at 72% of the manholes. This suggests that it would be prudent for future guidance to recommend multi-season sampling events when assessing potential VI impacts from subsurface piping networks.

Real-time Hourly Sampling Results. To assess if the changes observed in multi-season sampling results reflected long-term seasonal changes or shorter-term (hourly to daily) vapor concentration fluctuations, hourly grab sampling was conducted at selected manholes that had both consistent and highly variable multi-season results. Hourly samples collected from LD-01, LD-10 and SW-05 (Figure 6.3) for about five months (September 2017 to March 2018) were averaged for each day and plotted as presented in Figure 6.9, showing also the maximum and minimum result from each 24-h period.

Manhole headspace TCE concentrations were consistently below the MDL for over 90% of the sampling period in both LD-10 and SW-05, followed by spikes to 51 ppb_v and 45 ppb_v, respectively, in early spring. This pattern is consistent with their multi-season sampling results: at LD-10 and SW-05 the TCE headspace concentrations were <MDL for three of four events and three of five events, respectively. In contrast the LD-01 concentrations were mostly in the 50 – 120 ppb_v range, with differences between daily maximum and minimum TCE vapor concentration being <35% of the 24-h averaged TCE concentration values each day. LD-01 hourly TCE concentrations ranged from 50.3 ppb_v to 122.7 ppb_v with an averaged value of 89.9 ± 13.4 ppb_v (average ± standard deviation), which was consistent with the multi-season results that ranged from 49 - 103 ppb_v from seasonal synoptic survey samples.

To provide additional insight to short-term concentration variations, Figure 6.10 presents hourly sample results vs. time for a five-day period at the LD-01 location. A diurnal pattern is evident in the data with the TCE vapor concentrations reaching their highest level in late afternoon and decreasing during the night. This short-term (24 h) variability in TCE vapor concentration was not significantly different from the long-term (multi-season) variation. The ratio of daily maximum/minimum concentrations was typically <1.2, while it was about 2 for the multi-season sampling data at LD-01.

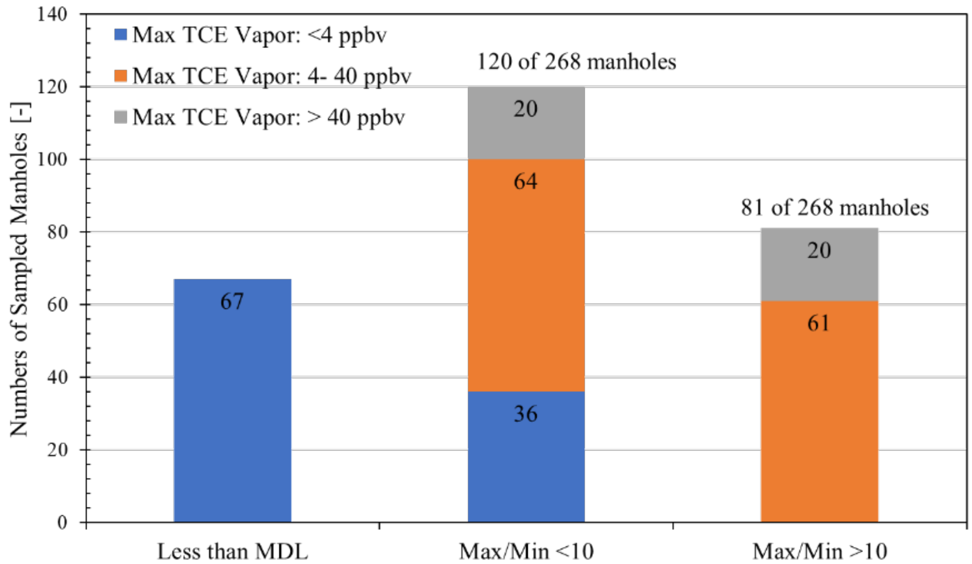


Figure 6.8. Summary of Temporal TCE Vapor Concentration Changes in Multi-season Grab Sample Results.

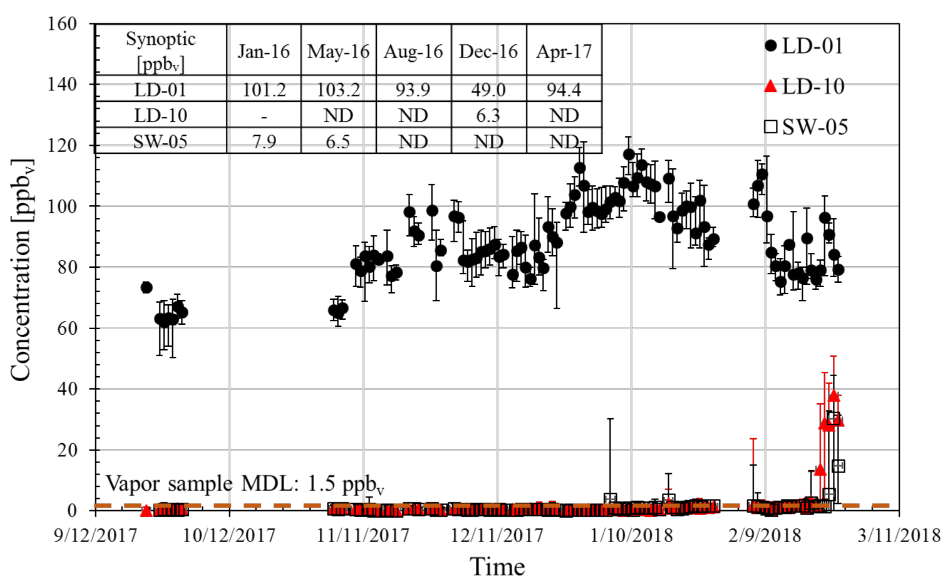


Figure 6.9. 24-h Averaged Manhole Headspace TCE Concentrations at LD-01, LD-10 and SW-05(see Figure 6.3).

Error bars denote the daily maximum and minimum values.

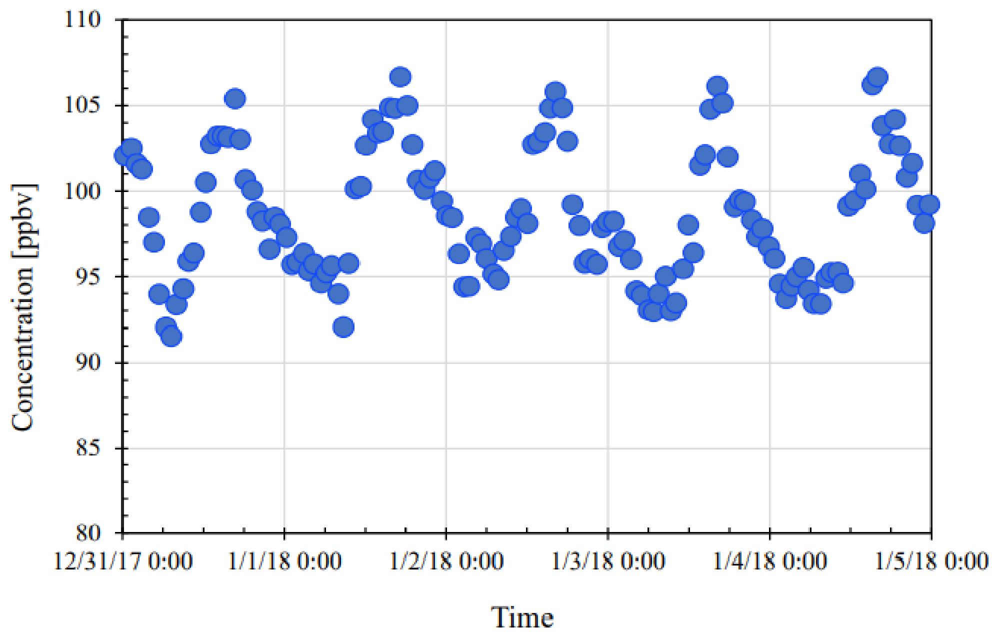


Figure 6.10. Diurnal Behavior of TCE Vapor Concentrations in the LD01 Manhole Headspace.

<u>24-hour Thermal Desorption Sampling Results</u>. To further assess the temporal variability in manhole headspace vapor concentrations, six week-long sampling events were conducted from March 2018 to January 2019. During each, 24-h time-integrated samples were collected from 13 manholes. The 13 manholes were selected based on their multi-season grab sampling results, with the goal of including locations with different patterns of results: two manhole locations where concentrations were consistently below the MDL (Group I in Figure 6.8); five manhole locations where concentrations varied by <10x (Group II in Figure 6.8); and six manhole locations where concentrations varied by more than 10x (Group III in Figure 6.8).

The results of this study are presented in Table 6.1 and Figure 6.11. A summary of the week-long period daily-sample results along with their multi-season grab sampling results are provided in Table 6.1. Figure 6.11 presents the averaged week-long sampling results for locations with concentrations >MDL, with the error bars spanning the maximum and minimum 24-h TCE vapor concentrations that were measured during each week-long sampling period.

Collectively the results are mostly consistent with the synoptic and extended hourly sampling results. At some locations, the concentrations appear relatively temporally stable and were similar to grab sample, 24-h sample, and weekly-average results for those locations (e.g., LD-01, -05, and -07). At those locations, grab samples collected at any time of the year would likely provide good insight to the concentrations, although increasing to weekly-average samples could decrease variability in sample results relative to grab or 24-h samples. At other locations (e.g., LD-02 and -03), the 24-h and weekly-average results span a wide range, but encompassing values similar to the multi-season grab samples. At those locations, multi-season sampling would be needed to characterize the range of vapor concentrations at those locations, and grab, 24-h, and weekly average samples would likely yield similar results.

Then there are other locations (e.g., LD-06) where the multi-season grab samples suggested much less temporal variability than was revealed in the 24-h and weekly-average results or the maximum concentration detected in grab sampling was much greater than either 24-h sample or weekly-average results (e.g., 30x at LD-04).

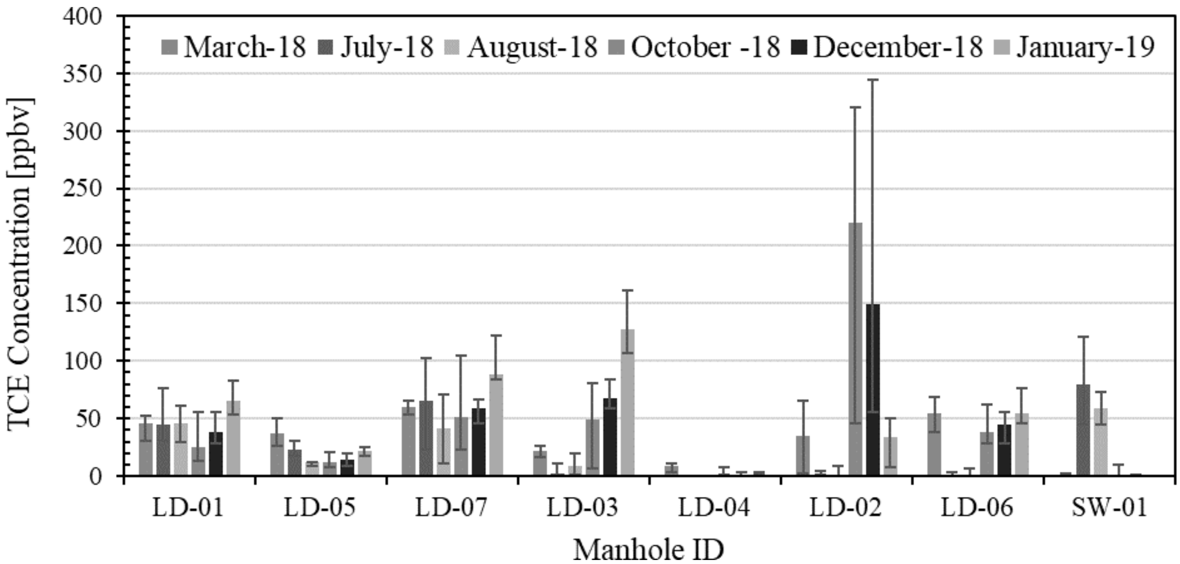


Figure 6.11. The Weekly Averaged TCE Headspace Concentrations of 24-h Samples with Error Bars Spanning the Maximum and Minimum 24-h Concentrations of Each Week-Long Sampling Period.

Table 6.1. Statistical Summary of the Week-long Period 24-h Sampling Results with Corresponding Seasonal Grab Sampling Results at Each Location.

Seasonal Variation	Manhole ID	TCE Vapor Concentration [ppb_V]								
		Multi-Season Grab Sample Results					Weekly Averages of the 24-h Sample Results		Averages Across the Six Week-Long Sampling Events	
		Jan-16	May-16	Aug-16	Dec-16	Apr-17	Maximum	Minimum	Max 24-h Value/Weekly AVG Value	Min 24-h Value/Weekly AVG Value
Group I: All < MDL	LD-08	NA	NA	<MDL(s)	<MDL(s)	<MDL(s)	0.1	<MDL(w)	3.2	0.27
	LD-09	NA	NA	<MDL(s)	<MDL(s)	<MDL(s)	<MDL(w)	<MDL(w)	2.6	0.17
Group II: <10x Multi-season Max/Min	LD-05	49.0	37.3	13.6	31.9	19.5	37.9	11.2	1.3	0.71
	LD-01	101.2	103.2	93.9	49.0	94.4	65.6	29.9	1.4	0.65
	LD-07	NA	191.0	103.5	79.8	88.9	94.4	42.8	1.4	0.60
	SW-02	NA	3.0	2.1	5.0	<MDL(s)	0.6	<MDL(w)	3.0	0.29
	LD-06	NA	NA	31.2	98.2	83.2	59.8	1.1	2.4	0.48
Group III: >10x Multi-season Max/Min	SW-01	NA	23.9	136.7	<MDL(s)	36.7	78.4	0.4	2.3	0.54
	LD-04	NA	2.5	410.0	39.0	14.4	7.9	0.1	2.6	0.31
	SW-03	<MDL(s)	<MDL(s)	11.8	<MDL(s)	<MDL(s)	0.1	<MDL(w)	2.7	0.022
	SW-04	NA	NA	9.1	2.9	<MDL(s)	0.9	0.1	2.9	0.19
	LD-02	NA	<MDL(s)	1.9	385.7	55.3	198.8	1.9	2.4	0.24
	LD-03	37.0	62.3	4.3	49.7	45.5	127.5	4.5	1.6	0.45

NA – No sample available;

MDL(s) – TCE detection limit for the synoptic samples: 1.5 ppb_V.

MDL(w) – TCE detection limit for 24h samples: 0.07 ppb_V

Implication for VI Alternative Pathway Sampling in Sewers and Other Subsurface Utility Conduits. Overall, the following observations are supported by the data collected in this study:

- Diurnal concentration changes in hourly TCE vapor samples were less than 50% at one intensely sampled location in this study. If concentration variations of this magnitude about an average are of concern, the uncertainty in concentration results can be minimized by collecting 24-h time-integrated samples.
- Individual 24-h average results ranged from 50% to 150% of the calculated weekly-average at some locations (e.g., LD-01 and -07), but also varied to a greater degree at other locations (e.g. LD-02 and -04). Thus, serious consideration should be given to week-long sample durations rather than grab samples or 24-h sample durations in designing alternate VI pathway assessment plans.
- Whether collecting grab, 24-h, or week-long samples, seasonal variability should be expected. This was greater than daily or weekly variability at many locations at our study site, so it is possible to measure concentrations of significance at some periods of the year while seeing insignificant concentrations at others. For example, over 10x seasonal variability was observed at 81 of 268 manholes in this study.
- Thus, multi-season synoptic events should be considered, as these are likely to provide more confidence in characterizing vapor distributions in subsurface utilities than one-time grab sampling events.
- Sampling location selection should not be overly constrained by dissolved plume delineation as concentrations of significance have been observed in this and other studies at locations outside of the dissolved plume footprint.

In brief, the results of this study suggest that robust alternate VI pathway sampling protocols would typically include week-long samples collected at different times of the year with samples collected at manhole locations overlying and outside the dissolved plume. Locations exterior to the plume might be chosen based on connectivity and how flow occurs in the sewer and drainage network, if that is known. It may be that week-long active vapor sampling at large numbers of locations might be impracticable at sites with large dissolved plumes like our study site, so we recommend that the utility and accuracy of passive sampling tools in sewer environments as alternatives to active sampling be evaluated in future studies.

6.1.2 Demonstration of use of external vapor source data to delineate vapor intrusion inclusion zones

As mentioned previously, external vapor source data can be used with theoretical and empirical screening-level calculations to cost-effectively identify a subset of buildings (the vapor intrusion pathway assessment "inclusion zones") that warrant building-specific testing when dealing with assessing VI impact in neighborhoods and other large areas with many buildings. This is illustrated below for the OU-8 area using groundwater data, vapor concentration data in sewers and land drains discussed in §6.1.1, and video camera survey data that was collected to determine land drain connections between homes and the main land drain piping network underlying the OU-8 neighborhoods. The results of this effort are then compared with indoor air TCE concentration data for homes in the OU-8 area collected from 2002 to 2012.

6.1.2.1 Use of groundwater data and screening-level model calculations to estimate VI pathway assessment inclusion zones for indoor air impacts via the soil-VI pathway.

USEPA VI guidance (EPA 2015) suggests an inclusion zone that extends approximately 100 feet outside the areas where groundwater or soil vapor concentrations exceed screening criteria concentrations has generally been used in determining which buildings to include in building-specific vapor intrusion investigations. An alternate site-specific approach uses diffusion-based mass balance screening-level model calculations. These calculations estimate the maximum possible VI impacts via the soil VI pathway, and can be performed at sites where groundwater or soil gas contaminant concentrations are available.

Screening-level model calculations can be performed using the EPA Johnson and Ettinger model spreadsheet (available online at https://www.epa.gov/vaporintrusion/epa-spreadsheet-modeling-subsurface-vapor-intrusion), or other diffusion-dominated screening calculations (e.g., Guo et al. 2015). Below, the use of the latter is illustrated. Results are similar to those using the EPA Johnson and Ettinger model spreadsheet as illustrated in Guo et al. (2015).

Table 6.2. summarizes important site-specific input values used in these calculations. Predicted indoor air concentrations are summarized in Figure 6.12 and 6.13 when varying groundwater and external soil gas sampling results and different sample collection depths are applied.

In this example analysis, results presented in Figure 6.12 and 6.13 were used to identify OU-8 areas subject to significant vapor intrusion via the mitigation action level (MAL) for Hill AFB OU-8 vapor intrusion management prior to 2008. As shown in Figure 6.12, groundwater TCE concentrations need to exceed 22 µg/L when the water table was 3 m below slab depth to create significant VI impact. External screening using external soil gas sampling results (Figure 6.13) can be applied similarly.

Table 6.2. Site-specific Input for One-dimensional Diffusion-dominated Screening-level Model Calculations.

Input Parameter	Unit	Value
Effective TCE Vapor Diffusion Coefficient (measured)[1]	cm^2/s	0.0042
Building Volume[2]	m^3	350
Building Foundation Area[2]	m^2	85
Air Exchange Rate[2]	h^{-1}	0.5
Henry's Law Constant (EPA 2015)	Dimensionless	0.4

1 – the median value of measured TCE effective diffusion coefficient in soil gas (Guo. et, al. 2015). 2 - Building parameters are selected based on a well-studied research house from ER-1686.

In this demonstration of screening model use, groundwater sampling results from 1998 to 2015 were considered. Groundwater samples were collected from 50 different locations in this study area, and their results range from 290 µg/L to less than detection limits. Using those data, the soil VI pathway assessment inclusion zone was determined as follows:

- A 3-m depth from foundation to groundwater was used, based on past studies and observations in the OU-8 area.
- As indicated from Figure 6.12, only those areas with concentrations >22 µg/L TCE in groundwater could have indoor air concentrations from the soil VI pathway that exceed the indoor air screening level of 2.1 mg/m^3.
- While not necessary, to add a level of conservatism, that concentration was reduced by about 30% to 15 µg/L for soil VI pathway inclusion zone identification.

The resulting soil VI pathway assessment inclusion zone is shown in Figure 6.14.

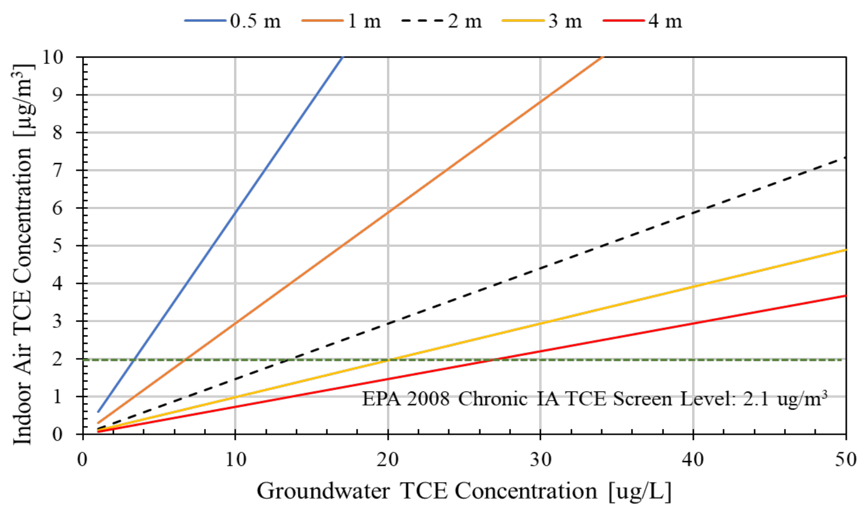


Figure 6.12. Indoor Air TCE Concentrations Predicted Using Table 6.2 Inputs and a Range of Groundwater Concentrations and Groundwater Depths Representative of the OU-8 Area.

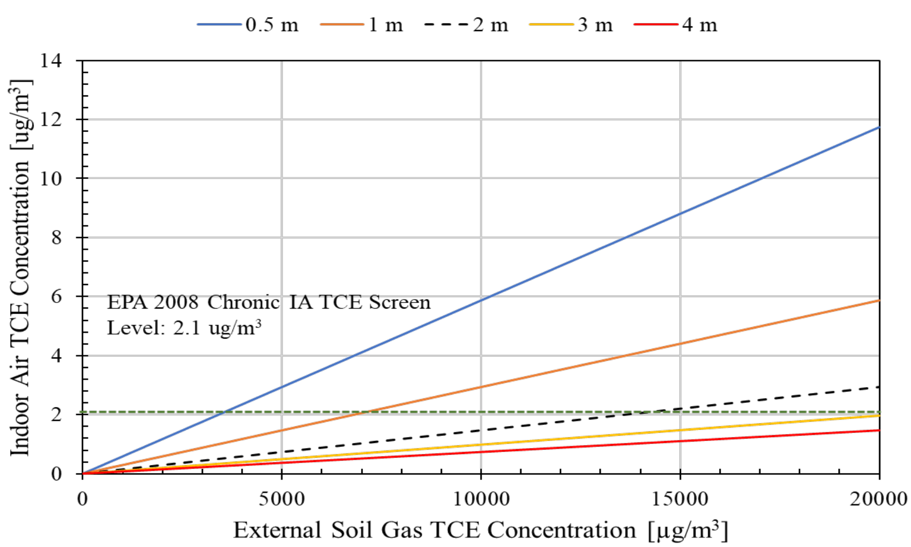


Figure 6.13. Indoor Air TCE Concentrations Predicted Using Table 6.2 Inputs and a Range of Soil Vapor Concentrations and Groundwater Depths Representative of the OU-8 Area.

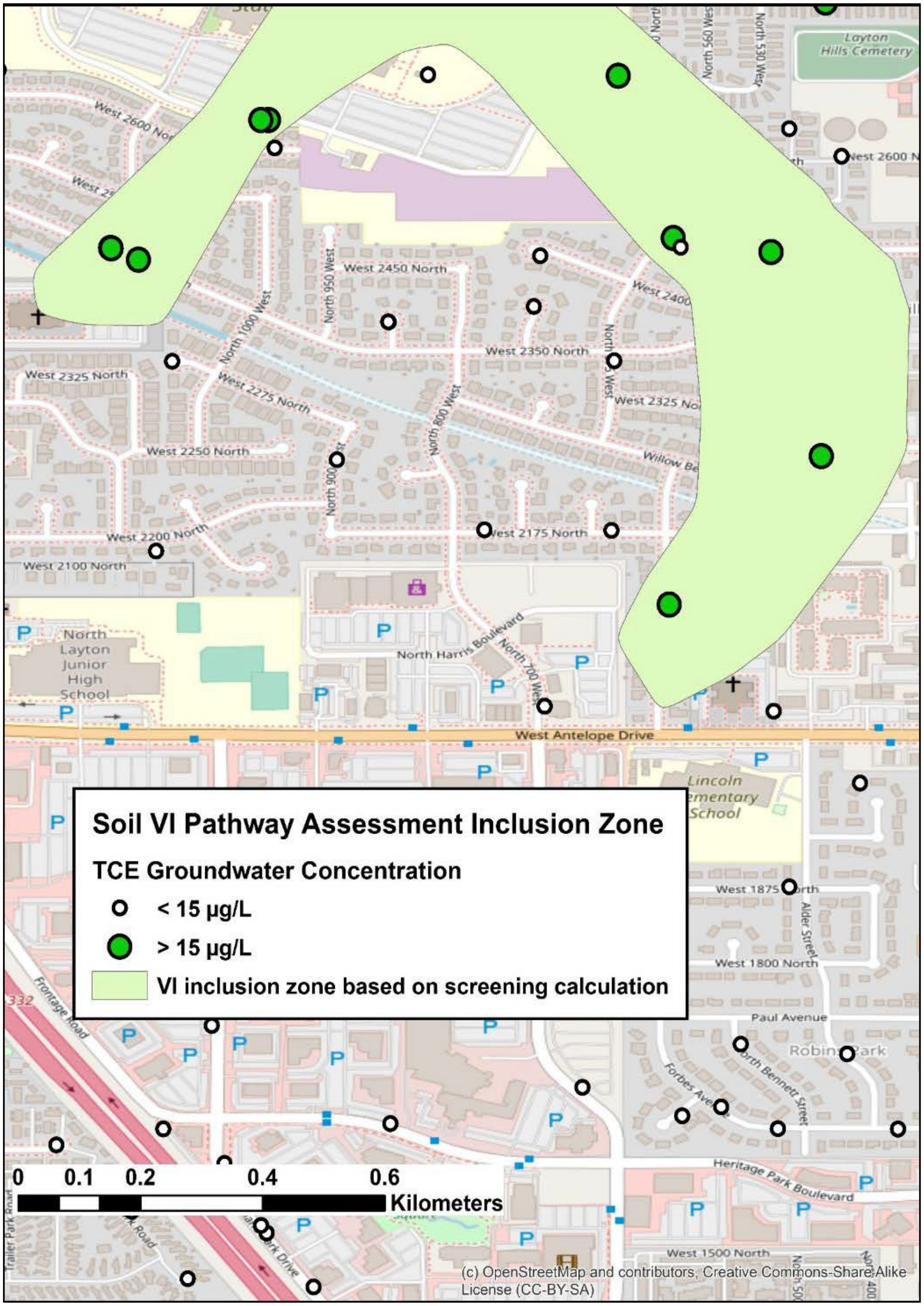


Figure 6.14. Example Soil VI Pathway Assessment Inclusion Zone for the OU-8 Area.

6.1.2.2 Use of subsurface utility vapor concentration data to estimate VI pathway assessment inclusion zones for indoor air impacts via the pipe-flow and sewer VI pathways.

Although generally-accepted guidance is not available at this time, results from ER-201505 provide some insight into the attenuation of VOC vapor concentrations from subsurface corridors into connected buildings (McHugh et al., 2018). According to the ER-201505 final report, indoor air concentrations resulting from subsurface piping vapors ranged from about 1/20 to less than 1/2500 of the source vapor concentrations in the piping networks. Based on this, the authors suggested multiplying source vapor concentrations by 1/30 = 0.03 to estimate indoor air concentrations resulting from the pipe-flow and sewer VI pathways. This recommendation was adopted for the illustrative analysis presented below, in which the following rules were adopted for identifying homes at risk from pipe-flow and sewer VI impacts:

- A manhole was considered a significant VOC source (marked in dark green in Figure 6.15) if TCE vapor concentrations were in excess of 12 ppb_v (1/0.03 = 30x the EPA indoor air screening level of 0.4 ppb_v = 2.1 mg/m^3).
- If an uninterrupted stretch of utility piping was bounded by manholes with vapor concentrations in excess of 12 ppb_v, then that entire stretch of utility was considered a possible source of significant VI impacts.
- For stretches of utility piping bounded by two manholes with concentrations above and below the 12 ppb_v screening level, linear regression of TCE vapor concentrations was used to identify the stretch of utility piping considered to be a possible source of significant VI impacts.

All buildings located along utility piping stretches identified as significant vapor sources were included in the pipe flow and sewer VI pathway assessment inclusion zone.

Figures 6.15 and 6.16 show the high-risk manholes and utility piping stretches identified as significant vapor sources for both the sanitary sewer and land drain systems, respectively. Figure 6.17 shows the combined inclusion zone from both sanitary sewer and land drain systems.

Figure 6.15. Significant Vapor Source Sewer Manholes and Utility Piping Stretches and Corresponding Sewer VI Pathway Assessment Inclusion Zones.

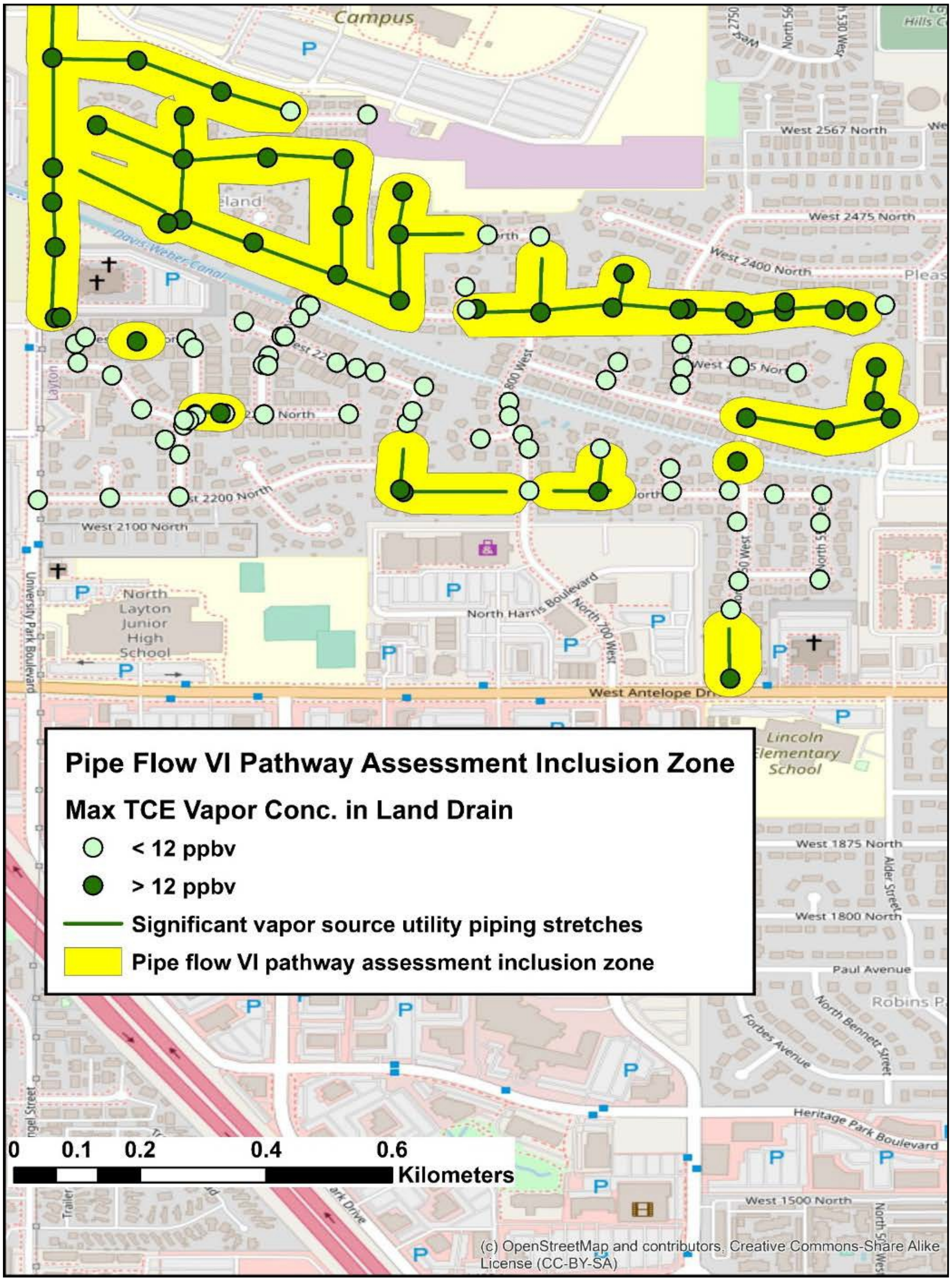


Figure 6.16. Significant Vapor Source Land Drain Manholes and Utility Piping Stretches and Corresponding Pipe Flow VI Pathway Assessment Inclusion Zones.

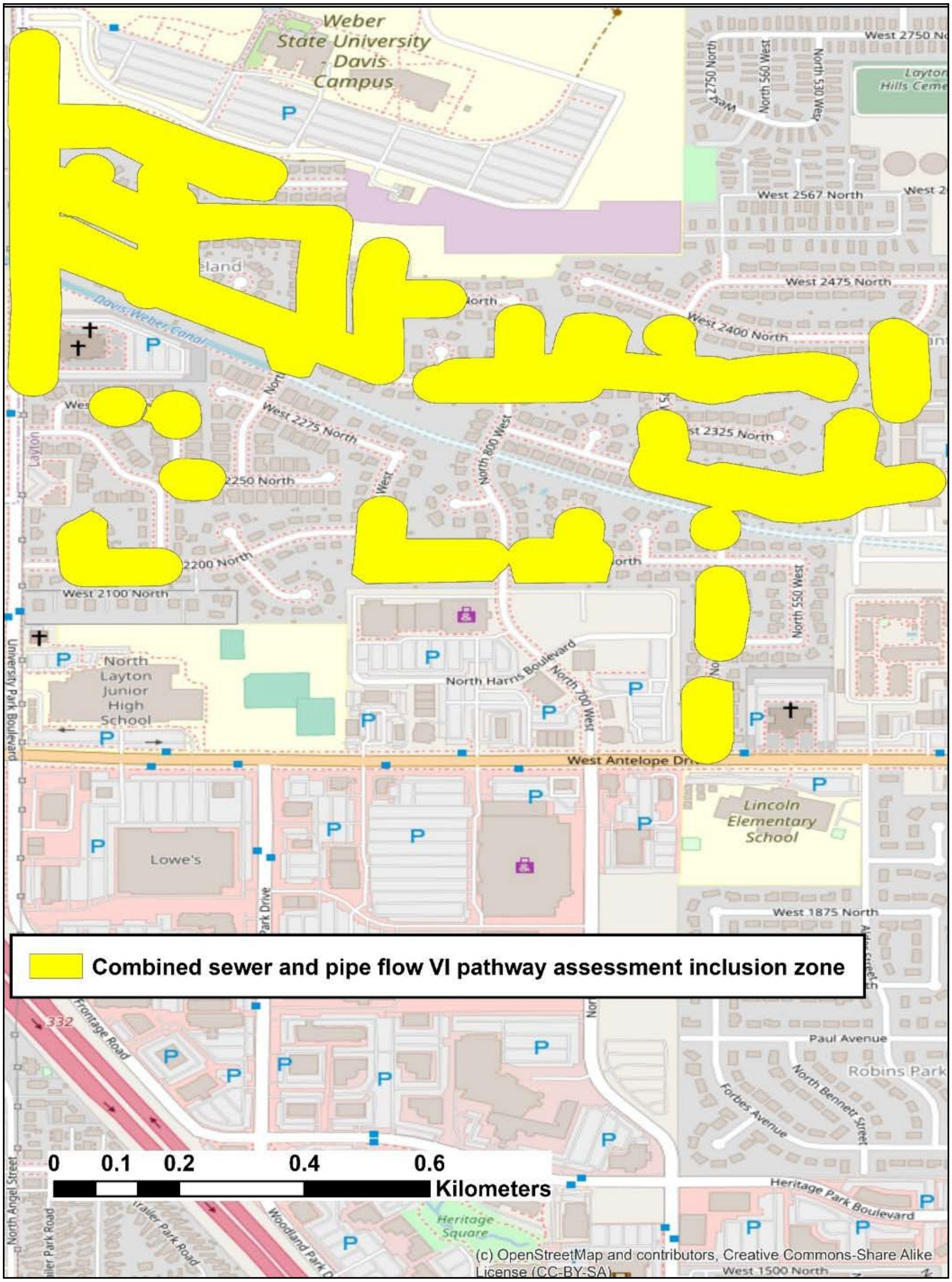


Figure 6.17. Combined Sewer and Pipeflow VI Pathway Assessment Inclusion Zone Based on Vapor Sampling Results from Sanitary Sewer and Land Drain Systems.

The results presented in Figure 6.16 and 6.17 are based on the assumption that all homes in the pathway assessment inclusion zones have physical connections to the land drain main piping under the neighborhood. That might not be the case, and the number of buildings requiring building-specific testing could possibly be reduced through in-line video camera inspection. The video feed can identify connections between utility corridors and adjacent buildings. The use of an inline video camera was demonstrated in an approximately 0.5 km by 1 km region of this study area, as shown in Figure 6.18. The total number of houses that were adjacent to inspected utility corridors was 145. In this case, inline video feed results indicated that about 38% of the buildings (55 of 154) likely have main land drain connections via lateral piping terminating in the foundation backfill beneath the buildings.

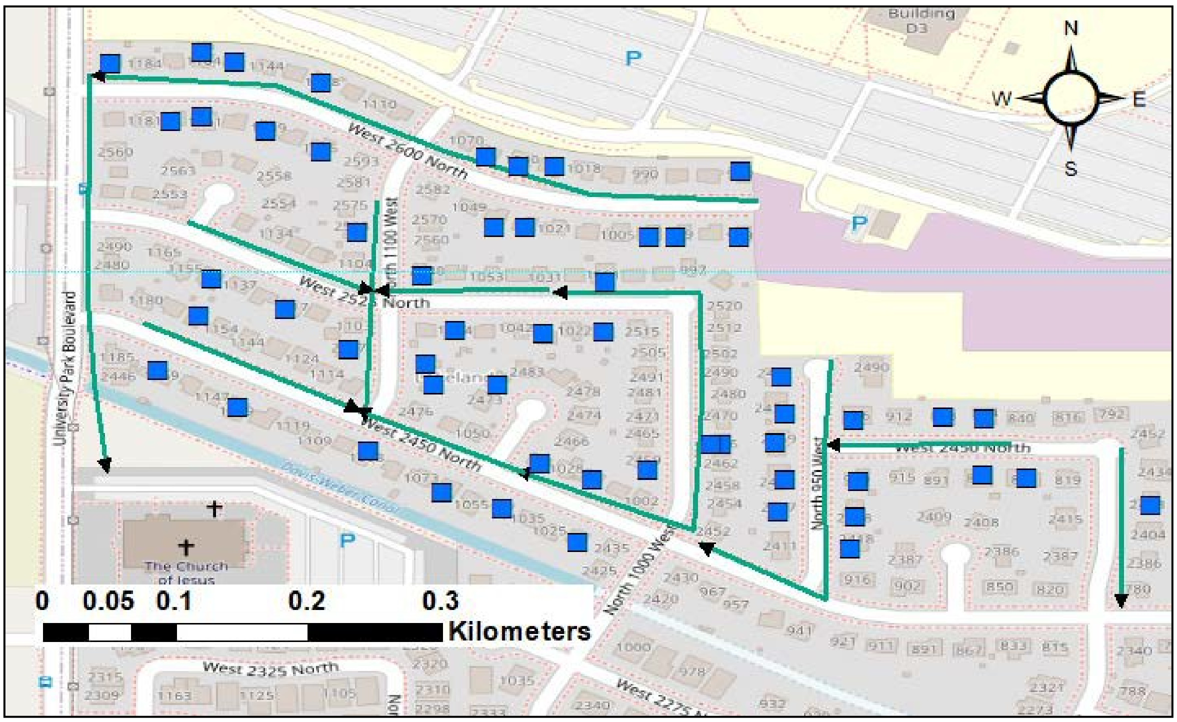


Figure 6.18. Video Inspected Land Drain in This Study Area, and Blue Boxes Denote Houses Physically Connected to the Land Drain Main Via Lateral Piping.

6.1.3 Validation assessment of the use of external source data to identify homes for building-specific testing using historical indoor air concentration data.

An attempt to validate the use of external source data to identify homes for building-specific testing was conducted using historical indoor air sampling results for homes in the OU-8 area. Of those, 623 of 884 homes in the OU-8 study area were sampled at least once in the 2002-2015 period. Overall, for 74% (461) of the tested homes, TCE was not detected in indoor air. The TCE indoor air concentration was greater than the detection limit but less than 0.4 ppb_v at least once in 11.2% (70) of all tested buildings, and it was greater than 0.4 ppb_v in 14.8% (92) of all tested houses. It is important to note that the sampling record for each home is fairly limited and much less than what would be desired for analysis of this type. In addition, the occurrence of TCE in indoor air in any home could also be the result of indoor air sources in that home.

The historical indoor air sampling results are presented in figures below in which homes are grouped into three categories by maximum detected TCE indoor air concentration: 1) less than the minimum detection limit (MDL); 2) between the MDL and the 0.4 ppb_v USEPA recommended indoor air screening level for TCE; and 3) >0.4 ppb_v.

- Figure 6.19 presents the maximum TCE indoor air concentrations and the associated vapor intrusion pathway assessment inclusion zone based on the soil VI pathway screening calculation.
- Figure 6.20 presents the maximum TCE indoor air concentrations and the associated vapor intrusion pathway assessment inclusion zone based on sewer and land drain vapor sampling results (pipe-flow and sewer VI pathway assessment).
- Figure 6.21 shows the maximum TCE indoor air concentrations and the associated combined vapor intrusion pathway assessment inclusion zone when considering the soil VI, pipe-flow, and sewer VI pathways.

With respect to these figures, in Figure 6.19:

- 204 of all 844 (~25%) homes in this study area are located inside the soil VI pathway assessment inclusion zone.
- 175 of 204 of the inside-inclusion-zone homes have been sample at least once, and 50 of those (28.6 %) have had TCE detected at least once in indoor air.
- 448 of 640 of the outside-inclusion-zone homes have been sample at least once, and 112 of those (25%) have had TCE detected at least once in indoor air.

A breakdown of the detected concentrations is presented below in Figure 6.22, categorized by location inside and outside of the VI pathway assessment inclusion zone. As can be seen, 141 of the 204 homes that were sampled (69%) in the soil VI pathway assessment inclusion zone did not have TCE detected in indoor air at or above 0.4 ppb_v when they were sampled. In addition, 58 of the 448 homes that were sampled outside the exclusion zone (13%) did have concentrations detected at or above 0.4 ppb_v. If these data were representative of indoor air concentrations in those homes, then it would suggest that the approach used for defining the soil VI pathway assessment inclusion zone was relatively conservative and that there is likely another VI pathway besides the soil VI pathway contributing to indoor air impacts outside the soil VI pathway assessment inclusion zone.

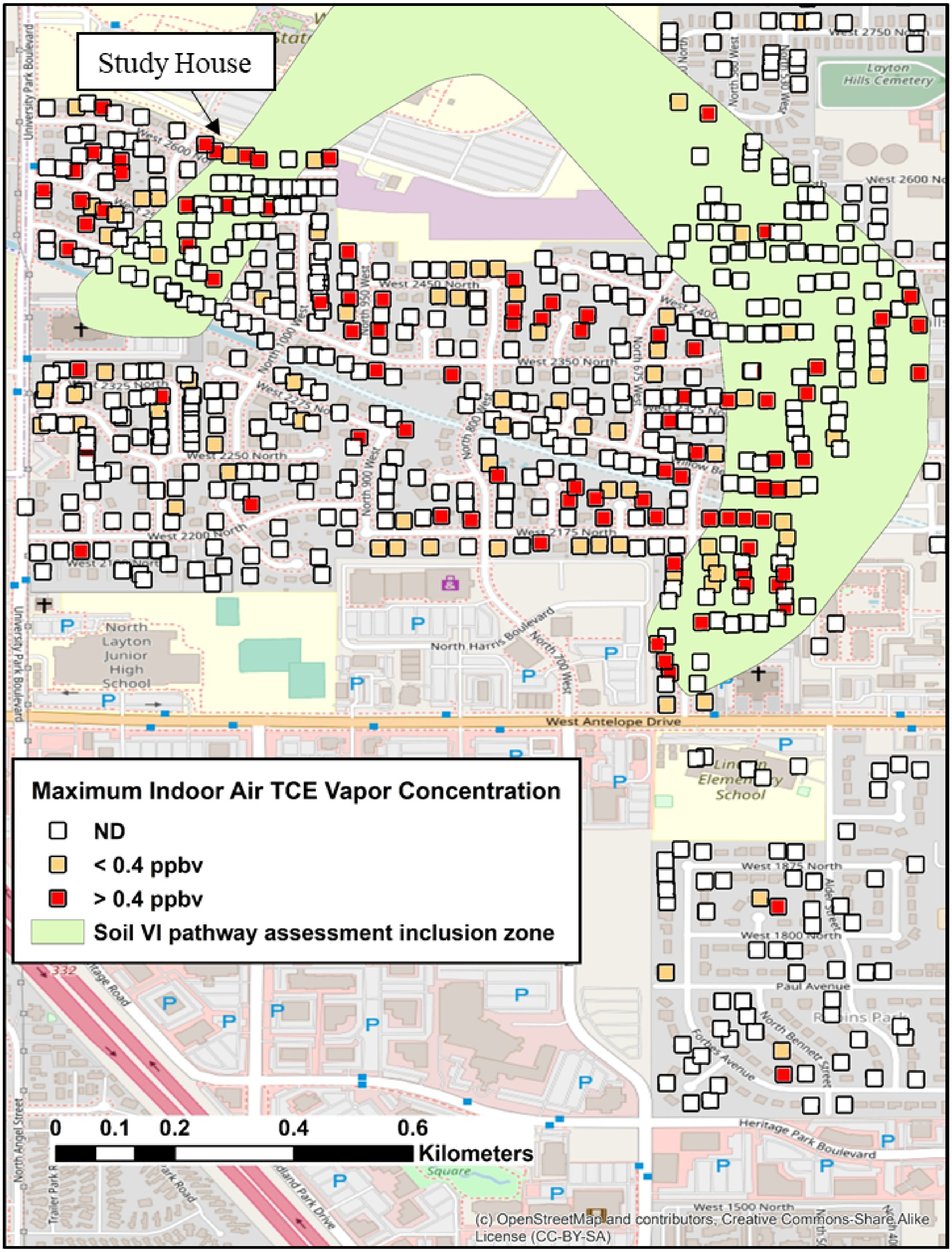


Figure 6.19. Maximum Historical TCE Indoor Air Concentrations and the Soil VI Pathway Assessment Inclusion Zone.

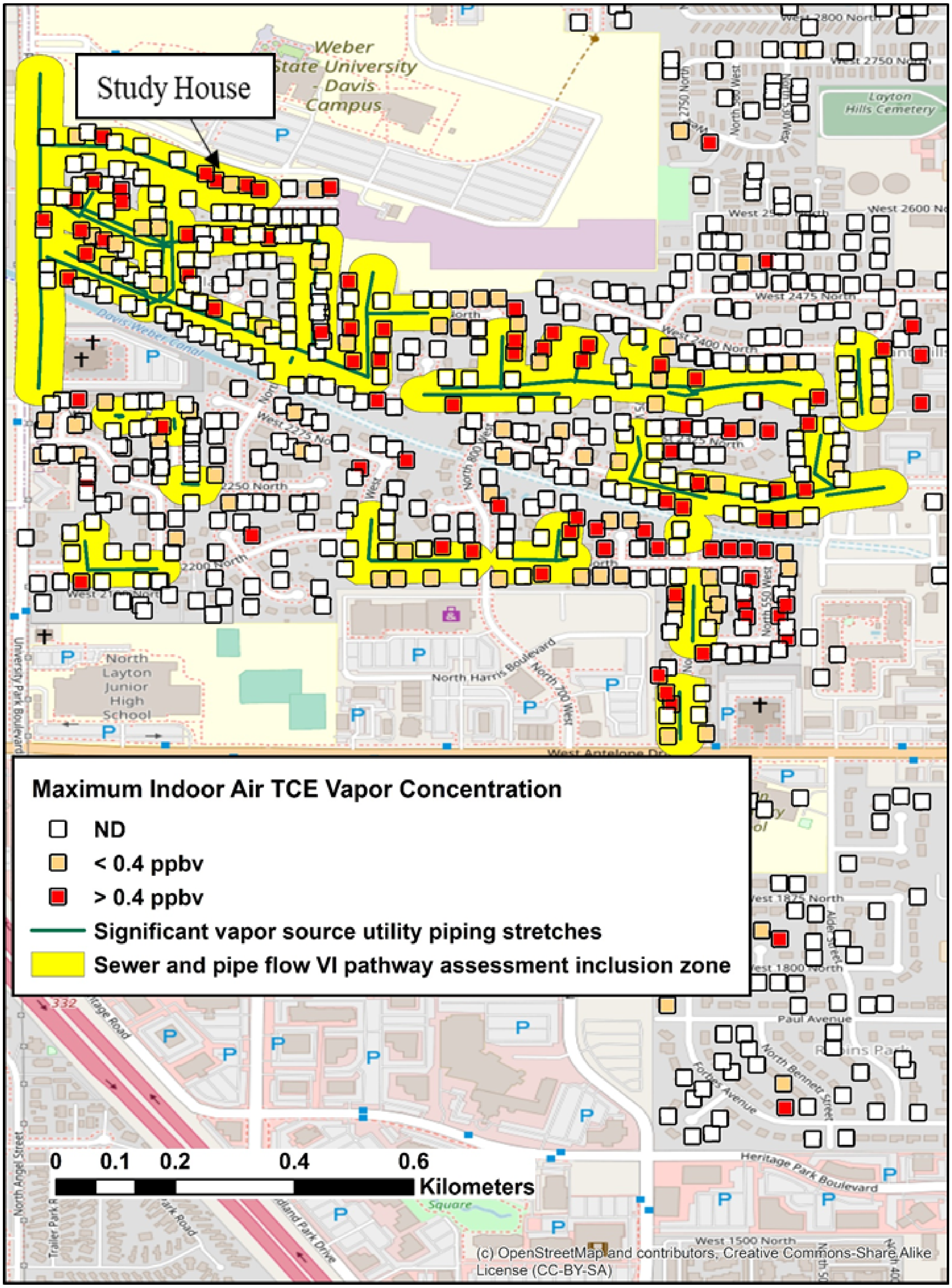


Figure 6.20. Maximum Historical TCE Indoor Air Concentrations and the Pipe Flow and Sewer VIPathway Assessment Inclusion Zone.

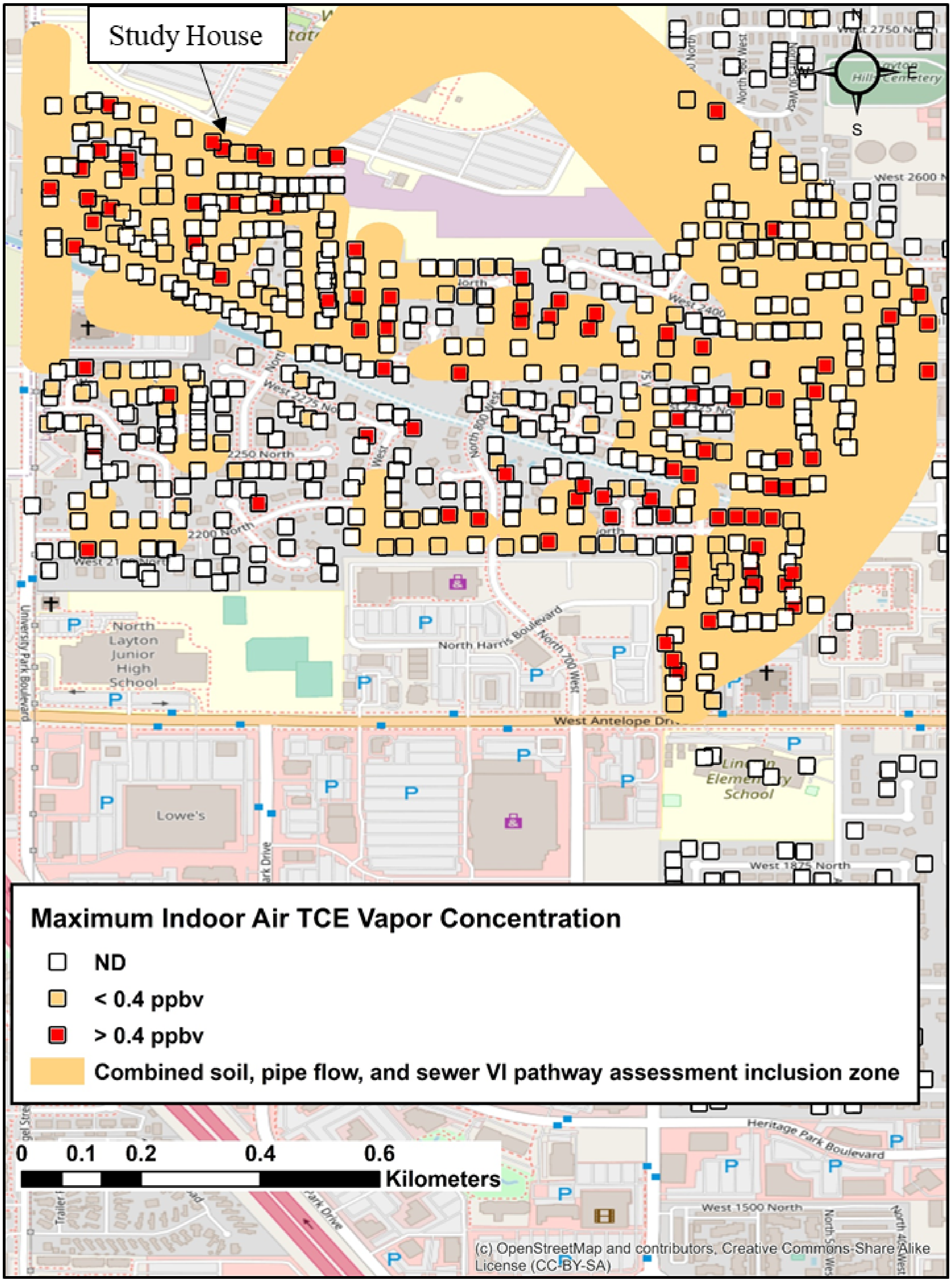


Figure 6.21. Maximum Historical TCE Indoor Air Concentrations and the Total Combined Soil, Pipe Flow, and Sewer VI Pathways Assessment Inclusion Zone.

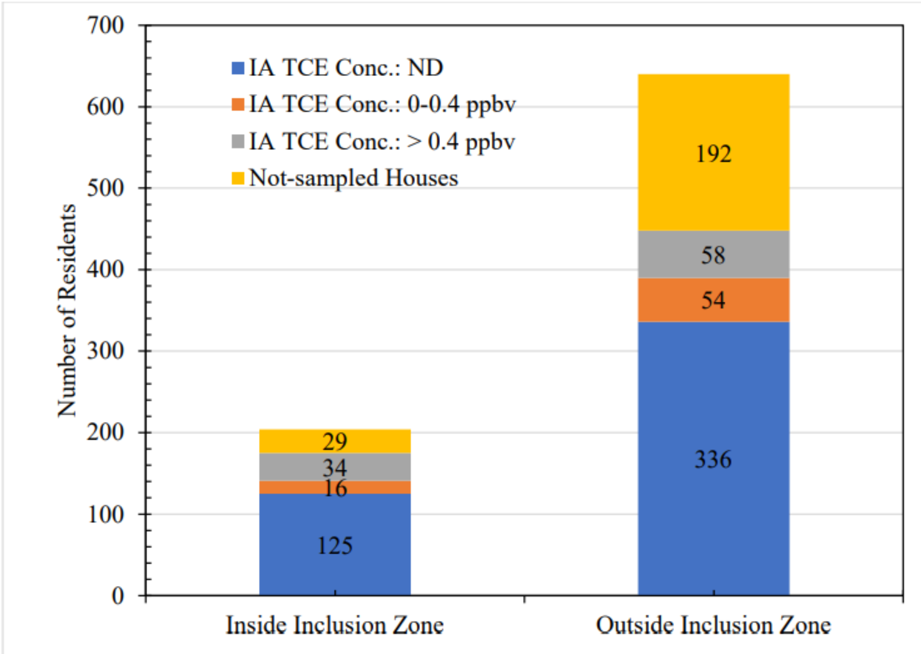


Figure 6.22. Summary of Historical Concentrations in Homes Inside and Outside the Soil VI Pathway Assessment Inclusion Zone.

In Figure 6.20:

- 310 of all 844 homes (37%) in this study area are located inside the pipe flow and sewer VI pathways assessment inclusion zone.
- 252 of 310 (81%) of the inside-inclusion-zone homes have been sample at least once, and 91 of those (36.1%) have had TCE detected at least once in indoor air.
- 371 of 534 (69%) of the outside-inclusion-zone homes have been sample at least once, and 71 of those (19%) have had TCE detected at least once in indoor air.

A breakdown of the detected concentrations is presented below in Figure 6.23, categorized by location inside and outside of the VI pathway assessment inclusion zone. As can be seen, 200 of the 252 homes (79%) sampled in the pipe flow and sewer VI pathways assessment inclusion zone did not have TCE detected in indoor air at or above 0.4 ppb_v when they were sampled. In addition, 40 of the 371 homes sampled outside the exclusion zone (11%) did have concentrations detected at or above 0.4 ppb_v. If these data were representative of indoor air concentrations in those homes, it would suggest that the approach used for defining the pipe flow and sewer VI pathways assessment inclusion zone was relatively conservative and that there may be another VI pathway besides the pipe flow and sewer VI pathway contributing to indoor air impacts outside the soil VI pathway assessment inclusion zone. The indoor air impacts could also be the result of indoor air sources.

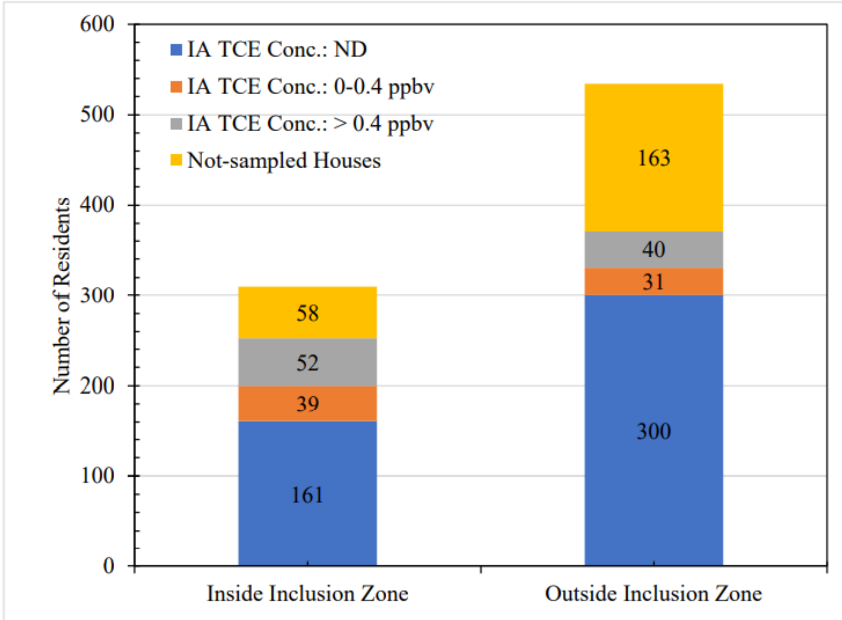


Figure 6.23. Summary of Historical Concentrations in Homes Inside and Outside the Pipe Flow and Sewer VI Pathways Assessment Inclusion Zone.

In Figure 6.21, which represents the combined VI pathways assessment inclusion zone:

- 422 of all 844 homes (50%) in this study area located inside the combined VI pathways assessment inclusion zone.
- 345 of 422 (82%) of the inside-inclusion-zone homes have been sample at least once, and 114 of those (33%) have had TCE detected at least once in indoor air
- 278 of 422 (66%) of the outside-inclusion-zone homes have been sample at least once, and 48 of those (17%) have had TCE detected at least once in indoor air.

A breakdown of the detected concentrations is presented below in Figure 6.24, categorized by location inside and outside of the VI pathway assessment inclusion zone. As can be seen, 275 of the 345 homes (80%) sampled in the combined VI pathways assessment inclusion zone did not have TCE detected in indoor air at or above 0.4 ppb_v when they were sampled. In addition, 22 of the 278 homes sampled outside the exclusion zone (8%) did have concentrations detected at or above 0.4 ppb_v. If these data were representative of indoor air concentrations in those homes, then it would suggest that the approach used for defining the combined VI pathways assessment inclusion zone was relatively conservative and that <10% of the homes outside the exclusion zone were at risk from significant VI impacts. Again, it is possible that some of those homes had measurable TCE impacts as a result of indoor air sources.

Overall, this use of external source data for pathway screening analysis reduced the number of homes that would be candidates for building-specific study by 50%. The data suggest that a less conservative analysis approach might result in a reduction of 75% of the homes in the study area, because 200 of the 844 homes in the inclusion zone had indoor air TCE concentrations less than 0.4 ppb_v.

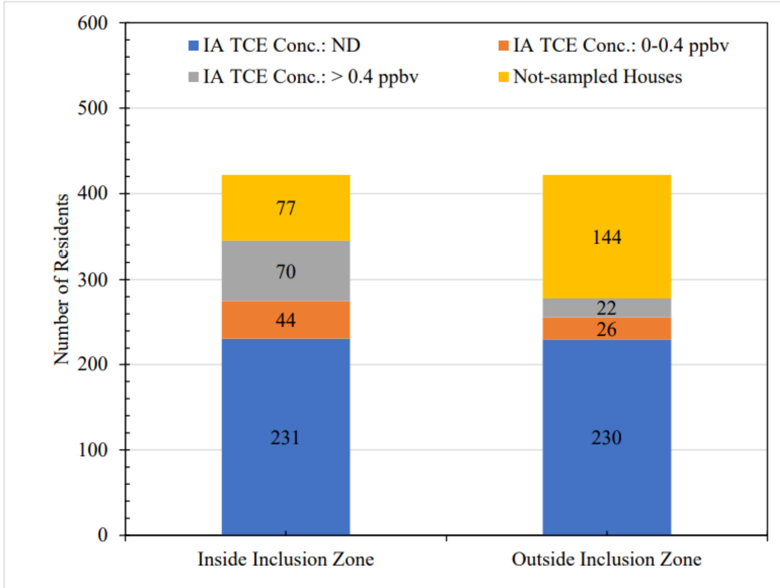


Figure 6.24. Summary of Historical Concentrations in Homes Inside and Outside the Combined VI Pathways Assessment Inclusion Zone.

Use of Video Survey Data

The analysis above assumes that all homes located in areas with land drain system piping have land drain lateral connections between the house and the land drain main line. The use of in-piping video survey inspections was examined to test that assumption in the sub-region shown above in Figure 6.18. In that sub-region there were 145 houses located adjacent to land drain system main lines in that area. The video surveys indicated that 55 of those 145 houses had possible connections to the land drain main lines.

In focusing only on those land drain stretches with vapor concentrations exceeding the screening threshold for pipe flow VI impacts, it was noted that these included 123 of the 145 homes in the test sub-area, and of those, only 49 homes had lateral connections to the land drain main lines. If this was the only VI pathway of concern in this area, then use of the video survey would have reduced the number of homes requiring building-specific testing by about 60%.

In this case, when considering the VI pathway assessment inclusion zone resulting from the sum of all three VI pathways (soil VI, pipe flow VI and sewer VI), use of video survey data would have reduced the number of homes requiring building-specific testing from 123 to 86, or a reduction of 37 homes (30%). That small investment in video surveys would have had a significant return-on-investment with respect to reducing building-specific testing costs.

Table 6.3 summarizes the historical indoor air sampling data available from homes in this region, divided into different groups of home by their location relative to pathway inclusion zones. It is important not to over-analyze these data given their limitations, but it is of interest that 2 of 14 homes (14%) located away from any inclusion zone had TCE detections above 0.4 ppb_v, which presumably had to be the result of indoor vapor sources. Similarly, 5 of 37 homes (14%) that did not have land drain lateral connections in the pipe flow VI zone also had TCE detections above 0.4 ppb_v.

This gives some indication of the frequency at which indoor air sources might be contributing significant concentrations to indoor air in homes in this neighborhood. That can be compared with the 7 of 30 homes (23%) with TCE detections above 0.4 ppb_v and having land drain lateral connections in the land-drain pathway-only inclusion zone, and the 11 of 56 homes (20%) of homes with TCE detections above 0.4 ppb_v in the aggregate combined VI pathways inclusion zone.

With a richer historical indoor air data set, it might be possible to draw conclusions about the significance of the impacts from the three possible VI pathways in these neighborhood areas, and a better understanding of the attenuation of vapor concentrations between land drain main lines and indoor air.

Table 6.3. Statistical Summary of Video Inspected Houses Relevant to Different VI Inclusion Zones and their Maximum TCE Indoor Air Concentration Records.

Number of Houses Located in the Land Drain Inclusion Zone Only					
67					
# connected to the land drain main system			# not connected to the land drain main system		
30			37		
> 0.4 ppbv	0-0.4 ppbv	ND*	> 0.4 ppbv	0-0.4 ppbv	ND
7	3	20	5	3	29
Number of Houses Located in the Aggregate Inclusion Zone from All VI Pathways					
56					
# connected to the land drain main system			# not connected to the land drain main system		
19			37		
> 0.4 ppbv	0-0.4 ppbv	ND	> 0.4 ppbv	0-0.4 ppbv	ND
6	2	11	5	5	27
Houses in Sewer and Soil Pathway ZonesOnly			**Houses Outside any VI Inclusion Zone**		
8			14		
> 0.4 ppbv	0-0.4 ppbv	ND	> 0.4 ppbv	0-0.4 ppbv	ND
0	0	8	2	6	6

* - None detected

6.1.4 Implications for external source screening

In this work, we investigated the temporal and spatial distributions of TCE vapors in land drain and sewer piping networks beneath the study area. Important lessons learned from that work include:

- Collecting 24-h time-integrated vapor samples is preferred over one-time grab sampling in utility piping. A related ESTCP project is evaluating the efficacy of using passive samplers over multi-week periods to even better characterize potentially fluctuating vapor concentrations.
- When conducting VOC surveys in utility corridors, multi-season synoptic events should be considered, as these are likely to provide more confidence in characterizing vapor distributions than single sampling events.

Lessons learned from using external vapor source data to reduce the number of buildings that would be candidates for building-specific testing include:

- The combined VI pathway assessment inclusion zone using groundwater data and vapor sampling results from subsurface utility networks eliminated about 50% of the total buildings from consideration for building-specific testing. On a site that is the scale of the study area in this work, that is a significant potential cost savings. For smaller sites with only a few buildings, it might be simpler to conduct building- specific tests on all of the buildings.

Practitioners should be aware of the following when performing analyses using external vapor source data from subsurface utility piping:

- The 1/30 attenuation factor for the pipe flow and sewer VI pathways used in the example above (e.g., indoor air concentration = 1/30 x utility line vapor concentration), while thought to be conservative at this time, was developed using data from only a few detailed site investigations and might change with time as more data are collected at other sites.

6.2 TASK 2: CONTROLLED PRESSURIZATION METHOD (CPM) PROTOCOL VALIDATION ANDDEMONSTRATION

The Task 2 objective was to develop a validated protocol for controlled pressure method (CPM) testing, which is a short-term diagnostic test that can be used to determine the maximum VI impact expected under natural conditions. CPM testing, in combination with external source strength data analysis can be used to determine the route by which subsurface vapors are entering indoor air. In this work, the CPM protocol development and validation occurred in a well- instrumented study house, followed by demonstrations in three residential and three industrial buildings.

6.2.1 Development and Validation of a Controlled Pressure Method (CPM) Test Protocolfor Vapor Intrusion Pathway Assessment

6.2.1.1 Background

Controlled pressure method (CPM) testing is a building-specific diagnostic investigative tool for vapor intrusion (VI) pathway assessment (Environmental, 2008; Guo et al., 2015; Holton et al., 2015; Hosangadi et al., 2017; Lutes et al., 2019; McHugh et al., 2012). CPM testing offers advantages over the indoor air sampling prescribed in many regulatory guidance documents (The Interstate Technology & Regulatory Council, 2014; US EPA, 2015). Studies have shown that indoor air sampling results can be influenced by seasonal, daily, or more frequent indoor-outdoor pressure variations driven by wind speed and direction, indoor-outdoor temperature differences, and other factors (Johnston and Gibson, 2014; Shen and Suuberg, 2016; Shirazi et al., 2020; Shirazi and Pennell, 2017; Ström et al., 2019). Under natural conditions, volatile organic chemical (VOC) concentrations in indoor air have been documented to vary up to several orders of magnitude over hours to days at some sites (Folkes et al., 2009; Holton et al., 2013; Johnston and Gibson, 2014; Luo et al., 2009; US EPA, 2012). With typical indoor air sampling approaches (e.g., summa canister), this variability can lead to false-negative or false-positive conclusions in VI pathway assessment (Holton et al., 2013). In contrast, CPM testing conducted in a study building having highly variable indoor air grab sample results under natural conditions yielded relatively constant daily average results over nine months (Holton et al., 2015), and the CPM test results were similar to the maximum concentration measured under natural conditions.

Based on results available to date, it also appears that negative pressure difference testing results are not significantly affected by weather conditions (e.g., wind, precipitation) (Holton et al., 2015; Guo et al., 2015; Ringer et al., 2005). Thus, CPM tests need only be conducted once and for <24 h, and decision-makers can reach conclusions about VI pathway presence and impact quicker and more confidently with CPM testing than with conventional indoor air sampling under natural conditions. An additional advantage of CPM testing vs. indoor air grab sampling is that indoor air sampling results can be confounded by unknown indoor air pollutant sources, while CPM testing can identify the presence of significant indoor sources (Beckley et al., 2014; McHugh et al., 2012).

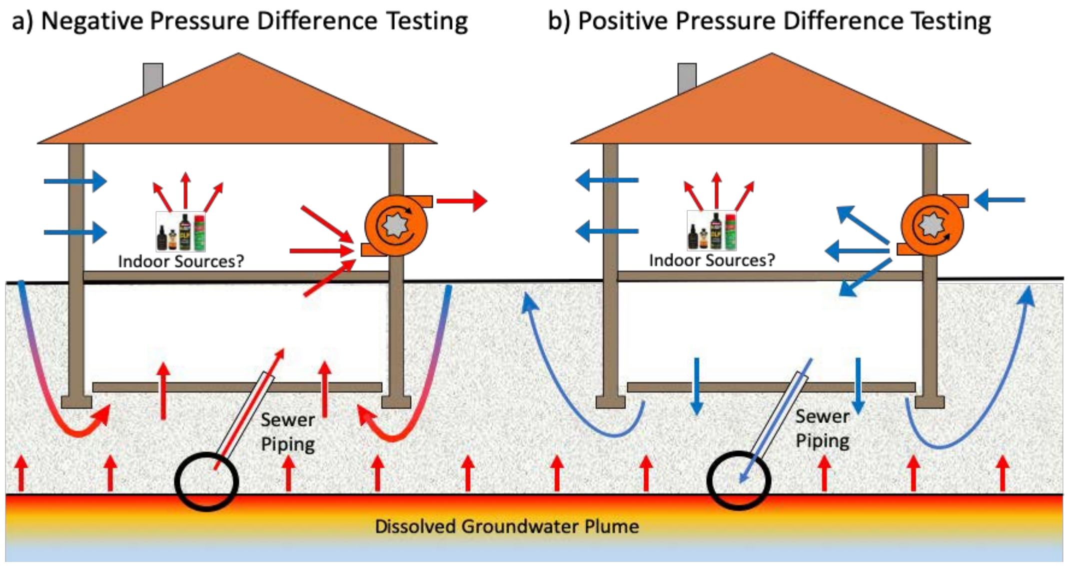


Figure 6.25. CPM Test Schematic : a) Negative Pressure Difference Testing that Induces Vapor Intrusion and b) Positive Pressure Difference Testing Hat Suppresses Vapor Intrusion.

As shown in Figure 6.25, CPM testing involves the use of blowers/fans installed in doorways or windows to create constant indoor-outdoor pressure differences. The negative pressure difference condition (Figure 6.25a) induces air movement from subsurface toward the test building via soil vapor intrusion pathways or subsurface piping networks. This is similar to what happens when natural conditions (e.g., wind, indoor-outdoor temperature difference) create an under-pressurized building condition. Conversely, the positive pressure difference condition suppresses vapor entry (Figure 6.25b).

It has been shown that CPM test results can be used to deduce whether the VI impact is primarily the result of vapor migration through soil or vapor migration through subsurface piping conduits (Guo et al., 2015). Lastly, as demonstrated in this work and others (Beckley et al., 2014; Environmental, 2008; McHugh et al., 2012), positive pressure difference CPM testing can help identify the presence of significant indoor air pollutant sources. During positive pressure difference testing, VOC entry via subsurface VI pathways is suppressed, and if indoor air contaminant vapors are still present at concentrations above outdoor ambient levels, it is likely indicative of an indoor air VOC source.

While studies to date have shown the benefits of CPM testing for VI pathway investigations, the use of this diagnostic tool is still in its early stages and guidance is needed to ensure it is practiced in a valid and consistent way. Based on CPM testing studies for radon (Collignan et al., 2012; Collignan and Powaga, 2014; Froňka and Moučka, 2005; Ringer et al., 2005) and VI risk assessment (Beckley et al., 2014; Guo et al., 2015; Holton et al., 2015; McHugh et al., 2012; Yao et al., 2019)[,24], basic CPM test design parameters include indoor-outdoor pressure difference (or exhaust fan flowrate), CPM test duration, exhaust fan location, and air sampling location(s) and protocol(s). In past studies, the indoor-outdoor pressure difference was typically controlled to about -5 to -10 Pa (indoor - ambient atmospheric pressure) (Guo et al., 2015; Holton et al., 2015; McHugh et al., 2012). CPM testing duration ranged from less than 8 h to almost 9 months (Beckley et al., 2014; Guo et al., 2015; Holton et al., 2015; McHugh et al., 2012; Yao et al., 2019)[,24]. With respect to sampling protocol, floor fan placement appeared to have noticeable impact on the efficiency of pressure control and the spatial distribution of indoor air pollutants in the USEPA (US EPA, 2012) study.

The goal of this study was to perform CPM tests under a range of operational conditions in a well-instrumented and previously monitored residence in order to recommend standardized conditions for CPM testing. These tests investigated the effects of exhaust fan placement, indoor- outdoor pressure difference, test duration, indoor air mixing, and where and how to collect air samples.

6.2.1.2 Materials and methods

Study House. The study house has been described in other publications (Guo et al., 2019, 2015; Holton et al., 2015, 2013; McHugh et al., 2012). In brief, it is a two-story, split-level house that overlies a groundwater plume with dissolved TCE concentrations ranging from 10-50 µg/L-H_2O. An open-ended land drain lateral pipe connects the sub-foundation area near the southeast corner of the house with the neighborhood land drain network present near the street. This important physical feature was discovered and confirmed to be a significant pathway for TCE vapor migration to indoor air at this house during the long-term CPM test reported by Holton et al. (Holton et al., 2015) and Guo et al. (Guo et al., 2015). A valve was installed on that pipe and CPM testing and natural condition results are available for both open- and closed-valve conditions[4]. The daily-average indoor air TCE concentration during CPM testing only varied by about 2x during the 270+ days of building negative pressurization; therefore, the impact of weather conditions on CPM test results is not considered significant. This is also supported by one radon intrusion study by Ringer et al. (2005), in which they suggested radon concentration during building depressurization was "building-specific" and "weather-independent".

Overall Experiment Design. Figure 6.26 shows the locations of vapor sampling, exhaust fan placement, and tracer release for the specific CPM testing conditions discussed below. The sample collection and blower operations were conducted using remotely controlled analyses and operations, so that the impact of occupant activities was minimized. The land drain valve was open throughout these tests.

Negative pressure difference CPM tests focused on determining impact of pressure difference and test duration on exhaust fan intake TCE vapor concentration with time: Four negative pressure difference conditions, ranging from about -4 to -14 Pa were tested for more than 48-h each.

During these tests, the exhaust fan was installed in the master bedroom (MB) window frame (Figure 6.26, for weather and long-term security considerations) and the exhaust fan flowrate was adjusted to achieve the desired pressure difference for each test. Indoor air samples were collected every 40 min from a sampling port located about 0.3 m in front of the center of the exhaust fan intake. Three floor fans were used for air mixing near the sample collection port. The cross-slab pressure difference (indoor – subslab) was recorded every 15 - 30 s at four locations and the indoor-outdoor pressure difference was measured relative to four outdoor locations and a manifolded composite of those four locations.

Negative pressure difference CPM tests focused on determining room-to-room variations in TCE vapor concentration: A single 7-d long negative pressure difference test was conducted with the exhaust blower placed in the master bedroom MB window frame. Indoor air samples were collected from the eight indoor locations (Figure 6.26) with and without floor fan mixing near the exhaust fan inlet.

Negative pressure difference CPM testing focused on determining the effect of exhaust fan location on fan intake TCE and SF_6 tracer concentration: Four negative pressure difference tests were conducted by installing the exhaust fan at four locations shown in Figure 6.26: the front door, patio door, garage into building door, and master bedroom window frame. During these tests, SF_6 tracer gas was released in Guest Bedroom 1 (GB1) to imitate an indoor air source. Air samples were collected near the exhaust fan intake with floor fan mixing as described above.

Each test was performed for more than 48 h.

Positive pressure difference CPM test with sub-slab SF_6 tracer gas release to determine appropriate test duration when implementing a positive pressure difference test immediately after a negative pressure difference CPM test: SF_6 tracer gas was released at 3 standard cubic centimeters per minute (SCCM) in the subslab location designated in Figure 6.26. The indoor-outdoor building pressure difference was initially negative and then was changed to positive using the exhaust fan installed in the master bedroom window. Indoor air was sampled at eight locations approximately every 10 h.

Positive pressure difference CPM testing focused on determining room-to-room variations in indoor source vapor concentration: With the blower installed in the master bedroom and blowing from outside into the bedroom, SF_6 tracer was released at the four indoor locations designated in Figure 6.26. The resulting indoor air SF_6 concentration distribution through the house was measured for each of those release conditions.

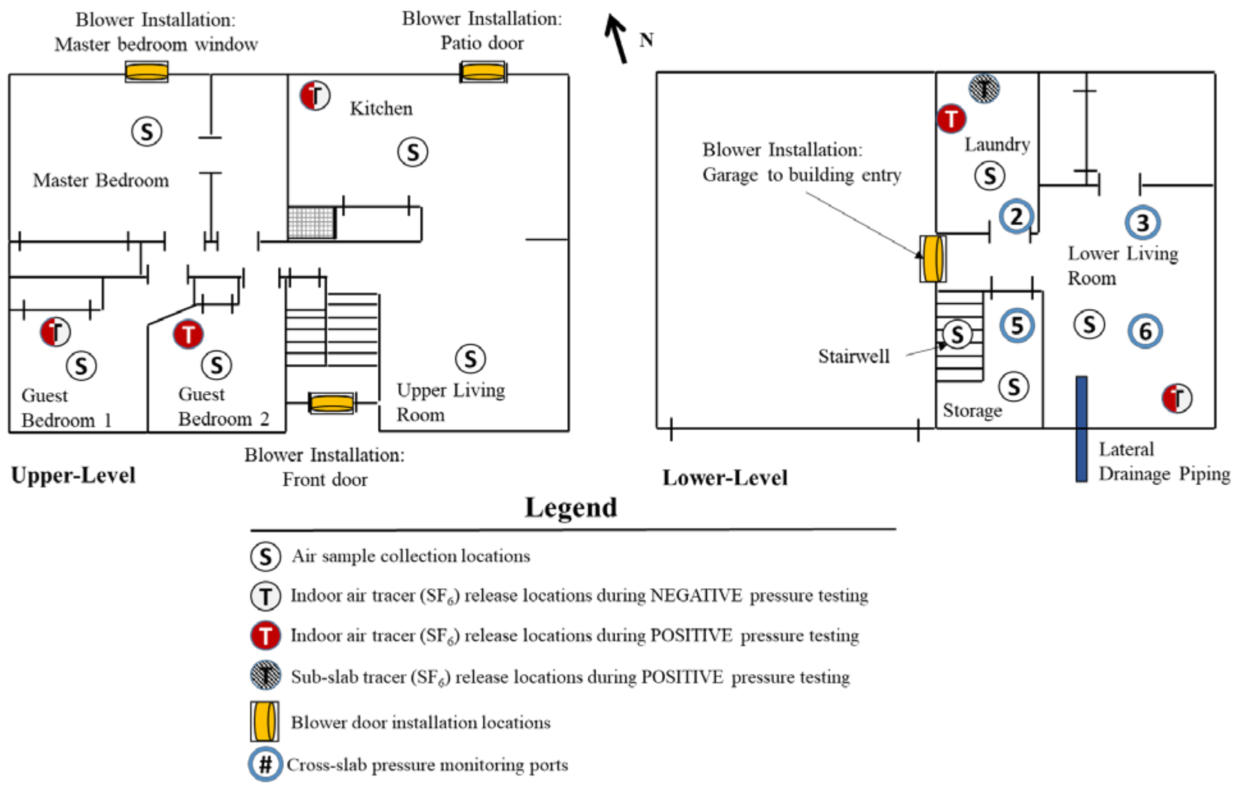


Figure 6.26. Schematic View of CPM Testing Sampling Locations and Exhaust Fan Placements.

Building Pressure Difference Control. Indoor-outdoor pressure differences were controlled by a Retrotec 6000 blower door system (Retrotec, WA), which includes a door frame, calibrated exhaust fan unit, digital fan speed controller, and real-time flowrate and pressure difference monitoring capabilities. By exhausting indoor air out of and blowing ambient air into the test building, this system created negative and positive indoor-outdoor pressure differences, respectively.

SF_6 Tracer Release and Indoor Air Sample Analyses. SF_6 tracer gas was released continuously at 3 SCCM using a 0-10 mL/min mass flow controller (Alicat Scientific, AZ) at those locations shown in Figure 6.26, to mimic either an indoor air or subsurface VOC source. The tracer was directly delivered to designated locations through 1/16 in diameter tubing without air mixing at the delivery location. SF_6 concentrations in air samples were quantified on-site and in real-time by gas chromatography using an SRI 8610C gas chromatograph (GC; SRI, CA) equipped with a VICI pulsed-discharge detector (PDD; Valco Instrument Co. Inc.). The detection limit for SF_6 measurement by this method was 4 ppb_v. Indoor air TCE concentrations were quantified on-site using an SRI 8610C GC equipped with a sample concentrator and an electron capture detector (ECD). GC/ECD calibration was performed prior to each CPM test, with the method detection limit for TCE being 0.009 ppb_v (0.05 $\mu g/m^3$). Air samples were collected every 40 min from each location using 0.32 cm diameter Nylaflow tubing. A minimum volume of 3x the tubing volume was flushed before each collection.

Pressure Difference Monitoring. Indoor - outdoor and indoor - sub-slab pressure differences were measured using Retrotec DM32 data logger (Retrotec, WA) and data were recorded every 15 - 30 s.

6.2.1.3 Demonstration results

Negative pressure difference CPM tests focused on determining impact of pressure difference and test duration on exhaust fan intake TCE vapor concentration with time: Negative pressure difference CPM tests were conducted under four indoor - outdoor pressure difference test conditions (about -4, -5, -10 and -14 Pa). Time-averaged cross-foundation (indoor – subslab) and indoor - outdoor pressure differences for the four tests were summarized in Table 6.4, 6.5 and Figures 6.27 to 6.30. These results suggested that a minimum 10 Pa differential should be created for negative pressure testing to achieve a consistent <0 indoor – subslab pressure differences.

Table 6.4. Summary of Pressure Differences Measured During the Negative Pressure Difference CPM Tests Focused on Determining Impact of Pressure Difference and Test Duration on Exhaust Fan Intake TCE Vapor Concentration with Time.

Indoor - Outdoor Pressure Difference* (time average ± standard deviation)	Exhaust Fan Flowrate	Indoor – Subslab Pressure Difference (time average ± standard deviation) [Pa]			
[Pa]	[m^3/min]	2-Subslab	3-Subslab	5-Subslab	6-Subslab
-3.8 ± 0.4	10.8 ± 0.1	-0.8 ± 0.2	-0.4 ± 0.2	-1.2 ± 0.3	-1.2 ± 0.3
-5.4 ± 0.4	13.6 ± 0.1	-1.2 ± 0.2	-0.6 ± 0.2	-2.0 ± 0.3	-2.0 ± 0.4
-10.5 ± 0.5	21.3 ± 0.1	-2.3 ± 0.3	-1.3 ± 0.3	-4.2 ± 0.4	-4.4 ± 0.5
-14.1 ± 0.8	27 ± 0.2	-3.2 ± 0.4	-1.7 ± 0.3	-5.7 ± 0.5	-5.8 ± 0.6

* - using the composite pressure reference point from the four exterior sides of the building.

Table 6.5. Summary of Indoor to Outdoor Pressure Differences During the Negative Pressure Difference CPM Tests Focused on Determining Impact of Pressure Difference and Test Duration on Exhaust Fan Intake TCE Vapor Concentration with Time.

Exhaust Fan Flowrate	Indoor - Outdoor Pressure Difference (time average ± standard deviation) [Pa]				
[m^3/min]	Outdoor air (composite)	Outdoor air (N)	Outdoor air (S)	Outdoor air (E)	Outdoor air (W)
10.8 ± 0.1	3.4 ± 0.4	4.6 ± 0.7	3.6 ± 0.8	3.8 ± 0.4	NA
13.6 ± 0.1	4.7 ± 0.5	6.2 ± 0.9	5.2 ± 1.2	5.4 ± 0.4	NA
21.3 ± 0.1	9.5 ± 0.5	11.2 ± 0.6	10.2 ± 0.8	10.5 ± 0.5	NA
27 ± 0.2	12.6 ± 0.9	15.8 ± 1.9	15.0 ± 2.9	14.2 ± 1.6	14.6 ± 1.1

NA - No sample available.

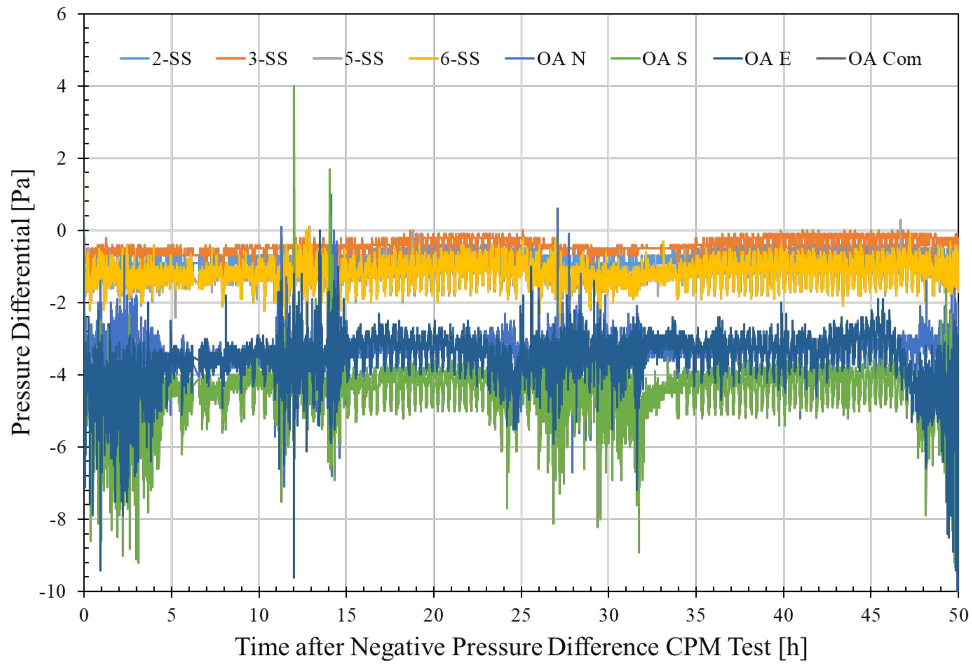


Figure 6.27. Real-time Monitoring Results for Indoor to Outdoor Air and Indoor Air to Sub-slab Soil Gas Pressure Differentials During -4 Pa Negative Pressure Difference CPM Tests.

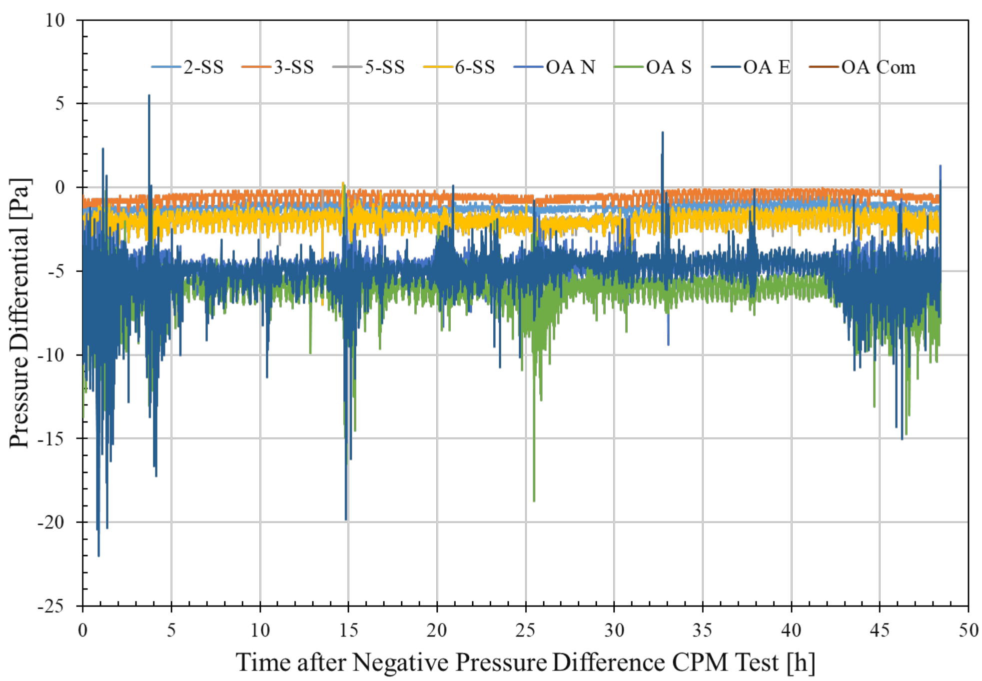


Figure 6.28. Real-time Monitoring Results for Indoor to Outdoor Air and Indoor Air to Sub-Slab soil Gas Pressure Differentials During -5 Pa Negative Pressure Difference CPM Tests.

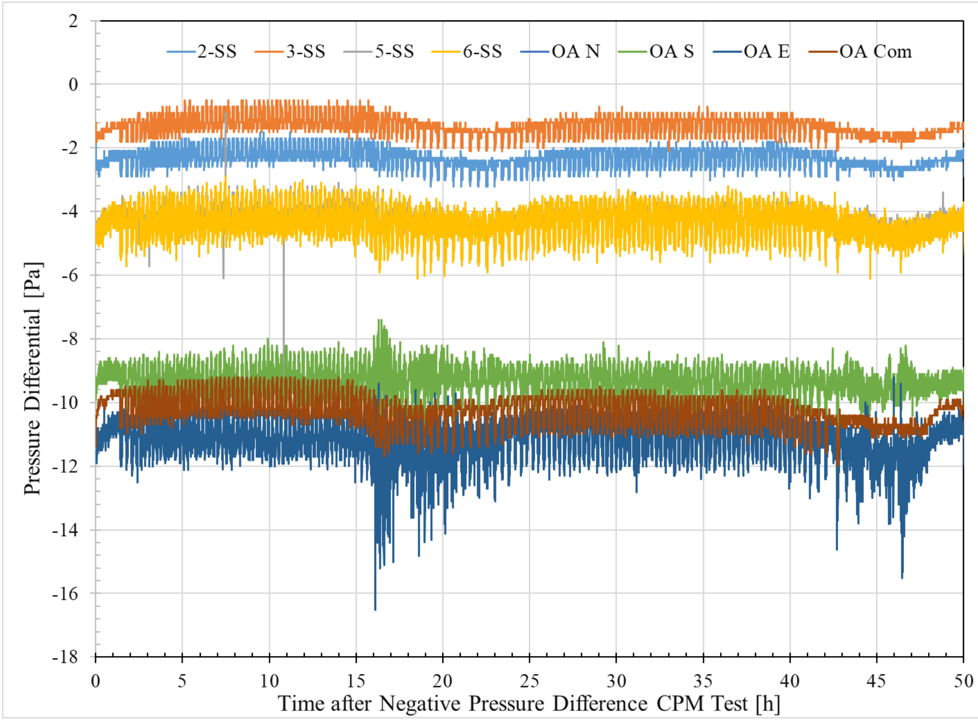


Figure 6.29. Real-time Monitoring Results for Indoor to Outdoor Air and Indoor Air to Sub-slab Soil Gas Pressure Differentials During -10 Pa Negative Pressure Difference CPM Tests.

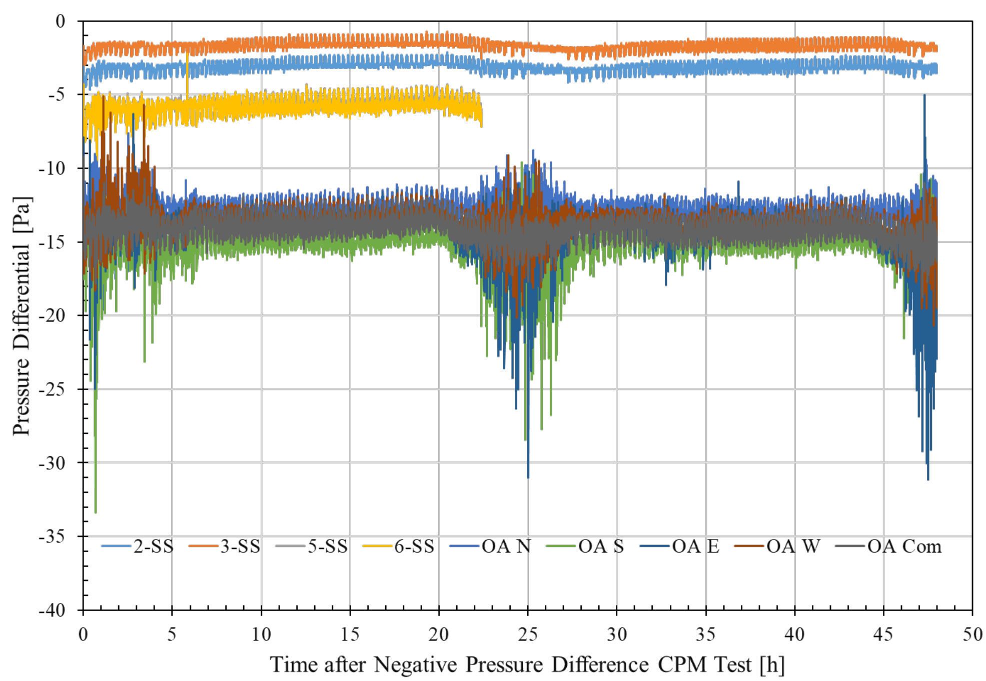


Figure 6.30. Real-time Monitoring Results for Indoor to Outdoor Air and Indoor Air to sub-Slab Soil Gas Pressure Differentials During -14 Pa negative pressure difference CPM Tests.

Figure 6.31 presents TCE vapor concentrations measured at the exhaust fan intake vs. time for the four negative pressure CPM tests. Dashed-line curves present the best-fit of a two-parameter well-mixed mass balance model (concentration=A[1-exp(-Bt)], with A and B as fitting parameters). The measured concentration vs. time responses were similar in shape for all four tests, with times to relatively steady concentrations decreasing with increasing pressure difference (and exhaust fan flowrate), and with the near-steady concentrations increasing with increasing pressure difference.

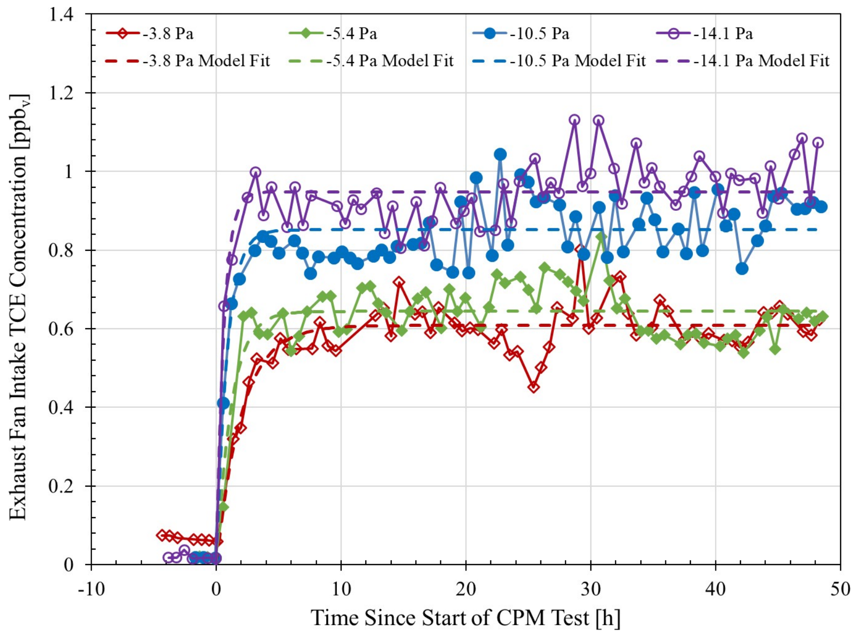


Figure 6.31. TCE Vapor Concentrations Measured at the Exhaust Fan Intake During CPM Tests Focused on Determining Impact of Pressure Difference and Test Duration on Exhaust Fan Intake TCE Vapor Concentration with Time.

Dashed lines are best-fit well-mixed mass balance modelcurves.

Table 6.6 summarizes the time-averaged TCE concentrations during the near-steady time period, the time to reach near-steady conditions, and the TCE emission rates into the building induced by each negative pressure CPM test. The time required to reach near-steady conditions was determined using the best-fit model curves. The time to near-steady conditions were the time where the best-fit model concentration was 95% of its steady-state value. Emission rates were determined by multiplying the time averaged exhaust fan flowrate and time-averaged near-steady inlet TCE concentration. As shown in Table 6.6, the decreases in time to reach near steady-state concentrations with increased negative pressure difference are inversely proportional to the ratios of the negative pressure differences. For example, the 1.7 h time to near steady concentrations at -14.1 Pa is approximately equal to the 6.1 h time to near steady concentrations at -3.8 Pa times the ratio 3.8 Pa/14.1 Pa (6.1 h x 3.8/14.1 = 1.6 h). Furthermore, when the time to near-steady concentrations is converted to a number of air exchange volumes (=flowrate x time to near- steady concentrations/building volume), the results from all four tests are similar quantitatively, with the results ranging from 8.1 to 11.2 air exchanges (or building volumes), and with an average of 9.2 air exchanges across the four test conditions. This is much longer than the three air exchange criterion that some practitioners use for CPM test duration.

These observations are significant to setting standard guidelines for CPM test indoor-outdoor pressure differences and test durations. For example, when testing an occupied residence, the residents will prefer shorter tests and certainly total test times of less than about 8 hours.

Knowing that about 9 air exchanges are needed will dictate the desired exhaust fan flowrate (=9x building volume/desired negative pressure test time). The access to some industrial and commercial buildings may be less restrictive than when dealing with residences, and longer test periods may be practical in those settings.

Table 6.6. Results from the Negative Pressure Difference CPM Tests Focused on Determining Impact of Pressure Difference and Test Duration on Exhaust Fan Intake TCE Vapor Concentrations with Time.

Indoor - Outdoor Pressure Difference* (time average ± standard deviation)	Time to Reach 95% Steady-State Concentration in Best-fit Model (T_{SS})	Air Exchange Rate** (Q/V_B)	Number of Air Exchanges Needed to Reach 95% Steady-State TCE Concentration Using Best-fitModel (T_{SS} x Q/V_B)	Time-Averaged Near-Steady TCE Concentration (time average ± standard deviation)	TCE Entry Rate
[Pa]	[h]	[1/h]	-	[ppb_V]	[g/d]
Blower off	-	0.2	-	0.04±0.02	-
-3.8 ± 0.4	6.07	1.85	11.24	0.61±0.06	0.05
-5.4 ± 0.4	3.62	2.34	8.46	0.64±0.06	0.07
-10.5 ± 0.5	2.55	3.65	9.30	0.85±0.07	0.14
-14.1 ± 0.8	1.75	4.63	8.08	0.95±0.07	0.20

* - using the composite pressure reference point from the four exterior sides of the building.

** - air exchange rate calculated by dividing the time-averaged exhaust fan flowrate (Q) given in Table 6.4 by building volume (V_B = 350 m^3).

The time-averaged near-steady TCE concentrations in Table 6.6 are all similar from a VI pathway decision-making standpoint, increasing only by about 50% for the 370% increase in negative pressure difference across the tests. The near-steady TCE concentrations for the -10.5 Pa and -14.1 Pa tests only differ by about 10%, reflecting compensating effects of increased TCE entry rates (linearly proportional to pressure difference increases) and increased air exchange rate (sub-linear relationship to pressure difference) through the house with increased negative pressure difference.

The 0.95 ppb_v value for the -14.1 Pa test is similar to, but about 50% lower than the 9.3 ug/m^3 (1.73 ppb_v) long-term mean concentration reported by Holton et al. (2015) for their 9-month CPM test at -11±4 Pa and 15±3 m^3/min exhaust fan flowrate for the same test house. It is also similar to the maximum TCE indoor air concentration measured in this house over 600 days under natural conditions (13 ug/m^3 = 2.4 ppb_v) and the CPM test result is about 15x greater than the long-term mean average daily concentration over 600 d of monitoring (0.35 ug/m^3 = 0.065 ppb_v)(Holton et al., 2013). The maximum TCE entry rate measured in this work (-14.1 Pa, 0.19g/day) was the same as the time-averaged value reported by Holton et al.(Holton et al., 2015) forlong-term CPM testing (-11±4 Pa, 0.2 g/d).

In total, the results from these four CPM tests, in combination with the Holton et al. (Holton et al., 2015, 2013) results, show that negative pressure difference CPM tests should be operated for at least 9 air exchanges prior to sampling. Given that the TCE exhaust concentrations for all tests in this work are similar to the maximum indoor air TCE concentration measured during 3-years of monitoring under non-pressure control conditions (Holton et al., 2013), increasing the exhaust flowrate (and consequently the indoor-outdoor pressure difference) is one strategy for decreasing the necessary test time.

It should be noted that in applying this recommendation, the full building air exchange volume should be used in any test design calculations or analysis, and not just the volume of room or lowest level into which the vapors enter. The effective air exchange volume of this study house (350 m^3) was determined by transient indoor air tracer response (Holton et al[14]), but in most cases practitioners will likely estimate building air exchange volumes using interior dimensions. This might overestimate the effective air exchange volume and lead to test durations longer than necessary, but that may be an acceptable trade-off vs. the cost of a transient tracer response test.

Indoor air TCE distribution during negative pressure difference CPM testing focused on determining room-to-room variations in TCE vapor concentration. Figure 6.32 presents a statistical summary of indoor air TCE monitoring results from eight indoor locations during an 8-d negative pressure difference CPM test (maximum, minimum, median and 25th and 75th percentile concentrations). The exhaust fan was installed in the master bedroom (MB) window and operated at a time-averaged flowrate of 21.2 m^3/min, which created a time-averaged indoor – outdoor pressure difference of -11 ± 0.7 Pa. Air mixing was employed near the exhaust fan intake. Sampling results from the first 3-h (the first 10 air exchanges) of testing were excluded for this statistical analysis, and at least 50 samples were collected from each location.

Results in Figure 6.32 show individual concentration measurements ranging from 0 – 9.5 ppb_v across all locations, with sampling location-specific variability being the least in the floor fan-mixed master bedroom (standard deviation/median=12%) and upper-level rooms (standard deviation/median=19%-33%) and greatest in the lower-level rooms and stairwell (standard deviation/median=31% - 110%). There is a 6x difference between the lowest and highest time-averaged median concentrations across the eight locations, with the lowest and highest median TCE concentrations in the laundry (0.4 ppb_v) and lower living room (2.5 ppb_v), respectively. It is known from previous studies (Guo et al., 2015; Holton et al., 2015, 2013) that the TCE vapor intrusion occurs primarily through a floor-foundation gap located in the vicinity of the storage and lower-level living rooms. This is consistent with the results in Figure 6.32 that suggest an air flow path from those rooms to the stairwell and to the upstairs rooms and finally the master bedroom where the exhaust fan is located. As such, in addition to sampling at the exhaust fan inlet, there is also value to sampling throughout a building during a negative pressure difference test, as the results can provide insight to the VI entry points and locations of any significant indoor sources.

The median exhaust fan intake TCE concentration (0.9 ppb_v) was about 2× larger and one-third lower than the lowest and highest median TCE concentrations, respectively. It is also similar to the average of the median concentrations from the other seven sampling locations (1.2 ppb_v).

This suggests that, if CPM test sample collection needs to be limited due to costs or logistical constraints, then priority should be given to near exhaust fan sampling as it is representative of the spatial average concentration across the building.

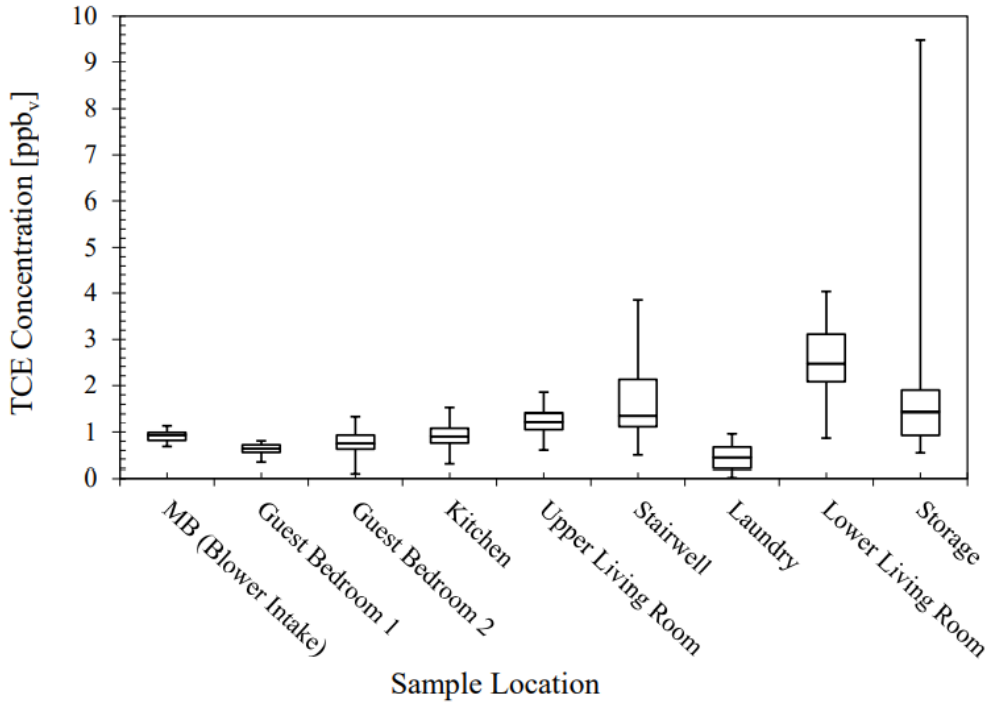


Figure 6.32. Statistical Summary of Long-term TCE Vapor Concentrations from Eight Indoor Locations During an 8-d Negative Pressure Difference CPM Test.

The whisker and box presentationshow the maximum, 75th percentile, median, 25th percentile and minimum concentrations, in order from top to bottom.

In this test, the variability of TCE concentration near the exhaust fan intake, where continuous in-room air mixing was applied, was the lowest of all sampling locations and only about 12% of its median value. To examine if this was a result of in-room floor-fan mixing, the spatial distribution of TCE vapor concentration near the exhaust fan intake was evaluated during a 4-d negative pressure difference CPM test, as described in Figure 6.33. The results show that floor fan mixing reduced both temporal and spatial variability; there is a reduction in both the maximum – minimum range at individual sampling locations and the range of median values

between the mixed and unmixed sampling conditions. Given its ease of implementation the associated reduction in sampling variability, air mixing near the exhaust fan intake should be conducted during CPM tests.

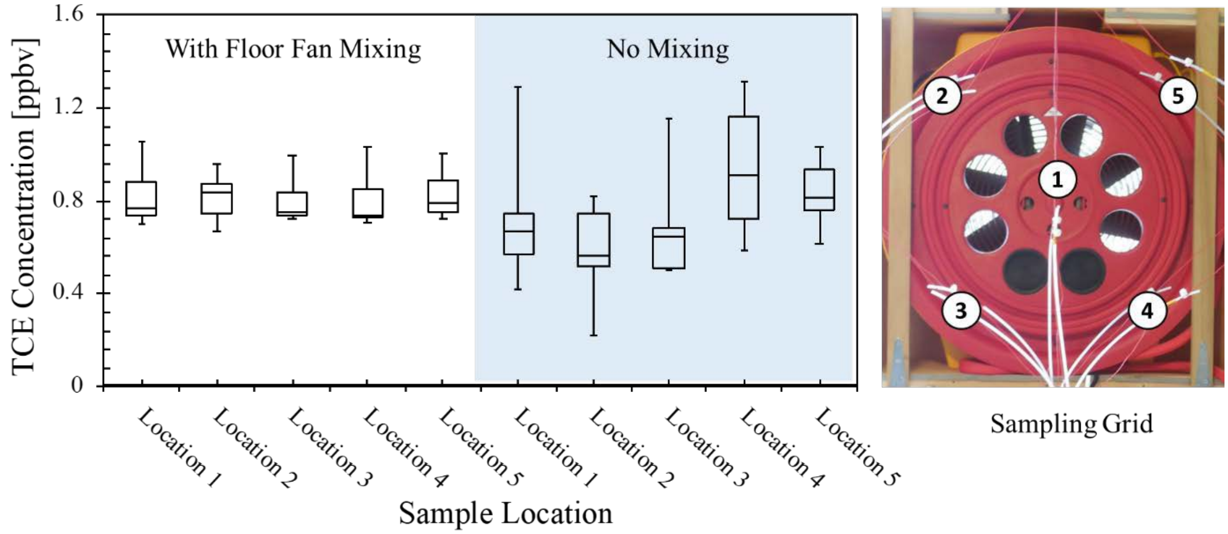


Figure 6.33. TCE Vapor Concentration Distribution Near the Exhaust Fan Intake and the Sampling Grid.

The whisker and box presentation shows the maximum, 75th percentile, median, 25th percentile and minimum concentrations, in order from top to bottom.

Negative pressure CPM testing using different exhaust fan installation locations. The impact of exhaust fan placement on CPM test results was evaluated through four negative pressure difference CPM tests in which the exhaust fan was installed at the locations shown in Figure 6.26 and operated at each with a flowrate of 21 m^3/min. The indoor – outdoor pressure differences for those tests were comparable at -10.3 Pa, -9.7 Pa, -10.8 Pa and -11.0 Pa for installations in the master bedroom window frame, front door, garage to building entry door, and patio door locations, respectively. During these tests SF_6 was released in Guest Bedroom 1 (Figure 6.26) to simulate an indoor source. Sampling for both TCE and SF_6 was conducted at the exhaust fan intake, with air mixing.

Figure 6.34 summarizes the TCE and SF_6 tracer concentrations measured near the exhaust fan intake after at least 13 air exchanges. The results indicate that exhaust fan placement is not expected to significantly impact concentrations measured near the exhaust fan intake during CPM tests, whether the concentrations are the result of subsurface or indoor sources. The differences between the median TCE vapor concentrations across the four CPM tests are less than 15% of their averaged value, with the maximum and minimum median values measured being 0.97 ppb_v and 0.77 ppbv (for the patio door and front door exhaust fan installations, respectively). Exhaust fan installation location showed similarly minimal effects for the SF_6 tracer results, although a slight decreasing trend in median concentration with increasing distance between the exhaust fan and tracer release locations was observed.

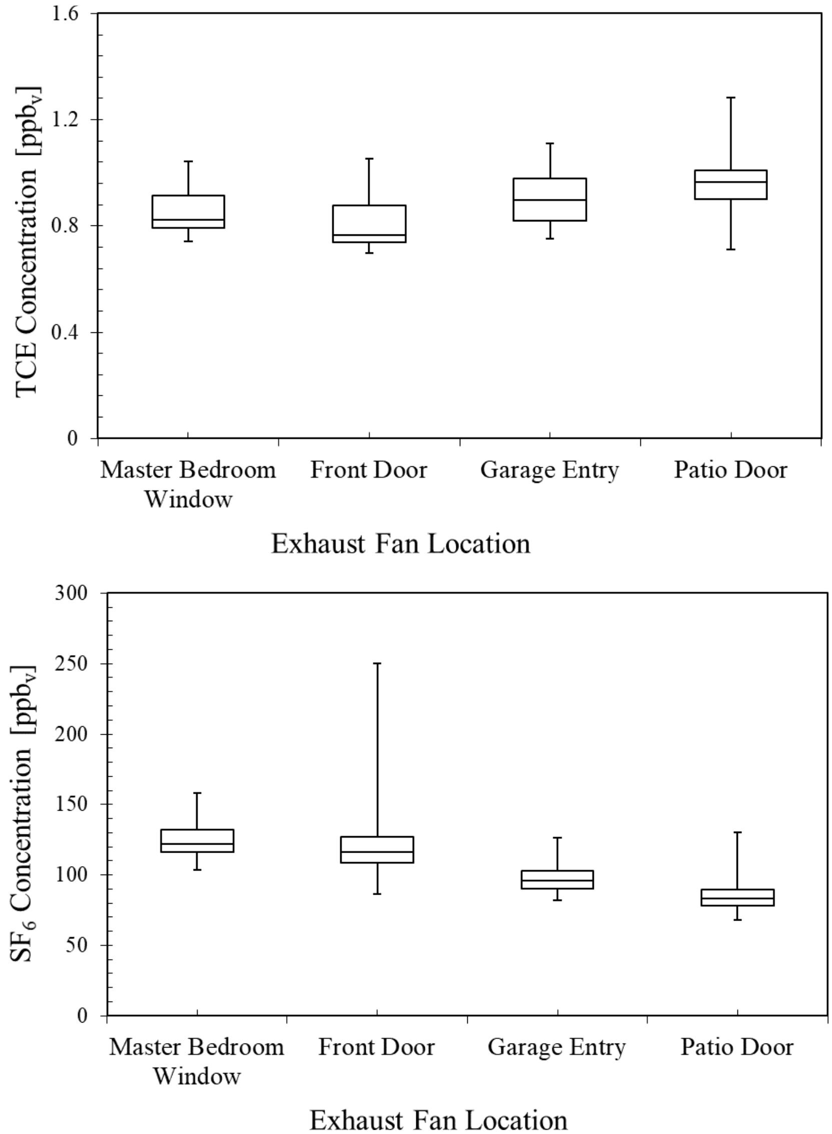


Figure 6.34. TCE and Vapor Concentrations Measured Near the Exhaust Fan Intake During Negative Pressure Difference CPM Testing with Different Exhaust Fan Locations.

The whisker andbox presentation shows the maximum, 75th percentile, median, 25th percentile and minimum concentrations, in order from top to bottom.

Positive pressure difference CPM test with sub-slab SF_6 tracer gas release to determine appropriate test duration when implementing a positive pressure difference test immediately after a negative pressure difference CPM test. A positive pressure difference CPM test need only be conducted in a building if a negative pressure difference CPM test results show a significant indoor air impact due either to VI or indoor sources. Thus, a positive pressure difference test, when needed, will generally follow a negative pressure difference CPM test.

Ideally, both would be conducted sequentially in one deployment to minimize the inconvenience to building occupants. To determine if this is practicable, testing was conducted during which SF_6 tracer was continuously released only at a sub-slab location beneath the laundry room (Figure 6.26).

First a negative pressure difference test was conducted to draw SF_6 into the test house for 12 h. This was immediately followed by a positive pressure difference test. Both were conducted with fan flowrates at about 20.8 m^3/min but in opposite directions and these created approximately -10 Pa and +10 Pa conditions. Indoor air SF_6 concentrations were monitored with time at seven indoor locations.

Figure 6.35 presents SF_6 concentration vs. time results. These demonstrate that: a) the negative pressure difference test induced SF_6 vapor intrusion from the subslab region, and b) the positive pressure difference test operating condition effectively shut off the VI pathway, as SF_6 concentrations at all seven indoor locations declined with time to below the SF_6 detection limit level. SF_6 concentrations at lower-level locations depleted more slowly than the upper-level locations, but they all decreased by 95% within 70 min of starting the positive pressure difference test, which is equivalent to about four air exchanges in this study house. Thus, the positive pressure difference tests can be conducted within about half of the time required for negative pressure difference tests, if both are conducted at the same flowrate.

Positive pressure difference CPM testing focused on room-to-room concentration variations resulting from indoor source release. As demonstrated, when operated correctly, a positive pressure difference test will suppress vapor intrusion. Thus, any chemicals measured long-term in indoor air during a positive pressure difference test will reflect either chemicals in ambient air or releases from indoor air sources. To assess how indoor air sampling during positive pressure difference tests can be used to assess the significance and location(s) of indoor air sources, SF_6 tracer was released at multiple indoor locations to imitate indoor air sources.

The first positive pressure CPM experiment investigated SF_6 distribution near its releasing location in the kitchen to assess the value of room air mixing when sampling. The results show that active air-mixing significantly reduced the significant spatial and temporal variability in SF_6 concentration within the kitchen. Detailed experimental conditions and results are described in Figure 6.36.

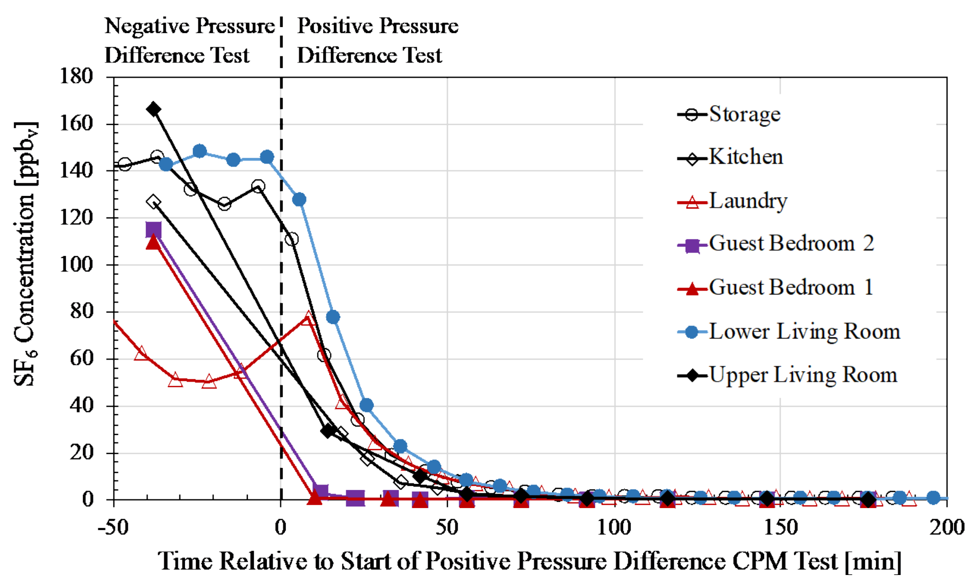


Figure 6.35. Indoor Air SF6 Monitoring Results During a Sequential Negative Pressure Difference to Positive Pressure Difference CPM Test with Subslab SF6 Tracer Gas Release.

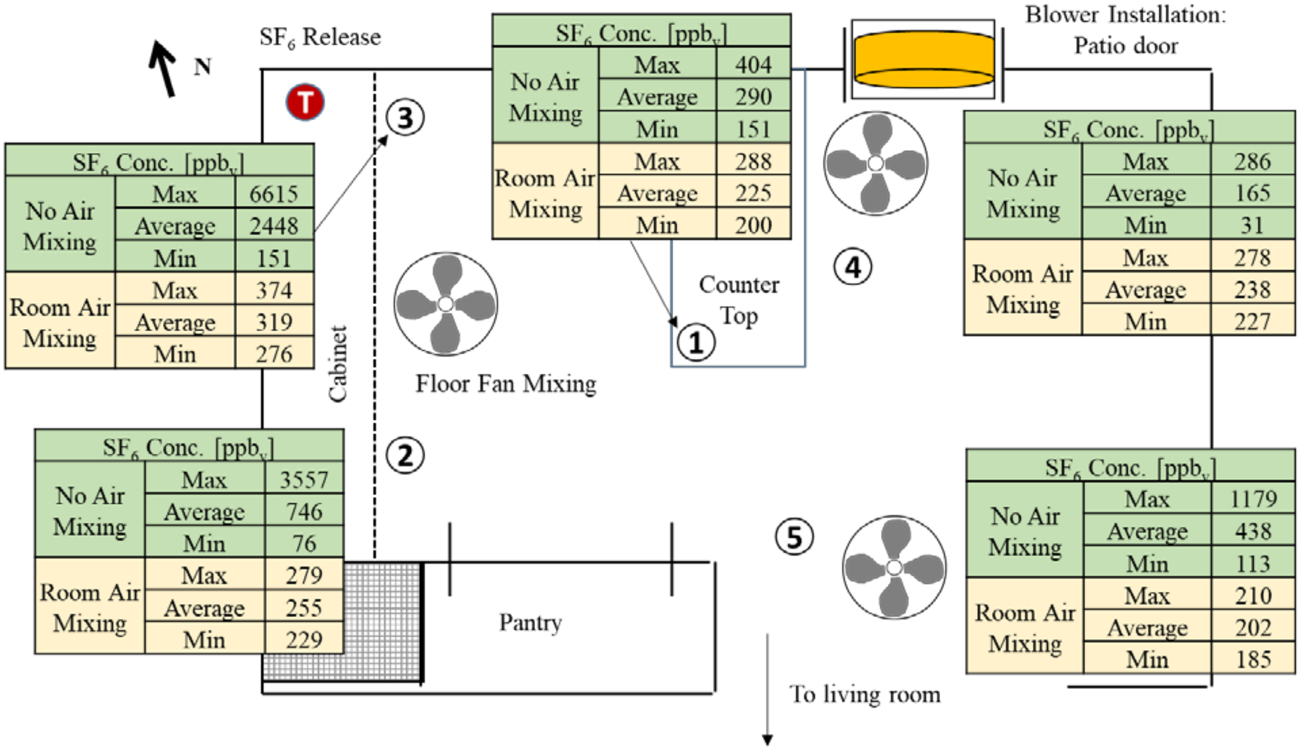


Figure 6.36. SF6 Sampling Results in the Kitchen Area During a Positive Pressure Difference CPM Test Having SF6 tracer Release and Sampling with and Without Active in-Room Air Mixing Using Floor Fans.

Based on these results, active in-room air mixing was used in subsequent tests focused on assessing the value of room-specific indoor air sampling during both negative and positive pressure difference CPM tests. In these tests, SF_6 was released in one of the following four rooms: Guest Bedroom 1, Guest Bedroom 2, Laundry, and the Lower Living Room (Figure 6.26), and samples were collected in all rooms. Indoor - outdoor pressure differences were maintained consistently at about -10 Pa and +10 Pa using the exhaust fan installed in the master bedroom window frame. Air samples from eight indoor locations were collected and analyzed after the first 3 h of negative pressure difference CPM testing (about 11 air exchanges) and the first 90 min of positive pressure difference CPM testing (about 5.5 air exchanges).

Table 6.7 summarizes the results. In brief, under both negative and positive pressure difference conditions, the highest SF_6 concentrations were always detected in the room where the tracer was released, and those concentrations were similar under both the negative and positive pressure difference conditions. In most of the other rooms the SF_6 concentration was significantly different during the two test conditions. These results indicate the value of sampling rooms throughout a building during CPM testing, especially for identifying significant VI entry and indoor source locations.

Table 6.7. Indoor Air SF6 Concentrations in Rooms with Indoor Source (SF6 Tracer) Release During Negative and Positive Pressure Difference Tests.

Tracer Release Locations	SF6 Concentration [ppbv]							
	Guest Bedroom 1		Guest Bedroom 2		Laundry		Lower Living Room	
Indoor – Outdoor Pressure	-10 Pa	+10 Pa	-10 Pa	+10 Pa	-10 Pa	+10 Pa	-10 Pa	+10 Pa
Sampling Locations								
Master Bedroom (exhaust fan)	138	35	79	<MDL*	82	<MDL	142	8
Guest Bedroom 1	325	488	53	<MDL	77	<MDL	140	29
Guest Bedroom 2	69	235	401	238	88	3	152	33
Kitchen	16	159	7	94	94	31	163	146
Upper Living Room	20	169	7	96	99	33	171	70
Laundry	9	168	8	88	285	376	67	146
Lower Living Room	12	165	7	91	108	97	423	458
Storage	12	120	7	92	117	93	242	65

MDL for SF6 monitoring is 4 ppbv.

6.2.1.4 Recommendations for CPM test guidelines

As stated in the introduction, the goal of this study was to conduct CPM tests under a range of operating conditions in a well-instrumented and previously monitored residence in order to recommend standardized conditions for CPM testing that would lead to confidence in use of CPM test results for VI pathway assessment. Tables 6.8 and 6.9 summarize the recommendations supported by the CPM tests discussed above, for negative and positive pressure test conditions, respectively. See Appendix D for CPM Test Guidelines. Arguably, these recommendations are supported by the testing results from a single building, but they also reflect our experiences at other buildings, as well as practical considerations for implementation. We anticipate these recommendations will be refined as more CPM testing is performed and experiences from a broader range of applications are considered. In particular, application of CPM testing to large buildings may require expanded testing systems and other operational conditions. For example, while single blower doors are effective for residential and smaller buildings, it is not difficult to envision scenarios in which multiple blowers are required in different locations to effectively control building pressure at large complexes. Multi-zonal pressure control (Hult et al., 2013) might be beneficial as well.

6.2.2 CPM Protocol Demonstration in Residential Buildings

6.2.2.1 Demonstration Buildings

Controlled Pressurization Method (CPM) demonstration tests have been conducted in Hill Air Force Base OU-8, a residential community which overlies a dilute dissolved chlorinated solvent plume. Three residential buildings were selected to demonstrate the CPM test protocol. This section presents the results of those residential-scale CPM demonstrations. For simplicity, the buildings were designated Residential Building #1 (RB1), Residential Building #2 (RB2), and Residential Building #3 (RB3). Figure 6.37 shows the locations of three residences and their relative positions to the groundwater plume in OU-8.

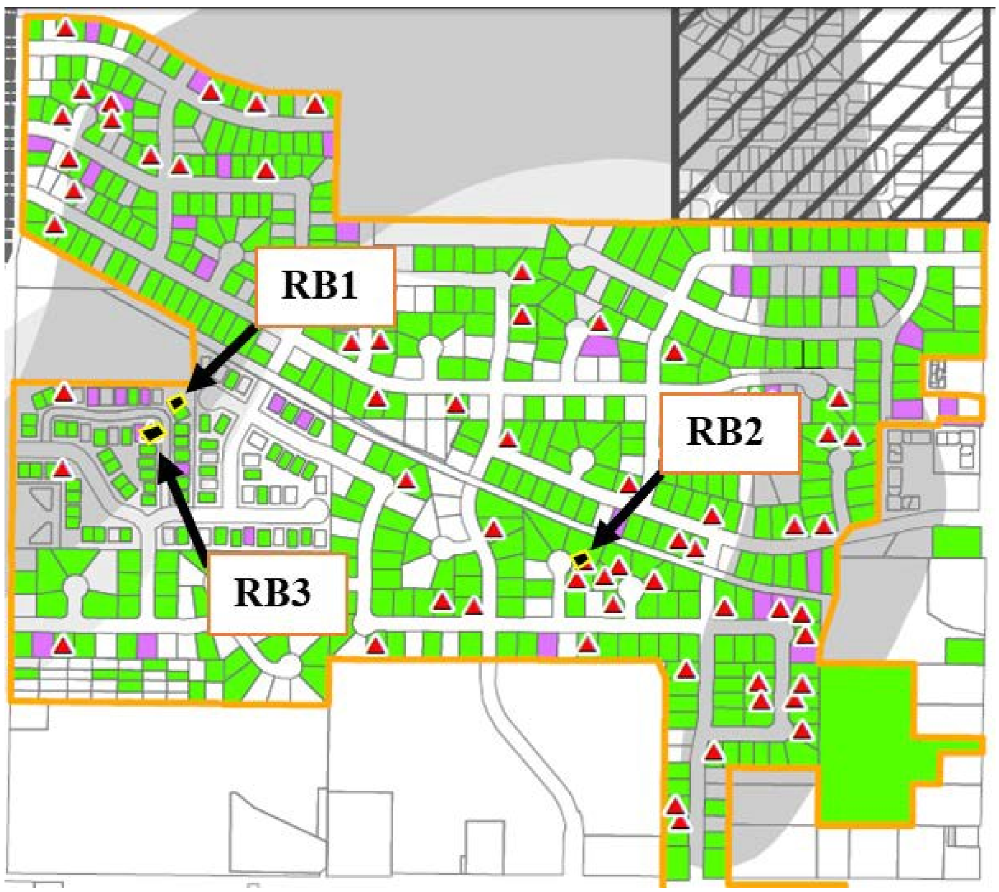


Figure 6.37. OU-8 Plume and the CPM Demonstration Buildings.

The grey area denotes the TCE groundwater plume (2015).

Table 6.8. Test Design Guidelines for Negative Pressure Difference CPM Tests.

Negative Pressure Difference CPM Tests	
Exhaust Fan Location	Install fan in any convenient location as results appear to be unaffected byplacement. Position it to exhaust air from the house. See also ASTM E779(American Society of Testing and Materials, 2010) and ISO 9972 (International Organization for Standardization, 2006) for pressuremonitoring and blower installation guidance.
Exhaust Fan Operating Conditions	Adjust the exhaust fan flowrate to achieve a consistent negative indoor –outdoor pressure difference in the range -10 Pa to -15 Pa during the test. Increasing the fan flowrate will decrease the test duration.
Test Duration	Conduct negative pressure difference CPM tests for at least 9 air exchangesbefore indoor air sampling; this will require a time = 9 x Building Volume/Fan Flowrate.
Operating Conditions Monitoring	The following capabilities are commonly instrumented on commerciallyavailable blower door setups: • Indoor – outdoor pressure difference measured relative to a composite reference point that connects open-ended tubing runningfrom all exterior sides of the building. • Exhaust fan flowrate (flow-calibrated equipment is preferred; tracertesting is an alternative option for flowrate measures).
Air Sample Collection (after 9 air exchanges)	EPA guidance (US EPA, 2015) for sample collection procedures and specificsampling techniques should be reviewer. The following sampling locations are recommended in the order of priority: • One or more samples collected near the fan intake with active floor-fan mixing near the fan intake (essential). • One or more ambient air samples (essential) • One or more samples collected from each room with active floor-fanmixing in each room during sample collection. These samples are optional, but very valuable if significant indoor air impacts are detected in the negative pressure difference CPM test.
Data Evaluation	Concentrations in vapor samples collected near the fan intake are expected to be representative of maximum short-term indoor air concentrations undernatural conditions. They are also expected to be greater than long-term average indoor air concentrations under natural conditions. If the observed concentrations are greater than levels of concern and greaterthan ambient air concentrations, it is important to note that this could be theresult of VI, indoor sources, or a combination of the two. Positive pressure difference testing will differentiate between the two. In-room sampling results may provide valuable insight to VI entry andindoor source release points.
Other	Negative pressure difference test results, when converted to emission ratescan be used to assess if alternate VI pathways might be contributing to significant indoor air impacts as discussed in Guo et al. (Guo et al., 2015) (2015).

Table 6.9. Test Design Guidelines for Positive Pressure Difference CPM Tests.

Positive Pressure Difference CPM Tests (only conducted if impact of significance is detected by a negative pressure difference test)	
Exhaust Fan Location	Install fan in any convenient location as results appear to be unaffected by placement. Position it to blow ambient air into the house.
Exhaust Fan Operating Conditions	Adjust the exhaust fan flowrate to achieve an indoor – outdoor pressuredifference in the range +10 Pa to +15 Pa to insure a consistent positive cross-foundation pressure difference during the test. Increasing the fanflowrate will decrease the test duration.
Test Duration	Conduct positive pressure difference CPM tests for at least 4 air exchangesbefore indoor air sampling; this will require a time = 4 x Building Volume/Fan Flowrate.
Operating Conditions Monitoring	The following are commonly instrumented on commercially availableblower door setups: • Indoor – outdoor pressure difference measured relative to a composite reference point that connects open-ended tubing runningfrom all exterior sides of the building. • Fan flowrate.
Air Sample Collection (after 9 air exchanges)	EPA guidance (US EPA, 2015) for sample collection procedures and specificsampling techniques should be used. The following sampling locations are essential: • One or more ambient air samples • One or more samples collected from each room with active floor-fanmixing in each room during sample collection.
Data Evaluation	Positive pressure difference tests will eliminate subsurface VI impacts; therefore, if indoor air concentrations are greater than levels of concern andgreater than ambient air concentrations, this indicates significant contributions from one or more indoor sources. In-room sampling results will indicate the locations of indoor source releases. If room-specific results were collected during the negative pressure difference test, these should be compared with positive pressure difference test results. Minimal changes in concentrations between the two in rooms with concentrations of concern will suggest the presence of indoor sources in those rooms.

Residential Building #1. Residential demonstration building #1 (RB1) is the north side unit of a two-story (ground floor and basement) duplex with an attached garage. The total footage of this unit is approximately 4000 ft^2, with a total building volume estimate of 40,000 ft^3. The house had 11 rooms/living spaces including the garage.

According to the Hill AFB vapor intrusion database, three indoor sampling events occurred during 2013 to 2014. Per the record, all results reported non-detectable concentrations for chlorinated volatile organic compounds (CVOCs).

Residential Building #2. Residential demonstration building #2 is a stand-alone, 3 story (2-story plus basement), 10 room, 2.5 bath residential structure. Each floor was approximately 700 ft^2, with a total indoor area of approximately 2,100 ft^2. The enclosed garage added an additional 400 ft^2. The total building volume was estimated at 20,000 ft^3.

According to the Hill AFB vapor intrusion database, 20 indoor air samples were collected between 2004 and 2014. During that period, TCE was detected once at 0.4 ppb_v and 1,2-DCA was detected 3 times with a maximum concentration of 1.3 ppb_v. PCE was also detected, but it was believed that PCE was from an indoor source.

A vapor intrusion mitigation system (sub-slab depressurization) was installed in the house, and it was in operation prior to CPM demonstration test.

Residential Building #3. Residential demonstration building #3 is a stand-alone, single story residence building with a basement. The total square footage for the residence was 4000 ft^2 including the attached garage. The total building interior volume was estimated at 32,000 ft^3. RB3 had a history of TCE impacts: Beginning in 2009, a total of 16 indoor air sampling events were conducted by Hill AFB and 10 of those events returned positive TCE vapor detections which an average of 0.6 ppbv and the maximum TCE vapor concentration was 0.9 ppb_v. A sub-slab depressurization system was installed and was operating prior to CPM demonstration test.

6.2.2.2 Demonstration Overview

CPM tests including both negative and positive pressure conditions were conducted in all three residential buildings. Building pressure conditions were manipulated using a commercial blower door (Retrotec, WA). Cross building-envelope pressure differentials were recorded in real-time. Indoor air and ambient outdoor air samples were collected during both negative and positive pressure testing.

CPM test conditions and activities are summarized in Table 6.10. Detailed procedures, operational parameters, sample collection and analytical results can be found in Appendix E. Negative and positive pressure CPM tests were conducted in two consecutive days in RB1 and RB2. One negative pressure CPM test and two positive pressure tests were conducted in RB3. The initial positive pressure test in RB3 showed detectable concentrations of contaminant suggesting a possible indoor source in the basement. A second positive pressure test with the vapor intrusion mitigation system running to ensure no influence from vapor intrusion indicated that there was no indoor air source.

Table 6.10. Summary of CPM Demonstration Activities and Operational Conditions.

<table>
<tr><th rowspan="2">Test</th><th rowspan="2">Parameter</th><th colspan="4">Demonstration Building</th></tr>
<tr><th>RB1</th><th>RB2</th><th colspan="2">RB3</th></tr>
<tr><td rowspan="5">Negative Pressure CPM test</td><td>Average IA – OA pressure differential [Pa]</td><td>-23.9</td><td>-12</td><td colspan="2">-18</td></tr>
<tr><td>Average air exhaust rate [CFM]</td><td>1584</td><td>1691</td><td colspan="2">1404</td></tr>
<tr><td>Test period [min]</td><td>439</td><td>330</td><td colspan="2">390</td></tr>
<tr><td>Air exchanges [-]</td><td>17.4</td><td>16.5</td><td colspan="2">13.7</td></tr>
<tr><td>Air Sample Collection (# of samples)</td><td>Ambient samples(9), indoor air samples near blower exhaust (7, every ~60 min), and indoor air samples from 8 indoor locations.</td><td>Ambient samples (3), indoor air samples near blower exhaust (5, every ~60 min)</td><td colspan="2">Ambient samples (9), indoor air samples near blower exhaust (8, every 40-60 min), and indoor air samples from 8 indoor locations.</td></tr>
<tr><td rowspan="5">Positive Pressure CPM test</td><td>Average IA – OA pressure differential [Pa]</td><td>22.2</td><td>11.2</td><td>17.5</td><td>17.3</td></tr>
<tr><td>Average air exhaust rate [CFM]</td><td>1590</td><td>1690.1</td><td>1423</td><td>1645</td></tr>
<tr><td>Test period [min]</td><td>290</td><td>100</td><td>310</td><td>250</td></tr>
<tr><td>Air exchanges [-]</td><td>11.5</td><td>5</td><td>11</td><td>10.3</td></tr>
<tr><td>Air Sample Collection (# of samples)</td><td>Ambient samples(5), indoor air samples from 12indoor locations</td><td>Ambient samples (3), indoor air samples from 10 indoor locations</td><td colspan="2">Ambient samples(3), indoor air samples from 13indoor locations</td></tr>
</table>

6.2.2.3 Demonstration results for residential buildings

Trichloroethene (TCE), tetrachloroethene (PCE) and their degradation daughter products (e.g., Dichloroethane (1,2-DCA), and trichloroethane) were the contaminants of concern for residential CPM test demonstration. Among those constituents, TCE was of the greatest concern since it was the primary constituent of concern associated with the OU-8 groundwater plume and has the lowest EPA indoor air screening level at 0.4 ppb_v. As such, TCE will be the focus of CPM results.

Residential Building #1. Important results both negative and positive CPM demonstrations in RB1 are summarized below. Detailed CPM demonstration results are provided in Appendix E.

- Ambient outdoor air concentrations: Analytical results of ambient outdoor air samples suggested no significant impact from external sources. TCE vapor concentrations fromall ambient samples were less than the detection limit.
- Negative pressure CPM testing:
  - A single blower successfully created and maintained a negative (-24 Pa) building pressure condition throughout CPM demonstration.
  - TCE concentrations of samples collected during negative pressure testing were slightly above ambient outdoor air concentrations, but below the EPA recommended indoor air screening level of 0.4 ppb_v. Air samples collected nearblower exhaust had TCE vapor concentrations ranging from 0.04 to 0.07 ppb_v, although area specific sampling showed concentrations up to 0.19 ppb_v (downstairs storage).
  - Real-time TCE concentrations near blower exhaust indicated that concentration equilibrium had been achieved around 260 min (~10x air exchanges) after negative pressure CPM test started.
- Indoor air sampling - Positive pressure CPM testing:
  - A single blower successfully created and maintained positive (+22 Pa) building pressure condition throughout CPM demonstration.
  - Room specific TCE indoor air concentrations range from 0.02 to 0.06 ppb_v. These results were all lower than EPA screening level of 0.4 ppb_v and were less than air samples that were collected during negative CPM testing.
  - 1,2-DCA concentrations in the Laundry, L-Lg Storage Rm, and L-Storage Cornerall showed elevated concentrations, suggesting those concentrations were from indoor air sources.

In summary, CPM demonstration results show that VI impacts to RB1 are not significant. The results are consistent with historic indoor air sampling results that were conducted by Hill AFB VI management team. According to the Hill AFB vapor intrusion database, four indoor air sampling events occurred between Jan. 2006 and Jan. 2009, all of which were non-detect for chlorinated volatile organic compounds (CVOCs). An additional sampling event was performed in Dec. 2014 and the indoor air concentrations at that time were also non-detect for chlorinated volatile organic compounds (CVOCs).

Residential Building #2. Important results both negative and positive CPM demonstrations in RB1 are summarized below. Detailed CPM demonstration results are provided in Appendix E.

- Ambient outdoor air samples: TCE concentrations in ambient outdoor air ranged from 0.06 to 0.09 ppb_v.
- Negative pressure CPM testing:
  - A single blower successfully created and maintained a negative (-12 Pa) building pressure condition throughout CPM demonstration.
  - Indoor air concentrations for TCE during negative CPM testing were in a range similar to that of ambient outdoor air.
  - Real-time TCE concentrations near blower exhaust indicated that concentration equilibrium had been achieved around 80 min (~7.5x air exchanges) after negative pressure CPM test started.
- Indoor air sampling - Positive pressure CPM testing:
  - A single blower successfully created and maintained positive (+11.2 Pa) building pressure condition throughout CPM demonstration.
  - Indoor air concentrations for TCE and PCE during positive CPM testing were in a range similar to that of ambient outdoor air.
  - 1,2-DCA indoor air concentrations during positive CPM testing were found 4-6 times greater than ambient level. The greatest 1,2-DCA indoor air concentration was found in 2nd West bedroom at 0.06 ppb_v, whereas it ranged around 0.03 ppb_v to 0.04 ppb_v in the rest locations.

CPM demonstration results show that VI impacts to RB2 are not significant. Positive pressure CPM testing results indicated a potential indoor source for 1,2-DCA. However, with maximum TCE and 1,2-DCA concentrations of 0.009 and 0.043 ppbv, respectively, they are well below the site-specific Hill AFB OU-15 mitigation action levels (MALs) (Air Force Civil Engineer Center/Environmental Division, 2017). This conclusion is consistent with historic indoor air sampling results according to the Hill AFB vapor intrusion database: TCE was detected only once out of 20 samples at 0.4 ppb_v over 10-years of monitoring program.

Residential Building #3. Important results both negative and positive CPM demonstrations in RB1 are summarized below. Detailed CPM demonstration results are provided in Appendix E.

- Ambient air samples: No significant impact from ambient outdoor VOC source was found during all demonstration. TCE vapor concentrations of ambient air samples were all non-detectable.
- Negative pressure CPM testing:
  - A single blower successfully created and maintained a negative (-18.7 Pa) building pressure condition throughout CPM demonstration.
  - Real-time TCE concentrations near blower exhaust indicated that concentration equilibrium had been achieved around 220 min (~10x air exchanges) after negative pressure CPM test started. TCE vapor concentration stabilized at around 0.1 ppb_v near the blower exhaust.

- Elevated indoor air TCE concentrations were detected in the lower level of RB3,with concentrations ranging from 0.29 ppb_v to 0.51 ppb_v.

- Positive pressure CPM testing 1 (VI mitigation system: off):
  - A single blower successfully created and maintained positive (+17.6 Pa) building pressure condition throughout CPM demonstration.
  - Indoor air samples were collected after 13+ air exchanges. CVOCs concentrations from multiple locations were found greater than ambient level. Greater-than-ambient-level CVOCs concentrations were detected in most lower-level rooms.

    The greatest TCE indoor air concentration was 0.3 ppb_v in lower-level pantryroom.
  - These results indicated the presence of an indoor air VOC source; however, the spatial distribution of CVOCs in lower level raised the question of either insufficient testing duration or insufficient air mixing during indoor air sampling. As a result, the positive pressure CPM test demonstration in RB3 was repeated on June 6, 2019.
- Positive pressure CPM testing 2 (VI mitigation system: on):
  - A single blower successfully created and maintained positive (+17.3 Pa) building pressure condition throughout CPM demonstration.
  - The pre-installed VI mitigation system, a sub-slab depressurization system, was turned on during this demonstration. The goal of positive pressure CPM testing isto identify any indoor air VOCs sources, if exist, this is accomplished by suppress VOCs entry from subsurface. By operating subslab depressurization system, it added another level of confidence that soil VI pathway didn't impact this testing building during positive CPM testing.
  - Indoor air samples were collected after 13+ air exchanges. All indoor air CVOCs concentrations from multiple locations were similar to ambient outdoor air concentrations. The greatest TCE concentration was 0.06 ppbv in lower level storage room, which is far less than the site-specific Hill AFB OU-15 MAL of 0.39 ppbv for residential (Air Force Civil Engineer Center/EnvironmentalDivision, 2017)

In summary, CPM test results in total indicated that TCE in indoor air was likely the result of vapor intrusion. The negative CPM testing results are comparable to historic indoor sampling data: 10 of 16 indoor air sampling events returned positive TCE vapor detections with an average of 0.6 ppbv and a maximum TCE vapor concentration of 0.9 ppb_v.

6.2.3 CPM Protocol Demonstration in Industrial Buildings

6.2.3.1 Demonstration buildings

CPM protocol demonstrations have been conducted in four industrial-scale buildings: Building 18, Travis Air Force Base, CA; and Buildings 2474, 2425, and 24176, Beale Air Force Base, CA. Detailed site descriptions for each can be found in Sections 4.3 and 4.4.

6.2.3.2 *CPM demonstration Overview*

CPM tests including both negative and positive pressure conditions were conducted in all demonstration buildings. Building pressure control in all buildings was managed using one or more blower door(s). The tests were conducted for a minimum of 10 air exchanges for each negative pressure CPM test and for 3 air exchanges for each positive CPM test. Both ambient outdoor air and indoor air samples were collected during each test. Samples were analyzed either on-site using GC-DELCD (calibrated daily) or sent back to ASU for GC-MS analysis. Detailed information of demonstration procedures, operational parameters, sample collection and analytical results are described in Appendices A, B, and C.

Table 6.11 summarizes important CPM test conditions and sampling for each test.

6.2.3.3 *Demonstration results for Building 18, Travis AFB*

Indoor air VOC concentrations under natural pressure conditions. Two periods of background indoor air sampling were conducted under natural pressure conditions prior-to and after CPM testing in Building 18. Sampling methods included the use of a multi-tube thermal desorption (TD; Markes MTS-32, Markes Ltd., England) tube sampler and passive samplers (Beacon Environmental, MA). The pre-test results revealed the presence of chlorinated solvent in building indoor air. The greatest CVOC concentrations were found on the south side: TCE and cis 1,2- DCE vapor concentrations in the office room were 55 ppb_v and 20 ppb_v, respectively. 24-h daily sampling in the main service area and hall showed about 10x temporal variation for TCE and cis 1,2 Dichloroethene (cis 1,2-DCE), and their averaged concentrations were around 5 ppb_v and 2 ppb_v, respectively. Detailed analytical results can be found in the Travis field report in Appendix E.

Ambient sampling results. Analytical results for ambient TCE concentrations were all less than ppbv, and cis 1,2-DCE was not detectable.

Negative Pressure CPM testing results. A -20 Pa negative building pressure condition was created and maintained with a single blower-door unit that was installed in the eastern man-door. Sampling results are summarized below:

- TCE concentrations near the blower door stabilized after about 370 min of building depressurization, which is roughly equivalent to 12 air exchanges. The stabilized vapor concentrations for TCE and cis 1,2-DCE were 6.1 ppb_v and 1.9 ppb_v, respectively.
- 11 indoor air grab samples were collected from specific rooms across the building after 370 min of testing. Over 100x spatial CVOC concentration variation was observed between rooms, with the greatest CVOC vapor concentrations found on the south side of the building, where the maximum concentration of 119.5 ppb_v for TCE was measured in Office 1. In contrast, samples collected from the north side contained < 1 ppb_v. The greatest concentrations found during negative pressure testing were roughly twice the pre-test natural pressure monitoring results.
- Both blower intake and room-specific indoor air samples had TCE concentrations well in excess of the EPA screening levels of 0.08 ppb_v for residential and 0.65 ppb_v for industrial buildings (USEPA, 2015/2020). Indoor air sample results were all more than 10x greater than ambient CVOCs levels.

Positive pressure CPM testing results. A +16.4 Pa positive building pressure condition was created and maintained by a single blower-door unit that was installed in the same location as for the negative pressure testing. Sampling results are summarized below:

- Indoor air TCE concentrations during positive pressure testing ranged from less than the detection limit to about 1 $ppb_{v.}$ These results were above ambient outdoor concentrations but orders of magnitudes less than negative pressure CPM testing results.
- The highest concentrations were found in the same area as the highest concentrations during negative pressure testing (Office 1).
- Regarding the low levels detected during positive pressure testing, given the presence of CVOCs in pre-test indoor air and historic sub-slab vapor concentrations of 508,000 ppb_v (CH2MHILL, 2010), it is possible that the indoor air concentrations during positive pressure testing were a result of off gassing from concrete and/or equipment that has been stored in the facility.

6.2.3.4 Demonstration results for Building 2474 (Community Center), Beale AFB

Indoor air VOC concentrations under natural pressure conditions. Both passive and active pre-test sampling results were non-detect for TCE.

Ambient sampling results. Ambient CVOC concentrations were all less than the calibrationlower limit (0.01 ppb_v).

Negative pressure CPM test 1 results. A -10 Pa negative building pressure condition was created and maintained by a single blower-door unit. Sampling results are summarized below:

- The blower unit was not able to maintain stable indoor to outdoor pressure differences. Over 10 Pa pressure swings were measured during the demonstration.
- In order to create ~10 Pa pressure differences, the blower unit only exhausted about 3440 cfm air out of the test building. The air exchange rate was approximately one air exchange per 73 min. By the end of this test, only about 8 building air exchanges were accomplished.
- TCE vapor concentrations near the blower intake were not steady after 8 air exchanges, indicating that a greater air exhaust rate or longer test duration should have been used.

Table 6.11. Summary of CPM Demonstration Activities and Operational Conditions at Industrial Sites.

Industrial Building		CPM test conditions	Average IA - OA pressure differential [Pa]	Average air exhaust rate [CFM]	Test period [min]	Air exchanges [-]	Air Sample Collection		
							Ambient outdoor Locations Samples per location	Blower exhaust	Location specific indoor air
Travis AFB Building 18		Negative CPM Demonstration	-20	4,500	550	16.7	2 / 4	9	11
		Positive CPM Demonstration	16	4,000	320	8.6	2 / 3	-	11
		Non-pressure control conditions	NA*	NA	22 days and 19 days	NA	Passive and active sampling at 2 / 3 indoor locations		
Beale AFB Building 2474 (Theater)		Negative CPM Demonstration	-21.9	7478	765	21.8	2 / 3	12	16
		Positive CPM Demonstration	5.9 (0-430 min), 12.5 (430-643 min)	3644 (0-430 min), 7339 (430-643 min)	643	12.5	2 / 3	-	32
		Non-pressure control conditions	NA	NA	21 days	NA	Passive and active sampling at 5 different indoor locations		
Beale AFB Building 2425 (Community center)		Negative CPM Demonstration	-10.3	19092	473	21.5	2 / 3	9	-
		Positive CPM Demonstration	10.5	184411	400	17.4	2 / 4	-	18
		Non-pressure control conditions	NA	NA	18 days	NA	Passive and active sampling at 11 differentindoor locations		
Beale AFB Building 24176 (Dorms)	Suite B124/125	Negative CPM Demonstration	-16.8	354	500	45	2 / 2	7	-
		Positive CPM Demonstration	10.34	358	110	10		-	Sample and Dup from125
		Non-pressure control conditions	NA	NA	4 days	NA	Passive and active sampling at 1 indoor location		
	Suite B103/104	Negative CPM Demonstration	-17.7	375	330	36	2 / 2	4	-
		Positive CPM Demonstration	14.4	373	48	4		-	Sample and Dup from103
		Non-pressurecontrol conditions	-	-	-	-	-	-	-

Industrial Building		CPM test conditions	Average IA - OA pressure differential [Pa]	Average air exhaust rate [CFM]	Test period [min]	Air exchanges [-]	Air Sample Collection		
							Ambient outdoor Locations Samples per location	Blower exhaust	Location specific indoor air
	Laundry	Negative CPM Demonstration	-18.1	353	400	30	2 / 2	5	-
		Positive CPM Demonstration	15.6	352	140	12		-	Center of Laundry
		Non-pressurecontrol conditions	NA	NA	4 days	NA	Passive and active sampling at 1 indoor location		

NA – Not available.

Negative pressure CPM test 2 results. A second negative pressure test was conducted, with about a -22 Pa negative building pressure created and maintained by a single blower-door unit running at 7480 cfm. Sampling results are summarized below:

- Although temporal fluctuations were found in indoor to outdoor pressure differences, the indoor-outdoor building pressure was kept at about15 Pa throughout the testing.
- TCE vapor concentrations near the blower intake ranged from 0.01 ppb_v to 0.03 ppb_v, with an averaged value of 0.015 ppb_v after 10 air exchanges. The highest location-specific indoor air TCE concentration was 0.018 ppb_v. These concentrations were above ambient outdoor concentrations, but well below the USEPA action level of 0.08 ppb_v.

Positive pressure CPM test results. A +16.3 Pa positive building pressure condition was created and maintained by a single blower-door unit running at 7340 cfm. After 4 air exchanges, samples were collected throughout the building. TCE concentrations from all indoor air samples were found to be close to ambient concentrations indicating that no indoor air sources of consequence were present within the building.

6.2.3.5 Demonstration results for Building 2425, Beale AFB

Indoor air VOC concentrations under natural pressure conditions. Both passive and active pre-test sampling results were non-detect for TCE.

Ambient sampling results. Ambient CVOCs concentrations were all less than the calibration lower limit (0.01 ppb_v).

Negative pressure CPM test results. Three blowers were used for pressure control and were operated at constant speeds to maintain as uniform a flowrate as possible. About a -10.3 Pa negative building pressure condition was created so that 21 building air exchanges occurred during the test. After 10 air exchanges, TCE concentrations near the blower intake were less than ppb_v, a concentration well below the EPA action levels of 0.08 ppb_v for residential and 0.65ppb_v for industrial buildings (USEPA, 2015).

Positive pressure CPM test results. A +10.5 Pa positive building pressure condition was created and maintained by three blowers that were installed in the same locations as for negative pressure testing. After 4 air exchanges, location specific sampling was performed at 18 indoor locations. No discernable CVOC concentrations were found in any of these locations, indicating that no indoor air sources of consequence were present within the building.

6.2.3.6 Demonstration results for Building 24176 (Dorms), Beale AFB

Three CPM tests were performed in Suites B124/125, B103/104 and the Laundry room, all on the ground level of Building 24176. Each CPM test demonstration was accomplished in a single day, the results are presented below.

Indoor air VOC concentrations under natural pressure conditions. Background pre-test indoor air sampling of suites B101/102, B105/106, B120/121, B124/125, B110 (Housekeeping) and the laundry was performed prior to the CPM demonstration. Both passive and active samplingresults showed non-detectable concentrations for TCE in air at all sampling locations.

Ambient sampling results. Analytical results for ambient outdoor air samples suggested no significant impact from external TCE sources, however, low-level background 1,1-DCE, and 1,2-DCA vapors were detected. Their average concentrations were 0.018 ppb_v and 0.034 ppb_v, respectively.

Negative pressure CPM test results. Negative pressure conditions were created using single blower door units in each individual room, the averaged indoor to outdoor pressure differences were -15 Pa, -18 Pa and -17 Pa for B124/125, B103/104 and the Laundry room, respectively. Analytical results for indoor air samples collected during negative CPM testing are summarized below:

- B124/125. TCE vapor concentrations near the blower intake were found to be greater than the ambient level with an averaged concentration of 0.012 ppb_v. 1,1-DCE, and 1,2-DCA vapor concentrations were at similar levels as ambient background.
- B103/104. No discernable CVOC concentrations were detected near the blower intake.
- Laundry room. TCE and PCE vapor concentrations near the blower intake were found to be greater than ambient outdoor levels with an average concentration of 0.016 ppb_v and 0.021 ppb_v, respectively. 1,1-DCE, and 1,2-DCA vapor concentrations were at concentrations similar to ambient outdoor.

Positive pressure CPM test results. Positive pressure conditions were created by reversing the blower direction to blow ambient air into test rooms, the averaged indoor to outdoor pressure differences were 11 Pa, 15 Pa and 11 Pa for B124/125, B103/104 and the Laundry room, respectively. Analytical results for indoor air samples collected during negative CPM testing are summarized below:

- B124/125. TCE vapor concentrations were non-detectable.
- B103/104. CVOC concentrations were similar to ambient outdoor concentrations.
- Laundry room. TCE vapor concentrations were non-detectable. However, PCE vapor concentrations were detectable at an average value of 0.13 ppb_v. Other CVOCs concentrations were similar to ambient outdoor sampling results.

In summary, TCE vapors were detectable at low concentrations, but greater than ambient outdoor levels during negative pressure CPM testing in Suite B124/125 and the laundry room suggesting some CVOC VI impacts in those rooms. Positive pressure CPM testing results in Suite B124/125 and the laundry room indicate no significant indoor air sources for TCE in those rooms. However, PCE vapor concentrations were detected in the laundry room during positive pressure testing suggesting an indoor air source for PCE may exist.

6.2.4 Summary

In Task 2, we developed and validated a CPM protocol for VI pathway assessment in a well-instrument residential home. This protocol is designed to determine if VI mitigation is needed by creating the worst-case VI impact in the test building. In this protocol, we first time developed validated CPM operational parameters including testing duration, building pressure differences, indoor air sampling method and data interpretations. All these procedural details are summarized in the CPM Test Guidelines (Appendix D).

CPM test demonstrations were performed in three residential homes and three industrial buildings. The demonstration results successfully identified 1 of 3 residential homes (RB3) and 1 of 3 industrial buildings (Facility 18, Travis AFB) that were impacted by significant vapor intrusion. This conclusion is also supported by historic indoor air sampling results in RB3 and long-term indoor air monitoring results in Facility 18, Travis AFB. Important experiences gained from field CPM demonstrations are listed below:

- For industrial-scale buildings that are composed of multiple separated zones (e.g., like apartments), multiple CPM tests in each separate section of the building should be considered.
- Multiple blower units may be required for large buildings or buildings with low air leakage.
- Pre-test visits to inspect building structure are beneficial for CPM test design.
- When performing CPM testing in large buildings, room-specific indoor air sampling during negative pressure CPM testing should be conducted as air concentrations can exceed thresholds in some locations (e.g., offices), while being significantly lower at the blower intake, as illustrated in the Travis AFB building demonstration.

6.3 TASK 3: VALIDATION OF THE LONG-TERM USE OF PASSIVE SAMPLERS UNDER TIME-VARYING INDOOR AIR CONCENTRATION CONDITIONS

The Task 3 objective was to validate the performance of passive samplers when deployed long-term in indoor environments with temporally variable concentrations. Performance validation included the comparison of passive sampling results to time-averaged active sampling results over the same sampling periods, in both residential and industrial buildings.

6.3.1 Passive samplers used in the validation testing

Four passive samplers were tested: The Waterloo Membrane Sampler, the Beacon Passive Sampler, the Beacon Chromosorb 106 Sampler, and the Beacon Carbopack X (CPX) passive sampler. Arrangements were made to test other samplers, but the manufacturers chose not to supply the analytical data for those samplers.

Passive sampler testing was performed using different deployment durations as summarized in Table 6.12.

Table 6.12. Summary of Passive Sampler Deployment Conditions.

Sampler	Residential Building Sampling	Industrial Building Sampling
Waterloo Membrane Sampler(WMS; vial type)	2 deployments of a single sampler for 26 and 28 days.	NA
Beacon Passive Sampler(vial type)	13 deployments with three samplers each time, ranging from 1 to 4 weeks in duration.	2-week deployments of 11 active/passive sampler sets Beale AFB Community Activity Center and one 18- day deployment of 4 active/ passive sampler sets atTravis AFB.
Beacon Chromosorb PassiveSampler (tube type)	13 deployments with three samplers each, ranging from1 to 4 weeks in duration.	NA
Beacon Carbopack X PassiveSampler (tube type)	5 deployments with three samplers each, ranging from1 to 4 weeks in duration.	NA

NA – Not applicable, no deployments

6.3.2 Long-term passive sampler validation at the vapor intrusion study house.

Validation of the passive samplers was performed in the well-instrumented research house described in Section 4. Passive sampler results were compared to results from active sampling using 24-h thermal desorption (TD) tube samplers for every deployment and GC-ECD grab samples for 4 of 13 deployments. Table 6.13 summarizes the detailed schedule for both passive and active sampling.

Passive samplers were placed in the basement level of the house and active samples were collected within 3 ft (1 m) of the passive sampler locations. Temperature and relative humidity were also monitored on a continuous basis during deployment. Figure 6.38 provides a photo of the sampling setup.

6.3.2.1 Analytical results for passive and active sampling

Chemical analyses focused on five chlorinated solvent species typically found within the study house: 1,1-dichloroethene (1,1-DCE), 1,1-dichlorothane (1,1-DCA), 1,1,1-trichloroethane (1,1,1-TCA), trichloroethylene (TCE) and perchloroethylene (PCE). Tables 6.14 – 6.18 provide statistical summaries of the analytical results from both active and passive sampling.

Table 6.13. Indoor Air Sampling Summary for Passive Sampler Validation Tests.

Validation Sampling Period [days]	Number of Active Samples Collected		Number of Passive Samplers Deployed			
	24-h TD Samples	GC-ECD Grab Samples	Waterloo Membrane Sampler	Beacon Chromosorb 106 Sampler	Beacon Sampler	Beacon Carbopack X Sampler
26	26, Daily	-	Single	Triplicate	Triplicate	Triplicate
22	22, Daily	149	Single	Triplicate	Triplicate	Triplicate
20	20, Daily	33	-	Triplicate	Triplicate	Triplicate
29	29, Daily	89	-	Triplicate	Triplicate	Triplicate
52	52, Daily	416	-	Triplicate	Triplicate	Triplicate
7	7, Daily	-	-	-	Triplicate	Triplicate
7	7, Daily	-	-	-	Triplicate	Triplicate
6	6, Daily	-	-	-	Triplicate	Triplicate
20	20, Daily	-	-	-	Triplicate	Triplicate
31	31, Daily	-	-	-	Triplicate	Triplicate
44	44, Daily	-	-	-	Triplicate	Triplicate
36	36, Daily	-	-	-	Triplicate	Triplicate
36	36, Daily	-	-	-	Triplicate	Triplicate

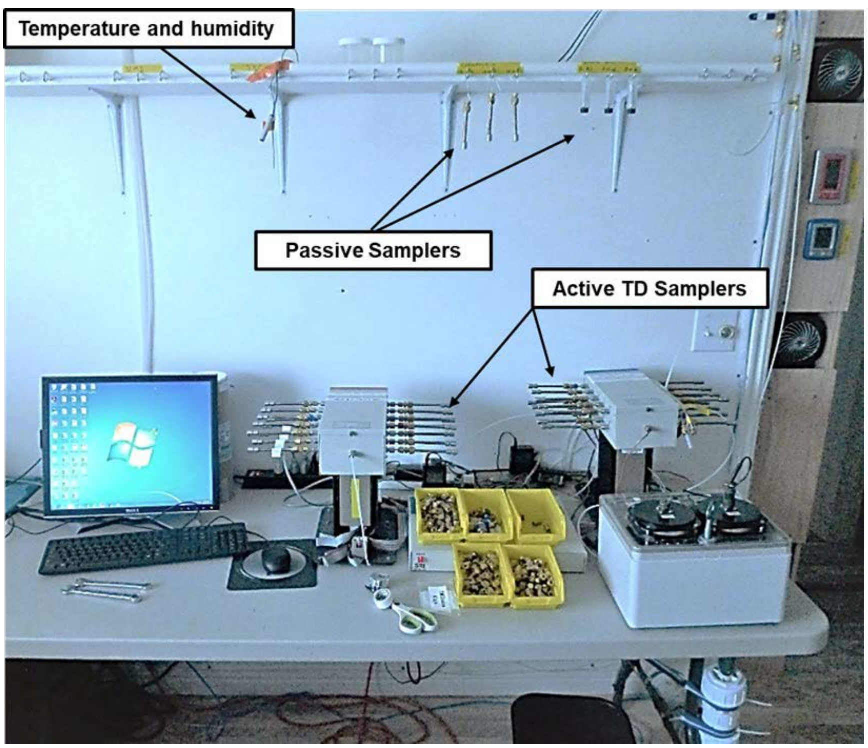


Figure 6.38. Deployment of Passive Samplers and Active Thermal Desorption (TD) Samplers In research House.

Table 6.14. TCE Indoor Air Monitoring Results for Active and Passive Sampling.

Sample period [day]	24-h active sample results [ppbv]			Average passive sampler results ± standard deviation [ppbv]			
	Maximum	Minimum	Average	WMS	Beacon Chromosorb 106	Beacon passive sampler	Beacon Carbopack X
26	3.40	9.6E-03	1.35	0.52	0.25 ± 0.008	1.29 ± 0.1	0.63 ± 0.004
22	6.07	9.6E-01	3.26	ND	0.39 ± 0.03	3.43 ± 0.27	1.65 ± 0.15
20	6.86	2.2E-01	2.68	NS	0.24 ± 0.01	3.04 ± 0.17	1.33 ± 0.05
29	4.22	2.2E-02	1.63		0.14 ± 0.01	1.86 ± 0.11	0.77 ± 0.01
52	4.67	3.2E-03	0.61		0.07 ± 0.01	0.72 ± 0.08	0.31 ± 0.01
7	7.88	4.2E-02	2.34		NS	2.12 ± 0.32	0.73 ± 0.05
7	6.27	1.2E-02	0.92			0.76 ± 0.05	0.26 ± 0.01
6	8.45	1.1E-03	1.36			0.96 ± 0.09	0.40 ± 0.01
20	8.45	1.1E-03	1.54			1.13 ± 0.14	0.53 ± 0.01
31	0.03	2.3E-03	0.01			ND	ND
44	2.31	6.2E-03	0.38			0.33 ± 0.09	0.15 ± 0.0
36	2.41	2.1E-02	0.63			0.42 ± 0.02	0.46 ± 0.01
36	4.26	8.9E-03	0.59			0.32 ± 0.02	0.33 ± 0.02

ND – Non-detectable.

NS – No sample deployed.

Table 6.15. PCE Indoor Air Monitoring Results for Active and Passive Sampling.

Sample period [day]	24-h active sample results [ppbv]			Average passive sampler results ± standard deviation [ppbv]			
	Maximum	Minimum	Average	WMS	Beacon Chromosorb 106	Beacon passive sampler	Beacon Carbopack X
26	1.33	8.1E-03	0.50	ND	0.11 ± 0.008	0.2 ±0.01	0.13 ±0.003
22	2.08	3.7E-01	1.11	ND	0.28 ± 0.01	0.62 ± 0.16	0.34 ± 0.03
20	1.89	7.0E-04	0.82	NS	0.20 ± 0.01	0.40 ± 0.06	0.24 ± 0.01
29	1.52	7.0E-04	0.60		0.11 ± 0.01	0.22 ± 0.01	0.16 ± 0.0
52	1.33	7.0E-04	0.19		0.05 ± 0.0	0.10 ± 0.02	0.07 ± 0.01
7	1.50	1.4E-02	0.50		NS	0.32 ± 0.06	0.16 ± 0.0
7	1.98	5.9E-03	0.31			0.14 ± 0.02	ND
6	2.13	2.1E-04	0.36			0.19 ± 0.02	0.09 ± 0.01
20	2.13	2.1E-04	0.39			0.16 ± 0.02	0.11 ± 0.01
31	0.02	7.7E-04	0.01			ND	ND
44	0.97	5.6E-03	0.13			0.07 ± 0.02	0.04 ± 0.0
36	1.52	6.8E-03	0.38			0.08 ± 0.02	0.11 ± 0.0
36	1.45	6.6E-03	0.22			0.05 ± 0.01	0.09 ± 0.01

ND – Non-detectable.

NS – No sample deployed.

Table 6.16. 1,1-DCE Indoor air monitoring results for active and passive sampling.

Sample period [day]	24-h active sample results [ppbv]			Average passive sampler results ± standard deviation [ppbv]			
	Maximum	Minimum	Average	WMS	Beacon Chromosorb 106	Beaconpassive sampler	Beacon Carbopack X
26	0.81	1.3E-03	0.28	ND	NS	0.45 ± 0.03	0.22 ±0.003
22	1.36	0.18	0.78	ND	NS	1.14 ± 0.11	0.4 ± 0.08
20	1.29	5.9E-02	0.60	NS	NS	1.06 ± 0.09	0.32 ± 0.03
29	1.50	< MDL	0.51		NS	0.55 ± 0.03	0.12 ± 0.01
52	1.18	< MDL	0.15		NS	0.22 ± 0.02	0.05 ± 0.01
7	1.67	8.7E-03	0.50		NS	0.68 ± 0.09	0.21 ± 0.03
7	1.74	< MDL	0.26			0.2 ± 0.0	U
6	2.23	< MDL	0.37			0.31 ± 0.03	0.14 ± 0.01
20	2.23	< MDL	0.38			0.36 ± 0.04	0.15 ± 0.01
31	0.02	< MDL	0.001			ND	ND
44	0.41	< MDL	0.06			0.12 ± 0.02	ND
36	0.73	< MDL	0.22			0.25 ± 0.03	0.16 ± 0.01
36	1.02	< MDL	0.15			ND	0.11 ± 0.01

ND – Non-detectable.

NS – No sample deployed.

Table 6.17. 1,1-DCA Indoor Air Monitoring Results for Active and Passive Sampling.

Sample period [day]	24-h active sample results [ppbv]			Average passive sampler results ± standard deviation [ppbv]			
	Maximum	Minimum	Average	WMS	Beacon Chromosorb 106	Beacon passive sampler	Beacon Carbopack X
26	0.35	2.1E-03	0.14	ND	NS	0.06 ±0.004	0.08 ± 0.0
22	0.57	0.10	0.34	ND	NS	0.16 ± 0.02	0.04
20	0.55	< MDL	0.26	NS	NS	0.15 ± 0.01	0.10 ± 0.01
29	0.37	< MDL	0.14		NS	0.07 ± 0.01	0.06 ± 0.0
52	0.48	< MDL	0.06		NS	0.03 ± 0.01	0.02 ± 0.01
7	0.48	3.5E-03	0.15		NS	0.09 ± 0.01	U
7	0.54	2.1E-03	0.08			ND	ND
6	0.52	< MDL	0.09			ND	ND
20	0.54	< MDL	0.11			0.05 ± 0.01	0.06 ± 0.01
31	0.01	< MDL	0.00			ND	ND
44	0.21	< MDL	0.03			0.02	ND
36	0.55	< MDL	0.13			0.03 ± 0.0	0.06 ± 0.0
36	0.49	< MDL	0.07			0.04 ± 0.01	0.04 ± 0.0

ND – Non-detectable.

NS – No sample deployed.

Table 6.18. 1,1,1-TCA Indoor Air Monitoring Results for Active and Passive Sampling.

<table>
<tr><th rowspan="2">Sample period [day]</th><th colspan="3">24-h active sample results [ppbv]</th><th colspan="4">Average passive sampler results ± standard deviation [ppbv]</th></tr>
<tr><th>Maximum</th><th>Minimum</th><th>Average</th><th>WMS</th><th>Beacon Chromosorb 106</th><th>Beaconpassive sampler</th><th>Beacon Carbopack X</th></tr>
<tr><td>26</td><td>0.46</td><td>2.9E-03</td><td>0.17</td><td>ND</td><td>0.08 ± 0.02</td><td>0.11 ± 0.001</td><td>0.19 ± 0.002</td></tr>
<tr><td>22</td><td>0.92</td><td>2.4E-01</td><td>0.55</td><td>ND</td><td>0.08 ± 0.01</td><td>0.29 ± 0.04</td><td>0.47 ± 0.04</td></tr>
<tr><td>20</td><td>0.88</td><td>3.2E-04</td><td>0.42</td><td rowspan="11">NS</td><td>0.04 ± 0.01</td><td>0.26 ± 0.01</td><td>0.20 ± 0.01</td></tr>
<tr><td>29</td><td>0.70</td><td>3.2E-04</td><td>0.27</td><td>ND</td><td>0.13 ± 0.02</td><td>0.19 ± 0.0</td></tr>
<tr><td>52</td><td>0.79</td><td>3.2E-04</td><td>0.12</td><td>ND</td><td>0.04 ± 0.02</td><td>0.09 ± 0.01</td></tr>
<tr><td>7</td><td>0.76</td><td>1.0E-02</td><td>0.25</td><td rowspan="8">NS</td><td>0.14 ± 0.02</td><td>0.19 ± 0.01</td></tr>
<tr><td>7</td><td>0.91</td><td>6.6E-03</td><td>0.14</td><td>0.04 ± 0.0</td><td>ND</td></tr>
<tr><td>6</td><td>0.93</td><td>3.2E-04</td><td>0.16</td><td>0.06 ± 0.01</td><td>0.10</td></tr>
<tr><td>20</td><td>0.93</td><td>3.2E-04</td><td>0.19</td><td>0.08 ± 0.01</td><td>0.14 ± 0.0</td></tr>
<tr><td>31</td><td>0.01</td><td>3.3E-03</td><td>0.00</td><td>ND</td><td>ND</td></tr>
<tr><td>44</td><td>0.40</td><td>3.2E-04</td><td>0.06</td><td>0.02 ± 0.01</td><td>0.04 ± 0.0</td></tr>
<tr><td>36</td><td>0.71</td><td>3.2E-04</td><td>0.18</td><td>0.05 ± 0.01</td><td>0.12 ± 0.01</td></tr>
<tr><td>36</td><td>0.68</td><td>4.9E-03</td><td>0.11</td><td>0.06 ± 0.01</td><td>0.10 ± 0.01</td></tr>
</table>

ND – Non-detectable.

NS – No sample deployed.

Waterloo Membrane Passive Sampler and Beacon Chromosorb 106 passive sampler results. Waterloo Membrane Sampler (WMS) and Beacon Chromosorb 106 passive samplers were deployed during the early stage of this validation test. A single WMS sampler was deployed for each of two sampling periods, and Beacon Chromosorb 106 samplers were deployed in triplicate for each of five sampling periods. Based on the poor agreement with active sampling results, use of these passive samplers was discontinued. Lessons-learned from use of each are:

- WMS sampler: The WMS sampler was not sensitive enough for low indoor air VOC concentrations. In later communications, the manufacturer indicated that use of the WMS sampler for indoor air monitoring was discontinued due to its lack of sensitivity at low concentrations.
- Beacon Chromosorb 106 sampler: In a comparison with active sampling data, it appeared that analytical results more closely resembled ambient air concentrations, rather than indoor air concentrations at the time of sampler collection. In a conversation with the manufacturer, the hypothesis was that chemicals were desorbing from the sampler.

Beacon passive sampler and Beacon Carbopack X passive sampler results. Analytical results for the Beacon and Beacon Carbopack X samplers were compared to the averaged results of 24-h TD samples collected during the passive sampling period. Key observations and conclusions include:

- Both passive samplers produced self-consistent results when multiple samplers were deployed. The standard deviation for indoor air concentrations measured by each triplicate sampling set was typically less than 10% of their averaged results.
- Both passive samplers produced results that correlated well with active sampler results, with passive sampler results being very similar to active sampling results for TCE and the Beacon Passive Sampler, greater than active sampling results for 1,1 DCE and the Beacon Passive Sampler, and generally about 50% less for all other chemical/sampler combinations. This can be seen in Figures 6.39 through 6.43, and in the table below that summarizes the slopes of passive sampler vs. active sampler results:

Passive Sampler	Slope of Passive Sampler vs Active Sampler Result				
	TCE	PCE	1,1-DCE	1,1-DCA	1,1,1-TCA
Beacon	0.99	0.49	1.35	0.49	0.72
Beacon Carbopack X (CPX)	0.44	0.49	0.46	0.47	0.52

- Consistent with the discussion above, differences between active and passive sampler concentrations were typically less than a factor 2 as shown in Figure 6.44.
- Figure 6.45 examines the impact of temporal variability on agreement between passive and active sampling results. The results suggest increasing difference between the results with increasing temporal variability during the sampling period (as characterized by the percent standard deviation of the 24-h active sampling results). From 50% to about 250% percent standard deviation in the 24-h active sampling results, the percent difference between passive and active sampling results increases by about 20% (e.g., from about 10% to about 30% for the Beacon Passive Sampler, and from about 50% to 70% for the Beacon CPX sampler.
- Figure 6.46 examines the impact of deployment period on agreement between passive and active sampling results. Prolonged sampler deployment does not appear to affect passive sampler performance. For this study, 6 of the 12 sampling deployments were for periods longer than four weeks and 7 deployments were for sampling periods less than 4 weeks.

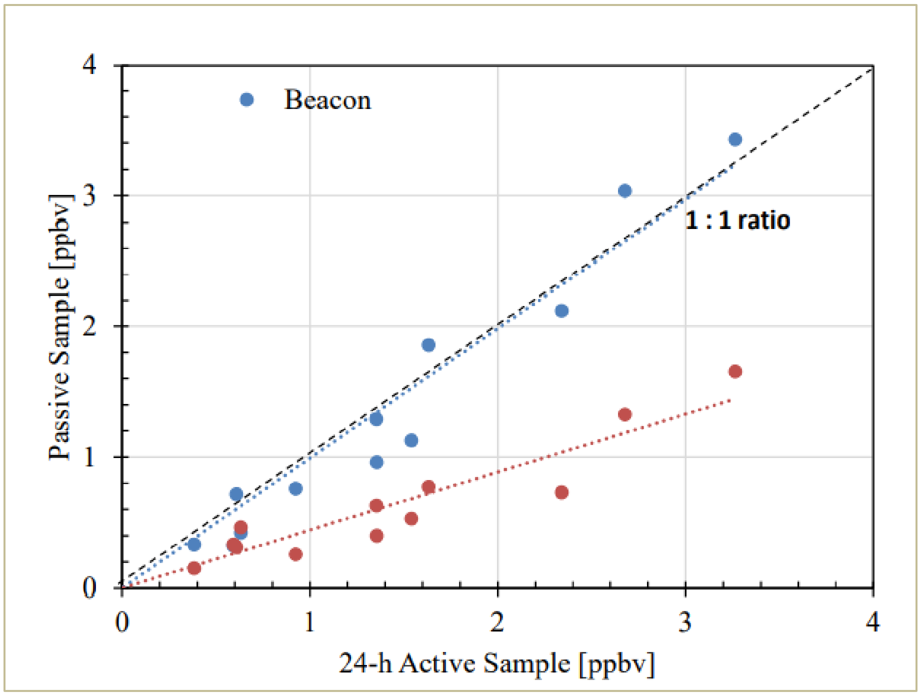


Figure 6.39. Passive Sampler Results vs Averaged 24-h TD Tube Sampling Results for Indoor Air TCE Vapor Concentrations.

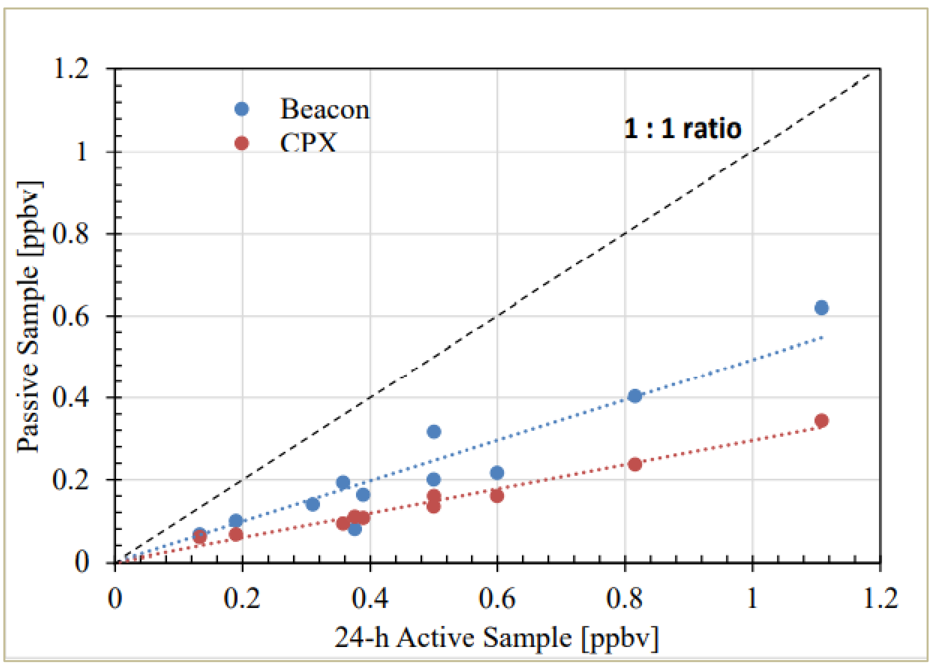


Figure 6.40. Passive Sampler Results vs Averaged 24-h TD Tube Sampling Results for Indoor Air PCE Vapor Concentrations.

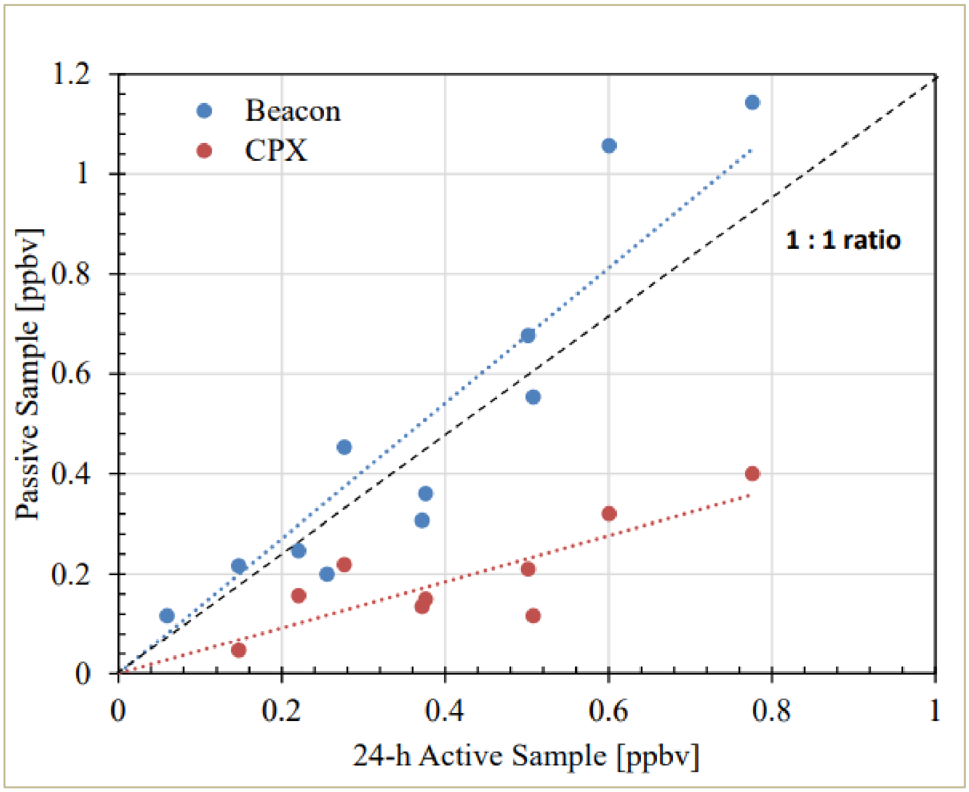


Figure 6.41. Passive Sampler Results vs Averaged 24-h TD Tube Sampling Results for Indoor Air 1,1-DCE Vapor Concentrations.

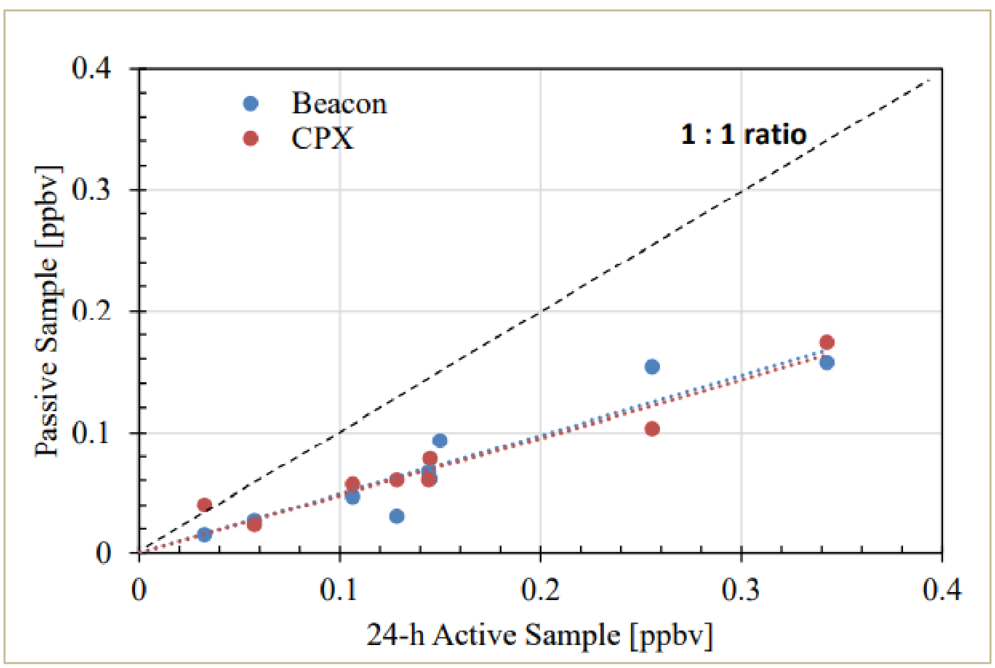


Figure 6.42. Passive Sampler Results vs Averaged 24-h TD Tube Sampling Results for Indoor Air 1,1-DCA Vapor Concentrations.

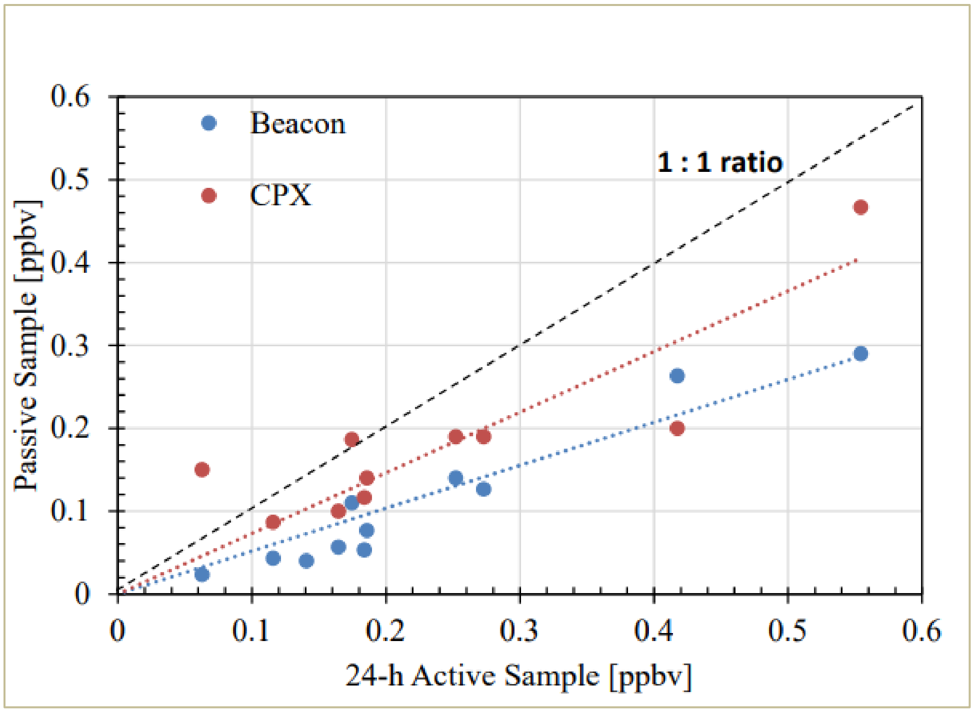


Figure 6.43. Passive Sampler Results vs Averaged 24-h TD Tube Sampling Results for Indoor Air 1,1,1-TCA Vapor Concentrations.

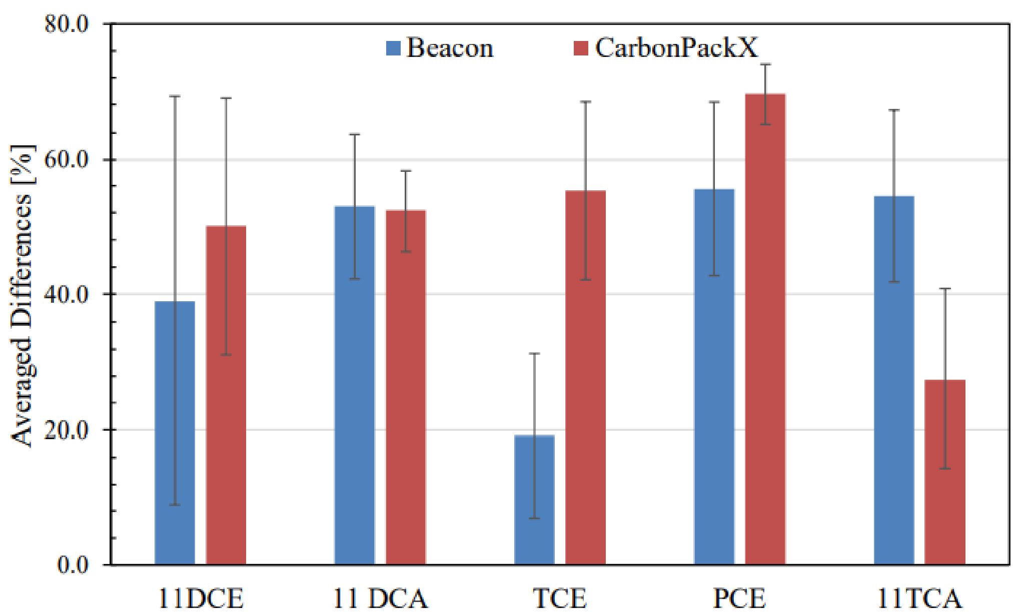


Figure 6.44. Averaged Difference Between Passive Sampler (As a Percentage of the Active Sample Result) and Averaged 24-h Active Sampling Results.

Error bars denote the maximum and minimumvalues of % differences.

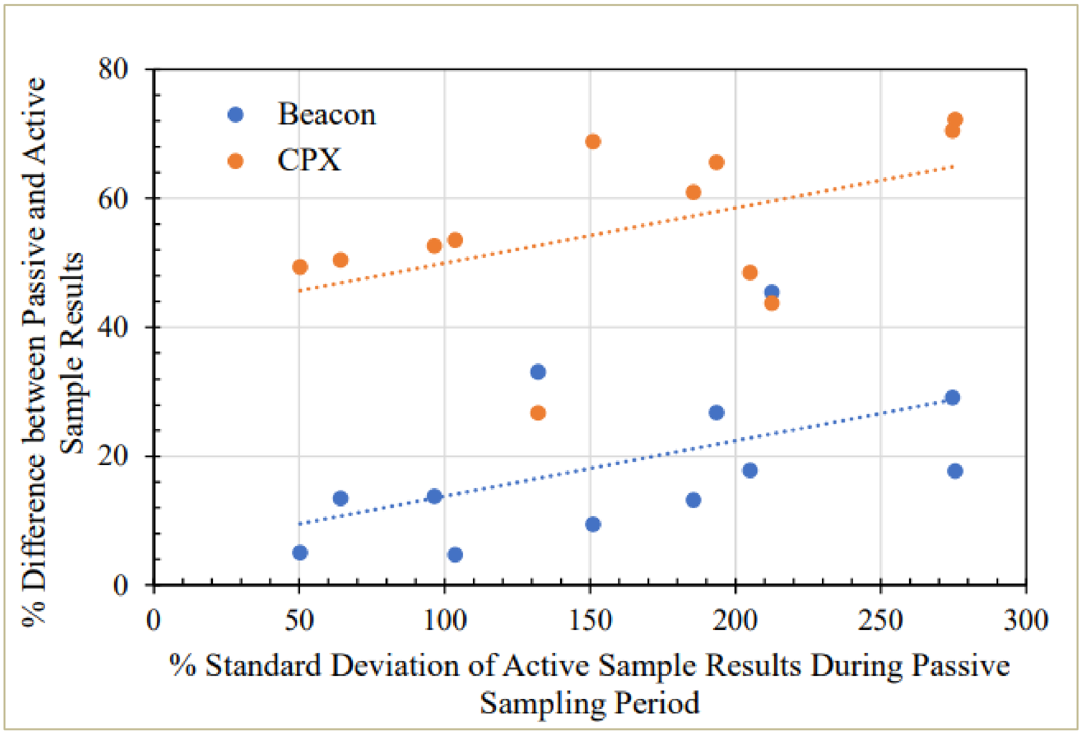


Figure 6.45. Relative Differences Between TCE Results for Passive and Active Sampling (As a Percentage of the Active Sample Result) vs. the Relative Standard Deviation of 24-h Active Sampling Results.

6.3.3 Passive sampler validation tests in industrial buildings

Passive sampling was conducted in the Beale AFB Community Activity Center and in the Travis AFB Facility 18. As with the study house results discussed above, indoor air passive sampling results were compared to active samples collected during the same deployment periods.

6.3.3.1 Passive sampler validation in Beale AFB Community Activity Center

Sampling was conducted for 18 days (Nov. 8 - Nov. 26, 2018) at 11 different indoor locations in Beale AFB Community Activity Center under natural building pressure conditions. The sampling locations are shown in Figure 6.47.

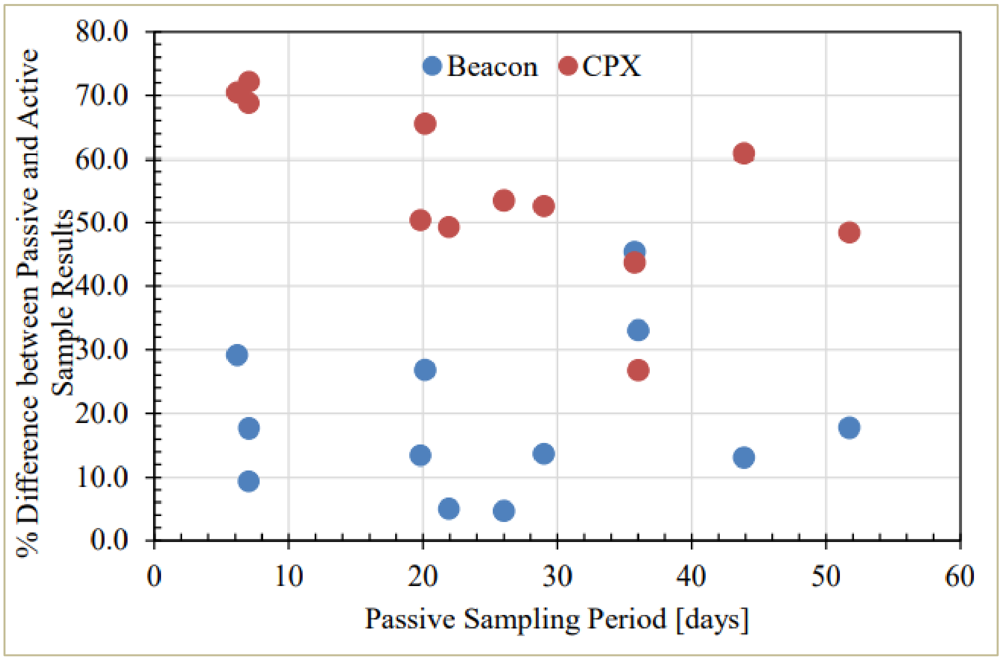


Figure 6.46. Relative Percent Differences Between TCE Results for Passive and Active Sampling (As a Percentage of the Active Sample Result) vs. the Duration of Sampling Event.

One non- detectable passive sampling result is not shown.

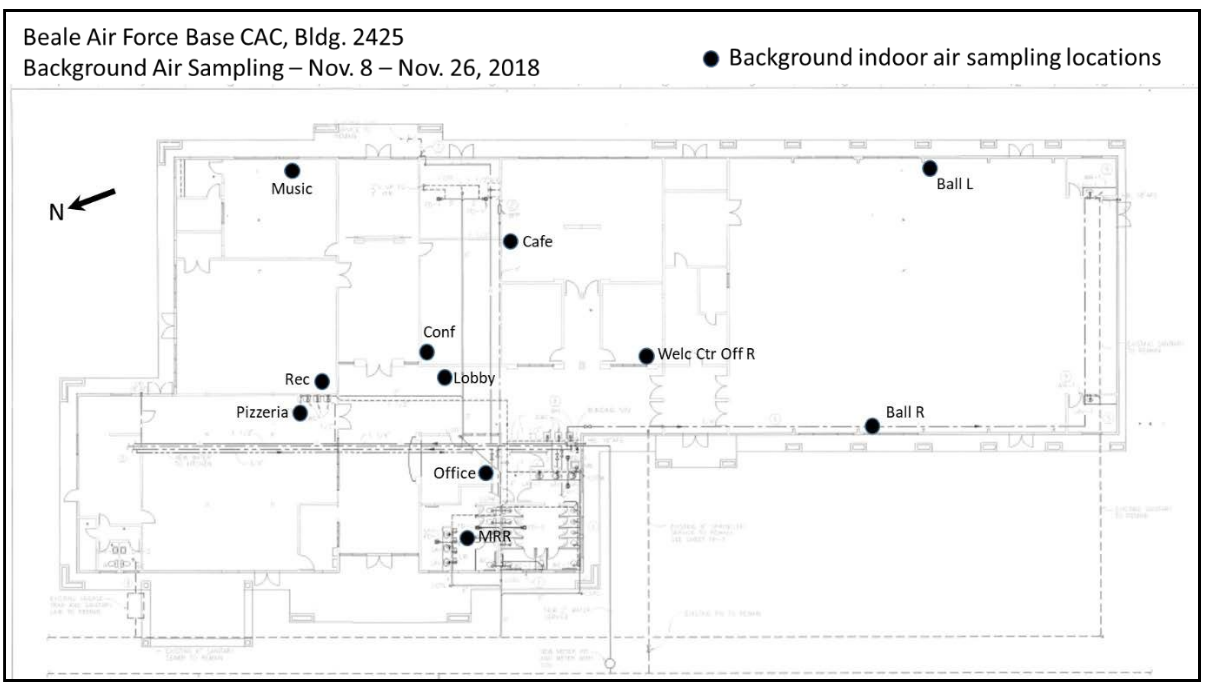


Figure 6.47. Nov. 8 Through Nov. 26, 2018 Sampling Locations in the Beale AFB Community Activity Center, Building 2425.

Based on the study house results, the Beacon Passive Sampler was selected for this 18-day sampling, and they were deployed simultaneously with thermal desorption (TD) tube samplers at each indoor location shown in Figure 6.47.

For the active TD tube sampling, a timed interval sampling technique – 10 minutes of active sampling every 1.5 hours - was developed to reduce collection volume to prevent TD tube sorbent saturation if indoor air concentrations were high. This interval sampling technique used a Gilian LFS-113 low flow air sampling pump (Sensidyne, FL) in constant pressure mode, a manifold with constant-flow restrictor orifices that served each active sampler, and TD tube samplers. The pump, while in operation, provided a constant negative pressure to maintain a consistent air flowrate through each restrictor orifice (40-60 mL/min) for each sampler. The flowrate was measured before and after sample deployments using a Gilian Gilibrator-2 air flow calibrator (Sensidyne, FL). A programmable digital timer was used to control pump runtime to a 10-minute interval every 1.5 hours continuously throughout the sampling period, for a total of 160 minutes per day. After deployment, both passive and active samplers were sent to Beacon Environmental Services for analyses. Figure 6.48 shows the deployment of both samplers.

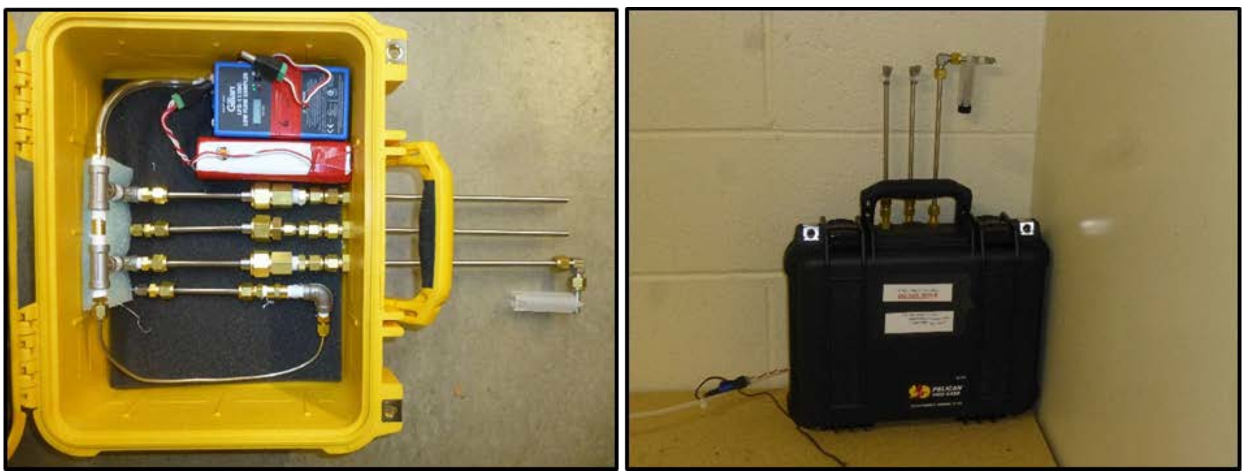


Figure 6.48. Active TD Tube Samplers in Triplicate with a Single Tube for Breakthrough Assessment, Pump, and Timer (left photo) and Passive Sampler Deployment (right photo).

Table 6.19 summarizes passive and active sampling results. In general, most sample analyses returned concentrations less than detection limits, with the exception of the Welcome Center office and the café locations. For the café location, the active TD sampler 1, 2- DCA vapor concentration was 0.04 ppb_v while the Beacon Passive Sampler results were below its detection limit of 0.18 ppb_v. For the Welcome Center office location, the active TD sampler result for 1, 2-DCA vapor concentration was 0.09 ppb_v, while the passive sampler result was 0.23 ppb_v.

Table 6.19. Laboratory Analytical Results for Nov. 8 through Nov. 26, 2018 active TD Tube and Passive Sampling During Natural Building Pressure Conditions, Beale AFB Community Activity Center, Bldg. 2425.

Location	Sample Type	Units	Analyte Concentration in Air[1]									
			TCE[2]	1,1-DCE[2]	t 1,2-DCE[2]	1,1-DCA[2]	c 1,2-DCE[2]	1,2-DCA[2]	1,1,1-TCA[2]	PCE[2]	Bromodichloromethane[2]	Dibromochloromethane[3]
Ball L	Passive	ug/m3	<1.19	<1.22	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.10
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	---	---	---	---	---	---	---	---	---	---
Ball R	Passive	ug/m3	<1.19	<1.22	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.10
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Cafe	Passive	ug/m3	<1.19	<1.22	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.10
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.02	<0.02	<0.02	<0.02	<0.02	0.04	<0.01	<0.01	<0.01	<0.01
MRR	Passive	ug/m3	<1.19	<1.23	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.11
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Welcome CenterOff R	Passive	ug/m3	<1.19	<1.22	<0.92	<0.48	<0.75	0.94	<0.99	<0.99	<0.98	<1.10
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	0.23	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.01	<0.02	<0.02	<0.02	<0.02	0.09	<0.01	<0.01	<0.01	<0.01
Conf	Passive	ug/m3	<1.18	<1.22	<0.91	<0.48	<0.75	<0.72	<0.98	<0.98	<0.98	<1.10
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Office	Passive	ug/m3	<1.19	<1.22	<0.92	<0.48	<0.75	<0.72	<0.98	<0.98	<0.98	<1.10
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Lobby	Passive	ug/m3	<1.20	<1.23	<0.92	<0.48	<0.75	<0.73	<0.99	<0.99	<0.99	<1.11
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	---	---	---	---	---	---	---	---	---	---
Rec	Passive	ug/m3	<1.19	<1.23	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.11
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.02	<0.03	<0.03	<0.03	<0.03	<0.03	<0.02	<0.02	<0.02	<0.01
Pizzeria	Passive	ug/m3	<1.19	<1.23	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.11
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	---	---	---	---	---	---	---	---	---	---
Music	Passive	ug/m3	<1.19	<1.23	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.11
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	---	---	---	---	---	---	---	---	---	---

1- For concentrations noted as "<", concentrations were non-detectable or less than the limits of quantitation shown.

2- Passive sampler concentrations reported in ug/m3 and converted to ppbv using the EPA Indoor Air Unit Conversion, Online Tools for Site Assessment Calculation (USEPA, 2020).

3- Passive sampler concentration reported in ug/m3 and converted to ppbv using the Eurofins Unit Conversion Calculator (Eurofins, 2020).

6.3.3.2 Passive sampler use in Travis AFB Facility 18

Indoor air passive sampling testing was also conducted in Travis AFB Facility 18 under natural building pressure conditions in November 2018 for 18 days. Two active sampling approaches were implemented during passive sampler deployment: a) multiple 24-h TD tube samples that were collected using an MTS-32 auto-sampler (Markes, Ltd., UK) and b) long-term time-interval single TD tube sampling as described in section 6.3.3.1. The former approach quantified daily average indoor air VOC concentrations to evaluate both the temporal variability and the average concentration levels of indoor air VOCs, while the later only measures the average indoor air VOC concentrations over the deployment period. Sampling schematics for both validation periods are shown in Figure 49.

- Passive sampler deployment: A single Beacon Passive Sampler was deployed in each of the following locations - the Hall, Main Service Bay, Office1, and Shower1. Passive samplers were returned to Beacon Environmental for analyses.
- Timed interval TD sampler deployment: Time interval TD samplers were installed within 30 cm of each passive sampler at the four indoor locations noted above. Samples were sent to Beacon Environmental for analyses.
- MTS-32 TD tube auto sampling. Two MTS-32 autosamplers were used to collect daily indoor air samples at the Hall and Main Service Bay locations. Samples were sent to ASU for analyses.

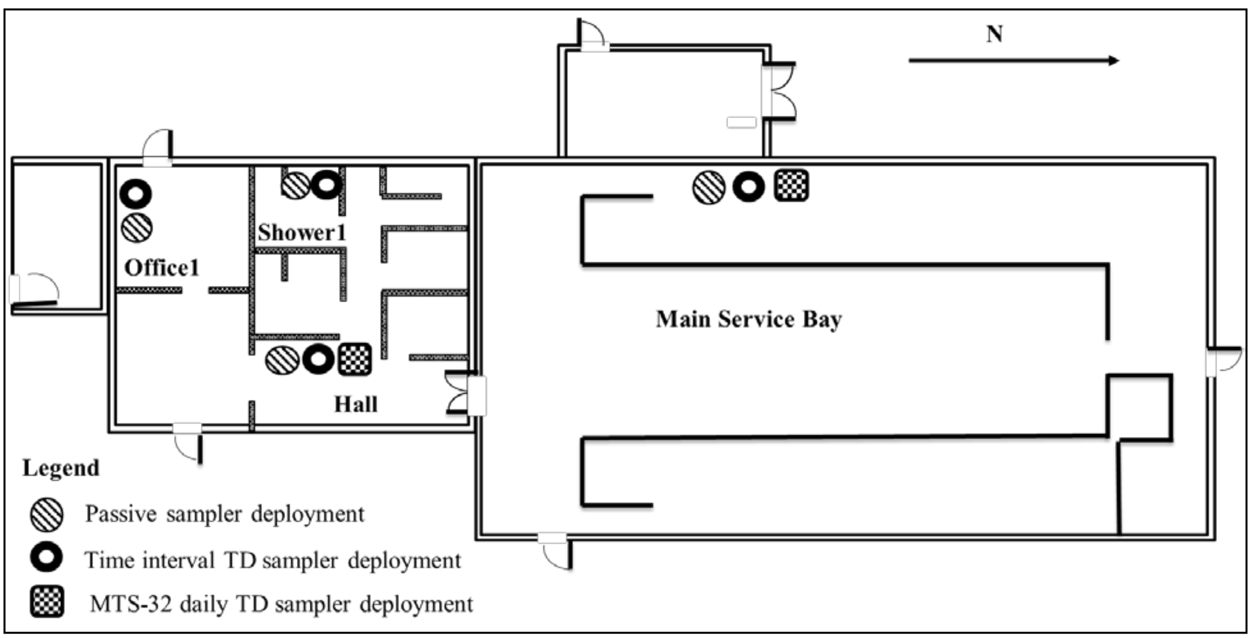


Figure 6.49. Schematic View of Passive and Active Sampling Plan.

Table 6.20 summarizes the passive and active sampling results from all locations. In general, passive sampling results agree well with active sampling results. Detailed comparisons for each air sampling location are as follows:

- Hall: 24-hr TD tube sampler results varied over 1000x during the 18-day sampling period for indoor air TCE vapor concentrations: the average 24-h TD tube sampler result was 4.32 ppb_v, with maximum and minimum values of 10.32 and 0.01 ppb_v, respectively. The passive sampler result (6.1 ppb_v) is in very close agreement to the whole time interval TD tube sampling result (6.55 ppb_v), and those in turn are within 50% of the calculated average of the individual 24-h results. While time interval TD tube sampling and average 24-h TD tube sampling results for cDCE are similar (1.66 ppb_v vs. 1.75 ppb_v), however, they are about 70% greater than the passive sampling results for the same period (1.0 ppb_v), which is consistent with observations from the study house.
- Main service bay: MTS-32 24-h TD tube sample TCE concentrations varied by 100x, with an average of 1.8 ppb_v. This value was about 40% and 26% smaller than Beacon passive sampler (2.5 ppb_v) and the whole time-interval TD tube sampler (2.2 ppb_v) results, respectively – similar to the relationship between TCE results from the Hall location.
- Office: Beacon passive sampler and whole time-interval TD tube sampler were deployed at this location. All detected chemical concentrations from active TD tube sampling were about one-third of the passive sampler results. The TD sampler measurements exceeded the upper calibration range for the analyses, so that might account for the differences noted.
- Shower1: Beacon passive sampler and time-interval TD tube sampler were deployed at this location. Both TCE and cDCE were detected. TCE concentrations for passive and TD samplers were 8 ppb_v and 7.26 ppb_v, respectively. Yet, active TD sampling concentrations for cDCE (2.03 ppb_v) were about 25% greater than the passive sampling result (1.6 ppb_v).

6.3.4 Key Conclusions from Passive Sampling Validation Testing

The use of long-term passive diffusive-adsorptive vapor samplers as a VI assessment tool that is complementary to or a replacement for short-term grab or long-term active sampling has been developing over the past few years and shows strong promise, provided care is taken in their use as discussed below. Previous developmental studies showed that passive samplers can produce results comparable to conventional sampling methods under well-controlled steady concentration conditions. This work evaluated the performance of passive samplers in field conditions with significant temporal variations in concentrations.

Of the four passive samplers selected at the start of this study, two were determined early on to yield poor results, and their use was discontinued. For the remaining two, there were clear linear correlations between passive sampling results and active sampling results, with passive sampling results being consistently similar to or lower than active sampling results by about 50%. The consistency in results suggests a difference in calibration between the two methods compared.

Table 6.20. Laboratory Analytical Results for 18-day Active TD Tube and Passive Sampling During Natural Building PressureConditions, Travis AFB Facility 18.

Sample Location	Sampling Method		VOCs Concentrations [ppbv]								
			11DCE	tDCE	11DCA	cDCE	12DCA	111TCA	Benzene	TCE	PCE
Hall	Passive-Beacon		<0.28	<0.21	<0.11	1.0	<0.16	<0.06	NA	6.1	<0.12
	TD-Beacon		U	0.05	U	1.75D	U	U	NA	6.55D	U
	MTS-32 Auto Sampler	Average	<MDL	0.10	0.01	1.66	0.03	<MDL	0.44	4.32	0.039
		Maximum	0.01	0.25	0.03	3.55	0.06	<MDL	1.65	10.32	0.146
		Minimum	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.01	0.01	<MDL
Main Service Bay	Passive-Beacon		<0.28	<0.21	<0.11	0.56	<0.16	<0.06	NA	2.5	<0.12
	TD-Beacon		U	U	U	0.4	U	U	NA	2.24D	U
	MTS-32 Auto Sampler	Average	<MDL	0.04	<MDL	0.66	<MDL	<MDL	0.13	1.78	0.02
		Maximum	0.01	0.10	<MDL	1.59	<MDL	<MDL	0.34	4.69	0.09
		Minimum	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.01	<MDL
Travis Office	Passive-Beacon		<0.28	0.38	<0.11	9.3D	<0.16	<0.06	NA	30.9D	0.14
	TD-Beacon		U	0.16	U	3.47E	U	U	NA	11.36E	0.04
TR shower1	Passive-Beacon		<0.28	<0.21	<0.11	1.6	<0.16	<0.06	NA	8.0D	<0.12
	TD-Beacon		U	0.04	U	2.03D	0.03	U	NA	7.26D	U

NA - Not applicable.

U - Less than limit of quantitation. The detailed information can be found in Appendix E.

D – Sample dilution performed.

E - Measurement exceeded upper calibration range of instrument.

Overall, the results of this study suggest that passive sampling, if deployed properly, can be a viable cost-effective tool for longer-term (multiple weeks) VI indoor air concentration assessment. As this is a relatively new sampling option with evolving passive sampling products on the market, further development is needed to ensure proper use of passive sampling.

Given that two of the four passive samplers tested produced poor results and the other two produced correlated, but consistently different results from active samplers, it is important that passive samplers be rigorously validated and calibrated prior to use – under both steady and time-varying test concentrations with comparison vs. active sampling methods. An industry standard approach to validation and calibration should be developed.

In addition, all demonstrations in this work were conducted under relatively stable indoor temperature and humidity conditions. It is unknown if the performance of passive samplers varies with significant temperature or humidity changes, and that should be evaluated.

6.4 SUB-SLAB DEPRESSURIZATION VI MITIGATION SYSTEM PERFORMANCE AT A RESIDENTIAL HOUSE WITH AN ALTERNATE VAPOR INTRUSION PATHWAY

When vapor intrusion (VI) pathway assessment identifies an unacceptable risk to an overlying building, mitigation is generally required. The presumptive remedy for VI impacts is a sub-slab depressurization (SSD) system. By drawing vapors from one or more extraction points installed through a foundation, the indoor to subsurface pressure differential favors flow from the house to the subsurface and contaminant vapors are collected from beneath the building. When designed properly, an SSD system can effectively prevent vapor intrusion from any VI pathway that requires vapor transport across or through a foundation (e.g., the soil and pipe flow VI pathways). An SSD system is unlikely to be effective when vapors enter the house through pipingthat directly connects indoor air to a vapor source, as is the case for the sewer VI pathway.

As this has not been done before, an experimental study was conducted to examine the effectiveness of a SSD system operated according to the design approach developed in ESTCP Project ER-201322. In particular, the goal was to test the system design paradigm at a building where vapor intrusion impacts were known to be the result of a pipe flow VI pathway. One of the reasons for conducting this experiment is that at many sites, practitioners may not know when alternate VI pathways are present – as they are hard to identify via inspection or conventional VI pathway assessment practices.

6.4.1 Experimental design

The study house in this work has been described previously in this report. In brief, it is a two-story, split-level house that overlies a groundwater plume with dissolved TCE concentrations ranging from 10-50 μg/L-H_2O. An open-ended land drainpipe lateral connects the sub-foundation area near the southeast corner of the house with a neighborhood land drain network containing TCE vapors. This important feature was discovered and confirmed to be a significant pathway for TCE vapor migration to indoor air at this house during the long-term controlled pressure method (CPM) testing reported by Holton et al. (2015) and Guo et al. (2015).

There is an SSD mitigation system in the house with a single extraction point in the laundry room near thenorth wall, as shown in Figure 6.50.

The effectiveness of the SSD mitigation system was evaluated under three different extraction flowrates: 26.8 ± 3.5 CFM, 53.7 ± 5.1 CFM and 110.8 ± 10 CFM. These are the minimum operable flowrate, 2 x the minimum flowrate, and the default (full speed) flowrate of this SSD system. All of these flowrates should be sufficient to protect this house from vapor intrusion, as determined through application of the ESTCP Project ER-201322 design approach presented in Appendix C.

While operating at each of the three extraction flowrates, indoor-outdoor pressure difference conditions that might occur naturally due to wind, indoor-outdoor temperature differences, or operation of indoor exhaust fans were simulated using a controllable blower (Retrotec, WA) installed in the upstairs master bedroom (MB) window. For reference, historic indoor-outdoor pressure difference monitoring data revealed that 24-h average indoor-outdoor pressure differences can range from -5 Pa to 3 Pa (ER-1686), with short-duration pressure differences as great as -30 Pa at this house.

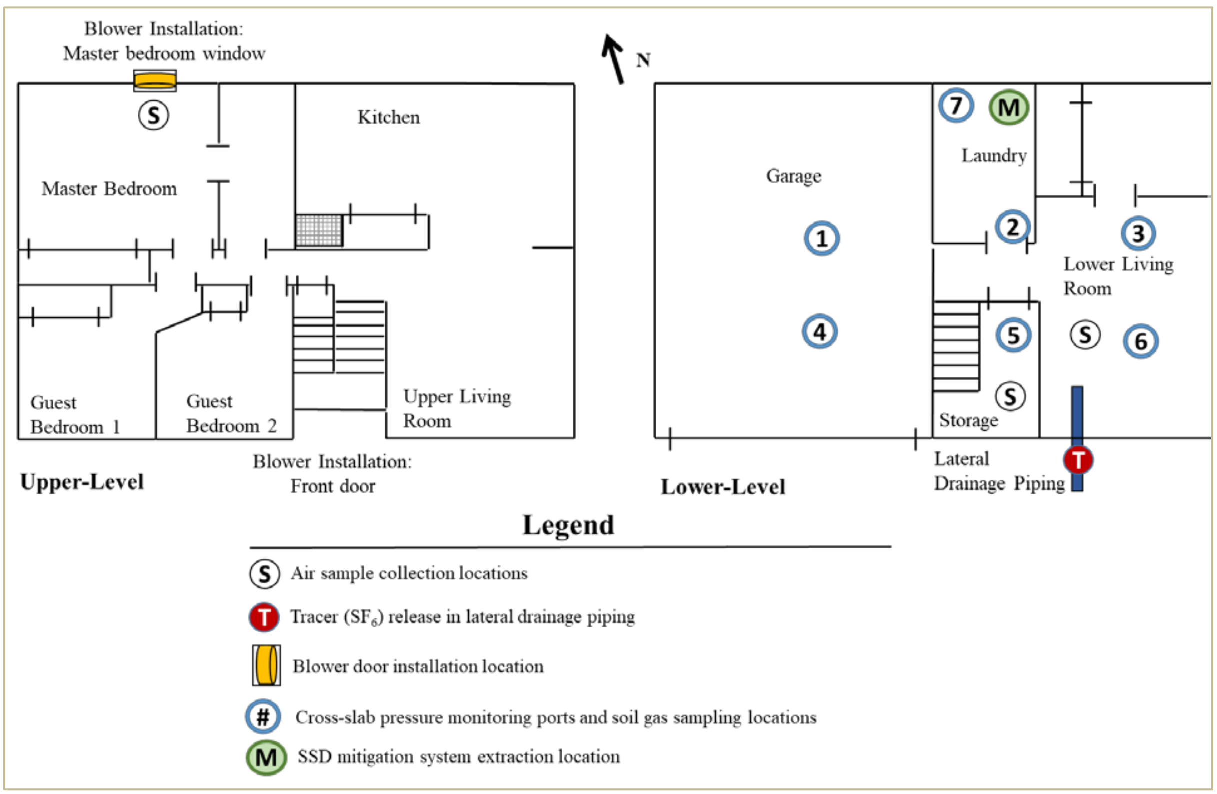


Figure 6.50. Schematic Showing Sampling and Monitoring Locations, Exhaust Fan Placement, and SSD Extraction Location.

The vapor phase tracer sulfur hexafluoride (SF_6) was released continuously into the land drain lateral pipe shown in Figure 6.50 during these tests. System effectiveness was then assessed by monitoring SF_6 appearance in indoor air. The SF_6 release rate was controlled at 3 SCCM using a 0-10 mL/min mass flow controller (Alicat Scientific, Tucson, AZ). SF_6 vapor samples were collected from the SSD vent pipe, and three indoor air locations:

the lower living room, blower intake and the lower-level storage room. GC-PDD was used to quantify SF_6 vapor concentrations with a minimum detection level of 5 ppb_v. Soil gas samples from different depths at the locations shown in Figure 6.50 were collected for each SSD system extraction flowrate andprior to or after any changes in blower flowrate.

Pressure differences across the building envelope are frequently used as indicators of SSD system effectiveness. Real-time indoor - outdoor and indoor - sub-slab pressure differences were measured using Retrotec DM32 data loggers (Retrotec, WA) and the results were recorded every 15 - 30 s. Indoor – sub-slab pressure difference monitoring locations are shown in Figure 6.50.

Table 6.21 summarizes operating conditions for each test conducted, including the SSD extraction flowrate and the indoor – outdoor pressure differences created using the blower installed in the master bedroom window.

Table 6.21. Summary of SSD Extraction Flowrates and Building Depressurization Conditions.

SSD System Extraction Flowrate [SCFM]	Indoor – Outdoor Pressure Differences Created by Operation of the Exhaust Blower Installed in the Master Bedroom Window		
	Average Indoor - Outdoor Pressure Difference [Pa]	Average Master Bedroom Window Blower Flowrate [SCFM]	Duration of Indoor-Outdoor Pressure Difference Condition [h]
27	-4.7	417	26
	-4.7	417	27
	-4.3	415	24
	-3.2	333	25.6
54	-6.6	556	30
	-7.6	556	50
	-7.1	555	35
	-6.6	430	54
	-2.8	290	50
	-2.8	289	21.5
110	-4.3	335	32
	-5.9	429	26
	-5.9	428	24
	-7.0	478	24
	-6.9	476	24
	-8.2	600*	15
	-8.2	600*	33.5
	-7.3	600*	19

* - Data logger failure. The value is estimated based on previously experimental results.

6.4.2 SSD system performance results

6.4.2.1 SSD system extraction flowrate: 27 SCFM

Figures 6.51, 6.52, and 6.53 present the indoor-outdoor pressure differences created by operation of the blower installed in the master bedroom window and the resulting SF_6 concentrations measured in the lower-level living room (LLR), the master bedroom (MB) near the exhaust fan intake, and the SSD system extraction pipe, respectively.

Table 6.22 summarizes the average cross-slab pressure differences measured at five monitoring points before and during the test.

Figure 6.54 presents a mass balance on the 3 SCCM SF_6 injected into the land drain lateral pipe, with amounts of SF_6 extracted, expressed as SCCM flowrates, from the subsurface via the SSD system extraction pipe and from inside the house by the blower installed in the master bedroom window.

Table 6.22. Average Cross-slab Pressure Differences Before and During the Negative Pressure Disturbances Created by Operation of the Blower in the Master Bedroom Window When the SSD System Flowrate Was 27 SCFM.

Building pressure disturbance [Pa]	Average indoor - subslab pressure differences [Pa]				
	Location 2	Location 3	Location 5	Location 6	Location 7
0.4 (no disturbance)	11.7	5	2.5	1.2	15.3
-4.7	9.1	3.7	0.1	-1.1	12.5
-4.7	8.9	3.6	0.1	-1.1	12.3
-4.3	8.6	3.5	-0.6	-2.0	12.1
-3.2	8.9	3.5	-0.3	-1.7	12.4

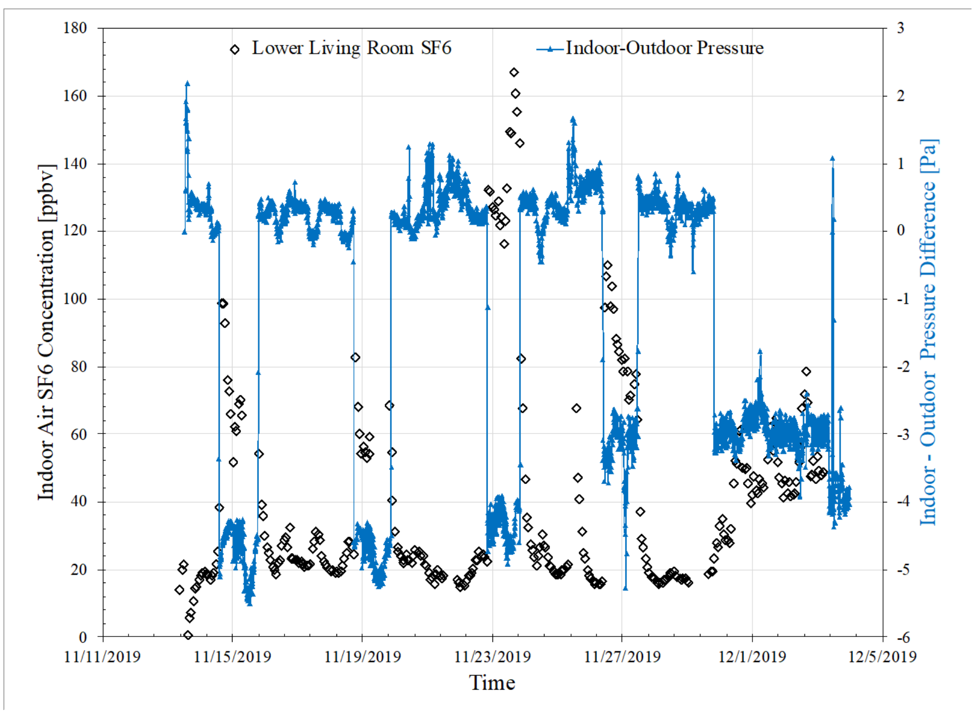


Figure 6.51. Indoor - Outdoor Pressure Differences and Indoor Air SF6 Concentrations in the Lower-level Living Room.

In these tests, the SSD system flowrate was 27 SCFM and the fourintermittent indoor-outdoor pressure disturbances were caused by operation of the blower installed in the master bedroom.

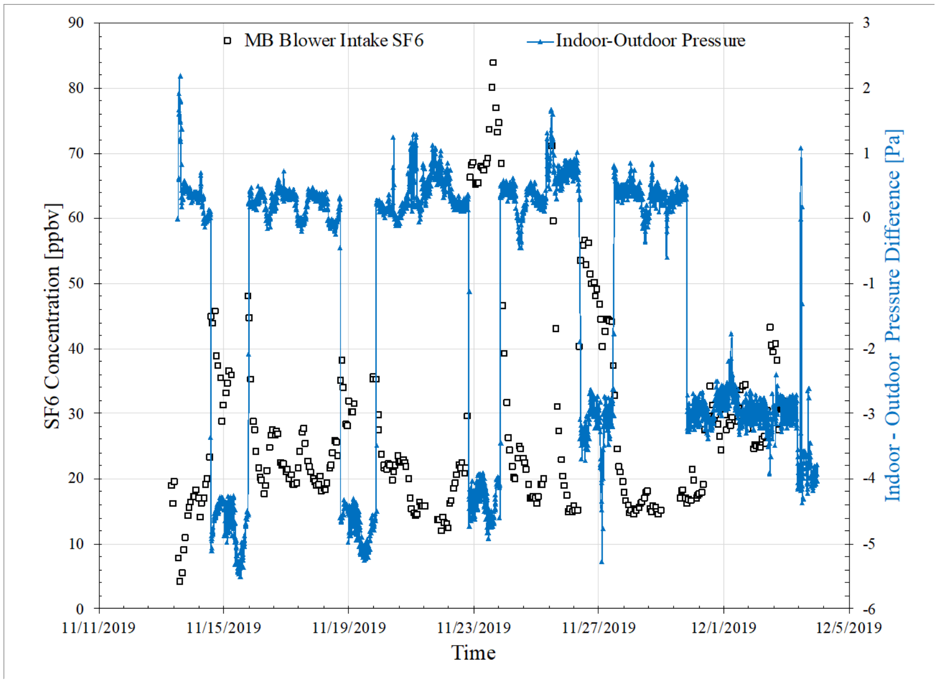


Figure 6.52. Indoor - Outdoor Pressure Differences and Indoor Air SF6 Concentrations in the Upper-level Master Bedroom Near the Blower Intake.

In these tests, the SSD system flowrate was 27 SCFM and the four intermittent indoor-outdoor pressure disturbances were caused by operation of the blower installed in the master bedroom.

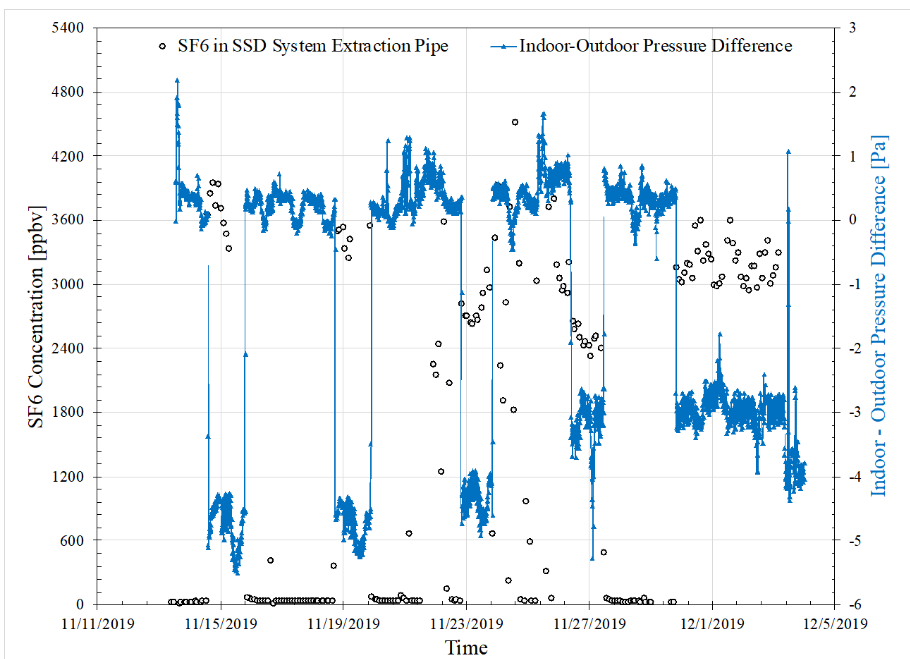


Figure 6.53. Indoor - Outdoor Pressure Differences and SF6 Concentrations in the SSD System Extraction Pipe.

In these tests, the SSD system flowrate was 27 SCFM and the four intermittentindoor-outdoor pressure disturbances were caused by operation of the blower installed in the master bedroom.

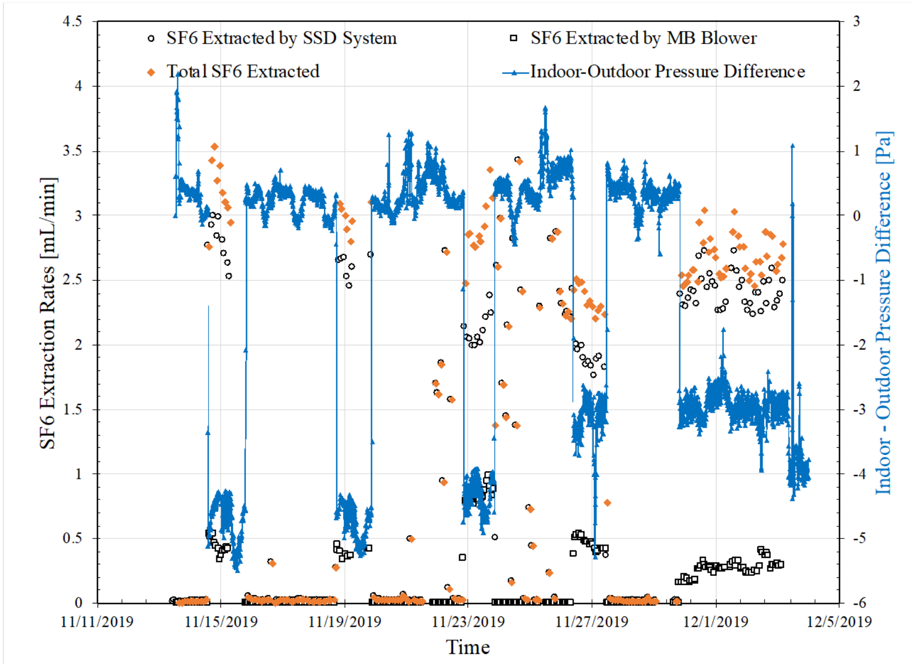


Figure 6.54. Indoor - Outdoor Pressure Differences and Amounts of SF6 Extracted by the SSD System and Blower in the House, Expressed as SF6 Flowrates.

For reference, a constant 3 SCCMSF$_6$ flowrate was delivered to the land drain lateral pipe during these tests.

These data collectively show the following when the SSD system was operated at the 27 SCFM extraction rate:

- Under undisturbed indoor - outdoor pressure conditions, the indoor – outdoor pressure differential was slightly positive (about 0.4 Pa) and all cross-slab pressure differences were positive, indicating vapor flow from the house into the soil as might be expected for SSD system operation. This is a condition that would inhibit vapor intrusion from the subsurface.
- Under increased negative indoor – outdoor pressure difference conditions ranging from -3 to -5 Pa, 3 of the 5 cross-slab pressure differences remained positive and the others became negative, indicating vapor flow from the house to the soil in some areas and vapor flow from soil gas to indoor air in others. The latter were located near where the land drain lateral pipe terminates beneath the foundation.
- Under undisturbed indoor - outdoor pressure conditions, SF_6 did not appear in either the SSD system vent pipe or the indoor air, suggesting that flow in the land drain lateral pipe was toward the land drain main and away from the house.
- Under increased negative indoor – outdoor pressure difference conditions ranging from - 3 to -5 Pa, about 0.3 to 0.5 SCCM of the 3 SCCM of SF_6 injected in the land drain lateral pipe (10% - 16%) was drawn into the house and the rest was mostly captured by the SSD system. Thus, when operating at 27 SCFM, the SSD system did not protect the house from vapor intrusion when experiencing -3 to -5 Pa indoor – outdoor pressure differences.

6.4.2.2 SSD system extraction flowrate: 54 SCFM

Figures 6.55, 6.56, and 6.57 present the indoor-outdoor pressure differences created by operation of the blower installed in the master bedroom window and the resulting SF_6 concentrations measured in the lower-level living room (LLR), the master bedroom (MB) near the exhaust fan intake, and the SSD system extraction pipe, respectively.

Table 6.23 summarizes the average cross-slab pressure differences measured at five monitoring points before and during the test.

Figure 6.58 presents a mass balance on the 3 SCCM SF_6 injected into the land drain lateral pipe, with amounts of SF_6 extracted, expressed as SCCM flowrates, from the subsurface via the SSD system extraction pipe and from inside the house by the blower installed in the master bedroom window.

Table 6.23. Average Cross-slab Pressure Differences Before and During the Negative Pressure Disturbances Created by Operation of the Blower in the Master Bedroom Window When the SSD System Flowrate Was 54 SCFM.

Building pressure disturbance [Pa]	Average indoor - subslab pressure differences [Pa]				
	Location 2	Location 3	Location 5	Location 6	Location 7
0.2 (no disturbance)	28.8	13.3	3.7	0.9	37.2
-6.6	25.6	11.9	0.6	-2.1	33.8
-7.6	26.2	12.2	0.9	-1.9	34.5
-7.1	26	12	0.7	-2	34.1
-6.6	28.6	13.3	1.7	-1.3	37.5
-2.8	27.6	12.8	2.4	-0.4	36
-2.8	27.5	12.8	2.2	-0.5	36

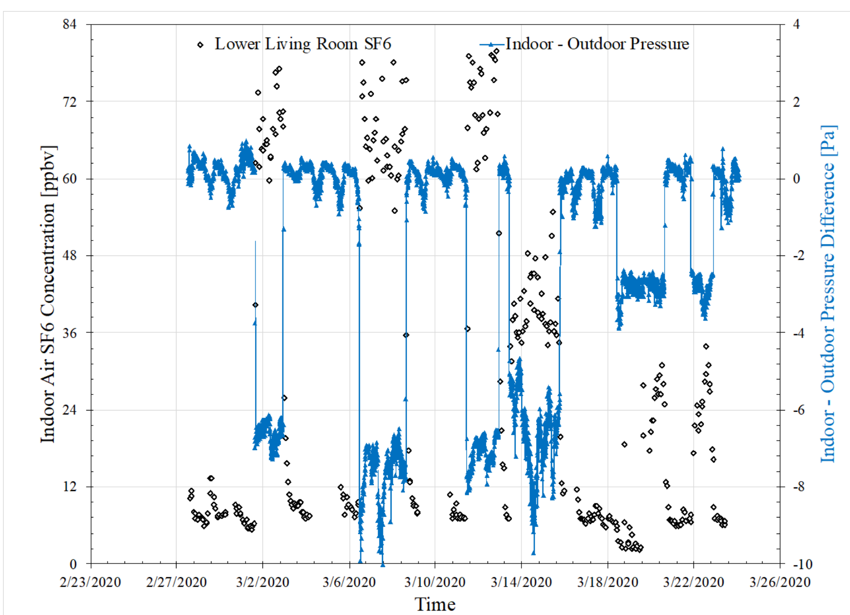


Figure 6.55. Indoor - Outdoor Pressure Differences and Indoor Air SF6 Concentrations in the Lower-level Living Room.

In these tests, the SSD system flowrate was 54 SCFM and the sixintermittent indoor-outdoor pressure disturbances were caused by operation of the blower installed in the master bedroom.

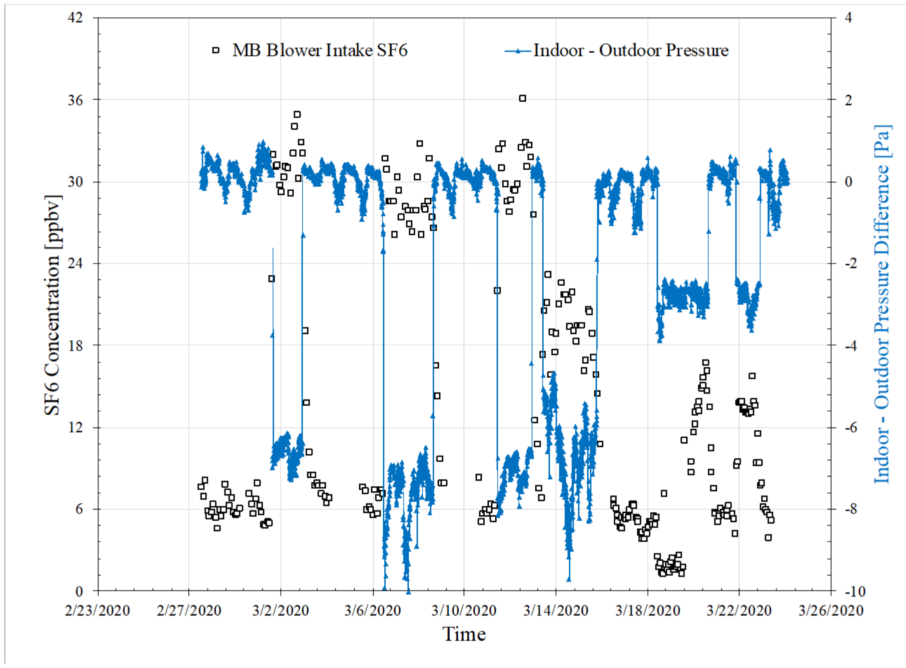


Figure 6.56. Indoor - Outdoor Pressure Differences and Indoor air SF6 Concentrations in the Upper-level Master Bedroom Near the Blower Intake.

In these tests, the SSD system flowrate was 54 SCFM and the six intermittent indoor-outdoor pressure disturbances were caused by operationof the blower installed in the master bedroom.

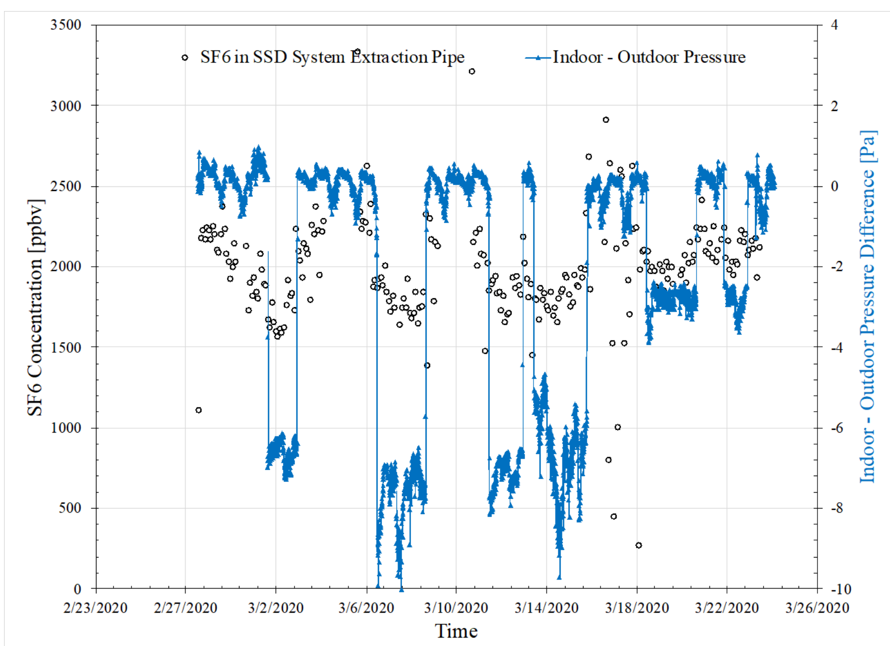


Figure 6.57. Indoor - Outdoor Pressure Differences and SF6 Concentrations in the SSD System Extraction Pipe.

In these tests, the SSD system flowrate was 54 SCFM and the six intermittentindoor-outdoor pressure disturbances were caused by operation of the blower installed in the master bedroom.

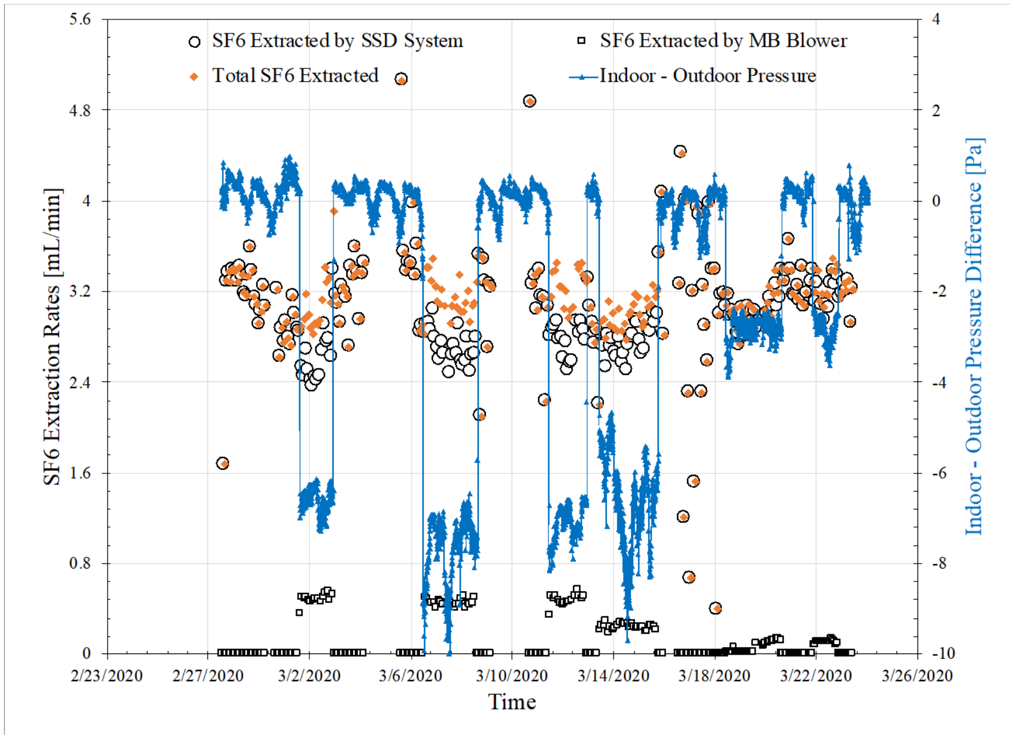


Figure 6.58. Indoor - Outdoor Pressure Differences and Amounts of SF6 Extracted by the SSD System and Blower in the House, Expressed as SF6 Flowrates, When the SSD System Was Operated at the 54 SCFM Extraction Rate.

For reference, a constant 3 SCCM SF_6 flowrate was delivered tothe land drain lateral pipe during these tests.

These data collectively show the following when the SSD system was operated at the 54 SCFM extraction rate:

- Under undisturbed indoor - outdoor pressure conditions, the indoor – outdoor pressure differential was slightly positive (about 0.2 Pa) and all cross-slab pressure differences were positive, indicating vapor flow from the house into the soil as might be expected for SSD system operation. This is a condition that would inhibit vapor intrusion from the subsurface.
- Under increased negative indoor – outdoor pressure difference conditions ranging from -3 to -8 Pa, 4 of the 5 cross-slab pressure differences remained positive. However, the remaining location (location 6) became negative. This indicated that there was vapor flow from the house to the soil in most areas and vapor flow from soil gas to indoor air near where the land drain lateral pipe terminates beneath the foundation.
- Under undisturbed indoor - outdoor pressure conditions, SF_6 appeared to be entirely captured by the SSD system.
- Under increased negative indoor – outdoor pressure difference conditions ranging from -3 to -8 Pa, about 0.3 to 0.6 SCCM of the 3 SCCM of SF_6 injected in the land drain lateral pipe (10% - 20%) was drawn into the house and the rest was captured by the SSD system.

Thus, when operating at 54 SCFM, the SSD system did not protect the house from vapor intrusion via the pipe flow pathway when experiencing -3 to -8 Pa indoor – outdoor pressure differences.

6.4.2.3 SSD system extraction flowrate: 110 SCFM

Figures 6.59, 6.60, and 6.61 present the indoor-outdoor pressure differences created by operation of the blower installed in the master bedroom window and the resulting SF_6 concentrations measured in the lower-level living room (LLR), the master bedroom (MB) near the exhaust fan intake, and the SSD system extraction pipe, respectively.

Table 6.24 summarizes the average cross-slab pressure differences measured at five monitoring points before and during the test.

Figure 6.62 presents a mass balance on the 3 SCCM SF_6 injected into the land drain lateral pipe, with amounts of SF_6 extracted, expressed as SCCM flowrates, from the subsurface via the SSD system extraction pipe and from inside the house by the blower installed in the master bedroom window.

Table 6.24. Average Cross-slab Pressure Differences Before and During the Negative Pressure Disturbances Created by Operation of the Blower in the Master Bedroom Window When the SSD System Flowrate Was 110 SCFM.

Building pressure disturbance [Pa]	Average indoor - subslab pressure differences [Pa]				
	Location 2	Location 3	Location 5	Location 6	Location 7
0.1 (no disturbance)	106.4	52.3	12.0	2.7	134.7
-4.3	105.0	52.5	10.2	1.0	133.3
-5.9	104.5	52.2	9.6	0.3	132.9
-5.9	104.3	52.1	9.7	0.4	132.7
-7	103.5	51.7	9.7	0.5	131.9
-6.9	NA*	NA	9.4	0.2	130.6
-8.2	102.7	50.7	9.4	0.2	131.2
-8.2	103.5	51.1	9.5	0.2	131.9
-7.3	103.6	51.1	9.9	0.5	132.3

NA – No readings available due to sensor disconnection.

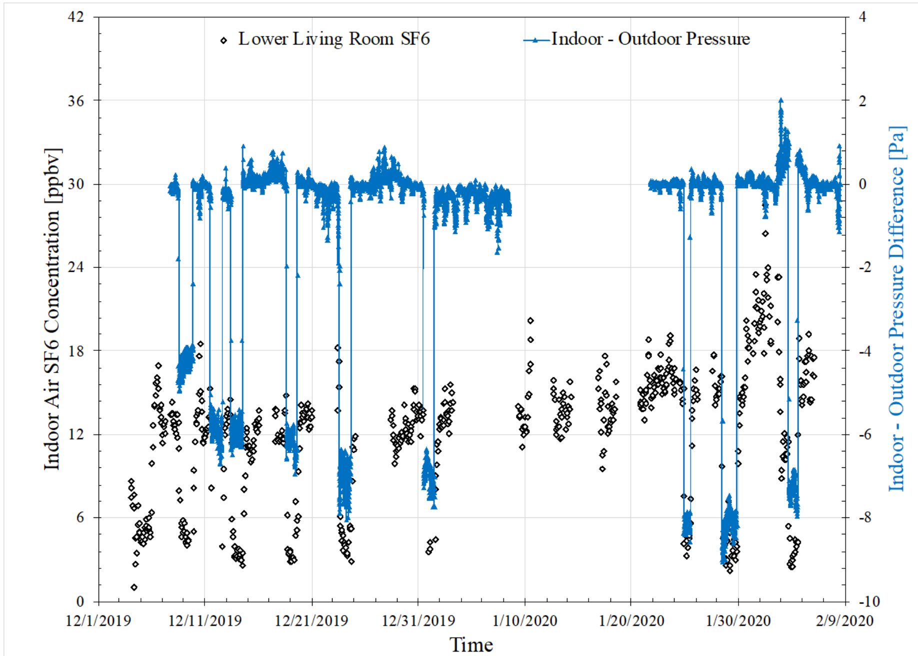


Figure 6.59. Indoor - Outdoor Pressure Differences and Indoor Air SF6 Concentrations in the Lower-level Living Room.

In these tests, the SSD system flowrate was 110 SCFM and the nineintermittent indoor-outdoor pressure disturbances were caused by operation of the blower installed in the master bedroom.

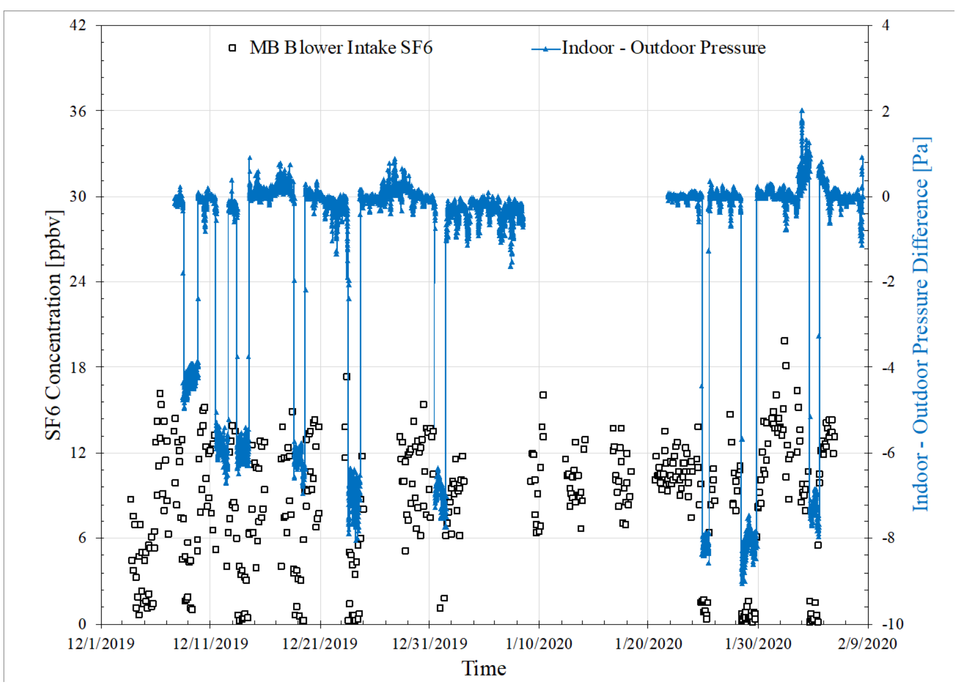


Figure 6.60. Indoor - Outdoor Pressure Differences and Indoor Air SF6 Concentrations in the Upper-level Master Bedroom Near the Blower Intake.

In these tests, the SSD system flowrate was110 SCFM and the nine intermittent indoor-outdoor pressure disturbances were caused by operation of the blower installed in the master bedroom.

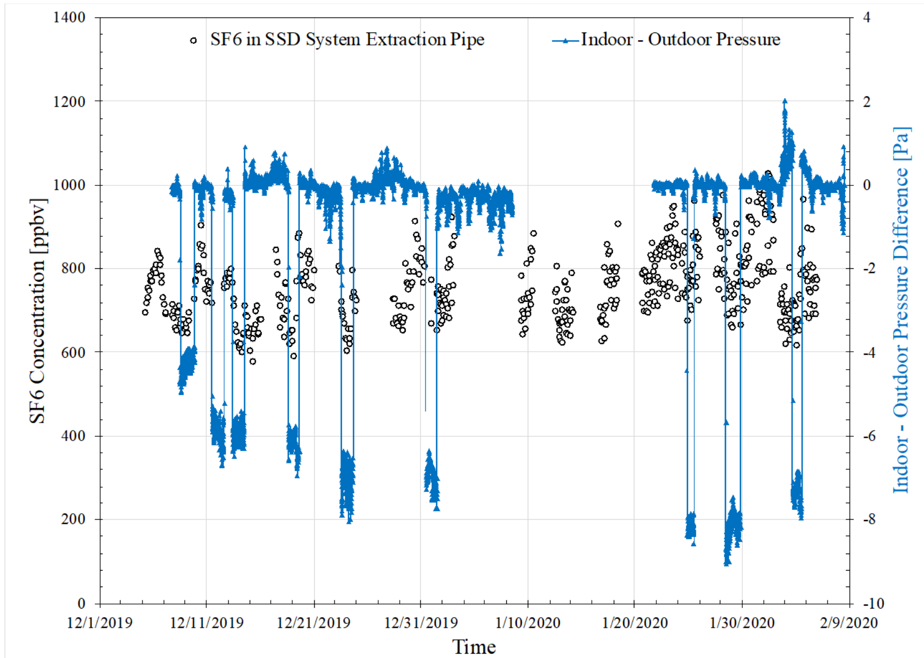


Figure 6.61. Indoor - Outdoor Pressure Differences and SF6 Concentrations in the SSD System Extraction Pipe.

In these tests, the SSD system flowrate was 110 SCFM and the nine intermittentindoor-outdoor pressure disturbances were caused by operation of the blower installed in the master bedroom.

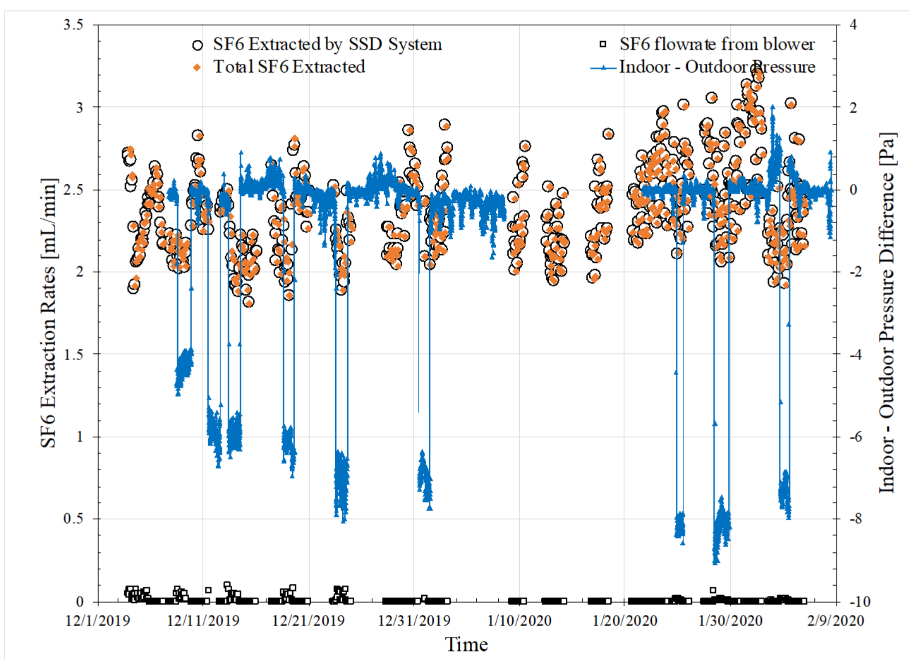


Figure 6.62. Indoor - Outdoor Pressure Differences and Amounts of SF6 Extracted by the SSD System and Blower in the House, Expressed as SF6 Flowrates, When the SSD System Was Operated at the 110 SCFM Extraction Rate.

For reference, a constant 3 SCCM SF_6 flowrate was delivered to the land drain lateral pipe during these tests.

These data collectively show the following when the SSD system was operated at the 110 SCFM extraction rate:

- Under undisturbed indoor - outdoor pressure conditions, the indoor – outdoor pressure differential was slightly positive (about 0.1 Pa) and all cross-slab pressure differences were positive, indicating vapor flow from the house into the soil as might be expected for SSD system operation. This is a condition that would inhibit vapor intrusion from the subsurface.
- Under increased negative indoor – outdoor pressure difference conditions ranging from -4 to -8 Pa, all of the cross-slab pressure differences remained positive indicating vapor flow from the house to the soil in all areas.
- Under undisturbed indoor - outdoor pressure conditions, SF_6 appeared to be entirely captured by the SSD system.
- Under increased negative indoor – outdoor pressure difference conditions ranging from -4 to -8 Pa, < 0.1 SCCM of the 3 SCCM of SF_6 injected in the land drain lateral pipe (<3%) was drawn into the house and the rest was captured by the SSD system. Thus, when operating at 110 SCFM, the SSD system protected the home from VI.

6.4.3 Conclusions from SSD System Testing at Sun Devil Manor

This was the first experimental study conducted to examine the effectiveness of a SSD system at a site with a known significant pipe flow pathway, with the SSD system operated in range of extraction flowrates calculated by the design approach developed in ESTCP Project ER-201322.

The results show that the SSD system extraction flowrate needed to be greater than that calculated via the ESTCP Project ER-201322 design guidelines to ensure a competent barrier against indoor impacts due to the pipe flow VI pathway. In this case a flowrate <27 SCFM was determined theoretically to be more than sufficient, yet extraction flowrates of 27 and 54 SCFM were observed experimentally not to be. For this house, an extraction flowrate of about 110 SCFM was required to ensure sustainable positive indoor – subsurface pressure differences and no flow of vapors to indoor air across the entire foundation.

6.5 TASK 5: COMPARISON OF THE VI ANALYSIS TOOLKIT AND THE CONVENTIONALREGULATORY APPROACH TO VAPOR INTRUSION PATHWAY ASSESSMENT

Most federal, state, and local regulatory guidance documents for assessing and mitigating the vapor intrusion pathway reflect USEPA's *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* (USEPA 2015). The paradigm outlined in that guidance includes: 1) a preliminary and mostly qualitative analysis that looks for site conditions that suggest that vapor intrusion might occur (e.g., the presence of vapor forming chemicals in proximity to buildings); 2) a multi-step and more detailed quantitative screening analysis that involves site-specific data collection and analyses that lead to identification of buildings requiring mitigation or continued monitoring; and 3) selection and design of mitigation systems, where needed. With respect to (2), regulatory guidance generally recommends consideration of "multiple lines of evidence" in decision-making, with the typical lines-of-evidence being groundwater, soil gas, sub-slab soil gas, and indoor air concentrations.

Of those, indoor air data are weighted most heavily and decision-making is rarely conducted without indoor air data, even though they are subject to significant uncertainty as the number of samples is typically small and concentrations will vary with time in some buildings. When conducting VI pathway assessments in neighborhoods where it is impractical to assess all buildings, USEPA recommends following a "worst first" investigation approach.

Criticisms of this approach, as practiced, are the following:

- Decisions are rarely made without indoor air data, and generally samples collected in different seasons are required, which delays decision-making.
- The collection of a robust indoor air data set that adequately characterizes indoor air concentrations could take years, given the typical frequency of data collection and the most common methods of sample collection (e.g., 24-h samples), therefore indoor air sampling might continue indefinitely at some sites.
- The "worst first" buildings might not be identified correctly by the logic outlined in USEPA's 2015 guidance, and the most impacted buildings might not even be located over a groundwater plume. Recent studies have shown significant VI impacts in homesas a result of sewer and other subsurface piping connections – which are not explicitly considered nor easily characterized through conventional VI pathway assessment.
- The presumptive remedy for VI mitigation (sub-slab depressurization) is not effective for all VI scenarios (e.g., not for those involving VI resulting from sewer connections).

The VI Analysis Toolkit components address the limitations above through the following:

- Guidance for characterizing vapor concentrations in sewers, land drains, and other subsurface piping, and estimating their potential impact to indoor air is included. Therefore, this important VI pathway is not overlooked, and the "worst-first" sites are more likely to be correctly identified and improper mitigation approaches are less likelyto be selected.
- Use of CPM tests offers a much quicker (<48 h) and more robust diagnostic tool for identifying VI impacts than random and prolonged seasonal indoor air grab sampling, as the results are insensitive to the test date and season.
- CPM tests results, in combination with analyses using external source strength screening data, can provide insight to the route by which vapors are reaching indoor air. This knowledge then ensures the proper selection and design of mitigation systems, if needed.
- Passive samplers will provide more useful time-integrated concentration data than typical 24-h indoor air samples for confirming decisions not to mitigate and to validate effectiveness of mitigation systems.

  It is important to note that the VI Toolkit components could easily be integrated into the conventional regulatory approach in the future, as they expand the options for the lines-of-evidence that are considered in decision-making.

Table 6.25 provides a comparison of the primary components used in VI pathway assessment in each of the two approaches discussed above.

Table 6.25. Comparison of Primary Lines-of-evidence for the Conventional and VI Diagnosis Toolkit Approaches to VI Pathway Assessment.

VI Pathway Assessment Components	Conventional Regulatory Approach (based on USEPA 2015)	VI Diagnosis Toolkit
Groundwater Concentrations	Yes	Yes
Soil Gas Concentrations	Yes	Yes
Sub-Slab Soil Gas Concentrations	Yes	Not needed
Indoor Air Concentrations	Yes (typically 24-h samples)	Yes (multi-week passive samplers)
Sewer and Other Connected Utility Vapor Concentrations	(no explicit guidance for collectionor use)	Yes
Video Surveys forSubsurface PipingConnections	No	Yes
Indoor SourceIdentification	Yes (through indoor air analysis)	Yes (through portable instruments and CPM Testing)
Risk-Based Concentration Screening Table Values	Yes	Yes
VI inclusion Zone Determination	Yes (based on groundwater and soil gas concentrations and lateral distance consideration)	Yes (based on groundwater, soil gas,and utility vapor concentrations and lateral distance)
Mathematical Modeling	Yes (limited as a line-of-evidence)	Inclusion Zone Determination andwith CPM Test Results for VI Pathway Identification
Controlled Pressure Method (CPM) Testing	No	Yes
Mitigation System Selection and Design	Sub-Slab Depressurization is the Presumptive Remedy	Yes Sub-Slab Depressurization is a presumptive remedy only if theSoil VI pathway is the only significant route to indoor air

7.0 COST ASSESSMENT

This ESTCP project did not involve the demonstration and cost-tracking of a specific technology. Instead, the focus was on demonstrating and validating the use of the VI Diagnosis Toolkit components to improve our ability to more accurately, cost-effectively, and confidently assess VI impacts to indoor air.

Costs for some of the VI Analysis Toolkit components are already well-understood in the industry (e.g., groundwater and soil gas sampling and analysis) and do not need to be addressed here. Four of the tools that were developed and demonstrated under this work, however, are new to vapor intrusion pathway assessment and so those are the emphasis of the cost analysis below.

7.1 COST DRIVERS

The primary cost drivers for use of the VI Assessment Toolkit were as follows:

- Labor costs: Labor costs are an underlying element associated with the implementationof all aspects of the toolkit, including any/all investigations and the design of the comprehensive VI conceptual model.
- Field costs: Field costs include, but are not limited to, drilling, well installation, groundwater and/or soil gas sampling, equipment/disposables, and analytical costs.
- Equipment: For CPM testing, the primary costs beyond labor would include blower-door equipment and sampling/analytical costs.
- Sampling and Analytical: Costs associated with passive sampler use would include passive sampler costs, labor costs associated with deployment/retrieval, and analytical.

7.2 COST ASSESSMENT

7.2.1 External vapor source strength screening in sewers, land drains, and other subsurface utilities

Sampling and analysis, consistent with the guidelines presented in this report, would incur the following costs for a neighborhood like the one used for the demonstration/validation in this work. It was roughly 3000 ft by 4000 ft (~1 km^2)in area and included about 780 homes. Within this area, there were about 270 manholes that were sampled on a seasonal basis. Cost estimates shown below in Table 7.1 are for a single sampling event.

Assumptions associated with the cost estimate include:

- The lung sampler used to collect vapor samples is owned. The cost estimate includes a 5% amortization per use.

Table 7.1. Estimated Sampling Costs for Manhole Sampling

Activity		Amount	Unit Cost	Total Cost
Equipment	Lung Sampler	1	$50	$50
Labor: Consultant	Prep	10 hr	$150/hr	$1,500
	Sampling	100 hr	$100/hr	$10,000
	Reporting	30 hr	$150/hr	$4,500
Analytical	Vapor Samples	270	$200/sample	$54,000
Miscellaneous	Consumables	-	-	$3,500
Total				$73,550

7.2.2 Video surveys of subsurface utility piping networks

In the Hill AFB OU-8 area, homes were built over a relatively shallow groundwater, so land-drains were installed to minimize damage from potential water intrusion in the sub-slab area. However, land-drains were not installed for every home constructed, and there was no record of land drain connections for neighborhood homes. In a situation like this, video surveys can provide insight into the connections. Video surveys of utilities such a land-drains, storm sewers, or sanitary sewers are a commercially available professional service. In addition, these services can provide videos of laterals off the main line leading to structures if such is deemed necessary.

In this demonstration project, videography was performed in land-drains along the equivalent length of 9 city blocks. The total on-site time required for the survey was 1.5 days. It is important to note that land-drain, storm sewer, or sanitary sewer videos require starts in multiplemanholes to enable access to the full length of the system. It is also valuable to have a knowledge of the system prior to investing in such work to minimize cost of the service.

Cost estimates for video surveys of the full neighborhood described above for manhole sampling is shown in Table 7.2. Estimates are based on a single utility (i.e. land-drain) for an approximate length of 42 city blocks within the area identified above.

Assumptions associated with the cost estimate include:

- $2500 per day for video service.
- hour field days video.
- 1 man crew for oversight, although oversight may not be needed for the duration.
- Minimal utility system interference that would prolong the time necessary for a video.

Table 7.2. Estimated Sampling Costs for Video Assessment of a Neighborhood

Activity		Amount	Unit Cost	Total Cost
Video Service	Daily videos	8	$2500	$20,000
Labor: Consultant	Preparation	10 hr	$150/hr	$1,500
	Oversight	80 hr	$100/hr	$8,000
	Reporting	30 hr	$150/hr	$4,500
Total				$34,000

7.2.3 Use of passive samplers

Passive samplers provide a less intrusive, efficient, and cost-effective way to accurately characterize long-term, time-averaged indoor air concentrations for up to three week deployments in indoor environments with temporally variable concentrations. In addition,results provide equivalent or better data than conventional sampling.

Since it is difficult to estimate how many samplers might be used in a single building deployment or with multiple deployments across a neighborhood, costs associated with passive sampler use will focus strictly on deployment, retrieval, and analytical cost on a per sample basis. This estimate does not reflect preparation time, travel time, or reporting time. The cost estimate for deployment, retrieval, and analysis of a single passive sampler is shown in Table 7.3.

Table 7.3. Cost Estimate for Deployment, Retrieval, and Analysis of a Single Passive Sampler

Activity		Amount	Unit Cost	Total Cost
Analytical		1	$200	$200
Labor: Consultant	Deployment	0.5 hr	$100/hr	$100
	Retrieval	0.5 hr		
Total				$300

Based on this per sample estimate, costs can be estimated as follows:

- for a single sample deployment in a residential setting - $300
- for a single sample deployment in 50 residential settings - $15,000
- for a 15 sample deployment in an industrial building - $3,000

7.2.4 Controlled pressure method (CPM) testing

Estimated costs for CPM testing will be dictated by the size and scope of the test. For example, industrial building tests could require more equipment and manpower than a residential house test. In addition, the scope of the test would also define cost: A test that includes only a negative pressure test will be less than one which includes both a negative and positive pressure test.

In addition, tests in which indoor air sources are identified during positive pressure testing would require removal of those sources and a complete CPM retest. Given that a single blower door unit and a two-person team could perform a residential-scale CPM test in two days, costs can be estimated as shown in Table 7.4.

Table 7.4. Estimated Sampling Costs for A Single Unit Residential Test

Activity		Amount	Unit Cost	Total Cost
Equipment	Blower Door Assembly	1	$500	$500
	Mixing Fans and Other	1	$50	$50
Labor: Consultant	Preparation	20 hr	$150/hr	$3,000
	On-site testing	40 hr	$100/hr	$4,000
	Reporting	30 hr	$150/hr	$4,500
Analytical	Vapor Samples	21	$200/sample	$4,200
Miscellaneous	Consumables	-	-	$1,000
Total				$17,250

Assumptions associated with the cost estimate include:

- Blower door equipment is owned. The cost estimate assumes a 5% amortization per use.
- Mixing fans and other support equipment are owned. The cost estimate assumes a 5% amortization per use.
- CPM test time at 10 hours per day. Assume 2-man crew for testing.
- No indoor air sources were found and no retesting was necessary.
- 10 rooms in house with location specific sampling for both negative and positive pressure testing
- No displacement of residents and associated room/board costs are considered.

8.0 IMPLEMENTATION ISSUES

The purpose of the study was to validate and demonstrate tools associated with the VI Diagnosis Toolkit. As indicated previously, the tools associated with the toolkit include the following:

- External VI Source Mass Flux Screening
- Indoor Air Source Screening
- Controlled Pressurization Method (CPM)
- Passive Samplers
- Comprehensive VI Conceptual Model

The approach, as it pertained to this project, was to:

1 Utilize the toolkit to assess potential vapor intrusion impacts within a neighborhood overlying a dilute chlorinated solvent plume;

2 To define parameters for Controlled Pressurization Method (CPM) testing and validate and demonstrate CPM testing to show that CPM tests would lead to the same/similar decision as standard air-quality testing at both the residential and industrial scale; and

3 To validate the use of passive samplers in indoor environments with temporally variable CVOS concentrations.

The toolkit incorporates fairly standard hardware and practices. For example, data needs for External VI Source Mass Flux Screening involve soils and/or groundwater data and vapor data from manholes, and CPM testing utilizes readily available blower door equipment from the Heating, Ventilation, Air Conditioning (HVAC) industry.

The VI Diagnosis Toolkit can be applied under current regulatory guidance and does not require any additional approvals, licenses, etc. beyond those normally associated with site investigations. No barriers to the collection of the necessary data are anticipated other than those presented by unique site conditions. For manhole sampling, however, it is recommended that manhole access approval is obtained from local governmental engineering departments and those entities are aware of sampling dates to avoid any issues with local law enforcement.

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APPENDIX A POINTS OF CONTACT

APPENDIX A: POINTS OF CONTACT

POINT OF CONTACT	ORGANIZATION	Phone / E-mail	Role in Project
Paul Dahlen	Arizona State University	480.727.2960 paul.dahlen@asu.edu	PI Investigator
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Yuanming Guo	Arizona State University	480.727.2916 yuanming.guo@asu.edu	Project Manager Investigator

APPENDIX B QA/QC

APPENDIX B. QAPP

B1.0 Purpose and Scope of Plan

This Quality Assurance Project Plan (QAPP) establishes the quality assurance guidelines to be utilized during this project. This QAPP has been developed to address the DoD requirements for precision, accuracy, representativeness, completeness, and comparability of data collected and generated during this demonstration. The QAPP also provides the quality assurance requirements for data handling, manipulation, and reporting. It has been designed to ensure the quality of the data gathered and generated, as well as the conclusions and recommendations reached from the use of the data.

B2.0 Quality Assurance Responsibilities

The project team will conduct indoor air, soil gas, groundwater, and possibly soil sampling and analyses in field environments, and analyses of the same in laboratory environments. The quality assurance activities incorporated in this project and described below will be used to maintain the accuracy and the precision of the system demonstration and the field analytical techniques. These activities include frequent equipment calibration checks, sample duplicate and replicate analyses, and sample blanks. The quality assurance activities are designed to trigger corrective action activities and diagnose potential sources of error.

Dr. Paul C. Johnson will be responsible for ensuring that the data collection activities conform to this QAPP. Dr. Johnson will be responsible for reviewing analytical data, identifying deviations from the established protocols and data quality objectives, and what corrections, if any, need to be made to the analytical procedures.

B3.0 Project Objectives

The objectives of this project are summarized in Table A.1 below. This QAPP focuses on the in-field data collection activities associated with the project.

B4.0 Experimental Measurements

The following section describes measurements to be made during this project.

B4.1 Depth-to-Groundwater Measurements

Depth to groundwater will be measured with a standard electronic interface probe (Solinst or similar). Typical devices are comprised of an electronic sensor attached to the end of a 50- to 200-ft measuring tape marked with 0.01-ft (or 0.001-m) increments. The electronic sensor will respond when it contacts water.

Table B.1. Project Objectives

Task	Performance Objective	Data Requirements
Task 1: External source and flux screening	Demonstrate that external screening methods identify at-risk neighborhood sub-areas and homes with potential for VI impact	Groundwater concentrations and vapor concentrations in land drains and sewers in OU-8 for four seasonal events, plus historical indoor air data set
Task 2: Controlled pressurization method (CPM) protocol validation and demonstration	Develop CPM protocol that is capable of determining if VI mitigation is needed and what type of mitigation system is appropriate	Indoor air concentrations, building exchange rates, and differential pressures under a range of CPM conditions (e.g., over-/under-pressurizations, active pipe flow VI, pre-existing soil gas clouds caused by indoor air sources); historical Sun Devil Manor data set
Task 3: Use of passive samplers under time-varying indoor air conditions	Demonstrate that passive samplers provide accurate results under conditions of large temporal variability over multi-week periods of time	Passive sampler results for 3-week sampling durations and indoor air sampling data
Task 4: VI Mitigation system performance under conditions with alternate vapor intrusion pathways	Assess if conventional VI mitigation systems are effective or inadvertently create adverse impacts under conditions with pipe flow and sewer VI	Indoor air and sub-slab soil gas concentrations, pressure differentials; building exchange rates
Task 5: Comparison of results to conventional MLE approach	Determine if Toolkit components are more practicable and lead to correct results	All data from Tasks 1 – 4 and historical ER-1686 data set

B4.2 Sample Collection Techniques

<u>Gas Sampling</u>
Gas sample collection techniques are briefly described below.

- Gas samples will be collected using one of the following techniques:
    - For real-time composite or discrete analyses, sample collection will utilize a vacuum pump, mass flow controller, and a gas sampling valve. Samples will be pulled directly on to sorbent tubes, TO-15 type traps, or into a sample loop.
    - For discrete analyses, samples will be collected in Tedlar bags using a lung sampler and a vacuum pump.
    - For continuous collection of thermal desorption sorbent tubes, sample collection will utilize a vacuum pump, mass flow controller, and an SRI gas sampling valve controlled by SRI software. Samples will be pulled directly on to the sorbent tubes through a Markes Difflok cap. Following a sampling run, tubes will be removed from the sampling valves and capped with Swagelok caps with Teflon

ferrules for sample preservation.

- For discrete sample collection using sorbent tubes, samples will be collected using a vacuum pump and mass flow controller. Samples will be collected directly onto the tube. Following the collection of samples on sorbent tubes, tubes will be capped with Swagelok caps with Teflon ferrules for sample preservation.

<u>Soil Gas:</u>
Soil gas sample collection techniques are briefly described below:

- Soil gas sampling will be facilitated with either temporary direct-push sampling locations or permanently installed soil gas sampling implants.
- Soil gas samples will be collected in Tedlar bags using a lung sampler and a vacuum pump or collected directly by analytical instrumentation for real-time analysis.
- Soil gas samples will be analyzed in the field or the lab for the same constituency as indicated for gas sampling.

<u>Water</u>
Water samples will be collected in a manner consistent with site conditions. For pumped samples, samples will be dispensed at a low flowrate directly and collected with zero-headspace in the appropriate sample containers as defined for the analyses of interest (usually 40 mL VOA vials). These samples will be maintained on ice and analyzed within 48-hours of collection. For laboratory analyses, samples will be preserved, maintained on ice, and shipped in a prioritized fashion (depending on holding times) to ASU for analyses. Sample containers, preservation, and holding times for analyses are shown in Table A.2.

All sample collection devices will be dedicated, single use disposable, or cleaned (decontaminated) prior to each use.

Table B.2. Sample Container, Preservation, and Holding Times for Chlorinated Hydrocarbon Water Analyses

Type of Analysis	Sample Container			Preservation	Holding Time
	Type	Volume	Cap Type		
Lab GC* - water	Glass	3 x 40 mL	Open with Teflon lined septum	Zero-headspace, HCl preserve, 4^{o}C	14 d

B4.3 Gas Sample Analysis

Discrete or real-time gas samples will be analyzed in the field using GC-ECD and/or GC-DELCD techniques for a standard analyte package of chlorinated compounds (e.g. TCE, DCE, DCA, TCA, PCE, VC).

Gas samples collected on sorbent tubes will be shipped to ASU for thermal desorption GCMS analysis. The analyte package will be similar to that used in the field.

Gas samples for SF_6 analysis will be collected in the same way as gas samples for chlorinated analysis (not suitable for collection on sorbent tubes). Gas samples will be analyzed using a gas chromatograph outfitted with a pulsed discharge detector (PDD). Methodologies and QA/QC for analysis is described in the main document above.

B4.4 Water Sample Analysis

Water samples will be shipped to ASU for analysis. Samples will be analyzed using a heated headspace technique and analyzed on the GC-DELCD. The analyte list for water samples will be the same as that for gas samples. Brief descriptions for water quality analyses are as follows:

Dissolved Chlorinated Compounds: Water samples will be collected with zero-headspace in a 40-mL VOA vial with a Teflon-lined septa type cap. Samples will be preserved with hydrochloric acid. Samples will be analyzed using a gas chromatography and a heated headspace method. The GC used will be an SRI Series 8610C or similar equipped with a FID, PID, and/or DELCD detectors. The GC will be calibrated to known dissolved concentrations of these analytes and the samples will be analyzed within the holding time specified. Methodology and QA/QC for analysis is described in the main document above.

B4.5 Sample Identification Procedures

Each sample will be labeled with a unique sample name/number coded to identify the sampling location and depth, the date and time of sample collection, and the initials of the sampler. This data, along with a brief sample description, will also be logged in the sampler's Field Book (see section 7.0 Documentation and Record Keeping) and onto a master field data sheet which is available for viewing by all site personnel.

Any samples shipped to an entity other than ASU will be logged on a chain-of-custody form, a copy of which will be sent with the samples to document sample receipt.

B5.0 Data Quality Parameters

Precision will be based on the relative percent difference (RPD) of duplicate analysis of samples. Accuracy will be determined by the percentage of analyte recovered (percent recovery [%R]) from a sample of known concentration. Laboratory QC will consist of analytical duplicates conducted for every 15 samples (1:15) submitted for analysis. One laboratory control sample will be included for every 20 samples (1:20) to ensure that the analytical equipment is operating properly. Laboratory controls will consist of standards of known concentrations. The calculation for each of these quantitative objectives is described in the following sections.

Accuracy: The percent accuracy is calculated from the general equation:

$$\% \text{Accuracy} = \frac{100\left(X - X_a\right)}{X_a} \quad \text{(A-1)}$$

where X is the parameter measured
X_a is the parameter's known value

The accuracy claimed by each field instrument manufacturer will be compared with the percent accuracy as measured from standard samples. If the percent accuracy is less than the required accuracy then corrective action will be initiated.

Precision: Precision for the field laboratory analytical procedures will be assessed by the analytical laboratory on an on-going basis. Dr. Johnson will review all analytical data to ensure that any questions concerning data validity are addressed at the earliest time possible.

Completeness: Percent completeness is defined by the general equation:

$$\% \text{Completeness} = 100\,\frac{D_o}{D_s} \quad \text{(A-2)}$$

where D_o = quantity of data obtained
D_s = quantity of data scheduled to be obtained

Completeness in meeting the scheduled data recovery objectives will increase throughout the project as the experience base in equipment operation characteristics increases. The completeness objective for operations during this study is 90% for each test parameter.

B6.0 Calibration Checks, Quality Control Checks, and Corrective Actions

Gas Chromatography

All GC-FID/DELCD/PDD analyses will be conducted on a dedicated SRI Instruments Model 8610C gas chromatograph using MXT or mol sieve or other suitable columns as appropriate for the analysis. The instrument will be calibrated each day (or as reasonable with ongoing calibration checks for continuous use) with at least three different concentrations spanning the concentration range of interest (e.g. 10, 100, 1000 µg/L for dissolved concentrations of chemicals of interest), and samples will be analyzed within the holding time specified. In addition, at least one calibration sample will be re-analyzed at a frequency of 1:20 samples to detect any instrument drift. If area counts from successive calibration analyses consistently deviate by more than 20%, or if retention times vary by more than 0.20 minutes, then the following routine checks are made to the equipment: a) leaking septum and b) change in gas flows. If those prove not to be the source of error, then a new standard is made and analyzed. If necessary, recalibration over the entire concentration range is repeated. Reporting levels will be established based on the calibration results.

Troubleshooting
The specific nature of all corrective actions and the operating limits that would trigger the need for corrective action for all aspects of analytical operations are too numerous to anticipate or list here. Most corrective actions will be empirical in nature as the following specific examples show:

Problem	**Corrective Action(s)**
Analysis of standard sample indicated analytical instrument accuracy has drifted outside established limits (calibration check every 20 samples).	· Perform replicate standard analysis. · Verify instrument parameters. · Inspect specific instrument operations. · Remake standards · Recalibrate instrument
Field meter(s) do not calibrate properly, or is providing suspect data.	· Replace or clean sensors. · Inspect meter/probe for damage. · Check battery. · Recalibrate and re-test.

B7.0 Documentation and Record-Keeping

B7.1 Quality Assurance Reports

A Field Book will be maintained by each field team member. Field books will contain a chronological record of all field work associated with the project and will be used to record all activities and relevant observations during the field sampling events. In addition, a file summary for each sampling event will be produced within 45 days of the sampling event. The format for that field summary is described below.

B7.2 Data Format

Field summaries will be produced for each field event. Given that there will be two field sites and the data collected from each may differ depending on site conditions, it is not possible to define a definitive data format at this point. However, the data presentation will include both tables and figures that, at a minimum, provide the following data:

- Sampling date
- Sampling time
- Location designation
- Position of sampling location
- Chlorinated solvent and petroleum hydrocarbon chemical concentrations
- Relevant notes for the collection and analysis of that sample

B7.3 Data Storage

All data and reports will be archived in both paper and electronic format. All electronic files will be backed-up on compact disks (CDs) at one-month intervals (minimum). All paper files (e.g., field log books) will be copied and archived in a project-specific file.

APPENDIX C UTILITY SURVEY RESULTS

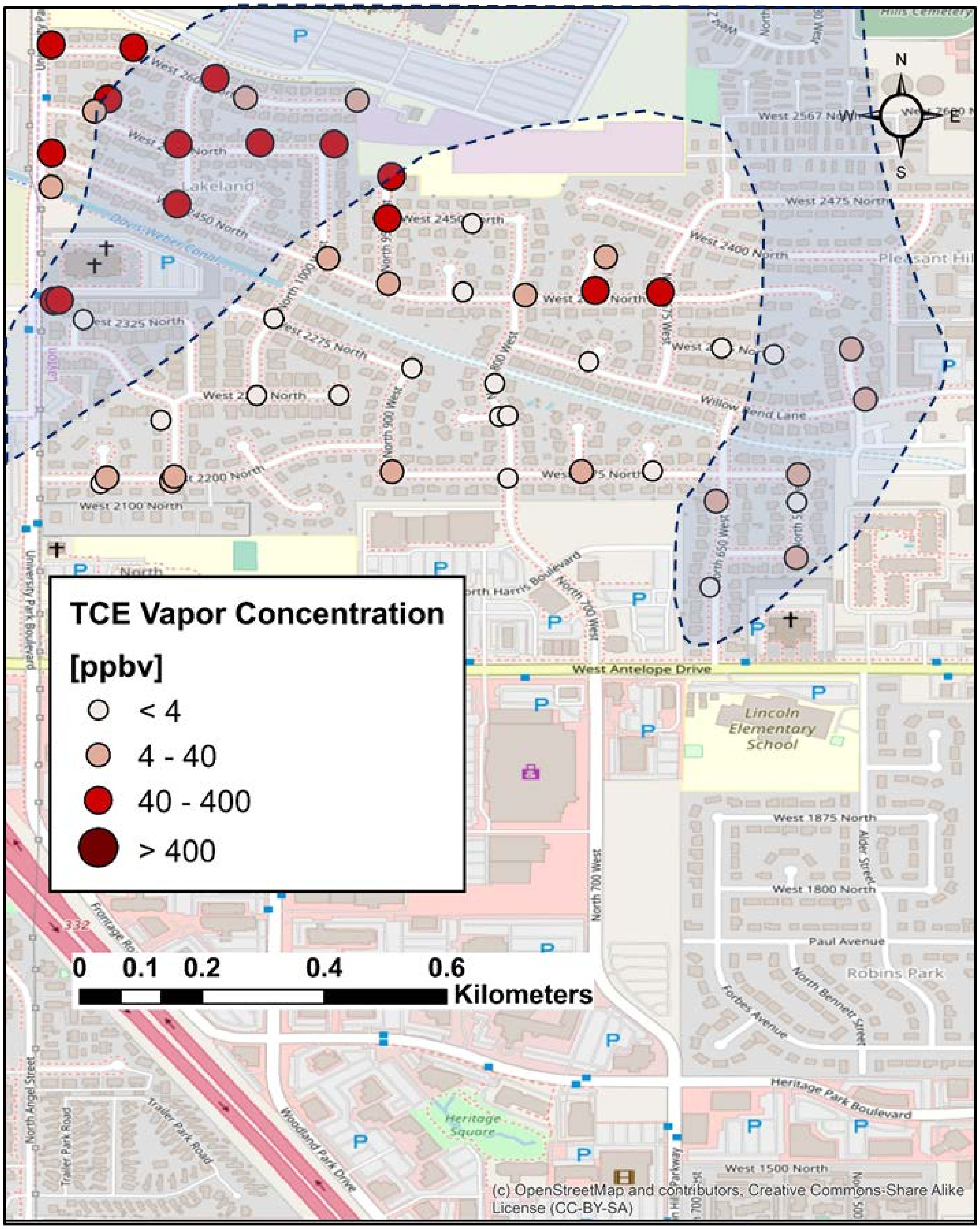

Figure E1. TCE concentrations in vapor samples collected from manhole headspace sampled during the January 2016 synoptic surveys, categorized relative to a 0.4 ppbv indoor air screening level. The shaded area indicates the extent of the TCE groundwater plume.

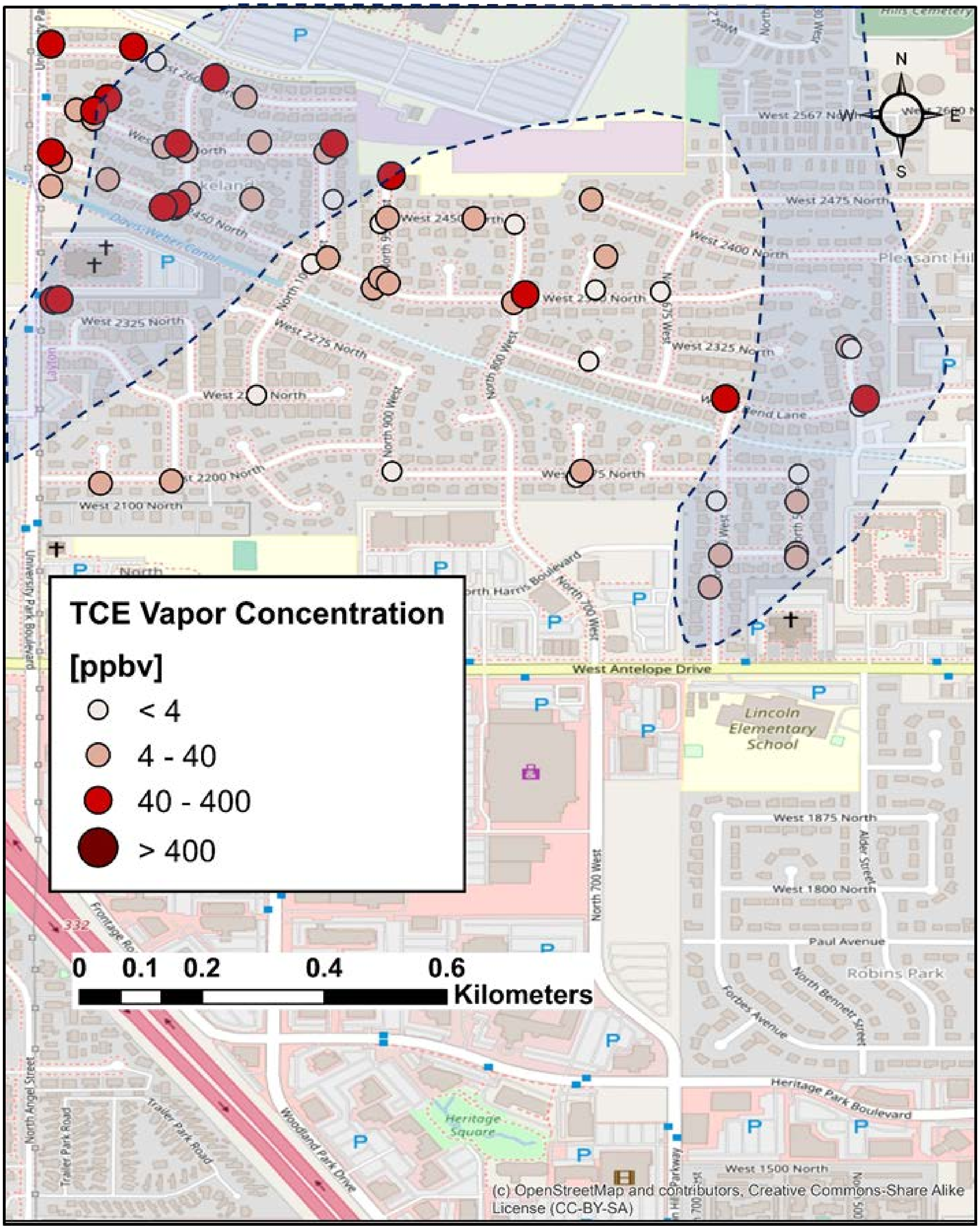

Figure E2. TCE concentrations in vapor samples collected from manhole headspace sampled during the May 2016 synoptic surveys, categorized relative to a 0.4 ppbv indoor air screening level. The shaded area indicates the extent of the TCE groundwater plume.

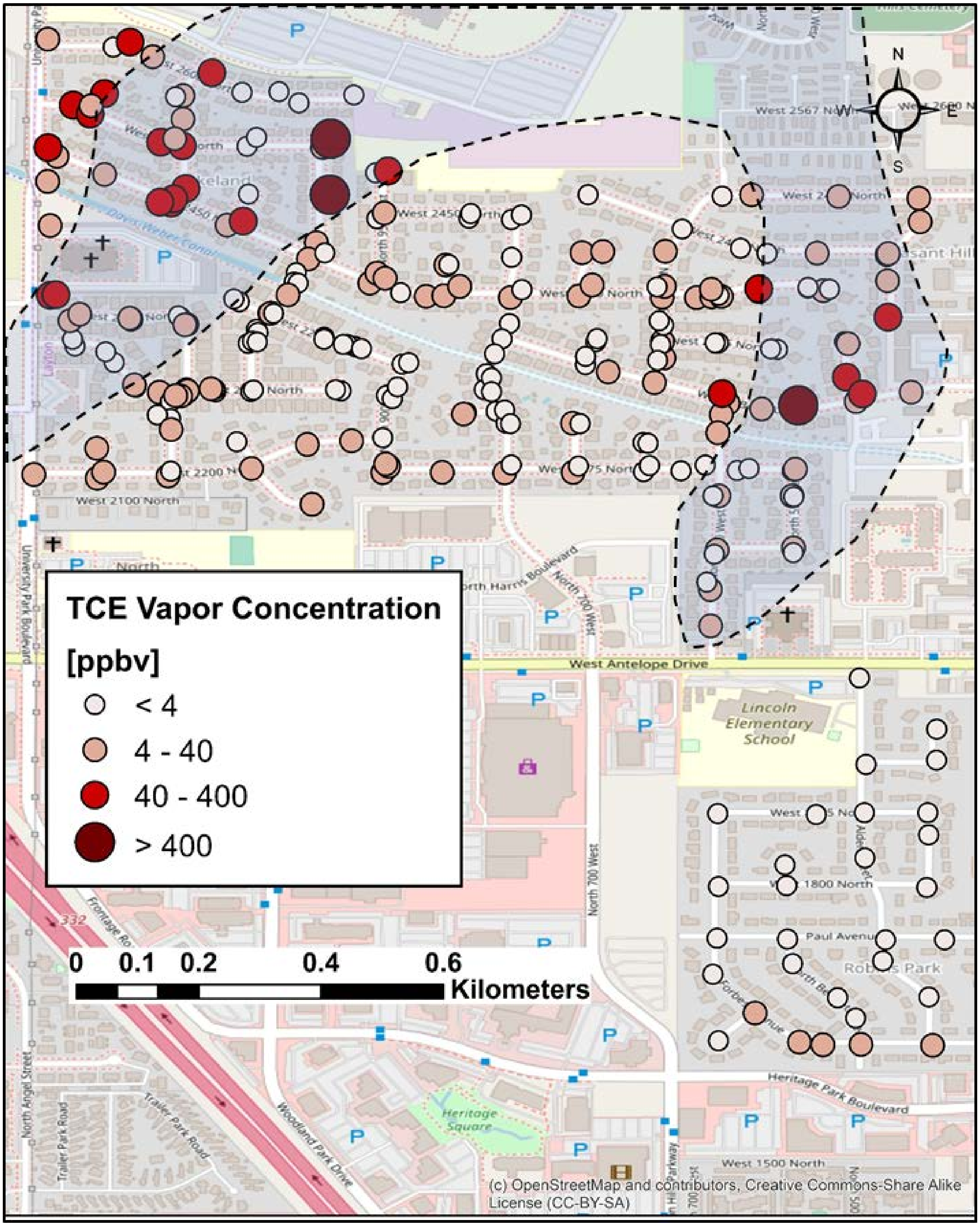

Figure E3. TCE concentrations in vapor samples collected from manhole headspace sampled during the August 2016 synoptic surveys, categorized relative to a 0.4 ppbv indoor air screening level. The shaded area indicates the extent of the TCE groundwater plume.

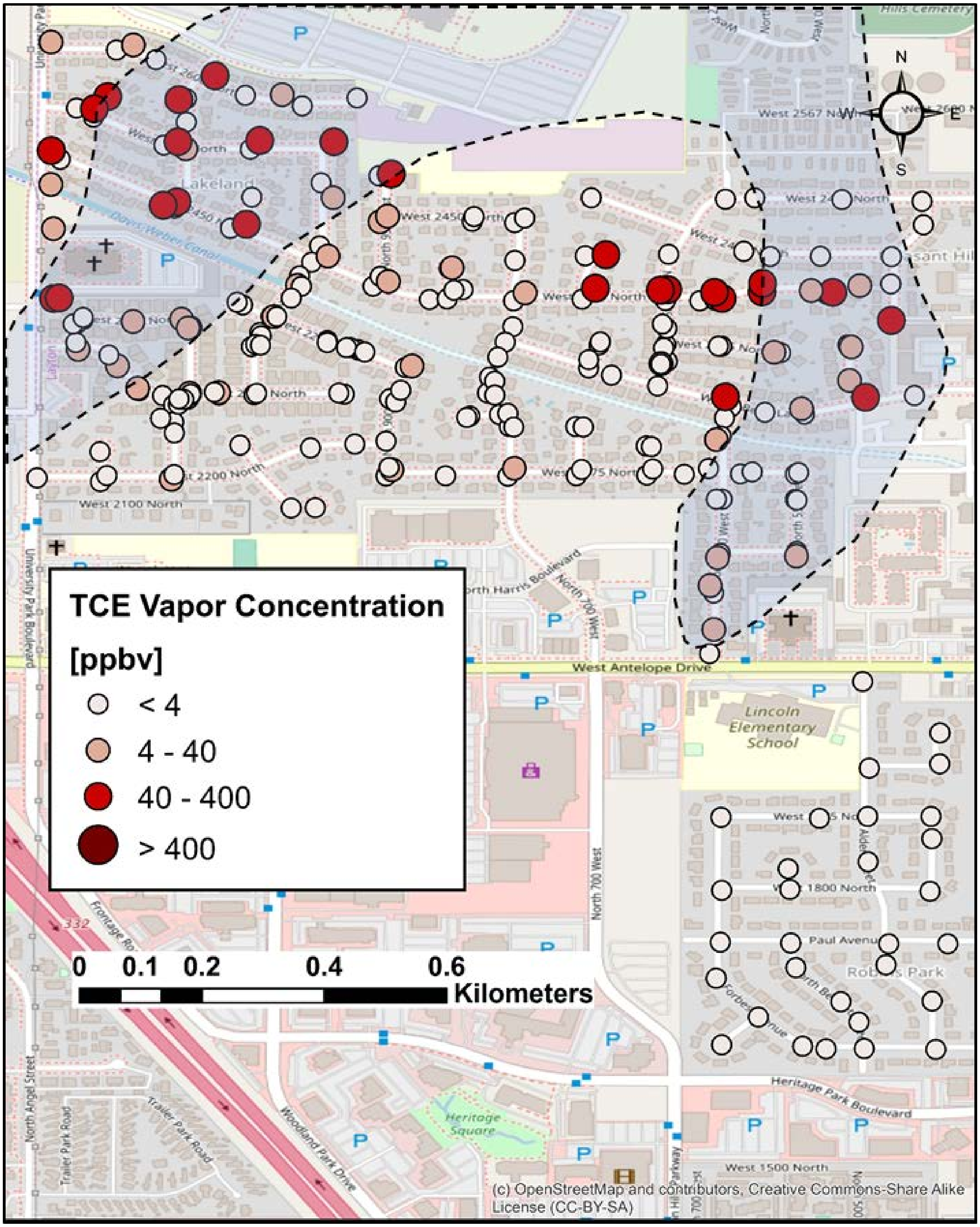

Figure E4. TCE concentrations in vapor samples collected from manhole headspace sampled during the December 2016 synoptic surveys, categorized relative to a 0.4 ppbv indoor air screening level. The shaded area indicates the extent of the TCE groundwater plume.

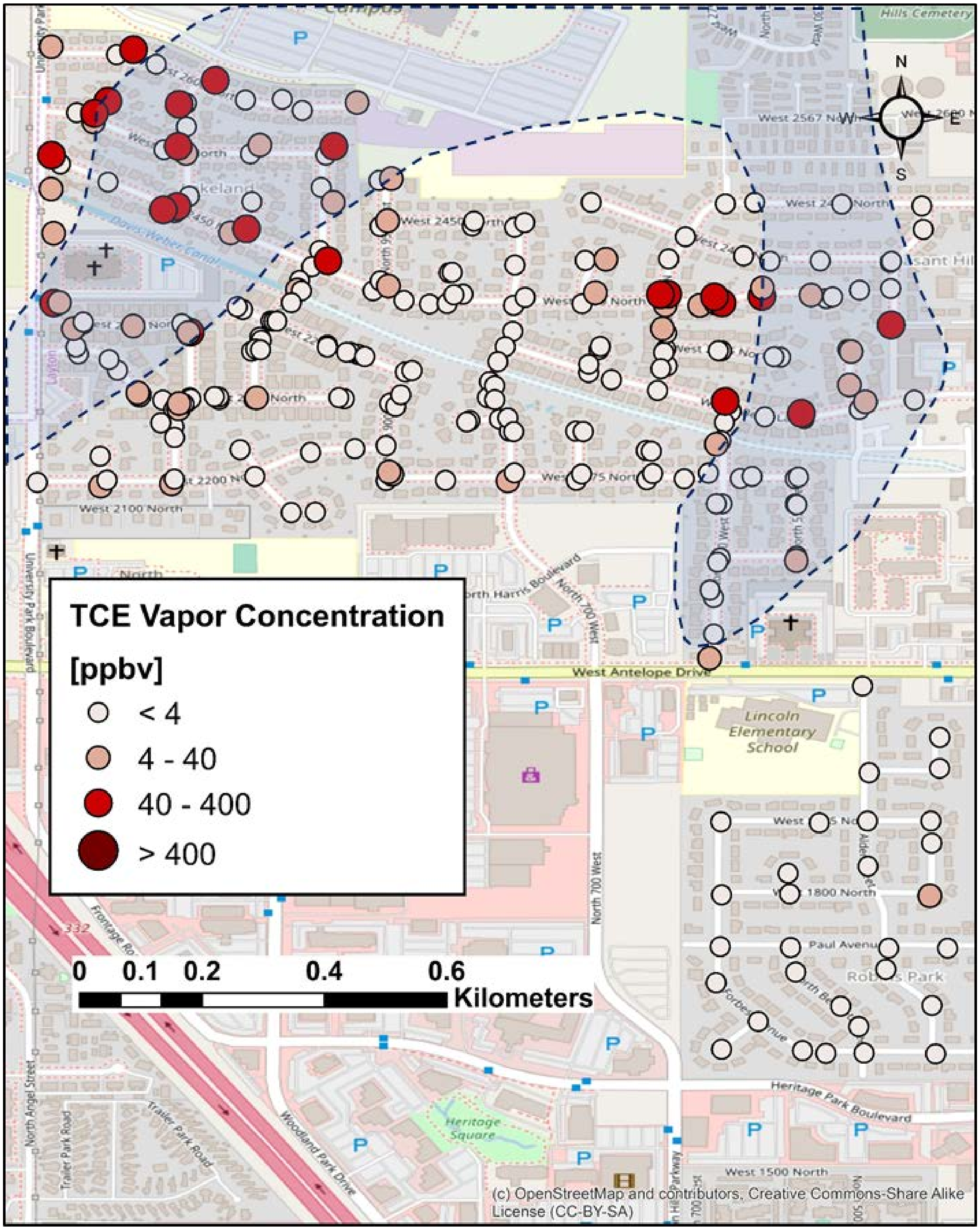

Figure E5. TCE concentrations in vapor samples collected from manhole headspace sampled during the April 2017 synoptic surveys, categorized relative to a 0.4 ppbv indoor air screening level. The shaded area indicates the extent of the TCE groundwater plume.

APPENDIX D CONSTANT PRESSURE METHOD (CPM) STANDARD OPERATING PROCEDURE

APPENDIX D. USE OF CONTROLLED PRESSURE METHOD (CPM) TESTING FOR VAPOR INTRUSION (VI) PATHWAY ASSESSMENT – CPM TEST GUIDELINES

Use of Controlled Pressure Method (CPM) Testing For Vapor Intrusion (VI) Pathway Assessment

CPM Test Guidelines

ESTCP Project ER-201501

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Colorado School of Mines and Arizona State University

October 2020

Use of Controlled Pressure Method (CPM) Testing For Vapor Intrusion (VI) Pathway Assessment

Purpose

This document provides background information and recommendations for practitioners who are planning to use controlled pressure method (CPM) tests for vapor intrusion (VI) pathway assessment.

Background – Why Conduct a CPM Test?

CPM testing is a building-specific diagnostic tool for vapor intrusion pathway assessment. CPM testing can be used to rapidly determine if VI is or is not of concern in a building that has been identified as having the potential for adverse VI impacts because of its proximity to subsurface contamination in soils, groundwater, or utilities. CPM testing can be used for both residential and industrial buildings. This is a concept that has been used for many years for radon intrusion testing (e.g., Froňka et al. 2005, Ringer et al. 2005, Collignan et al. 2012, 2014).

CPM testing is attractive relative to other building-specific VI pathway test options (e.g., sub-slab soil gas sampling, prolonged indoor air monitoring, etc.) because one to two days of CPM testing can provide:

- a measure of the maximum indoor air concentration that might occur due to vapor intrusion at any future time under natural conditions,
- an answer to the question as to whether or not a measured indoor air impact is actually the result of VI or instead caused by indoor vapor sources, and
- determination of the VI pathways, if any, that are significant contributors to indoor air impacts.

CPM testing is much quicker and more definitive than relying on multi-season, indoor air grab sampling for VI pathway assessment. Research studies at a well-instrumented house showed that, unlike indoor air concentrations that varied significantly daily and seasonally under natural conditions, CPM test results were relatively constant and not dependent on weather or the day or season of application (Holton et al. 2013, 2015). That is why a single one- to two-day CPM test is generally sufficient for VI pathway assessment purposes.

After conducting a CPM test, it might be decided: a) that VI does not pose a significant risk to the building occupants health and no further testing is required, b) that additional indoor air monitoring is necessary, for example using multi-week passive samplers, or c) mitigation is necessary. In the case of the latter, CPM test data are valuable to mitigation system design.

VI Pathway Conceptualization and CPM Test Overview

Before conducting CPM tests and interpreting the data, it is important to understand how VI is conceptualized, and to recognize that VI behavior and indoor air impacts can be dependent on building-specific features that are not usually known, but might be revealed through CPM test data analysis.

With respect VI pathway conceptualization, chemical vapors can move from subsurface sources, travel through the soil matrix and eventually enter an overlying or adjacent building via foundation cracks or other means. VI can also result from vapor transport through subsurface piping networks, either directly to indoor air or to the sub-slab soil region and then through the foundation. These VI pathways were named the “soil VI”, “sewer VI”, and “pipe flow” VI pathways by Guo et al. (2015), and are depicted conceptually in Figure 1.

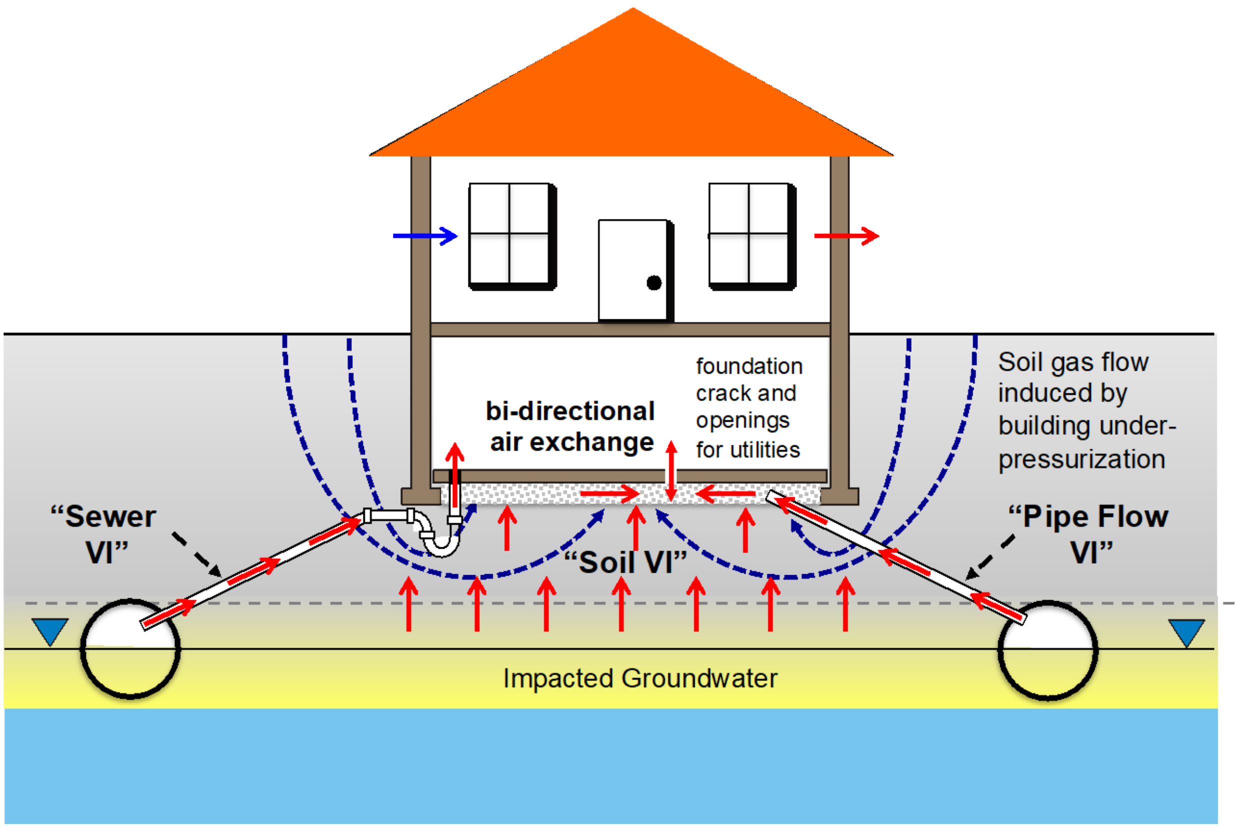

Figure 1. Conceptualization of possible vapor intrusion pathways (Guo et al. 2015).

Under natural conditions, indoor-outdoor pressure differences occur due to wind, indoor-outdoor temperature differences, building ventilation system operation, and other environmental and building use factors. When its indoor pressure is less than the local atmospheric pressure, a building is said to be “under-pressurized” and that condition will cause outdoor air and soil gas to be drawn into it. When its indoor pressure is greater than the local atmospheric pressure, a building is said to be “over-pressurized” and that condition will cause indoor air to flow to the atmosphere and down into the soil gas or a sub-floor crawl space area. The extent to which a building is under- or over-pressurized varies with time; indoor-outdoor and indoor-sub-slab pressure difference measurements under natural conditions typically show rapid (seconds) short-term pressure difference fluctuations about long-term daily and seasonally changing averages. It is that time-dependent pressure difference dynamic that causes VI impacts to vary significantly with time in some buildings.

CPM tests overcome this natural variability in pressure differences by creating a constant indoor-outdoor pressure difference through use of an exhaust fan mounted in a door or window as shown conceptually in Figure 2.

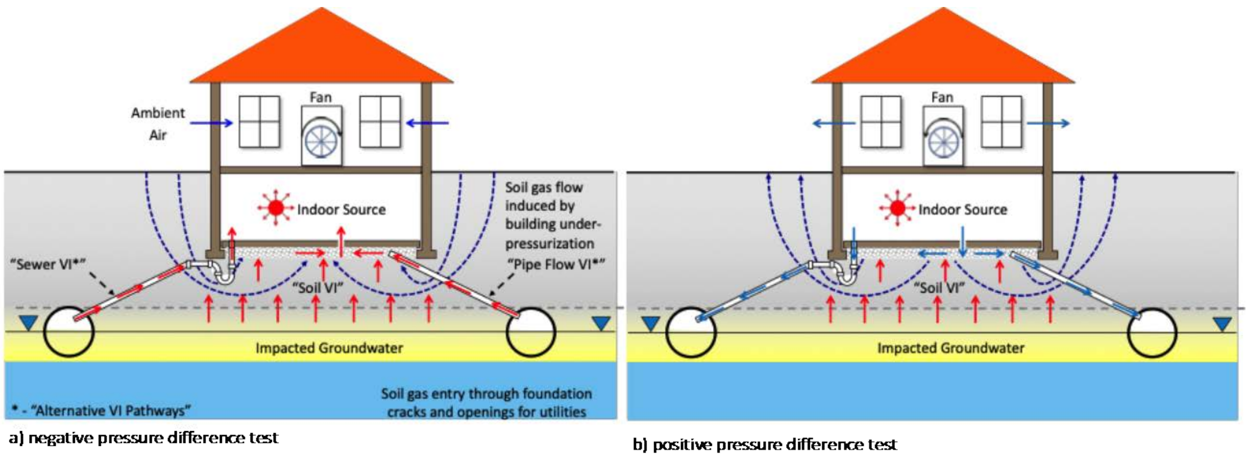

Figure 2. CPM test schematic: a) negative pressure difference test and b) positive pressure difference test (after Guo et al. 2020).

A "negative pressure difference" CPM test (Figure 1a) induces soil gas and subsurface vapor movement toward the building, similar to what happens when natural conditions (e.g., wind, indoor-outdoor temperature difference) create an under-pressurized building condition. The "positive pressure difference" CPM test, shown in Figure 2b, suppresses vapor entry. By conducting both negative pressure difference and positive pressure difference tests, one can directly measure worst-case VI impacts and identify the contributions, if any, from indoor air sources.

Use of CPM Testing for Building-Specific VI Pathway Assessment

Figure 3 presents the high-level logic and recommended sequence of activities and decisions associated with CPM test application and data analysis. The logic requires little explanation, but a few components deserve some discussion.

First, with respect to decision-making components in this figure, selecting chemical-specific levels of concern is a key and often a negotiated step involving input from regulators, stakeholders, and responsible parties. In addition to reviewing local and regional risk-based screening levels, and ensuring that the selected levels of concern are not less than ambient background concentrations, it is also important to consider the fact that CPM tests represent short-term worst-case conditions. For example, at the study house mentioned above, indoor air concentrations during CPM testing were similar to the maximum hourly and daily indoor air concentrations observed under natural conditions over a multi-year period of time, and they were also more than an order-of-magnitude greater than the long-term average indoor air concentration observed under natural conditions.

Second, while the figure shows evaluation of negative pressure difference CPM test results before proceeding, if necessary, to positive pressure difference testing – practical considerations might dictate conducting a positive pressure difference test before knowing the negative pressure test results, especially if vapor samples are sent for analysis to remote laboratories with multi-week delays in obtaining the results. This consideration illustrates the value of employing a mobile analytical lab or mobile analytical equipment for air sample analysis during CPM testing.

Finally, use of CPM test data with other site data to determine active VI pathways before deciding to proceed with mitigation and/or continued indoor air monitoring is discussed below after presentation of the recommended CPM test design guidelines.

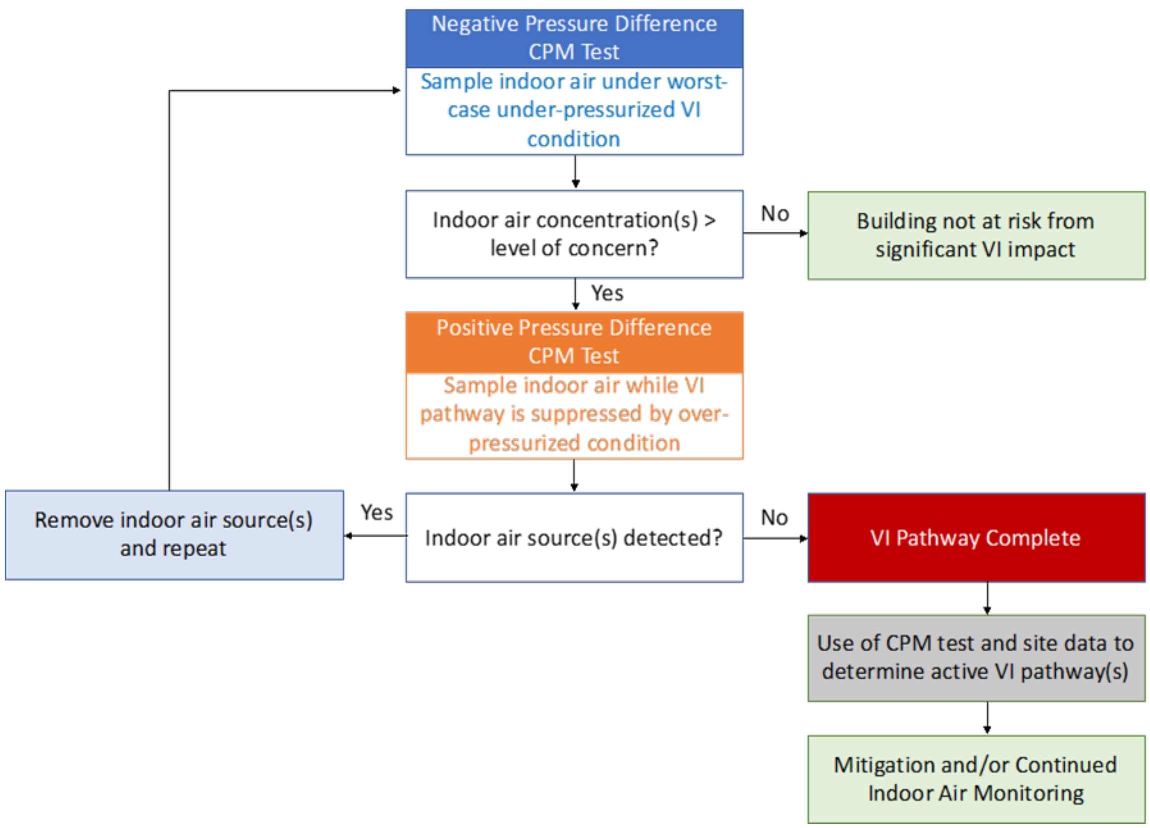

Figure 3. Logic associated with CPM test application and decision-making.

Recommended CPM Test Design Guidelines

Guo et al. (2020) conducted a systematic study of CPM test design specifics in a well-instrumented house, looking at factors such as blower door placement, blower flowrates, indoor air mixing, and CPM test duration. From that they developed proposed CPM test guidelines for both negative and positive pressure difference CPM tests, and then demonstrated their application at residential and industrial buildings (ESTCP ER201501 Final Report, 2020). Those guidelines are presented below in Tables 1 and 2.

Appendix A provides practical step-by-step guidelines for conducting CPM tests.

Key Equipment Selection

Key equipment for CPM tests include blower doors, differential pressure transducers, fans, and air samplers. A few comments on these are included below:

<u>Blower door panels:</u> A commercial "blower door panel", such as those used for HVAC leak testing, is recommended for CPM testing. These usually have an adjustable rigid frame covered with air-impermeable cloth, or rigid panels that can be sized to fit tightly in an open doorway. The panel also has an elasticized cutout(s) to hold one or more blowers (typically brand specific).

Blower capacity needs to be sized to manage a minimum cross-envelope differential pressure of 10 Pa and >9 building volumes of flow within an 8-hour period. A single commercial blower door panel is generally sufficient for a typical residential house and two or more blower panels are needed for industrial buildings.

<u>Pressure monitoring equipment</u>: Real-time differential pressure monitoring with a minimum resolution of 1 Pa is necessary for CPM testing. Commercial HVAC leak testing blower door panels often include a control module that measures and controls fan speed and indoor-outdoor pressure difference. If not using a commercial blower door unit, a real-time differential pressure monitoring instrument is needed.

<u>Air mixing fans</u>: Vertically pivoting, industrial type fans – usually available from the hardware store are required for air mixing in front of the blower intake and in rooms to be sampled. Depending on room size, multiple fans may be necessary.

<u>Air sampling equipment</u>: Air samplers such as Summa canisters and sorbent tubes for remote laboratory analysis, and/or syringes or Tedlar bags for on-site analysis are needed.

Photos of a typical CPM test blower door test set-up are presented in Figure 4.

Table 1. Test design guidelines for negative pressure difference CPM tests (Guo et al. 2020).

Negative Pressure Difference CPM Tests	
Exhaust Fan Location	Install fan in any convenient location as results appear to be unaffected by placement. Position it to exhaust air from the house. See also ASTM E779 and ISO 9972 for pressure monitoring and blower installation guidance.
Exhaust Fan Operating Conditions	Adjust the exhaust fan flowrate to achieve a consistent negative indoor – outdoor pressure difference in the range -10 Pa to -15 Pa during the test. Increasing the fan flowrate will decrease the test duration.
Test Duration	Conduct negative pressure difference CPM tests for at least 9 air exchanges before indoor air sampling; this will require a time = 9 x Building Volume/Fan Flowrate.
Operating Conditions Monitoring	The following capabilities are commonly instrumented on commercially available blower door setups: • Indoor – outdoor pressure difference measured relative to a composite reference point that connects open-ended tubing running from all exterior sides of the building. • Exhaust fan flowrate (flow-calibrated equipment is preferred; tracer testing is an alternative option for flowrate measures).
Air Sample Collection (after 9 air exchanges)	USEPA guidance (2015) for sample collection procedures and specific sampling techniques should be reviewed. The following sampling locations are recommended in the order of priority: • One or more samples collected near the fan intake with active floor-fan mixing near the fan intake (essential). • One or more ambient air samples (essential) • One or more samples collected from each room with active floor-fan mixing in each room during sample collection. These samples are optional, but very valuable if significant indoor air impacts are detected in the negative pressure difference CPM test.
Data Evaluation	Concentrations in vapor samples collected near the fan intake are expected to be representative of maximum short-term indoor air concentrations under natural conditions. They are also expected to be greater than long-term average indoor air concentrations under natural conditions. If the observed concentrations are greater than levels of concern and greater than ambient air concentrations, it is important to note that this could be the result of VI, indoor sources, or a combination of the two. Positive pressure difference testing will differentiate between the two. In-room sampling results may provide valuable insight to VI entry and indoor source release points.
Other	Negative pressure difference test results, when converted to emission rates can be used to assess if alternate VI pathways might be contributing to significant indoor air impacts as discussed in Guo et al. (2015).

Table 2. Test design guidelines for positive pressure difference CPM tests (Guo et al. 2020).

Positive Pressure Difference CPM Tests (only conducted if impact of significance is detected by a negative pressure difference test)	
Exhaust Fan Location	Install fan in any convenient location as results appear to be unaffected by placement. Position it to blow ambient air into the house.
Exhaust Fan Operating Conditions	Adjust the exhaust fan flowrate to achieve an indoor – outdoor pressure difference in the range +10 Pa to +15 Pa to insure a consistent positive cross-foundation pressure difference during the test. Increasing the fan flowrate will decrease the test duration.
Test Duration	Conduct positive pressure difference CPM tests for at least 4 air exchanges before indoor air sampling; this will require a time = 4 x Building Volume/Fan Flowrate.
Operating Conditions Monitoring	The following are commonly instrumented on commercially available blower door setups: • Indoor – outdoor pressure difference measured relative to a composite reference point that connects open-ended tubing running from all exterior sides of the building. • Fan flowrate.
Air Sample Collection (after 9 air exchanges)	USEPA guidance for sample collection procedures and specific sampling techniques should be reviewed. The following sampling locations are essential: • One or more ambient air samples • One or more samples collected from each room with active floor-fan mixing in each room during sample collection.
Data Evaluation	Positive pressure difference tests will eliminate subsurface VI impacts; therefore, if indoor air concentrations are greater than levels of concern and greater than ambient air concentrations, this indicates significant contributions from one or more indoor sources. In-room sampling results will indicate the locations of indoor source releases. If room-specific results were collected during the negative pressure difference test, these should be compared with positive pressure difference test results. Minimal changes in concentrations between the two in rooms with concentrations of concern will suggest the presence of indoor sources in those rooms.

Figure 4. Photos from an industrial multi-blower and residential single blower door CPM test deployment.

Use of CPM Test Data with Other Site Data to Identify Active VI Pathways

Should CPM testing reveal potential VI impacts of significance, it will be necessary to decide if mitigation and/or continued indoor air monitoring is needed. Critical to that decision is development of the best possible VI site conceptual model, as some mitigation approaches are effective for certain VI pathways but not others. For example, the typical presumptive VI remedy – a sub-slab depressurization system – can protect against soil VI pathway impacts, but not sewer VI pathway impacts.

Guo et al. (2015) illustrate the use of site and CPM test data from a study house where an unknown pipe flow VI pathway was detected through data analysis and later confirmed by excavation near the house. Their analysis followed this sequence of steps:

a) Calculation of the measured chemical vapor emission rate, $E_{measured}$ [mg/d], from the house during the negative pressure difference CPM test:

$$E_{measured} = C_I \times Q_{blower} \times 1440 \text{ min/d}$$

where C_I [mg/m^3] is the indoor air concentration measured at the blower intake and Q_{blower} is the blower flowrate [m^3/min], both measured toward the end of the negative pressure difference CPM test (after 9 building exchange volumes per Table 1).

b) Estimation of the chemical vapor emission rate associated with the soil VI pathway only, using the USEPA spreadsheet implementation of the Johnson and Ettinger model:

$$E_{estimated} = C_{I,estimated} \times V_B \times E_B$$

where $C_{I,estimated}$ [mg/m^3] is the indoor air concentration estimated in the USEPA spreadsheet, and V_B and E_B are the building volume [m^3] and indoor air exchange rate [1/day], both input to the USEPA spreadsheet implementation of the Johnson and Ettinger model.

c) Comparison of $E_{measured}$ and $E_{estimated}$. When $E_{measured} >> E_{estimated}$, this is an indication of the presence of a significant VI pathway other than the soil VI pathway, or poor site characterization data.

d) Differentiating between pipe flow and sewer VI pathways, if suspected of being present, requires additional testing – the most straight-forward is conducting a CPM negative pressure test while also implementing sub-slab depressurization (SSD). If impacts detected during CPM testing alone continue during a dual CPM+SSD test, this is an indication that the dominant VI pathway is via sewer VI. If impacts detected during CPM testing alone are reduced during a dual CPM+SSD test, this is an indication that the dominant VI pathway is pipe flow VI.

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Appendix A. Practical Considerations for Conducting CPM Tests

Safety

Proper safety precautions should be observed when conducting CPM testing. At least two personnel are recommended for CPM testing.

Time Planning for CPM Testing

Assume one full day for negative pressure testing and another day for positive pressure testing. Negative pressure testing is the most time intensive aspect of CPM testing as it requires 9 building volumes of air flow (see Table 1). For typical blower exhaust flowrates necessary to achieve the minimum pressure of -10 Pa, a full day is necessary. Increasing the blower flowrate during negative pressure testing is a viable option to ensure the test can be performed in a single day.

Presence of Building Occupants During CPM Testing

Negative pressure testing is designed to draw contaminants into the test structure. As such, contaminant exposure is a risk if building occupants are present. Usually building occupants are not present during CPM testing.

Pre-Test Activities

Pre-test communication with homeowners or building managers/occupants should occur. A discussion with the homeowner, building manager, and/or occupants should include following topics:

- CPM basics and activities to be conducted by testing personal,
- Building specifics including building size, ventilation networks, HVAC system operation, etc.,

Activity restrictions for any occupants present during the test, such as creating unintentional building openings. With respect to building entrance and egress, occupants should be asked to refrain from entrance/egress during the test, and if it is necessary, to make transitions as quickly as possible and to leave doors in the position they were found (closed or ajar).

- A review of possible indoor air sources should be conducted with the homeowner, building manager, and/or occupants. If any are identified, those should removed prior to testing.

Ensure that power is available for each blower door installation. Also, it is good to power each blower door on separate circuits: Blowers and associated equipment may require up to 15 amps per unit, and in some cases, 20 amps.

Ensure that all doors inside the structure (including closet doors to closets, pantries, storerooms, etc.) are open to ensure effective airflow throughout the structure.

Survey the structure to identify any large vents or exhaust equipment that might affect building pressurization. Seal or close-off any vents or exhaust equipment identified.
Turn off HVAC system.

Turn off the vapor recovery system (radon and/or hydrocarbon mitigation system), if one exists.

Blower Door, Blower, and Pressure Monitoring Installation

Identify blower door installation location(s). A suitable exterior opening through the building envelope is needed (e.g. door or window) for blower door installation. The opening should be in an area “connected” with the rest of the structure via open doorways. Note that a doorway into an enclosed garage is not a suitable location for blower door installation since the garage is “connected” to the rest of the structure and would not allow ventilation to the atmosphere.

Choose a location in which the blower intake and exhaust is unimpeded both inside and outside the structure. Weather protection should also be considered.

Install the blower door into the selected building opening as per manufacturer’s instructions. For negative pressure testing, install the blower/fan to blow indoor air out of the structure. For positive pressure testing, install the blower/fan to blow outdoor air into the structure.

Install cross-building envelope differential pressure monitoring reference points. The indoor pressure monitoring point should be at least 3m (10 ft) away from and out of the direct path of the blower exhaust. If the structure is open throughout its interior as is required for CPM testing, only a single indoor reference point is necessary.

The outdoor pressure-monitoring point should be at least 3 m (10 ft) away from and out of the direct path of the blower exhaust. A composite outdoor reference (composite pressure reference with monitoring from multiple sides/aspects of the building) is recommended as it effectively reduces the variability associated with wind loading or short-term gusts of wind. Pressure monitoring should avoid areas of air turbulence including building corners, alcoves, or near the eves or roofline.

Ambient (Outdoor) Air Sample Collection

Ambient (outdoor) air sample(s) should be collected outside the building envelope prior to and during CPM testing. Individual grab samples from two or more locations or a spatial composite air sample from the perimeter of the structure are recommended.

Controlled Building Pressure Testing Steps

Negative Pressure Difference Testing:

1. Estimate the interior volume of the structure to be tested ($V_{building}$).

2. Initiate blower/fan operation and set the speed to obtain a minimum cross-envelope pressure differential of approximately -10 Pa and a flowrate capable of achieving >9 building volumes within the allotted test time.

3. Measure the blower flowrate (Q_{blower}) and determine the minimum period of operation ($T_{ss,neg}$) to achieve steady conditions. $T_{ss,neg}$ is defined as the time to reach 9 air exchanges ($T_{ss,neg} = 9 \times V_{building}/Q_{blower}$).

4. CPM testing start time is defined as the time that cross-envelope pressure differential stabilizes (less than 20% pressure fluctuation).

5. Continue blower operation until $T_{ss,neg}$ is reached, or on-site analytical results indicate concentration equilibrium has achieved if on-site analytical is applied.

6. Survey the building after startup and periodically during the CPM test to ensure all doors are positioned in the manner intended. Frequently doors will open/close as a result of blower operation and occupants may open/close doors and neglect to reposition them as needed for the test. Rapid changes in indoor-outdoor building pressure are sometimes an indication of the opening/closing of doors and windows.

7. Install an air sampler approximately 30 cm (1 ft) from intake face of the blower such that it is centered both vertically and horizontally in front of the blower intake.

8. Install air mixing fans in the same room as the blower and orient fans to optimize air mixing within that room and near the blower intake. Air mixing fans are necessary to minimize spatial variability and to ensure an accurate assessment of air concentration.

9. If on-site analytical is utilized, collect samples periodically (i.e. at each building air exchange) from in front of the blower intake to verify that steady conditions are achieved.

10. If on-site analytical is not applicable, air samples should be collected from in front of the blower intake after $T_{ss,neg}$ is reached. Collect a sample(s) and label with pertinent information. More than one sample would be helpful for quality assurance purposes. Consider collecting three samples after 8, 9, and 10 exchange volumes.

If samples are to be collected from individual rooms to help identify VI entry points and indoor vapor sources, those should be collected after $T_{ss,neg}$ is reached.

Positive Pressure Difference Testing:

1. Install the blower/fan in the same location as for the negative pressure difference test, but with the fan reversed so that it blows ambient air into the structure.

2. Initiate blower/fan operation and set the speed to obtain a minimum cross-envelope pressure differential of approximately +10 Pa and a flowrate capable of achieving >4 building volumes within the allotted test time.

3. At least one grab sample should be collected in each room/common area of the test building. Prior to sample collection, close the door(s) to the room and mix the air for at least 1 minute, and maintain fan operation during sample collection.

4. During the sampling process, mix and sample each room discretely. Do not mix more than one room at a time as this will confound interpretation if contaminant is detected.

5. When sampling a room is complete, turn-off the mixing fan in that room before opening the door and moving to the next room.

6. Label all samples and send to lab for analysis. The label should include necessary information including sampling time and location.

Post-Test Procedures

Post-test procedures include equipment demobilization and restoring the structure to its original condition prior to the test. While equipment demobilization is self-explanatory, restoring the structure to its pre-test condition is not as apparent. Pay attention to the following when restoring the structure to its pre-test condition
:

- Removal of tape or covers used to block vents.
- Closing/opening doors as appropriate throughout the structure.
- Turn on HVAC system as appropriate; inspect HVAC and/or water heater pilot lights to ensure they are still operational or re-light as necessary. It is not uncommon that pressure testing creates an abnormal flux of air through the HVAC and/or water heater and extinguishes the pilot.
- Restore operation of VI or radon mitigation system (if present).

Reporting

The field investigation report should include the following:

- <u>Introduction</u>: Identify the objective and context of the investigation program. Provide a description of the test building and relevant information such as contaminant of concern, contaminant source, building information etc.

- Methods: Describe the sampling methods, sampling locations and rational for location selection. Describe the CPM testing process. Instrument calibration and QA procedures should also be included if on-site analytics are applied.
- Results: Tabulate results and summarize them in time series if applicable. Include applicable measurement limits and uncertainty.
- Data Interpretation: Discuss the results from negative and positive pressure testing processes, and perform the analyses discussed in the main body of this document.
- Appendices: Field notes, laboratory analytical reports, and investigation details should be provided in appendices, as appropriate.

APPENDIX E CPM DEMONSTRATION REPORTS – RESIDENTIAL-SCALE RB1, RB2, AND RB3; INDUSTRIAL-SCALE TRAVIS AFB BLDG. 18 AND BEALE AFB BLDGS. 2425, 2474, AND 24176.

APPENDIX E. SITE SPECIFIC CPM DEMONSTRATION REPORTS:

Residential-Scale:

- RB1
- RB2
- RB3

Industrial-Scale:

- Travis AFB Bldg. 18
- Beale AFB Bldg. 2425
- Beale AFB Bldg. 2474
- Beale AFB Bldg. 24176

Controlled Pressure Method (CPM) Testing
Residential-Scale Demonstration, RB1
ESTCP ER#201501

Arizona State University SSEBE
Oct. 12, 2020

1. OVERVIEW

Controlled pressure method (CPM) testing for vapor intrusion (VI) pathway assessment was developed to evaluate the maximum VI related impact to a structure in a short period of time. Its use has been studied in various Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) funded projects (ER#200707, ER#1686, and ER#201501). In the most recent project, ER#201501, CPM testing has been included as one of a suite of tools to more expediently and confidently define the presence of vapor intrusion pathways in structures.

During CPM testing, the controlled negative pressurization of a test structure induces a worst-case vapor intrusion scenario. Assessment of exhaust air contaminant concentrations provides an estimate of the average indoor air concentration, while area specific samples define local responses to this worst-case scenario. By creating that worst-case VI scenario, CPM testing is most effectively used to identify and rule out structures where VI impacts are non-existent (e.g. test concentrations are less than or equal to ambient outdoor concentrations) and/or of no regulatory concern. If, however, contaminant concentrations approach or are in excess of a regulatory concern during negative pressure testing, positive pressure testing, which suppresses VI, should then be used to rule out (or identify) indoor air source(s). If VI impacts are confirmed, concentrations will either be high enough to define the immediate need for mitigation, or alternatively, should be used as a line of evidence in a multiple lines of evidence approach to define risk.

Use of CPM testing as the primary tool for VI assessment is effective since it recognizes that:

- multiple VI pathways can exist, including:
    - the traditional "*soil VI*" conceptualization (source → through soil → through foundation to indoor air); and
    - "*pipe flow VI*" from sources such as land drains and sanitary sewers.
- the VI pathways discussed above may be present, but not discernible by traditional site characterization; and
- VI concentrations vary both spatially and temporally.

ESTCP project ER#201501 included the demonstration of the CPM test protocol in both residential- and industrial-scale buildings. In brief, the CPM Test Guidelines (ER201501 Final Rpt. Appendix D) use negative- and positive-pressure testing of the structure as follows:

- Negative pressure testing of a structure was used to induce a worst-case VI scenario. During negative pressure testing, after a minimum of nine building air exchanges, air quality was tested at the blower intake/exhaust and if of interest, throughout the structure. If concentrations during negative pressurization were less than ambient outdoor concentrations or regulatory concerns, then the VI impact was considered minimal or non-existent and testing would be complete. If, however, concentrations exceeded ambient outdoor concentrations and were of regulatory concern, then VI impacts could be a concern. At this point, a positive pressure test was necessary to rule out indoor air sources.
- Positive pressure testing was used to identify the presence/impact of an indoor air source(s). During positive pressure testing, VI was suppressed, and after a minimum of four building air exchanges air quality was tested throughout the structure. If no contaminant was present in the building, then only VI was present. If, however, contaminants were detected in indoor air, that indicated an indoor air source was present that would require removal followed by additional CPM testing.

Controlled Pressurization Method (CPM) demonstration tests were conducted within the Hill Air Force Base Operational Unit – 15 (OU-15; formerly covered under OU-8), an area which included a residential community overlaying a dilute dissolved chlorinated solvent plume. The residential area was an effective area for CPM test demonstration based on the extensive historical indoor air and groundwater data set that had been collected for the area by Hill AFB and the work that had been performed under SERDP project ER#1686 and ESTCP project ER#201501. For demonstrations purposes, three residential structures within or adjacent to the plume area were selected for testing (see Figure 1).

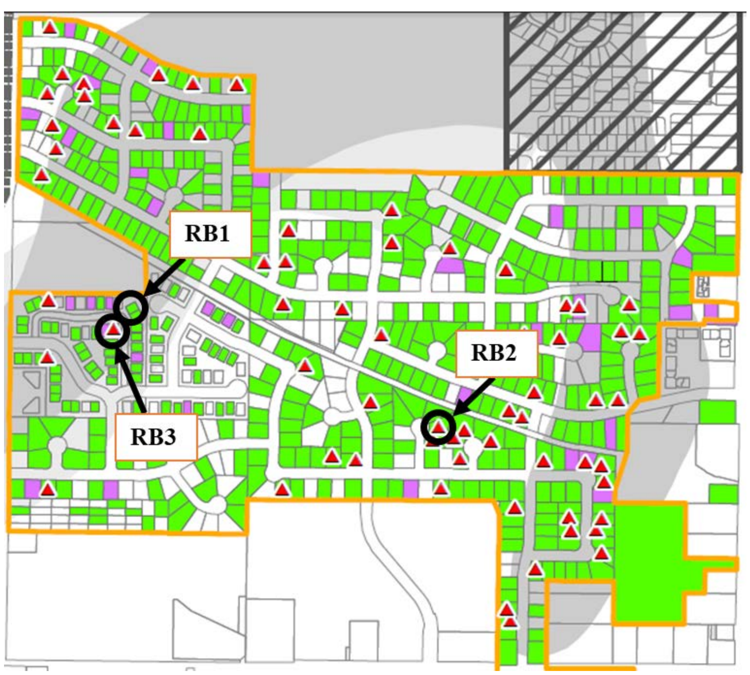

Figure 1. Location of CPM residential demonstration buildings relative to the Hill Air Force Base OU-8 TCE groundwater plume shown in grey.

This document presents the results of a residential-scale CPM demonstration in Residential Building #1 (RB1), Layton, UT. The objectives of this demonstration were to demonstrate the controlled pressure method in a residential-scale building and to improve current CPM protocols based on knowledge gained from the demonstration.

RB1 was initially tested during a single day test on Oct. 9, 2018, but the analytical dataset was difficult to resolve, possibly attributable to the new carpet that had been installed just prior to the test. In addition, subsequent work with CPM testing indicated that performing the negative and positive pressure tests on separate days was beneficial. As such, a second round of testing was performed on June 5 and 6, 2019. It is that second round of testing that will be reported in this document.

2. RESIDENTIAL BUILDING #1 (RB1)

Residential demonstration building #1 was the north side unit of a two-story (ground floor and basement which opened to a sub-grade porch) duplex with an attach garage. The total square footage of indoor floor-space for this house was approximately 4000 ft^2, and the total building volume was estimated at 40,000 ft^3. The house had 11 rooms/living spaces including the garage.

According to the Hill AFB vapor intrusion database, four indoor air sampling events occurred between Jan. 2006 and Jan. 2009, and an additional sampling event was performed in Dec. 2014. Those tests indicated that indoor air concentrations for chlorinated volatile organic compounds (CVOCs) of concern were below mitigation action levels (MALs).

3. CPM TEST BUILDING PRESSURE CONTROL, AIR SAMPLING, AND ANALYTICAL METHODS

3.1 BUILDING PRESSURE CONTROL

Building pressure control was managed with a Retrotec 5100 blower door system (Retrotec, WA). This system included the following:

- Variable speed blower (blower): A Retrotec 1000 blower was operated using the DM32 digital blower control (Retrotec, WA). Blower flowrate was managed via blower speed and intake shrouds that controlled the cross-sectional area of intake.
- DM32 digital blower controller and pressure monitor: The DM32 (Figure 2) measured and recorded 1) indoor vs. outdoor pressure differential, and 2) blower flowrate as determined by a fan shroud vs. reference differential pressure. Datalogging included, but was not limited to time, date, blower flowrate, and differential pressure. Data was recorded on user defined intervals of 30 seconds.
- In this demonstration, the indoor to outdoor pressure differential was measured between a single indoor pressure port and a composite outdoor pressure reference. The composite

outdoor pressure reference provided a more stable and reliable outdoor reference by minimizing short-term pressure fluctuations from wind loading or turbulence generated by building faces. The outdoor reference included pressure ports from three (3) aspects of the residence, manifolded together for a single outdoor reference point.

- Adjustable frame with blower door cloth (blower door): The "blower door" included an adjustable frame and cover cloth with a cutout for the blower. The blower door was installed in a man-door doorframe. Figure 3 shows a blower door with a blower in place.

Figure 2. Retrotec DM32 controller with display.

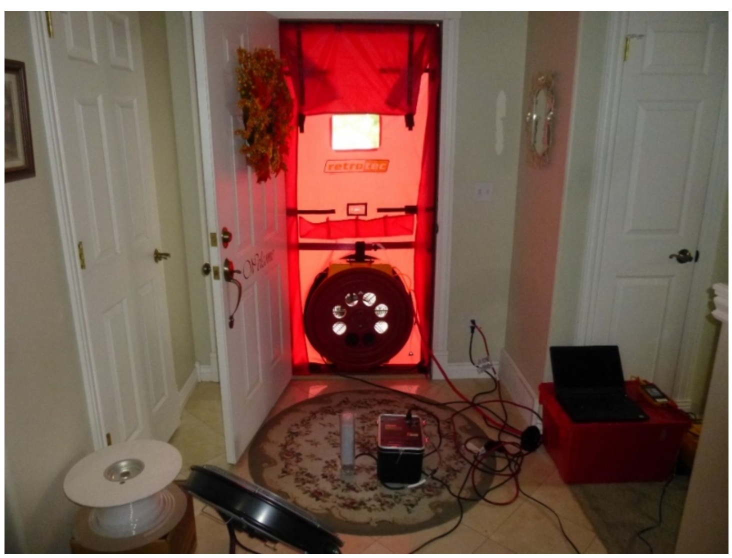

Figure 3. Blower door installation and the use of floor fans to facilitate air mixing near the blower intake sampling area.

3.2 AIR SAMPLING AND ANALYTICAL PROCEDURE

CPM test air sampling included both indoor air and ambient outdoor samples, both of which utilized grab sampling. Indoor air sampling was specific to the type of test performed: Negative pressure CPM testing required a blower intake sample for building concentration and optional area specific sampling. Positive pressure CPM testing required area specific sampling. To eliminate spatial variations during sampling and to ensure greater sample consistency, air mixing was employed in the sampling area using fans (e.g. box/floor fans).

Air sampling and associated analytical was performed using the following methods:

- Grab Sampling: Grab Sampling with Tedlar bags and a vacuum sampler was used to collect indoor and ambient outdoor air samples during CPM testing. These samples were analyzed at the near-by ASU research house and analytical results were obtained the same day of sample collection.
- Analytical: On-site grab sample analyses were performed using an SRI 8610C gas chromatograph (SRI, CA) equipped with a sorbent concentrator and a dry electrolytic conductivity detector (DELCD). The DELCD was well suited for analytical due to its selective nature for only chlorinated and brominated compounds.

The GC-DELCD system was calibrated before negative and positive pressure testing. Calibration concentrations ranged from 0.01 to 10 ppb_v for both negative and positive pressure testing. Calibration standards were prepared by dilution in clean Tedlar bags using Zero-air and a custom chlorinated compound calibration gas stock (Scotty Analyzed Gases).

For analytical, a suite of chlorinated volatile organic hydrocarbons (CVOCs) based on Trichloroethene and its daughter products was of interest. Those that responded well to the DELCD detector used for chromatography were as follows:

- Trichloroethene (TCE)
- t-1,2 Dichloroethene (t1,2-DCE)
- 1,2 Dichloroethane (1,2-DCA)
- 1,1,1 Trichloroethane (1,1,1-TCA)
- 1,1,2 Trichloroethane (1,1,2-TCA)
- Tetrachloroethene (PCE

While results for all contaminants will be reported, the contaminant of interest for discussion purposes will be TCE. TCE is the contaminant of interest since this building resides over a TCE contaminant plume and because of its low regulatory limit. TCE is typically the focal point and regulatory driver for those contaminants shown.

4. CPM TEST DEMONSTRATION AND RESULTS

The goal of this CPM demonstration was not to perform a VI risk assessment, but rather, validate CPM testing for VI pathway assessment.

The demonstration proceeded as follows:

- June 5, 2018: CPM Demonstration. Negative pressure testing. Sampling included ***Grab sampling with on-site analytical***.
- June 6, 2018: CPM Demonstration. Positive pressure testing. Sampling included ***Grab sampling with on-site analytical***.

4.1 CPM Demonstration

CPM testing was performed over a two-day period as described above; negative pressure testing on June 5 and positive pressure testing on June 6. For each test, the blower-door/blower was installed in the front doorway of the house. Figure 3 shows the blower door installation.

For testing, a higher flowrate was used to ensure a minimum of nine (9) indoor air exchanges and/or concentration equilibrium was achieved in the time available.

Air sampling during negative pressure testing focused on blower intake, indoor area specific, and ambient outdoor sampling. Blower intake samples, functionally a composite of indoor air, were collected throughout the test to determine when concentration equilibrium was achieved and for the final test concentration. To eliminate spatial variations in the vicinity of the blower during sampling, air mixing was employed in the sampling area using fans (e.g. box/floor fans; See Fig. 3). Indoor area specific sampling was performed to determine local responses to negative pressurization. As with blower intake sampling, air mixing was employed in the sampling area using fans. Ambient outdoor air sampling was performed in three locations to determine the baseline concentration of contaminants drawn into the house.

Air sampling during positive pressure testing included indoor area specific and ambient outdoor sampling. Again, to eliminate spatial variations during indoor sampling, air mixing was employed in the sampling area using fans. Ambient outdoor air sampling was performed in three locations to determine the baseline concentration of contaminants drawn into the house.

4.1.1 CPM Demonstration – Negative Pressure Test, June 5, 2019

A single blower was used for pressure control and was operated at a constant speed to maintain as uniform a flowrate as possible. Operational conditions with blower-door operation were as follows:

- Flowrate: 1585 cfm average
- Approximate indoor vs. outdoor differential pressure: –24 Pa average
- Duration of negative pressure testing: 410 min.
- Air turnover rate: ~25.5 min per building volume
- Building volume air exchanges: ~16+ air exchanges

Figure 4 provides a time series graphic of flowrate and differential pressure.

Blower intake grab samples were collected during negative pressure testing to determine if/when concentration equilibrium was achieved. Samples were collected at a defined location 1 to 2 ft from the blower intake. Figure 5 provides a graphic of blower intake concentration vs. elapsed time. Based on this data, TCE concentrations do not show a strong pattern of equilibrium. However, after 16 air exchanges when final blower intake sampling was performed, a point well in excess of the recommended nine (9) air exchanges was achieved. In addition to blower intake sampling, area specific samples were collected in eight (8) locations prior to cessation of the negative pressure condition.

Three (3) rounds of ambient outdoor air grab samples were collected from three (3) locations (north (N), east (E), and west (W)) outside the building during the test. Those samples provided a baseline concentration for air quality and was representative of air that was drawn into the building during pressure testing.

Analytical Results – Negative Pressure Test

Table 2 shows CVOC contaminant concentrations for this event.

The indoor composite air concentration (at the blower) for TCE was less than site-specific Hill AFB OU-15 mitigation action level (MAL) of 0.39 ppbv for residential (Air Force Civil Engineer Center/Environmental Division, 2017). In addition, no other analyte exceeded MALs. However, area specific concentrations for TCE in Master Bdrm. and L-Storage, and 1,2-DCA in L-Lg Storage Rm and L-Storage, were elevated above background. As such, a positive pressure test was performed to determine if there was a contribution from indoor air sources.

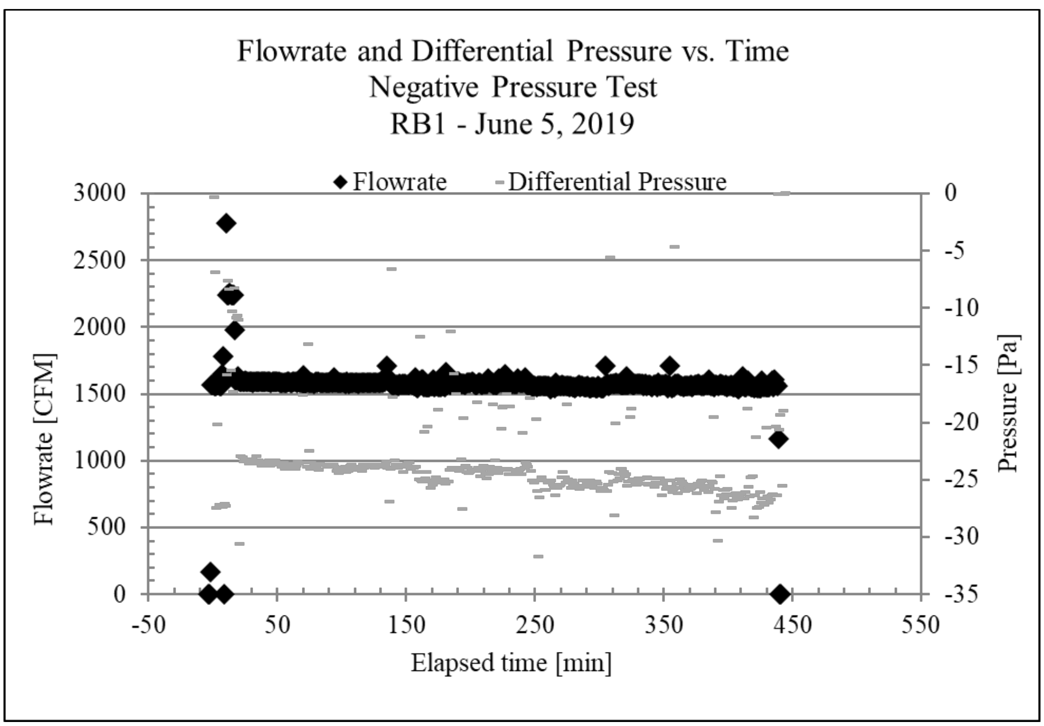

Figure 4. RB1 Blower flowrate and differential pressure vs time, June 5 negative pressure test.

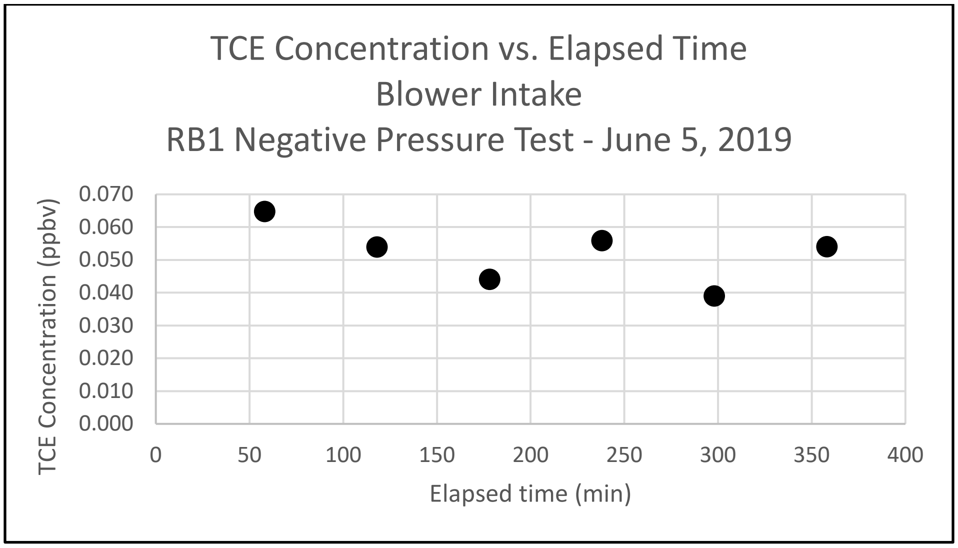

Figure 5. RB1 TCE Air Concentration at the blower intake, June 5, 2019 negative pressure test.

Table 2. Indoor and ambient outdoor air sampling results for June 5, 2019 negative pressure test.

Location	Elapsed time (min)	Analyte Concentration in Air (ppbv)					
		TCE[1]	t-1,2-DCE[1]	1,2- DCA[1]	1,1,1-TCA[1]	1,1,2-TCA[1]	PCE[1]
Amb-W	35	0.013	0.052	0.055	ND	ND	0.010
Amb-N	35	ND	ND	0.028	ND	ND	0.009
Amb-E	35	ND	ND	0.030	ND	ND	0.016
Amb-W	155	ND	ND	0.039	ND	ND	0.007
Amb-N	155	ND	ND	0.025	ND	ND	ND
Amb-E	155	ND	ND	0.026	ND	ND	0.009
Amb-W	335	ND	ND	0.028	ND	ND	0.007
Amb-N	335	ND	ND	0.024	ND	ND	0.007
Amb-E	335	ND	ND	0.025	ND	ND	ND
Blower-final	418	0.069	0.049	0.050	0.011	ND	0.009
Garage	---	0.042	ND	0.026	0.006	ND	0.008
Kitchen	---	0.067	0.042	0.044	0.008	0.013	0.008
Master Bdrm	---	0.124	0.046	0.054	0.019	ND	0.014
Sewing-Craft	---	0.074	0.044	0.051	0.009	ND	0.006
L-Lg Storage Rm	---	0.051	0.050	0.121	ND	ND	0.011
L-Living	---	0.063	0.087	0.070	0.011	ND	0.017
L-Storage	---	0.195	0.047	0.141	ND	ND	0.028
L-Kid	---	0.040	0.052	0.059	0.009	ND	0.012

ND - Non-detectable
1 – Lower calibration limit of 0.05 ppbv. Highlighted concentrations were detectable and estimated based on extended calibration curve.

4.1.2 CPM Demonstration – Positive Pressure Test, June 6, 2019

A single blower was used for pressure control and was operated at a flowrate similar to that used for negative pressure testing. Operational conditions with blower-door operation were as follows:

- Flowrate: 1591 cfm average
- Approximate indoor vs. outdoor differential pressure: 22 Pa average
- Duration of positive pressure testing: 290 min.
- Air turnover rate: ~26 min per building volume
- Building volume air exchanges: ~11+ air exchanges

Figure 6 provides a time series graphic of flowrate and differential pressure.

After a minimum four air exchanges and prior to cessation of the increased pressure condition, grab sampling was performed in 14 area specific locations.

In addition, two (2) sets of ambient outdoor air grab samples were collected from up to three (3) locations (north (N), east (E), and west (W) outside the building. Those samples provided a baseline concentration for air quality and was representative of air that was drawn into the building during pressure testing.

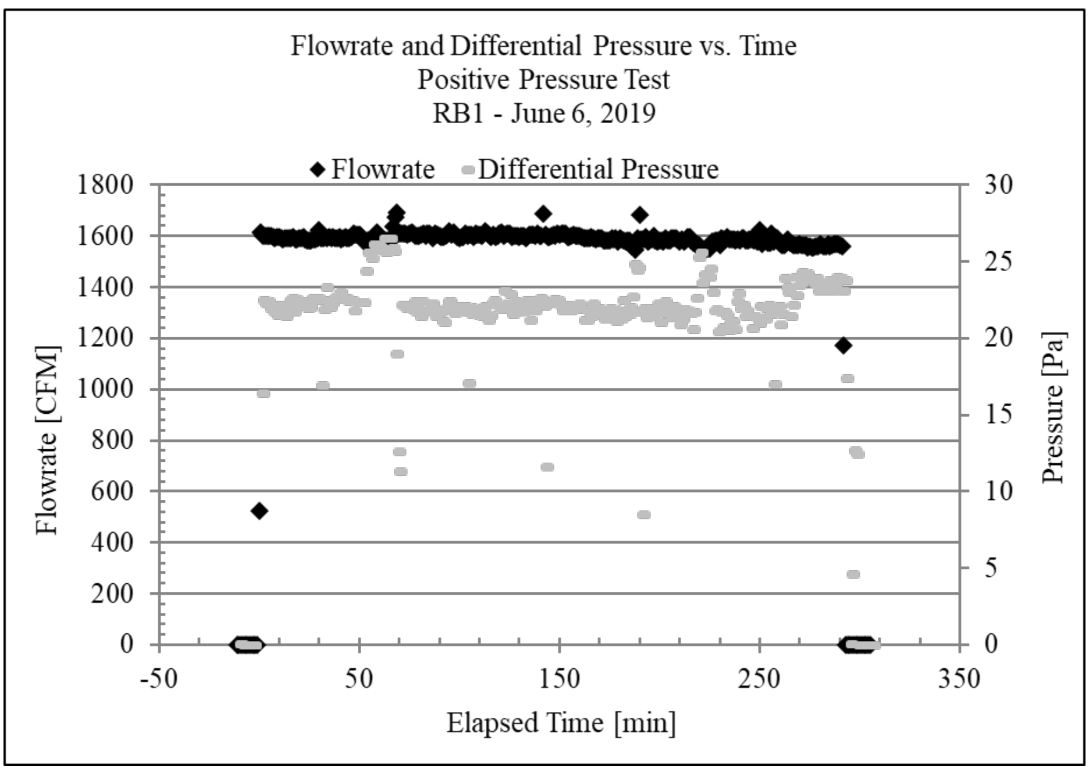

Figure 6. RB1 Blower flowrate and differential pressure vs time, June 6, 2019 positive pressure test.

Analytical Results – Positive Pressure Test

Table 3 shows CVOC contaminant concentrations for this event.

Results indicate 1,2-DCA concentrations in the Laundry, L-Lg Storage Rm, and L-Storage Corner all showed elevated concentrations. Since positive pressure eliminates the potential for vapor intrusion, these detects suggested those concentrations were from indoor air sources. This information, however, was non-specific in that it indicated the presence of a source, but was not indicative of the specific source. Given the location of the lower level detects (defined with a prefix L) and the coincidence of the laundry above those lower level locations, it is also possible that those concentrations could be related to off-gassing concrete.

Table 3. Indoor and ambient outdoor air sampling results for June 6, 2019 positive pressure test.

Location	Analyte Concentration in Air (ppbv)					
	TCE[1]	t-1,2-DCE[1]	1,2- DCA[1]	1,1,1-TCA[1]	1,1,2-TCA[1]	PCE[1]
Amb-E	0.013	ND	0.048	ND	ND	0.026
Amb-W	ND	ND	0.025	ND	ND	0.019
Amb-N	ND	ND	0.025	ND	ND	0.019
Amb-E	ND	ND	0.055	ND	ND	0.008
Amb-W	ND	ND	0.064	ND	ND	0.007
Sewing-Craft	0.030	ND	0.039	0.009	ND	0.011
Garage	0.059	ND	0.033	0.008	ND	0.012
Kitchen	0.040	ND	0.030	0.008	ND	0.010
Laundry	0.067	ND	0.117	0.067	ND	0.031
MB	0.043	ND	0.035	0.013	ND	0.021
Living Room	0.041	ND	0.030	0.011	ND	0.008
L-Office	0.023	ND	0.050	0.008	ND	0.009
L-Kid	0.026	ND	0.041	0.010	ND	0.012
L-Living	0.032	ND	0.040	0.009	ND	0.018
L-Storage	0.020	ND	0.046	0.009	ND	0.011
L-Storage dup	0.023	ND	0.057	0.008	ND	0.016
L- Lg Storage Rm	0.024	ND	0.197	ND	ND	0.011
L-Bath	0.053	ND	0.070	0.041	ND	0.021
L-Storage Corner	0.025	ND	0.172	ND	ND	0.024

ND - Non-detectable
1 – Lower calibration limit of 0.05 ppbv. Highlighted concentrations were detectable and estimated based on extended calibration curve.

5. CPM DEMONSTRATION SUMMARY

5.1 SUMMARY OF CPM NEGATIVE PRESSURE TESTING

As indicated previously, negative pressure testing induces a worst-case-scenario for vapor intrusion. As such, the concentrations noted during the test were the probable maximum concentrations for this structure.

With 16 building air exchanges, the optimum number of nine (9) air exchanges had been achieved and air concentrations in exhaust were consistently below 0.08 ppbv.

The indoor composite air concentration (at the blower) for TCE was less than site-specific Hill AFB OU-15 MAL of 0.39 ppbv for residential. In addition, no other analyte exceeded MALs. However, area specific concentrations for TCE in Master Bdrm. and L-Storage and 1,2-DCA in L-Lg Storage Rm and L-Storage, were elevated. As such, a positive pressure test was performed to determine if there was a contribution from indoor air sources.

5.2 SUMMARY OF CPM POSITIVE PRESSURE TESTING

As stated previously, positive pressure testing was conducted at approximately the same flowrate as the negative pressure test. After meeting the minimum condition of four air exchanges, location specific sampling was performed.

Results indicate 1,2-DCA concentrations in the Laundry, L-Lg Storage Rm, and L-Storage Corner all showed elevated concentrations. As indicated, this information was non-specific in that it indicated the presence of a source, but did not indicate what the source was; it is possible that those concentrations could be related to off-gassing concrete or other.

6. CPM DEMONSTRATION CONCLUSIONS

The objectives of this demonstration were to demonstrate the controlled pressure method in a residential-scale building and to improve current CPM protocols based on knowledge gained from the demonstration.

As stated in the Introduction, CPM testing creates a worst-case scenario and is most effectively used as a tool rule out structures where VI impacts are non-existent (e.g. test concentrations are less than or equal to ambient outdoor concentrations) and/or of no regulatory concern. During negative pressure testing, neither the composite indoor air concentration at the blower nor any area specific sample exceeded OU-15 MALs. Those results correlated with earlier testing performed by Hill AFB.

Positive pressure testing for indoor air sources indicated elevated 1,2-DCA concentrations in area-specific locations, suggesting the possible presence of indoor air sources, or possibly off-gassing concrete.

It was not the purpose of this study to perform a risk assessment nor identify indoor air sources. Since testing was performed for demonstration purposes only, Arizona State University is not in the position to provide guidance. Questions or concerns regarding vapor intrusion should be directed toward Hill Air Force Base as the responsible party.

7. REFERENCES

Air Force Civil Engineer Center/Environmental Division, 2017. Operable Unit 15 – Site ZZ113 Feasibility Study Report. Report prepared by EA Engineering, Science, and Technology, Inc., Layton, UT for the Air Force Civil Engineering Center/Environmental Division, JBSA Lackland Air Force Base, Texas.

Controlled Pressure Method (CPM) Testing
Residential-Scale Demonstration, RB2
ESTCP ER#201501

Arizona State University SSEBE
Oct. 12, 2020

1. OVERVIEW

Controlled pressure method (CPM) testing for vapor intrusion (VI) pathway assessment was developed to evaluate the maximum VI related impact to a structure in a short period of time. Its use has been studied in various Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) funded projects (ER#200707, ER#1686, and ER#201501). In the most recent project, ER#201501, CPM testing has been included as one of a suite of tools to more expediently and confidently define the presence of vapor intrusion pathways in structures.

During CPM testing, the controlled negative pressurization of a test structure induces a worst-case vapor intrusion scenario. Assessment of exhaust air contaminant concentrations provides an estimate of the average indoor air concentration, while area specific samples define local responses to this worst-case scenario. By creating that worst-case VI scenario, CPM testing is most effectively used to identify and rule out structures where VI impacts are non-existent (e.g. test concentrations are less than or equal to ambient outdoor concentrations) and/or of no regulatory concern. If, however, contaminant concentrations approach or are in excess of a regulatory concern during negative pressure testing, positive pressure testing, which suppresses VI, should then be used to rule out (or identify) indoor air source(s). If VI impacts are confirmed, concentrations will either be high enough to define the immediate need for mitigation, or alternatively, should be used as a line of evidence in a multiple lines of evidence approach to define risk.

Use of CPM testing as the primary tool for VI assessment is effective since it recognizes that:

- multiple VI pathways can exist, including:
  - the traditional "*soil VI*" conceptualization (source → through soil → through foundation to indoor air); and
  - "*pipe flow VI*" from sources such as land drains and sanitary sewers.
- the VI pathways discussed above may be present, but not discernible by traditional site characterization; and
- VI concentrations vary both spatially and temporally.

ESTCP project ER#201501 included the demonstration of the CPM test protocol in both residential- and industrial-scale buildings. In brief, the CPM Test Guidelines (ER201501 Final Rpt. Appendix D) use negative- and positive-pressure testing of the structure as follows:

- Negative pressure testing of a structure was used to induce a worst-case VI scenario. During negative pressure testing, after a minimum of nine building air exchanges, air quality was tested at the blower intake/exhaust and if of interest, throughout the structure. If concentrations during negative pressurization were less than ambient outdoor concentrations or regulatory concerns, then the VI impact was considered minimal or non-existent and testing would be complete. If, however, concentrations exceeded ambient outdoor concentrations and were of regulatory concern, then VI impacts could be a concern. At this point, a positive pressure test was necessary to rule out indoor air sources.
- Positive pressure testing was used to identify the presence/impact of an indoor air source(s). During positive pressure testing, VI was suppressed, and after a minimum of four building air exchanges air quality was tested throughout the structure. If no contaminant was present in the building, then only VI was present. If, however, contaminants were detected in indoor air, that indicated an indoor air source was present that would require removal followed by additional CPM testing.

Controlled Pressurization Method (CPM) demonstration tests were conducted within the Hill Air Force Base Operational Unit – 15 (OU-15; formerly covered under OU-8), an area which included a residential community overlaying a dilute dissolved chlorinated solvent plume. The residential area was an effective area for CPM test demonstration based on the extensive historical indoor air and groundwater data set that had been collected for the area by Hill AFB and the work that had been performed under SERDP project ER#1686 and ESTCP project ER#201501. For demonstrations purposes, three residential structures within or adjacent to the plume area were selected for testing (see Figure 1).

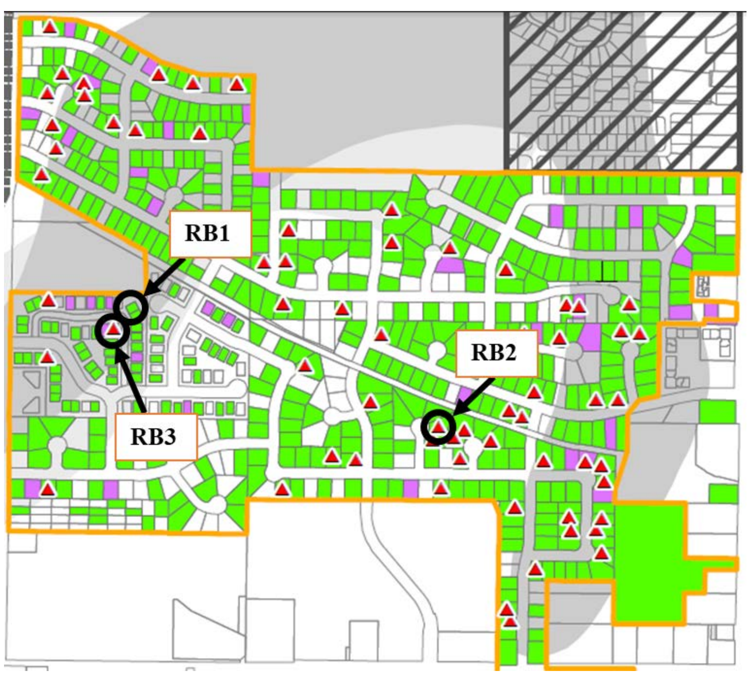

Figure 1. Location of CPM residential demonstration buildings relative to the Hill Air Force Base OU-8 TCE groundwater plume shown in grey.

This document presents the results of a residential-scale CPM demonstration in Residential Building #2 (RB2), Layton, UT. The objectives of this demonstration were to demonstrate the controlled pressure method in a residential-scale building and to improve current CPM protocols based on knowledge gained from the demonstration.

2. RESIDENTIAL BUILDING #2 (RB2)

Residential demonstration building #2 is a stand-alone, 3 story (2-story plus basement), 10 room, 2.5 bath residential structure. Each floor was approximately 700 ft2, with a total indoor floor-space of approximately 2,100 ft^2. The enclosed garage added an additional 400 ft2. For test purposes, the internal volume of the structure was estimated at 20,000 ft3.

According to the Hill AFB vapor intrusion database, 20 indoor air samples were collected between 2004 and 2014. During that period, Trichloroethene (TCE) was detected once at 0.4 ppbv, a concentration approximately equivalent to the mitigation action level (MAL) of 0.39 ppbv (Air Force Civil Engineer Center/Environmental Division, 2017) and 1,2-Dichloroethane (1,2-DCA) was detected 3 times with a maximum concentration of 1.3 ppbv, a concentration roughly five times the MAL. PCE was also detected, but it was believed that PCE was from an indoor source.

A vapor recovery system (subslab depressurization) was installed in the house, and it was in operation prior to the test. This system, however, was powered off during CPM testing to minimize interference associated with that system.

3. CPM TEST BUILDING PRESSURE CONTROL, AIR SAMPLING, AND ANALYTICAL METHODS

3.1 BUILDING PRESSURE CONTROL

To facilitate testing, the structure's vapor recovery system was turned off.

Building pressure control was managed with a Retrotec 5100 blower door system (Retrotec, WA). This system included the following:

- Variable speed blower (blower): A Retrotec 1000 blower controlled by the DM32 digital blower control (Retrotec, WA). Blower flowrate was managed via blower speed and intake shrouds that controlled the cross-sectional area of intake.
- DM32 digital blower controller and pressure monitor: The DM32 (Figure 2) measured and recorded 1) indoor vs. outdoor pressure differential, and 2) blower flowrate as determined by a fan shroud vs. reference differential pressure. Datalogging included, but was not limited to time, date, blower flowrate, and differential pressure. Data was recorded on user defined intervals of 30 seconds.

- In this demonstration, the indoor to outdoor pressure differential was measured between a single indoor pressure port and a composite outdoor pressure reference. The composite outdoor pressure reference provided a more stable and reliable outdoor reference by minimizing short-term pressure fluctuations from wind loading or turbulence generated by building faces. The outdoor reference included pressure ports from three (3) aspects of the residence, manifolded together for a single outdoor reference point.
- Adjustable frame with blower door cloth (blower door): The "blower door" included an adjustable frame and cover cloth with a cutout for the blower. The blower door was installed in a man-door doorframe. Figure 3 shows a blower door with a blower in place.

3.2 Air Sampling and Analytical Procedure

CPM test air sampling included both indoor air and ambient outdoor samples, both of which utilized grab sampling. Indoor air sampling was specific to the type of test performed: Negative pressure CPM testing required a blower intake sample for building concentration and optional area specific sampling. Positive pressure CPM testing required area specific sampling. To eliminate spatial variations during sampling and to ensure greater sample consistency, air mixing was employed in the sampling area using fans (e.g. box/floor fans).

Air sampling and associated analytical was performed using the following methods:

- Grab Sampling: Grab Sampling with Tedlar bags and a vacuum sampler was used to collect indoor and ambient outdoor air samples during CPM testing. These samples were analyzed at the near-by ASU research house and analytical results were obtained the same day of sample collection.

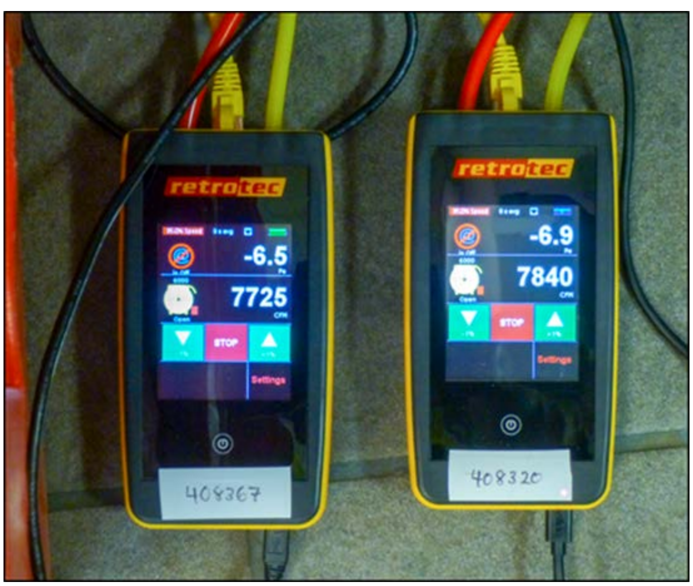

Figure 2. Retrotec DM32 controller with display.

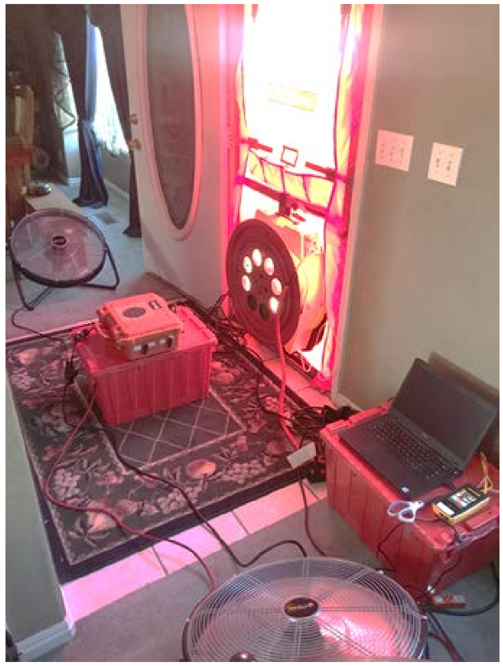

Figure 3. Blower door installation and the use of floor fans to facilitate air mixing near the blower intake sampling area.

- Analytical: On-site grab sample analyses were performed using an SRI 8610C gas chromatograph (SRI, CA) equipped with a sorbent concentrator and a dry electrolytic conductivity detector (DELCD). The DELCD was well suited for analytical due to its selective nature for only chlorinated and brominated compounds.

  The GC-DELCD system was calibrated before negative and positive pressure testing. Calibration concentrations ranged from 0.01 to 10 ppb_v for both negative and positive pressure testing. Calibration standards were prepared by dilution in clean Tedlar bags using Zero-air and a custom chlorinated compound calibration gas stock (Scotty Analyzed Gases).

For analytical, the focus were the chlorinated volatile organic hydrocarbons (CVOCs) Trichloroethene (TCE), 1,2-Dichloroethane (1,2-DCA) and Tetrachloroethene (PCE). While results for all contaminants will be reported, the contaminant of interest for discussion purposes will be TCE. TCE is the contaminant of interest since this building resides over a TCE contaminant plume and because of its low regulatory limit. TCE is typically the focal point and regulatory driver for those contaminants shown.

4. CPM TEST DEMONSTRATION AND RESULTS

The goal of this CPM demonstration was not to perform a VI risk assessment, but rather, validate CPM testing for VI pathway assessment.

The demonstration proceeded as follows:

- Oct. 12, 2018: CPM Demonstration. Negative and positive pressure testing. Sampling included ***Grab sampling with on-site analytical***.

4.1 CPM Demonstration

CPM testing was performed in a single day as indicated above. At this point in CPM development, the goal was to accomplish the full CPM test including both negative and positive pressurization in a single day.

For both the negative and positive pressure tests, the blower-door/blower was installed in the front doorway of the house as shown in Figure 3.

Air sampling during negative pressure testing focused on the blower intake. Blower intake concentrations, functionally a composite of indoor air, were collected during the test to determine when concentration equilibrium was achieved and for the final test concentration. To eliminate spatial variations in the vicinity of the blower during sampling, air mixing was employed in the sampling area using fans (e.g. box/floor fans; See Fig. 3). Ambient outdoor air sampling was performed in three locations to determine the baseline concentration of contaminants drawn into the house.

Air sampling during positive pressure testing included indoor area specific and ambient outdoor sampling. Again, to eliminate spatial variations during indoor sampling, air mixing was employed in the sampling area using fans. Ambient outdoor air sampling was performed in three locations to determine the baseline concentration of contaminants drawn into the house.

4.1.1 CPM Demonstration – Negative Pressure Test

A single blower was used for pressure control and was operated at a constant speed to maintain as uniform a flowrate as possible. Operational conditions with blower-door operation were as follows:

- Flowrate: 1690 cfm average
- Approximate indoor vs. outdoor differential pressure: –12 Pa average
- Duration of negative pressure testing: 328 min.
- Air turnover rate: ~11.8 min per building volume
- Building volume air exchanges: ~27 air exchanges

Figure 4 provides a time series graphic of flowrate and differential pressure vs elapsed time.

Blower intake grab samples were collected during negative pressure testing to determine if/when concentration equilibrium was achieved. Samples were collected at a defined location 1 to 2 ft from the blower intake. Figure 5 provides a graphic of blower intake concentration vs. elapsed time. Based on this data, concentration equilibrium was achieved prior to sampling. In addition, the minimum number of nine (9) building air exchanges was also achieved.

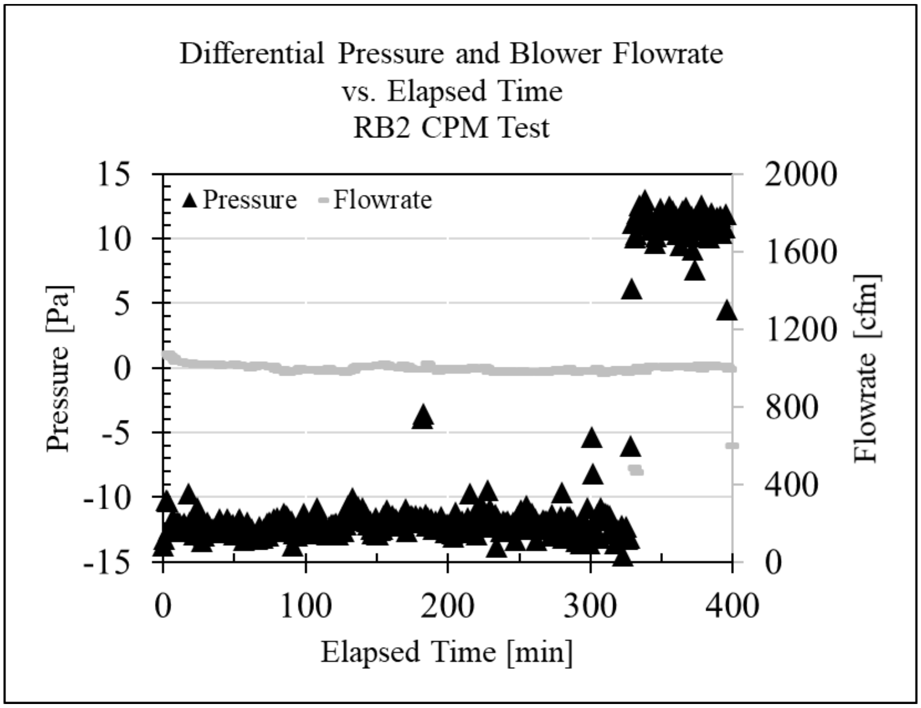

Figure 4. Blower flowrate and differential pressure vs time – RB2 CPM test.

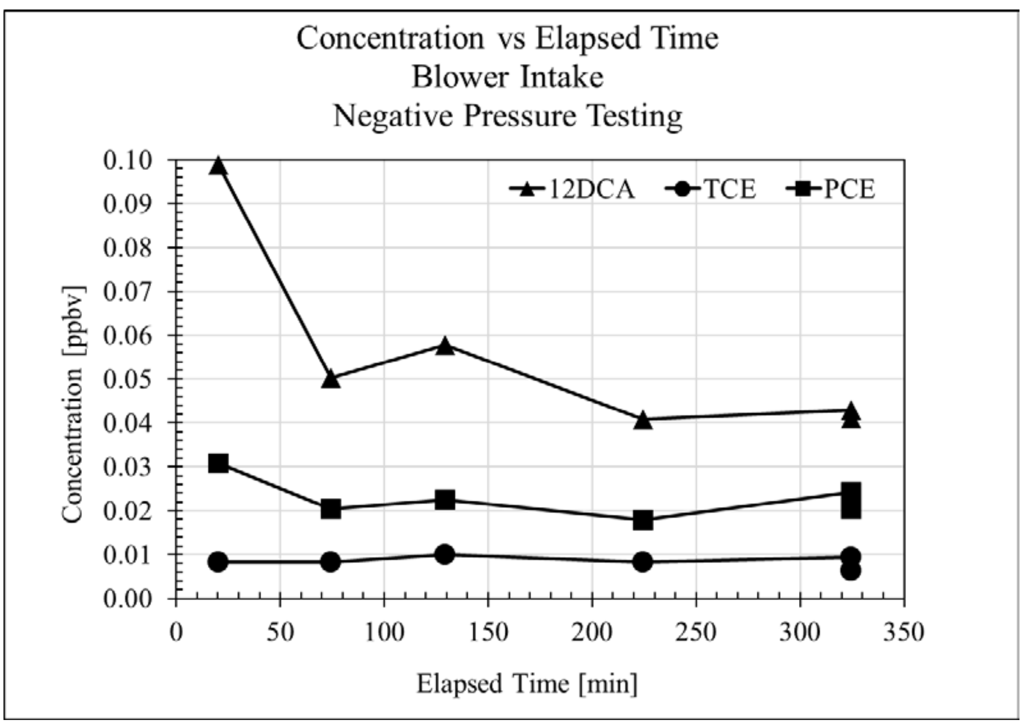

Figure 5. TCE, PCE, and 1,2-DCA air concentrations at the blower intake – RB2 negative pressure test.

Ambient outdoor air grab samples were collected from three (3) locations (north (N), east (E), and west (W)) outside the building during the test. Those samples provided a baseline concentration for air quality and was representative of air that was drawn into the building during pressure testing.

<u>Analytical Results – Negative Pressure Test</u>

Final CVOC concentrations for the negative pressure test is shown in Table 1.

The indoor composite air concentration (at the blower) for TCE was less than site-specific Hill AFB OU-15 mitigation action level (MAL) of 0.39 ppbv for residential (Air Force Civil Engineer Center/Environmental Division, 2017). In addition, no other analyte exceeded MALs. At this point, while no further testing was necessary, a positive pressure test was performed for demonstration purposes.

Table 1. Final blower intake CVOC analyte concentrations – RB2 negative pressure test.

Analyte	Analyte Concentration in Air[1] (ppbv)	
	Indoor Air (blower intake)	Ambient Outdoor (maximum : average concentration)
TCE	0.009	0.009 : 0.008
1,2-DCA	0.043	0.016 : 0.010
PCE	0.024	0.016 : 0.014

1 – Lower calibration limit of 0.05 ppbv. Concentrations were detectable and estimated based on extended calibration curve.

4.1.2 CPM Demonstration – Positive Pressure Test, June 6, 2019

A single blower was again used for pressure control and was operated at a flowrate consistent with the negative pressure test. Operational conditions with blower-door operation were as follows:

- Flowrate: 1700 cfm average
- Approximate indoor vs. outdoor differential pressure: 11.2 Pa average
- Duration of positive pressure testing: 68 min.
- Air turnover rate: ~11.8 min per building volume
- Building volume air exchanges: ~5.7 air exchanges

Figure 4 provides a time series graphic of flowrate and differential pressure vs elapsed time.

After a minimum four air exchanges and prior to cessation of the increased pressure condition, grab sampling was performed in 10 area specific locations.

<u>Analytical Results – Positive Pressure Test</u>

Table 2 shows CVOC analyte concentrations for this event.

When adjusted for ambient outdoor concentrations, while TCE was non-existent in indoor air, 1,2-DCA and PCE showed somewhat elevated concentrations. Since the positive pressure tests eliminates the potential for vapor intrusion, those detections suggested one or more indoor air source(s). However, there was no effort to identify or remove indoor air sources with this test.

Table 2. Indoor and ambient outdoor air sampling results – RB2 positive pressure test.

Sample Type	Sample Location	Analyte Concentration in Air[1] [ppbv]		
		TCE	1,2-DCA	PCE
Ambient Outdoor	Outdoor Average	0.008	0.010	0.014
Area Specific Indoor	Basement Living Room	0.006	0.036	0.009
	Basement Living Room dup	0.009	0.035	0.011
	Basement Bath/Storage	0.010	0.041	0.014
	Basement Bedroom	0.009	0.042	0.013
	Garage	0.005	0.036	0.043
	Kitchen	0.007	0.032	0.011
	Dining room	0.005	0.027	0.010
	Living room	0.006	0.036	0.010
	2nd Master Bedroom	0.008	0.045	0.014
	2nd East Bedroom	0.006	0.043	0.014
	2nd West Bedroom	0.006	0.061	0.022

ND - Non-detectable
1 – Lower calibration limit of 0.05 ppbv. Highlighted concentrations were detectable and estimated based on extended calibration curve.

5. CPM DEMONSTRATION SUMMARY

<u>Summary of CPM Negative Pressure Test 1</u>

As indicated previously, negative pressure testing induces a worst-case-scenario for vapor intrusion. As such, the concentrations noted during the test were the probable maximum concentrations for this structure.

With 27 building air exchanges, the optimum number of nine (9) air exchanges had been met. In addition, real-time data indicated that concentration equilibrium had roughly been achieved.

The indoor composite air concentration (at the blower) for TCE was less than site-specific Hill AFB OU-15 MAL of 0.39 ppbv for residential. In addition, no other analyte exceeded MALs.

Summary of CPM Positive Pressure Testing

Positive pressure testing was conducted at approximately the same magnitude of differential pressure as the negative pressure test. After meeting the minimum condition of four air exchanges, location specific sampling was performed.

While TCE concentrations were not indicative of an indoor air source, 1,2-DCA suggested diffuse sourcing within the structure. Since these concentrations do not suggest a specific point source, detections could be associated with off-gassing of house contents after the negative pressure test.

PCE was elevated in the garage and a second story bedroom. Since PCE detects were location specific, those detections could be associated with indoor air sources.

6. CPM DEMONSTRATION CONCLUSIONS

The objectives of this demonstration were to demonstrate the controlled pressure method in a residential-scale building and to improve current CPM protocols based on knowledge gained from the demonstration.

As stated in the Introduction, CPM testing creates a worst-case scenario and is most effectively used as a tool rule out structures where VI impacts are non-existent (e.g. test concentrations are less than or equal to ambient outdoor concentrations) and/or of no regulatory concern. During negative pressure testing, the composite indoor air concentration at the blower did not exceed OU-15 MALs. However, with maximum TCE and 1,2-DCA concentrations of 0.009 and 0.043 ppbv, respectively, CPM test concentrations were lower than the maximum concentrations realized during earlier Hill AFB testing of 0.4 and 1.3 ppbv, respectively.

Blower outlet air concentrations during negative pressure testing represent a composite view of indoor air quality. In addition, negative pressure testing draws ambient outdoor air into the structure. As such, those concentrations could likely be less than maximums detected during location specific sampling as performed by Hill AFB. During the early stages of CPM test development, a period coincident with the testing of RB2, it was believed that the single outlet concentration during negative pressure testing could provide the detail necessary for decision purposes. As such, no indoor area-specific sampling was performed. However, testing within this structure and in others revealed that location-specific sampling during negative pressure testing would provide added insight into building behavior.

During positive pressure testing, PCE was detected in specific locations, suggesting possible indoor air sources. 1,2-DCA, on the other hand, indicated a diffuse presence across the structure, possibly related to off-gassing of house contents. Such diffuse detections, if related to off-gassing of contents, could point toward the presence of a more continuous source of 1,2-DCA, such as VI.

This data corroborates earlier findings that 1,2-DCA could be associated with vapor intrusion, while PCE was likely related to indoor air sources.

Since this testing was performed for demonstration purposes only, Arizona State University is not in the position to provide guidance. However, this structure has a vapor recovery system for VI mitigation and it is our understanding the Air Force has been active in the management of that system and the associated problem. ASU recommends that the owners continue operation of that system for protection.

7. REFERENCES

Air Force Civil Engineer Center/Environmental Division, 2017. Operable Unit 15 – Site ZZ113 Feasibility Study Report. Report prepared by EA Engineering, Science, and Technology, Inc., Layton, UT for the Air Force Civil Engineering Center/Environmental Division, JBSA Lackland Air Force Base, Texas.

Controlled Pressure Method (CPM) Testing
Residential-Scale Demonstration - RB3
ESTCP ER#201501

Arizona State University SSEBE
Oct. 12, 2020

1. OVERVIEW

Controlled pressure method (CPM) testing for vapor intrusion (VI) pathway assessment was developed to evaluate the maximum VI related impact to a structure in a short period of time. Its use has been studied in various Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) funded projects (ER#200707, ER#1686, and ER#201501). In the most recent project, ER#201501, CPM testing has been included as one of a suite of tools to more expediently and confidently define the presence of vapor intrusion pathways in structures.

During CPM testing, the controlled negative pressurization of a test structure induces a worst-case vapor intrusion scenario. Assessment of exhaust air contaminant concentrations provides an estimate of the average indoor air concentration, while area specific samples define local responses to this worst-case scenario. By creating that worst-case VI scenario, CPM testing is most effectively used to identify and rule out structures where VI impacts are non-existent (e.g. test concentrations are less than or equal to ambient outdoor concentrations) and/or of no regulatory concern. If, however, contaminant concentrations approach or are in excess of a regulatory concern during negative pressure testing, positive pressure testing, which suppresses VI, should then be used to rule out (or identify) indoor air source(s). If VI impacts are confirmed, concentrations will either be high enough to define the immediate need for mitigation, or alternatively, should be used as a line of evidence in a multiple lines of evidence approach to define risk.

Use of CPM testing as the primary tool for VI assessment is effective since it recognizes that:

- multiple VI pathways can exist, including:
    - the traditional "*soil VI*" conceptualization (source → through soil → through foundation to indoor air); and
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- Negative pressure testing of a structure was used to induce a worst-case VI scenario. During negative pressure testing, after a minimum of nine building air exchanges, air quality was tested at the blower intake/exhaust and if of interest, throughout the structure. If concentrations during negative pressurization were less than ambient outdoor concentrations or regulatory concerns, then the VI impact was considered minimal or non-existent and testing would be complete. If, however, concentrations exceeded ambient outdoor concentrations and were of regulatory concern, then VI impacts could be a concern. At this point, a positive pressure test was necessary to rule out indoor air sources.
- Positive pressure testing was used to identify the presence/impact of an indoor air source(s). During positive pressure testing, VI was suppressed, and after a minimum of four building air exchanges air quality was tested throughout the structure. If no contaminant was present in the building, then only VI was present. If, however, contaminants were detected in indoor air, that indicated an indoor air source was present that would require removal followed by additional CPM testing.

Controlled Pressurization Method (CPM) demonstration tests were conducted within the Hill Air Force Base Operational Unit – 15 (OU-15; formerly covered under OU-8), an area which included a residential community overlaying a dilute dissolved chlorinated solvent plume. The residential area was an effective area for CPM test demonstration based on the extensive historical indoor air and groundwater data set that had been collected for the area by Hill AFB and the work that had been performed under SERDP project ER#1686 and ESTCP project ER#201501. For demonstrations purposes, three residential structures within or adjacent to the plume area were selected for testing (see Figure 1).

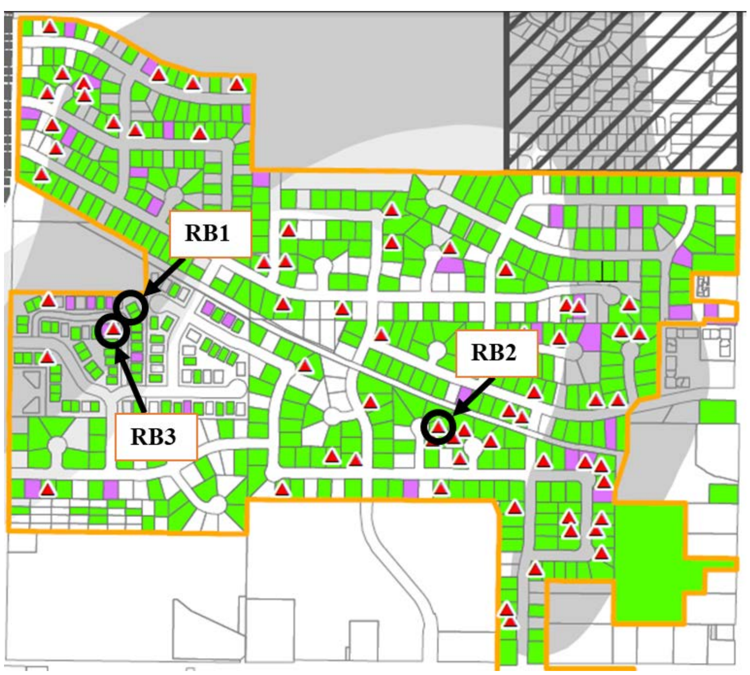


Figure 1. Location of CPM residential demonstration buildings relative to the Hill Air Force Base OU-8 TCE groundwater plume shown in grey.

This document presents the results of a residential-scale CPM demonstration at Residential Building #3 (RB3), Layton, UT. The objectives of this demonstration were to demonstrate the controlled pressure method in a residential-scale building and to improve current CPM protocols based on knowledge gained from the demonstration.

RB3 was initially tested on Oct. 9, 2018 as a single day test, which included both negative and positive pressure testing. However, subsequent work with CPM testing indicated that performing the negative and positive pressure tests on separate days was more effective. As such, a second round of testing was performed on June 3, 4, and 6, 2019. It is that second round of testing that will be reported in this document.

2. RESIDENTIAL BUILDING #3 (RB3)

Residential building 3 (RB3) is a stand-alone, single-story residential structure with basement. The total square footage of indoor floor-space was 4,000 ft2 including the attaching garage. The total building interior volume was estimated at 32,000 ft3.

RB3 has a history of indoor air problems. According to the Hill AFB vapor intrusion database, 16 indoor air sampling events were conducted, ten (10) of which showed Trichloroethene (TCE) concentrations. The average for TCE detections was 0.6 ppbv with a maximum of 0.9 ppbv. Based on that data, the air force installed a sub-slab depressurization system for vapor intrusion mitigation. This system, however, was powered off during CPM testing to minimize interference associated with that system.

3. CPM TEST BUILDING PRESSURE CONTROL, AIR SAMPLING, AND ANALYTICAL METHODS

3.1 BUILDING PRESSURE CONTROL

Building pressure control was managed with a Retrotec 5100 blower door system (Retrotec, WA). This system included the following:

- Variable speed blower (blower): A Retrotec 1000 blower was operated using the DM32 digital blower control (Retrotec, WA). Blower flowrate was managed via blower speed and intake shrouds that controlled the cross-sectional area of intake.

A second positive pressure test required the use of a Retrotec 5000/6000 blower using the DM32 blower control (Retrotec, WA). Blower flowrate was also managed via blower speed and intake shrouds that controlled the cross-sectional area of intake.

- DM32 digital blower controller and pressure monitor: The DM32 (Figure 2) measured and recorded 1) indoor vs. outdoor pressure differential, and 2) blower flowrate as determined by a fan shroud vs. reference differential pressure. Datalogging included, but was not limited to time, date, blower flowrate, and differential pressure. Data was recorded on user defined intervals of 30 seconds.

- In this demonstration, the indoor to outdoor pressure differential was measured between a single indoor pressure port and a composite outdoor pressure reference. The composite outdoor pressure reference provided a more stable and reliable outdoor reference by minimizing short-term pressure fluctuations from wind loading or turbulence generated by building faces. The outdoor reference included pressure ports from four (4) aspects of the residence, manifolded together for a single outdoor reference point.
- Adjustable frame with blower door cloth (blower door): The “blower door” included an adjustable frame and cover cloth with a cutout for the blower. The blower door was installed in a man-door doorframe. Figure 3 shows a blower door with a blower in place.

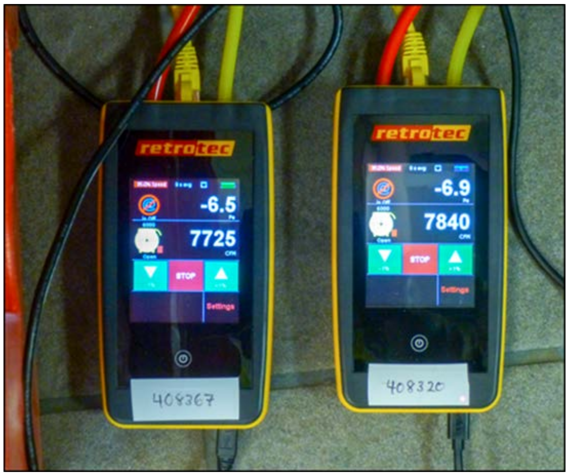


Figure 2. Retrotec DM32 controller with display.

Figure 3. Blower door installation.

3.2 AIR SAMPLING AND ANALYTICAL PROCEDURE

CPM test air sampling included both indoor air and ambient outdoor samples, both of which utilized grab sampling. Indoor air sampling was specific to the type of test performed: Negative pressure CPM testing required a blower intake sample for building concentration and optional area specific sampling. Positive pressure CPM testing required area specific sampling. To eliminate spatial variations during sampling and to ensure greater sample consistency, air mixing was employed in the sampling area using fans (e.g. box/floor fans).

Air sampling and associated analytical was performed using the following methods:

- Grab Sampling: Grab Sampling with Tedlar bags and a vacuum sampler was used to collect indoor and ambient outdoor air samples during CPM testing. These samples were analyzed at the near-by ASU research house and analytical results were obtained the same day of sample collection.

- Analytical: On-site grab sample analyses were performed using an SRI 8610C gas chromatograph (SRI, CA) equipped with a sorbent concentrator and a dry electrolytic conductivity detector (DELCD). The DELCD was well suited for analytical due to its selective nature for only chlorinated and brominated compounds.

The GC-DELCD system was calibrated before negative and positive pressure testing. Calibration concentrations ranged from 0.01 to 10 ppb_v for both negative and positive pressure testing. Calibration standards were prepared by dilution in clean Tedlar bags using Zero-air and a custom chlorinated compound calibration gas stock (Scotty Analyzed Gases).

For analytical, a suite of chlorinated volatile organic hydrocarbons (CVOCs) based on trichloroethene and its daughter products was of interest. Those that responded well to the DELCD detector used for chromatography were as follows:

- Trichloroethene (TCE)
- 1,1 Dichloroethene (1,1-DCE)
- t-1,2 Dichloroethene (t1,2-DCE)
- c-1,2 Dichloroethene (c1,2-DCE)
- 1,2 Dichloroethane (1,2-DCA)
- 1,1,1 Trichloroethane (1,1,1-TCA)
- Tetrachloroethene (PCE)

While results for all contaminants will be reported, the contaminant of interest for discussion purposes will be TCE. TCE is the contaminant of interest since this building resides over a TCE contaminant plume and because of its low regulatory limit, TCE is typically the focal point and regulatory driver for those contaminants shown.

4. CPM TEST DEMONSTRATION AND RESULTS

The goal of this CPM demonstration was not to perform a VI risk assessment, but rather, validate CPM testing for VI pathway assessment.

The demonstration proceeded as follows:

- June 3, 2019: CPM Demonstration. Negative pressure testing. Sampling included ***Grab sampling with on-site analytical***.
- June 4, 2019: CPM Demonstration. Positive pressure test 1. Sampling included ***Grab sampling with on-site analytical***.
- June 6, 2019: CPM Demonstration. Positive pressure test 2. Sampling included ***Grab sampling with on-site analytical***.

4.1 CPM DEMONSTRATION

CPM testing was performed over a three-day period as described above; negative pressure testing on June 3 and positive pressure testing on June 4 and 6. For each test, the blower-door/blower was installed in the front doorway of the house. Figure 3 shows the blower door installation.

For testing, a higher flowrate was used to ensure a minimum of nine (9) indoor air exchanges and/or concentration equilibrium was achieved.

Air sampling during negative pressure testing focused on the blower intake, indoor area specific, and ambient outdoor sampling. Blower intake concentrations, functionally a composite of indoor air, were collected throughout the test to determine when concentration equilibrium was achieved and the final concentration. To eliminate spatial variations in the vicinity of the blower during sampling, air mixing was employed in the sampling area using fans. Indoor area specific sampling was performed to determine localized responses to negative pressurization. As with blower intake sampling, air mixing was employed in the sampling area using fans. Ambient outdoor air sampling was performed in three to four locations around the house to determine the baseline concentration of contaminants drawn into the house.

Air sampling during positive pressure testing included indoor area specific and ambient outdoor sampling. Again, to eliminate spatial variations during indoor sampling, air mixing was employed in the sampling area using fans. Ambient outdoor air sampling was performed in three to four locations to determine the baseline concentration of contaminants drawn into the house.

4.1.1 CPM Demonstration – Negative Pressure Test, June 3, 2019

A single blower was used for pressure control and was operated at a constant speed to maintain as uniform a flowrate as possible. Operational conditions with blower-door operation were as follows:

- Flowrate: 1405 cfm average
- Approximate indoor vs. outdoor differential pressure: –18.7 Pa average
- Duration of negative pressure testing: 380 min.
- Air turnover rate: ~22.8 min per building volume
- Building volume air exchanges: ~16+ air exchanges

Figure 4 provides a time series graphic of flowrate and differential pressure.

Blower intake grab samples were collected during negative pressure testing to determine if/when concentration equilibrium was achieved. Samples were collected at a defined location 1 to 2 ft from the blower intake. Figure 5 provides a graphic of blower intake concentration vs. elapsed time. Based on this data, concentration equilibrium and a point well in excess of the recommended nine (9) air exchanges was achieved prior to sampling.

Subsequent to reaching concentration equilibrium and the recommended nine (9) air exchanges and prior to the cessation of the negative pressure condition, final sampling was performed. Sampling included a blower intake sample and area specific sampling in eight (8) locations.

Three (3) sets of three (3) ambient outdoor air grab samples were collected from among four (4) locations (north (N), east (E), south (S), and west (W)) outside the house. Those samples provided a baseline concentration for air quality and was representative of air that was drawn into the structure during testing.

Analytical Results – Negative Pressure Test

Table 2 shows CVOC contaminant concentrations for this event.

While the indoor composite air concentration (at the blower) for TCE was less than the site-specific Hill AFB OU-15 mitigation action level (MAL) of 0.39 ppbv for residential (Air Force Civil Engineer Center/Environmental Division, 2017), many area-specific locations were in excess. As such, it was necessary to perform a positive pressure test to rule out indoor air sources.

Table 2. Indoor and ambient outdoor air sampling results for June 5 negative pressure test.

Location	Analyte Concentration in Air (ppbv)						
	TCE[1]	1,1-DCE	t 1,2-DCE	c 1,2-DCE[1]	1,2-DCA[1]	1,1,1-TCA[1]	PCE[1]
Ambient Outdoor Average	0.007	0.088	0.079	ND	0.042	0.001	0.017
Blower Intake	0.107	0.148	ND	0.036	0.066	0.21	0.021
L-Guest	0.291	0.050	0.218	0.067	0.088	ND	0.019
L-Bath	0.428	0.103	0.306	0.108	0.097	0.073	0.022
L-East Bdr	0.444	0.102	0.309	0.121	0.095	0.069	0.019
L-Storage	0.382	ND	0.276	0.107	0.087	0.061	0.013
L-Office	0.501	ND	0.357	0.144	0.119	0.057	0.023
L-Office Dup	0.519	0.126	0.435	0.142	0.093	ND	0.016
L-Pantry	0.511	0.116	0.344	0.143	0.107	0.057	0.020
Stair	0.415	ND	0.253	0.106	0.080	ND	0.014

ND - Non-detectable
1 – Lower calibration limit of 0.05 ppbv. Highlighted concentrations were detectable and estimated based on extended calibration curve.

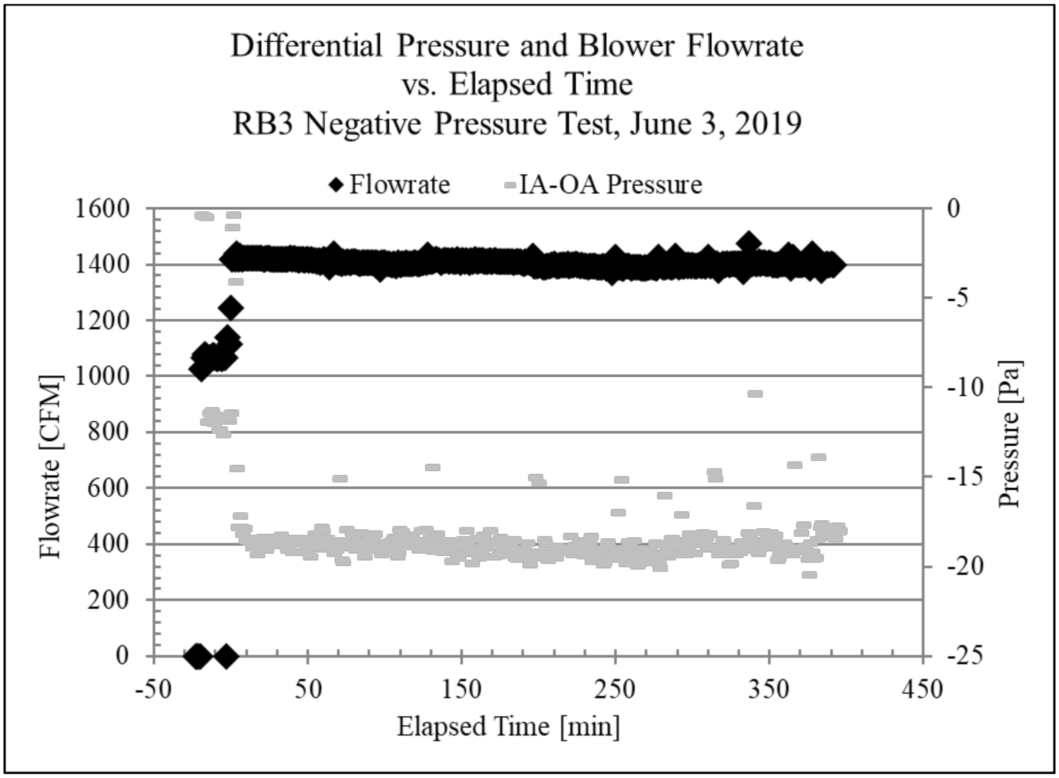


Figure 4. RB3 Blower flowrate and differential pressure vs time, June 3, 2019 negative pressure test.

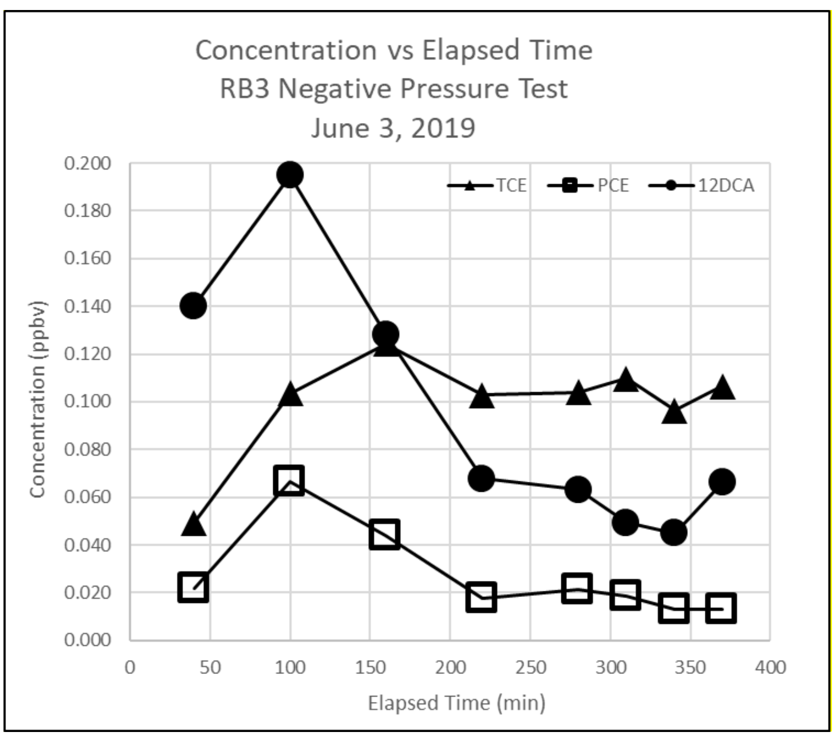


Figure 5. Analyte Concentration at the blower intake, June 3, 2019 negative pressure test.

4.1.2 CPM Demonstration – Positive Pressure Test 1, June 4, 2019

A single blower was used for pressure control and was operated at a flowrate consistent with that used during negative pressure testing. Operational conditions with blower-door operation were as follows:

- Flowrate: 1425 cfm average
- Approximate indoor vs. outdoor differential pressure: 17.6 Pa average
- Duration of positive pressure testing: 310 min.
- Air turnover rate: ~22.5 min per building volume
- Building volume air exchanges: ~13+ air exchanges

Figure 6 provides a time series graphic of flowrate and differential pressure.

After a minimum four air exchanges and prior to cessation of the increased pressure condition, grab sampling was performed in 13 area specific locations.

In addition, six (6) ambient outdoor air grab samples were collected from among four (4) locations (north (N), east (E), south (S), and west (W)) outside the house. Those samples provided a baseline concentration for air quality and was representative of air that was drawn into the structure during testing.

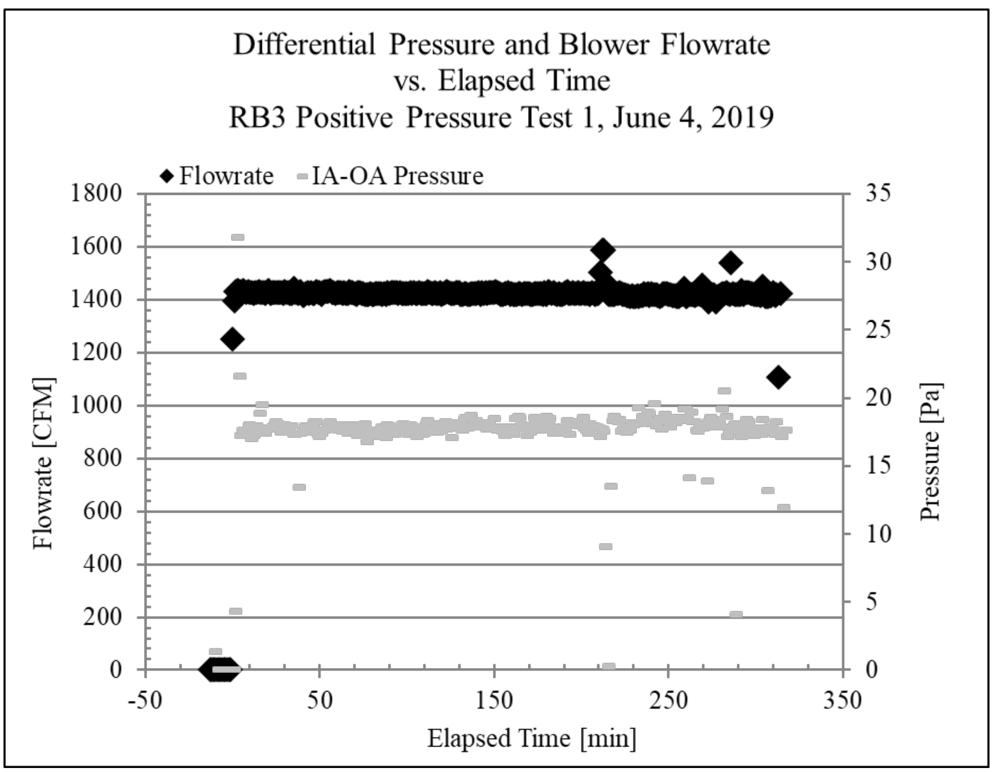


Figure 6. RB3 Blower flowrate and differential pressure vs time, June 4, 2019 positive pressure test 1.

Table 3. Indoor and ambient outdoor air sampling results for June 4, 2019 positive pressure test 1.

Location	Analyte Concentration in Air (ppbv)						
	TCE[1]	1,1-DCE[1]	t 1,2-DCE[1]	c 1,2-DCE	1,2-DCA[1]	1,1,1-TCA[1]	PCE[1]
Ambient Outdoor Average	0.010	0.090	0.044	ND	0.037	0.002	0.012
TV	0.148	ND	0.044	ND	0.036	0.014	0.011
Kitchen	0.018	ND	0.040	ND	0.025	0.005	0.007
MB	0.131	ND	0.039	ND	0.032	0.013	0.009
Office	0.140	ND	0.040	ND	0.033	0.011	0.009
Office-Dup	0.115	ND	0.042	ND	0.028	0.013	0.012
Garage	0.016	ND	0.039	ND	0.033	0.004	0.015
L-Storage	0.151	ND	0.039	ND	0.065	0.035	0.011
L-Play	0.223	0.037	ND	ND	0.084	0.064	0.019
L-Guest	0.147	ND	0.046	ND	0.196	ND	0.009
L-Office	0.150	ND	0.047	ND	0.067	0.036	0.010
L-Office Dup	0.140	ND	0.046	ND	0.188	ND	0.016
L-Pantry	0.296	0.050	0.052	ND	0.102	0.059	0.023
L-Bath	0.157	ND	0.041	ND	0.069	0.043	0.011
L-TV	0.201	0.051	0.069	ND	0.087	0.044	0.014
L-East Bdr	0.160	ND	0.058	ND	0.087	0.055	0.017

ND - Non-detectable
1 – Lower calibration limit of 0.05 ppbv. Highlighted concentrations were detectable and estimated based on extended calibration curve.

<u>Analytical Results – Positive Pressure Test 1</u>

Table 3 shows CVOC contaminant concentrations for this event.

Results indicated the presence of numerous analytes at elevated concentrations throughout the structure. This diffuse occurrence of analytes was confusing, since indoor air sources will typically present as single analytes in discrete areas. As such, the test was repeated on June 6.

4.1.3 CPM Demonstration – Positive Pressure Test 2, June 6, 2019

A single blower was used for pressure control. During this test, a Retrotec 5000 blower was used. Due to operational characteristics and differences that might exist in flow determination between blowers, it was believed that operating this test using a similar differential pressure as that used in positive pressure test 1 would be more effective than trying to duplicate the flowrate. Operational conditions with blower-door operation were as follows:

- Flowrate: 1645 cfm average
- Approximate indoor vs. outdoor differential pressure: 17.3 Pa average
- Duration of positive pressure testing: 254 min.

- Air turnover rate: ~19.4 min per building volume
- Building volume air exchanges: ~13+ air exchanges

Figure 7 provides a time series graphic of flowrate and differential pressure.

After a minimum four air exchanges and prior to cessation of the increased pressure condition, grab sampling was performed in 13 area specific locations.

In addition, five (5) ambient outdoor air grab samples were collected from among four (4) locations (north (N), east (E), south (S), and west (W)) outside the house. Those samples provided a baseline concentration for air quality and was representative of air that was drawn into the structure during testing.

Analytical Results – Positive Pressure Test 2

Table 4 shows CVOC contaminant concentrations for this event. When TCE was adjusted for ambient background concentrations, there was no definitive evidence of an indoor air source. 1,2-DCA, on the other hand,

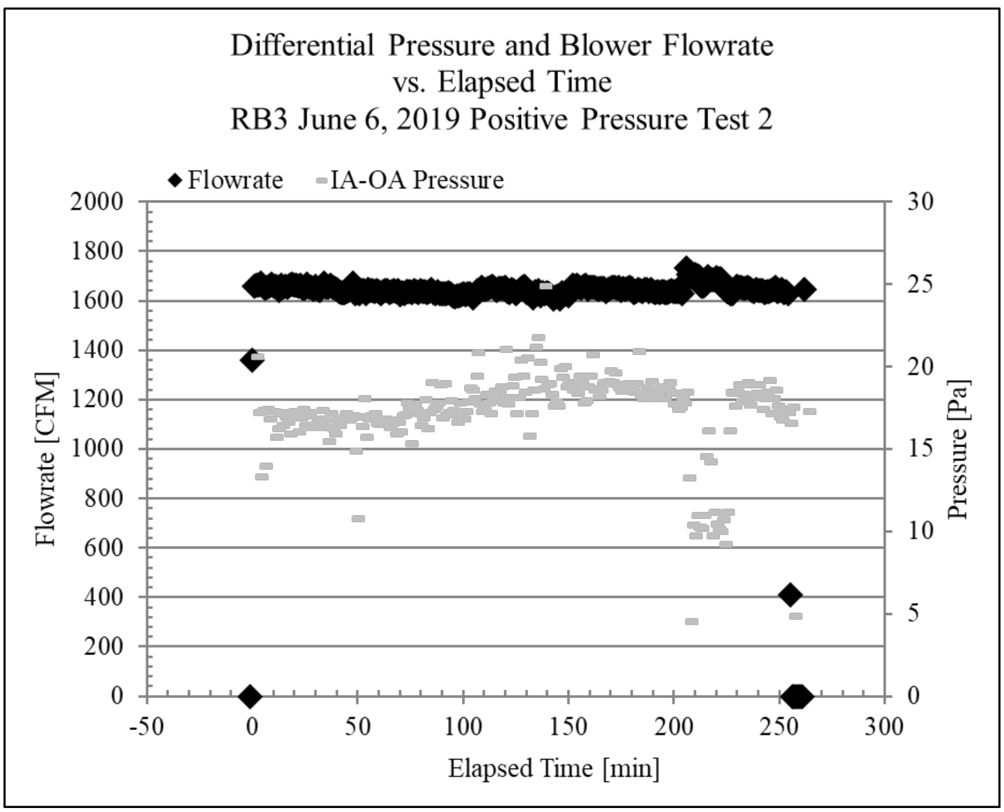


Figure 7. RB3 Blower flowrate and differential pressure vs time, June 6, 2019 positive pressure test 2.

Table 4. Indoor and ambient outdoor air sampling results for June 6, 2019 positive pressure test 2.

Location	Analyte Concentration in Air (ppbv)						
	TCE[1]	1,1-DCE	t 1,2-DCE[1]	c 1,2-DCE[1]	1,2-DCA[1]	1,1,1-TCA[1]	PCE[1]
Ambient Outdoor Average	0.039	0.083	0.011	0.002	0.036	0.010	0.017
MB	0.039	ND	ND	ND	0.031	0.012	0.014
Office	0.032	ND	ND	0.007	0.037	0.019	0.012
Office Dup	0.030	ND	ND	0.006	0.027	0.014	0.008
TV	0.025	ND	ND	ND	0.031	0.010	0.012
Garage	0.034	ND	ND	0.007	0.208	ND	0.042
Kitchen	0.033	ND	ND	0.005	0.034	0.008	0.013
Laundry	0.054	ND	ND	ND	0.061	0.046	0.011
L-TV	0.056	ND	ND	0.007	0.064	0.040	0.013
L-Guest Bdrm1	0.028	ND	ND	ND	0.030	0.009	0.011
L-Office	0.052	ND	ND	0.008	0.073	0.040	0.014
L-Office Dup	0.044	ND	ND	ND	0.081	0.040	0.013
L-Play	0.056	ND	ND	0.006	0.063	0.035	0.014
L-Pantry	0.032	ND	ND	0.006	0.050	0.025	0.014
L-Bdrm/Storage	0.057	ND	ND	0.008	0.079	0.039	0.014

ND - Non-detectable
1 – Lower calibration limit of 0.05 ppbv. Highlighted concentrations were detectable and estimated based on extended calibration curve.

5. CPM DEMONSTRATION SUMMARY

5.1 SUMMARY OF CPM NEGATIVE PRESSURE TESTING

As indicated previously, negative pressure testing induces a worst-case-scenario for vapor intrusion. As such, the concentrations noted during the test could likely have been worst-case-scenario concentrations.

With 16 building air exchanges, the optimum number of nine (9) air exchanges had been met. In addition, real-time data indicated that concentration equilibrium had roughly been achieved.

While the indoor composite air concentration (at the blower) for TCE was less than the site-specific Hill AFB OU-15 mitigation action level (MAL) of 0.39 ppbv for residential (Air Force Civil Engineer Center/Environmental Division, 2017), many area-specific locations were in excess. As such, it was necessary to perform a positive pressure test to rule out indoor air sources.

5.2 SUMMARY OF CPM POSITIVE PRESSURE TESTING

The initial positive pressure test was conducted the next day following the negative pressure test and at approximately the same flowrate as the negative pressure test. After meeting the minimum condition of four (4) air exchanges at the elevated flowrate and differential pressure condition, location specific sampling was performed.

However, the presence of elevated concentrations of CVOCs throughout the structure was confounding. The character of the CVOC signature across the structure was not indicative of an indoor air source. Reflection on the sampling process suggested that residual CVOC vapors were present in the house and failure to isolate rooms when mixing air for sampling effectively resulted in mixing the whole house and distributing vapors. As such, a second positive pressure was performed.

The second positive pressure test was performed two (2) days after the initial positive pressure test and three (3) days after the negative pressure test. Since a larger blower was used for pressurization, the choice was made to run the 2nd positive pressure test at the same differential pressure as the initial positive pressure test rather than the same flowrate. After meeting the minimum condition of four (4) air exchanges at the elevated flowrate and differential pressure condition, location specific sampling was performed.

The second positive pressure test indicated that there were no indoor air sources within the structure.

6. CPM DEMONSTRATION CONCLUSIONS

The objectives of this demonstration were to demonstrate the controlled pressure method in a residential-scale building and to improve current CPM protocols based on knowledge gained from the demonstration.

As stated in the Introduction, a complete VI pathway was defined as vapor intrusion with indoor vapor contaminant concentrations in excess of a regulatory limit or action level. In addition, CPM testing creates a worst-case scenario and is most effectively used as a tool to rule out structures where no complete VI pathway exists. During negative pressure testing, composite indoor air concentrations at the blower indicted CVOC concentrations in excess of EPA screening levels, with area specific concentrations in excess of five times higher. Since a complete VI pathway could not be ruled out, a positive pressure testing was performed to rule out indoor air sources.

Positive pressure test 2 indicated that there were no indoor air sources present. As such, it was determined that this structure had a complete VI pathway. This correlated with Hill Air Force base testing that also indicated a complete VI pathway.

Of interest in this demonstration are the differences noted between positive pressure tests 1 and 2. The first test indicated the presence of CVOC vapors throughout the structure, the signature of which was not indicative of an indoor air source, whereas, positive pressure test 2 indicated that there were no indoor air sources present. It is believed that leading into positive pressure test 1, residual CVOC vapors were still present in the lower level of the house and that the four (4) air turnovers was not sufficient to exhaust those vapors. Then, during area specific sampling with air mixing, a failure to isolate each room during sampling effectively mixed the CVOC vapors throughout the structure. When positive pressure test 2 was performed two (2) days later, indoor air concentrations were closer to ambient outdoor concentrations and each indoor area sampled was isolated prior to air mixing. These results suggested that in tighter homes with basements, the standard four (4) air turnovers might be inadequate and/or a period of ventilation might be required prior to testing and clarified the need to isolate sampling spaces prior to air mixing.

While it was not the goal of this study to perform a risk assessment nor identify indoor air sources, data from these tests indicate that a complete vapor intrusion pathway is present. The information corroborates the earlier findings by Hill Air Force Base that a complete vapor intrusion pathway exists in this structure.

Since this testing was performed for demonstration purposes only, Arizona State University is not in the position to provide guidance. However, ASU does recommend that the vapor mitigation system installed by Hill Air Force Base been continuously operated as intended. Questions or concerns regarding vapor intrusion should be directed toward Hill Air Force Base as the responsible party.

7. REFERENCES

Air Force Civil Engineer Center/Environmental Division, 2017. Operable Unit 15 – Site ZZ113 Feasibility Study Report. Report prepared by EA Engineering, Science, and Technology, Inc., Layton, UT for the Air Force Civil Engineering Center/Environmental Division, JBSA Lackland Air Force Base, Texas.

Industrial Scale Controlled Pressure Method Test Demonstration for Vapor Intrusion Pathway Assessment – ESTCP ER#201501

Facility 18, Site SS016, Travis Air Force Base, California

Arizona State University SSEBE, Oct. 12, 2020

1. INTRODUCTION

1.1 BACKGROUND

Controlled pressure method (CPM) testing for vapor intrusion (VI) pathway assessment was developed to evaluate the maximum VI related impact to a structure in a short period of time. Its use has been studied in various Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) funded projects (ER#200707, ER#1686, and ER#201501). In the most recent project, ER#201501, CPM testing has been included as one of a suite of tools to more expediently and confidently define the presence of vapor intrusion pathways in structures.

During CPM testing, the controlled negative pressurization of a test structure induces a worst-case vapor intrusion scenario. Assessment of exhaust air contaminant concentrations provides an estimate of the average indoor air concentration, while area specific samples define local responses to this worst-case scenario. By creating that worst-case VI scenario, CPM testing is most effectively used to identify and rule out structures where VI impacts are non-existent (e.g. test concentrations are less than or equal to ambient outdoor concentrations) and/or of no regulatory concern. If, however, contaminant concentrations approach or are in excess of a regulatory concern during negative pressure testing, positive pressure testing, which suppresses VI, should then be used to rule out (or identify) indoor air source(s). If VI impacts are confirmed, concentrations will either be high enough to define the immediate need for mitigation, or alternatively, should be used as a line of evidence in a multiple lines of evidence approach to define risk.

Use of CPM testing as the primary tool for VI assessment is effective since it recognizes that:

- multiple VI pathways can exist, including:
  - the traditional "*soil VI*" conceptualization (source → through soil → through foundation to indoor air); and
  - "*pipe flow VI*" from sources such as land drains and sanitary sewers.
- the VI pathways discussed above may be present, but not discernible by traditional site characterization; and
- VI concentrations vary both spatially and temporally.

ESTCP project ER#201501 included the demonstration of the CPM test protocol in both residential- and industrial-scale buildings. In brief, the CPM Test Guidelines (ER201501 Final Rpt. Appendix D) use negative- and positive-pressure testing of the structure as follows:

- Negative pressure testing of a structure was used to induce a worst-case VI scenario. During negative pressure testing, after a minimum of nine building air exchanges, air quality was tested at the blower intake/exhaust and if of interest, throughout the structure. If concentrations during negative pressurization were less than ambient outdoor concentrations or regulatory concerns, then the VI impact was considered minimal or non-existent and testing would be complete. If, however, concentrations exceeded ambient outdoor concentrations and were of regulatory concern, then VI impacts could be a concern. At this point, a positive pressure test was necessary to rule out indoor air sources.
- Positive pressure testing was used to identify the presence/impact of an indoor air source(s). During positive pressure testing, VI was suppressed, and after a minimum of four building air exchanges air quality was tested throughout the structure. If no contaminant was present in the building, then only VI was present. If, however, contaminants were detected in indoor air, that indicated an indoor air source was present that would require removal followed by additional CPM testing.

This document presents the results of the industrial-scale CPM demonstration at Travis Air Force Base Facility 18, Travis Air Force Base, California. The objectives of this demonstration were: a) to demonstrate the controlled pressure method in an industrial-scale building; b) perform long-term, pre- and post- CPM test air-quality assessments to demonstrate that the CPM test would lead to the same/ similar decision as standard air-quality testing; and 3) to improve current CPM protocols based on knowledge gained from the demonstration.

2. SITE DESCRIPTION

Facility 18, Site SS016, Travis Air Force Base, California is a former aircraft engine degreasing facility and is currently used as an access restricted storage area. It is a two-story structure with an approximate areal footprint of 6,000 ft2. It consists of a large, single room service bay on the north end of the building with an adjoining office/bathroom/ shower/ kitchen area on the south end (See Fig. 1). Ground floor office space is on the far southern end. Above the office/bathroom/shower/kitchen area is a 2^{nd} floor office space with an approximate 6 – 7 ft ceiling. The building interior volume was estimated at about 120,000 ft3, assuming a 20 ft average ceiling height.

Facility 18 is part of Site SS016, a chlorinated solvent (primarily trichloroethene (TCE) and its degradation daughter products) groundwater plume area. The southern wall of Facility 18 is roughly 20 ft from the source area for that plume. The source area has been excavated and a bioreactor was installed for remedial purposes (see Fig. 1). Although TCE groundwater

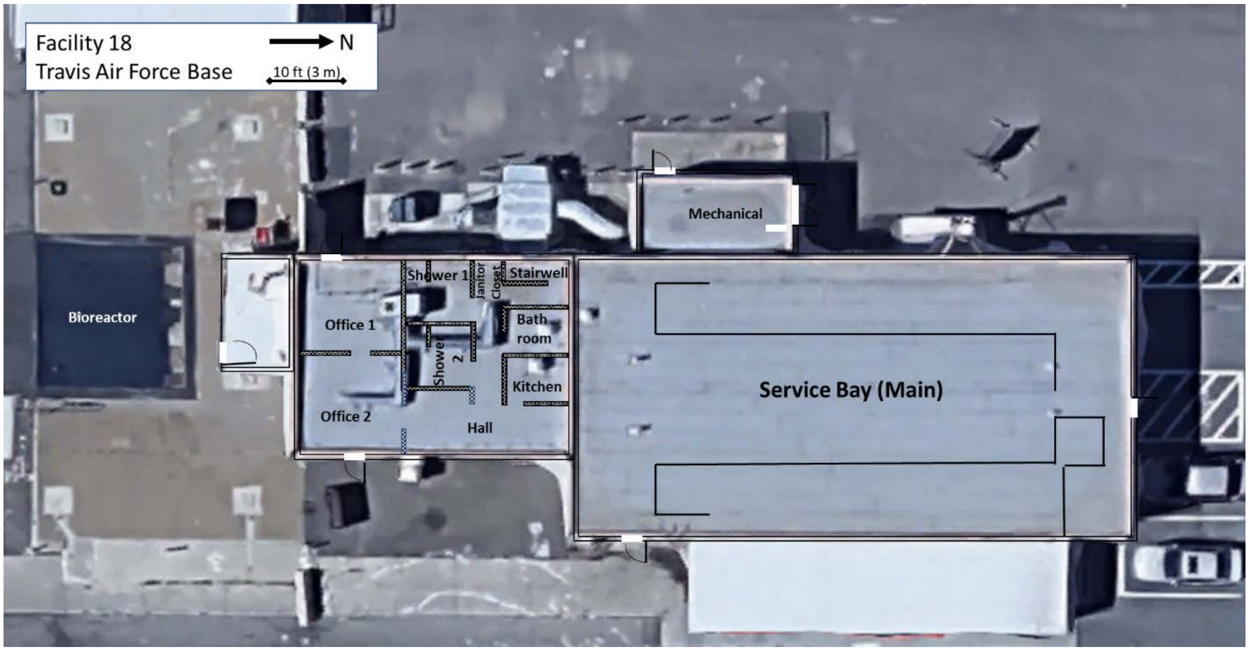


Figure 1. Overhead view of Facility 18, Travis Air Force Base with a ground floor floorplan overlay.

concentrations indicated a decreasing trend after source zone remediation, 2016 groundwater investigations still showed TCE concentrations ranging from <10 to over 2000 µg/L near Facility 18 (2016 Annual GRISR).

A VI risk assessment was conducted in Facility 18 during the 2008-2010 timeframe, prior to DNAPL source zone remediation (CH2Hill, 2010). Three indoor air samples were collected during this investigation from the office, the main storage room, and a shower drain. The greatest TCE vapor concentration was detected in the office at 1.33 ppb_v. At the same time, a subslab air sample showed a TCE concentration of 508,000 ppb_v. The building was deemed a VI risk and was evacuated. Since that time, with the exception of use as a storage facility, Facility 18 has been an entrance restricted, unoccupied building.

3. CPM TEST BUILDING PRESSURE CONTROL, AIR SAMPLING, AND ANALYTICAL METHODS

The CPM demonstration followed early versions of the CPM Test Guidelines (ER201501 Final Rpt. Appendix D) with some modification to account for size and construction of the building and to incorporate knowledge gained from prior industrial-scale tests.

3.1 BUILDING PRESSURE CONTROL

Building pressure control was managed with a Retrotec 6000 blower door system (Retrotec, WA). This system included the following:

- Variable speed blower (blower): Blower was operated using the DM32 digital blower control (Retrotec, WA). Blower flowrate was managed via blower speed and intake shrouds that control the cross-sectional area of intake.
- DM32 digital blower controller and pressure monitor: The DM32 (Figure 2) measured and recorded 1) indoor vs. outdoor pressure differential and 2) blower flowrate as determined by a fan shroud vs. reference pressure differential. Data logging included, but was not limited to time, date, blower flowrate, and differential pressure. Data was recorded on user defined intervals of 30 seconds.
- In this demonstration, the indoor to outdoor pressure differential was measured between a single indoor pressure port and a composite outdoor pressure reference. The composite outdoor pressure reference provided a more stable and reliable outdoor reference by minimizing short-term pressure fluctuations from wind loading or turbulence generated by building faces. The outdoor reference included pressure ports from six (6) aspects of the building, manifolded together for a single outdoor reference point.
- Adjustable frame with blower door cloth (blower door): The "blower door" included an adjustable frame and cover cloth with a cutout for the blower. The blower door was installed in a man-door doorframe. Figure 2 shows a blower door with a blower in place.

3.2 Air Sampling and Analytical Procedure

CPM test air sampling included both indoor air and ambient outdoor samples, both of which utilized grab sampling. Indoor air sampling was specific to the type of test performed: Negative pressure CPM testing required a blower intake sample (functionally a composite of indoor air)

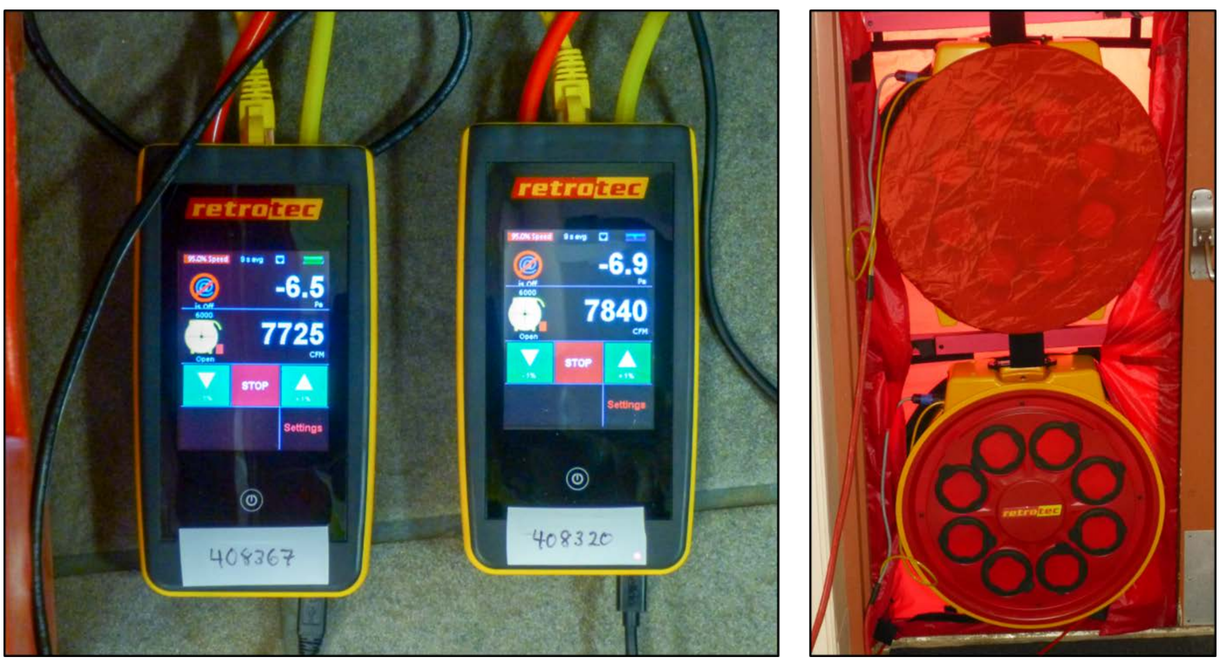


Figure 2. Retrotec DM32 with display (left) and blower door with a 2-blower door cloth and blowers (right).

for building concentration, and optional area specific samples. Final samples for negative pressure testing should be performed after a minimum of nine (9) building air exchanges. Positive pressure CPM testing required area specific sampling, and sampling should proceed after a minimum of four (4) building air exchanges. To eliminate spatial variations during sampling and to ensure greater sample consistency, air mixing was employed in the sampling area using fans (e.g. box/floor fans).

Ambient outdoor sampling was performed to determine the baseline concentration of analytes and was representative of the air quality of air drawn into the structure during pressure testing.

Long term, indoor air sampling utilized long-term thermal desorption tube sampling techniques and/or passive sampler technology.

Air sampling and associated analytical was performed using the following methods:

- Grab Sampling: Grab Sampling with Tedlar bags and a vacuum sampler was used to collect indoor and ambient outdoor air samples during CPM testing. These samples were analyzed on-site and analytical results were obtained the same day of sample collection.

On-site grab sample analyses were performed using an SRI 8610C gas chromatograph (SRI, CA) equipped with a sorbent concentrator and a dry electrolytic conductivity detector (DELCD). The DELCD was well suited for analytical due to its selective nature for only chlorinated and brominated compounds.

The GC-DELCD system was calibrated before negative and positive pressure testing. Calibration ranged from 0.5 to 20 ppb_v for negative pressure testing and 0.1 to 10 ppb_v for positive pressure testing. Calibration standards were prepared by dilution in clean Tedlar bags using zero-air and a calibration gas stock (Scotty Analyzed Gases custom mix).

For on-site analytical, a suite of chlorinated volatile organic hydrocarbons (CVOCs) based on Trichloroethene and its daughter products was of interest. Those that responded well to the DELCD detector used for chromatography were as follows:

  - Trichloroethene (TCE)
  - cis 1,2 Dichloroethene (c 1,2-DCE)
  - trans 1,2 Dichloroethene (t 1,2-DCE)
  - 1,1 Dichloroethane (1,1-DCA)
  - 1,2 Dichloroethane (1,2-DCA)
  - 1,1,1 Trichloroethane (1,1,1-TCA)
  - Tetrachloroethene (PCE)

- Thermal Desorption (TD) tube sampling: TD tube sampling involved actively pulling air through a multi-bed, sorbent packed tube at a controlled flowrate. The flowrate and duration of collection determined the volume of air sampled. The averaged air concentration was calculated using the absorbed VOC mass and the total sample volume.

Short-Term (< 2 hr) TD Tube Sampling: ***Short-term TD tube*** sampling utilized a Gilian LFS-113 air pump (Sensidyne, FL) as follows:

- Single tube sample collection: Pump was used independently in constant flow mode to control flowrate through the TD tube.
- Duplicate/triplicate tube sample collection: A single pump was used in constant pressure mode to provide a continuous pressure source to a manifold with restrictor orifices to control flowrate for multiple tubes.

Sampling flowrates were determined prior to use using the Sensidyne Gilibrator-2 calibrator bubble flowmeter (Sensidyne, FL).

Long-term (18-21 days) TD tube sampling: Long-term TD tube sampling was performed as follows:

- 18- to 21-day, timed interval sampling: 18- to 21-day, timed interval sample collection used a single Sensidyne Gilian LFS-113 (Sensidyne, FL) pump in constant pressure mode to provide a continuous pressure source to a manifold with restrictor orifices to control flowrates for multiple tubes. The active sampling time was timer controlled to reduce collection volume to prevent TD tube sorbent saturation if indoor air concentrations were high. Active sampling was performed for 10-minute intervals every 1.5 hours throughout the sampling period, a total of 160 minutes per day. See Figure 3 for sampler photo.

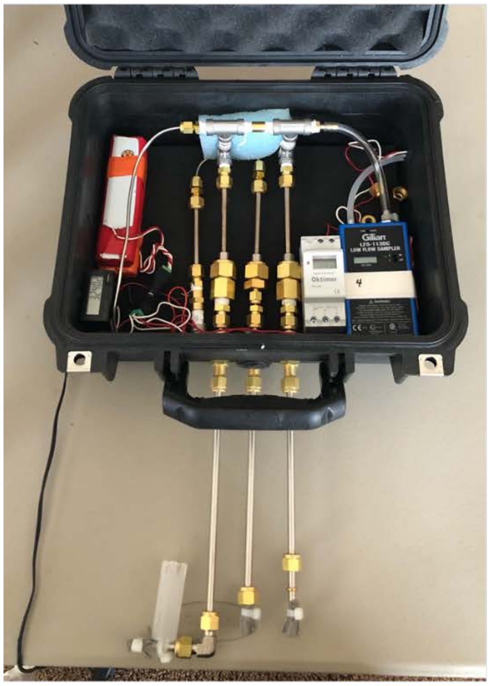
Sample integrity was maintained using Markes Difflok caps (Markes International, United Kingdom). In addition, to ensure that contaminant breakthrough did not occur, for each tube set, a backup TD tube was placed downstream of one of the tubes and was analyzed for the presence of contaminant. All backup TD tubes returned non-detect for VOCs.

Sampling flowrates were measured prior-to and subsequent-to sampling using the Gilian Gilibrator-2 calibrator (Sensidyne, FL). The difference between two measures were less than 6% for all tube samples.

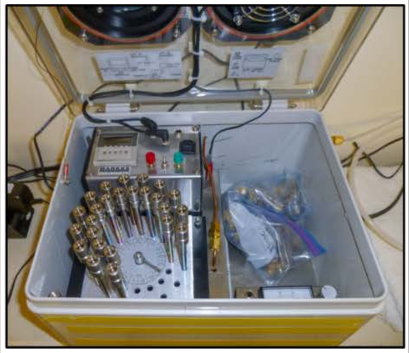
A single TD tube and the backup TD tube both supplied by Beacon Environmental Services, were shipped back to them for analysis. Other tubes deployed were from ASU and used for research purposes, the results for which will not be addressed in this report.

- 18- to 21-day MTS-32 autosampling: 18- to 21-day long-term auto-sampling was also performed us an MTS-32 autosampler (Markes, Ltd., UK). The MTS-32 provided a flowrate controlled service for up to 31 TD tubes. Tubes were deployed sequentially for 24 hours each. Flowrate was controlled at 50 ml/min using a vacuum configured mass flow controller (Alicat Scientific, Tucson, AZ).

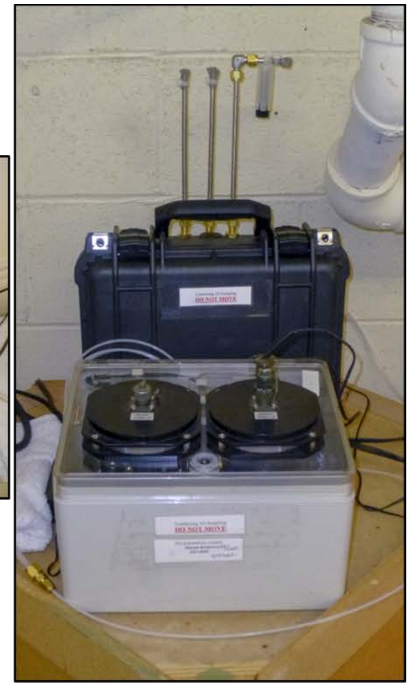
- Passive Sampling: ***Passive samplers*** were deployed for continuous, long-term sampling for a 18 to 21 day period. Passive samplers used were the Beacon Sampler (Beacon Environmental Services, MD) and were sent to Beacon Environmental Services for analysis.



Long-term, timed interval, active TD tube sampler with passive sampler holder



MTS-32 active TD tube autosampler



MTS-32 and Active/passive sampler set deployed

Figure 3. TD tube and Passive sampling devices and deployment thereof.

4. CPM Test Demonstration and Results

As previously indicated, Facility 18 was deemed a VI risk during a 2008-2010 risk assessment. As such, the goal of this CPM demonstration was not to perform a formal VI risk assessment, but rather, to validate CPM testing for VI pathway assessment. Therefore, in addition to CPM testing, two conventional long-term indoor air monitoring events were performed to characterize background indoor air concentrations to provide a point of comparison for the CPM test results.

The demonstration proceeded as follows:

- Sept. 11 - Oct. 2, 2018: Background indoor air sampling. Sampling included long-term ***TD tube sampling*** and ***Passive sampling***.
- Nov. 6-7, 2018: CPM Demonstration. 2-Day CPM test. Sampling included ***Grab sampling*** and short-term ***TD tube sampling***.
- Nov. 8-26, 2018: Background indoor air sampling. Sampling included long-term ***TD tube sampling*** and ***Passive sampling***.

4.1 CPM Demonstration

CPM testing was performed over a two-day period; negative pressure testing on day 1 and positive pressure testing on day 2. A single blower was used for pressure control and was operated at a constant speed to maintain as uniform flowrate as possible. Flowrate was determined by adjusting the blower speed to achieve an approximate indoor-to-outdoor pressure differential of -20 Pa. While a magnitude of 10 Pa was the baseline for a pressure testing as shown in the SOP, an increased negative differential pressure of 20 Pa (-20 Pa) was used to increase flowrate and decrease the time required for negative pressure testing and to offset pressure fluctuations that could occur during the windy conditions anticipated during the test. That flowrate was then used for positive pressure testing also.

Air sampling during negative pressure testing included blower intake, area specific indoor, and ambient outdoor sampling. Blower intake concentrations, functionally a composite of indoor air, were collected during the test to determine when concentration equilibrium was achieved. Final indoor air sampling included a blower intake and area specific sampling while still under pressurized conditions. Ambient outdoor air sampling was performed in two locations throughout the test to determine the baseline concentration of analytes drawn into the building.

Air sampling during positive pressure testing included indoor area specific and ambient outdoor sampling. Ambient outdoor air sampling was performed at the same two locations as used for negative testing to determine the baseline concentration of contaminants drawn into the building.

While results for all analytes will be reported, the analyte of primary interest for discussion purposes will be TCE. TCE is the analyte of interest since this building resides or is adjacent to a TCE contaminant plume, and because of its low regulatory limit, TCE is frequently a focal point and regulatory driver.

Negative Pressure Testing, Nov. 6, 2018:

The blower-door/blower was installed in the eastern man-door adjacent to the overhead door. Figures 4 and 5 show the blower installation and installation location, respectively.

Blower operation was initiated and blower speed was adjusted to achieve the -20 Pa indoor to outdoor differential pressure. Operational conditions for blower-door operation were as follows:

- Flowrate: 4050 cfm average
- Indoor vs. outdoor differential pressure: –20 Pa average
- Duration of negative pressure testing: 550 min
- Air turnover rate: ~30 min per volume
- Building volume air exchanges: 18+ air exchanges

Figure 6 provides a time series graphic of flowrate and differential pressure. Note that outliers or increasing data spread in either flowrate or differential pressure are typically related to increasing outdoor wind speed or gusting winds: Wind activity generates an erratic outdoor pressure references and can also affect overall differential pressures across the building envelope.

Nine (9) blower intake grab samples were collected throughout negative pressure testing to determine when concentration equilibrium was achieved. Samples were collected at a defined location 1-2 ft from the blower intake as a composite representation of building air quality.

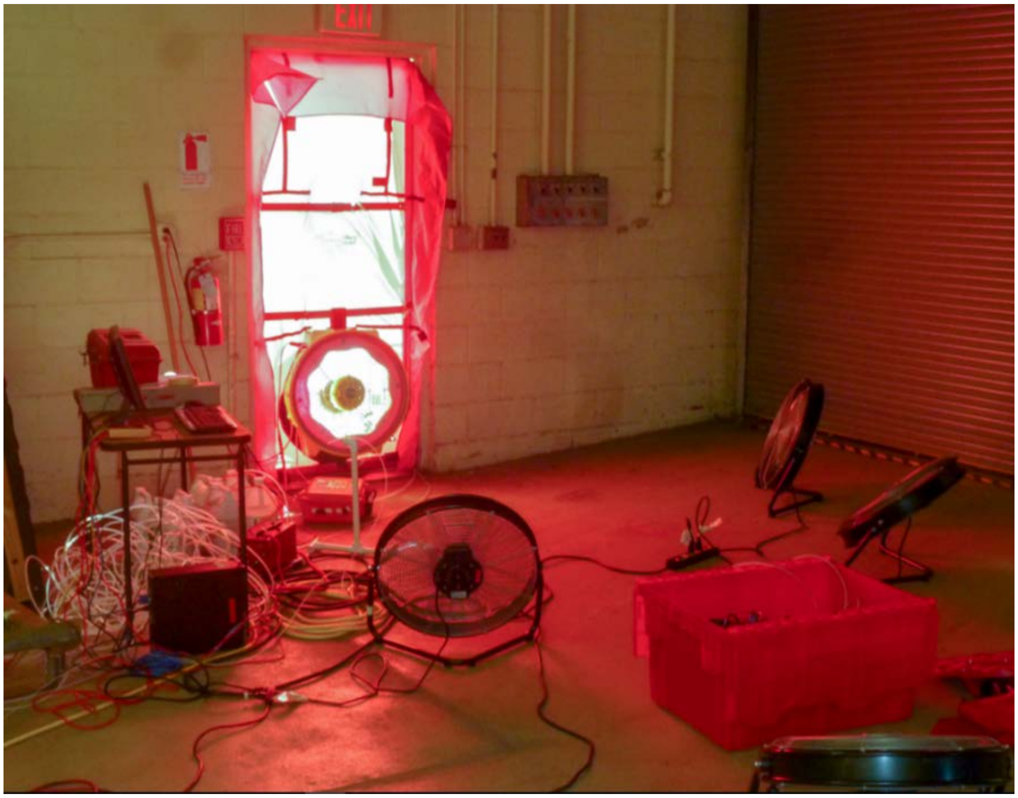


Figure 4. The blower door installation and the air mixing near blower intake with floor fans.

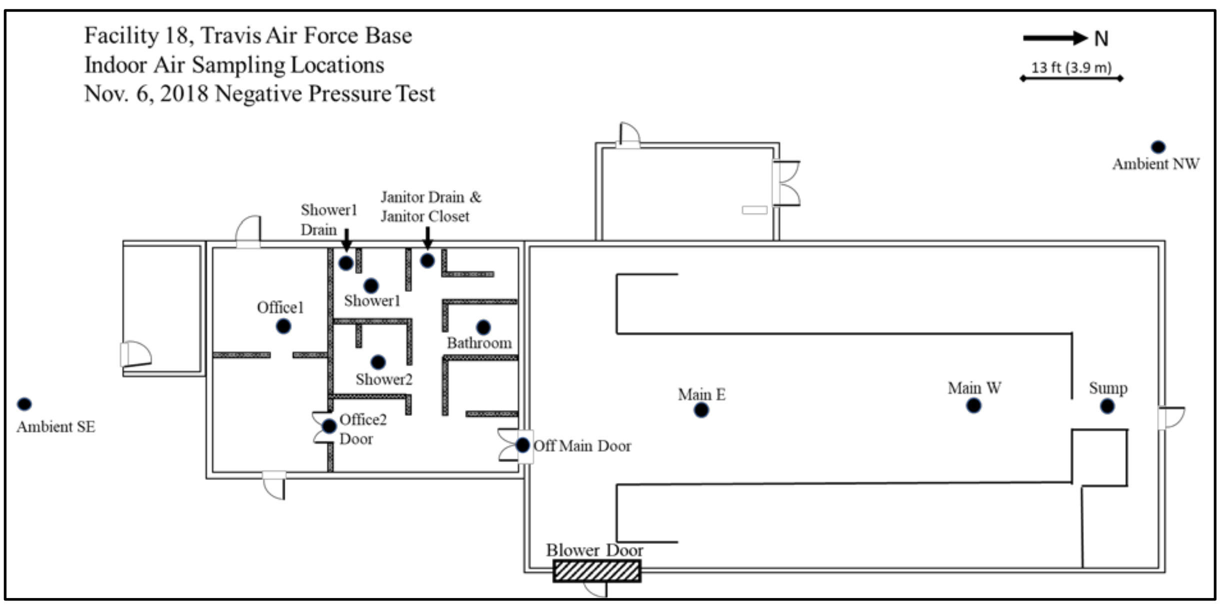


Figure 5. Blower door installation location and sampling location map for indoor and ambient outdoor air grab samples during negative pressure testing.

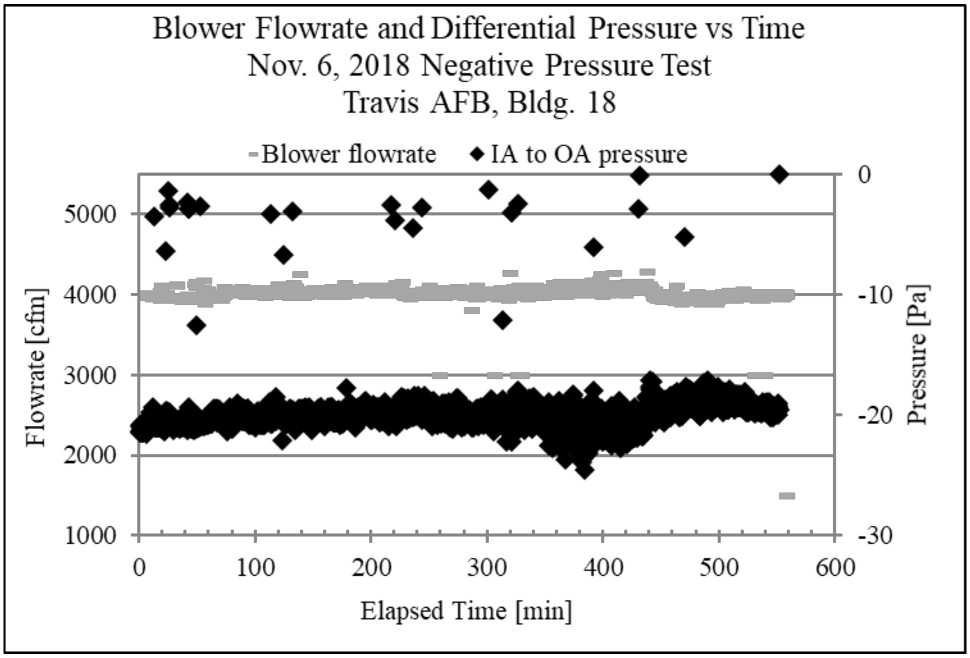


Figure 6. Indoor to outdoor pressure differential and blower flowrate vs. elapsed time for negative pressure testing. Differential pressure outliers increased scatter is typically associated with wind gusts and/or increasing wind speed.

Figure 7 provides a graphic of blower intake TCE concentration vs. elapsed time. Based on this graphic, elapsed time until equilibrium and number of air turnovers was as follows:

- Elapsed time until concentration equilibrium: ~370 min
- Number of air exchanges until concentration equilibrium: 12

Four (4) ambient outdoor air grab samples were collected from two (2) locations (southeast and northwest) outside the building. These samples provided a baseline concentration for air quality and was representative of air that was drawn into the building during pressure testing. Samples were collected 60 min, 170 min, 330 min, and 500 min after the test started.

After a minimum of nine (9) air exchanges and blower intake concentration equilibrium had had been confirmed (~450 min, ~15 air exchanges), the following indoor air samples were collected:

- Blower intake: grab samples and four (4) simultaneously collected short term TD tube samples.
- Area specific sampling: Grab samples at eleven (11) indoor locations (see Figure 5), either in specific rooms or in locations where air would cumulate in route to the blower (e.g. hallways).

<u>Analytical Results – Negative Pressure Testing</u>

Table 1 shows CVOC concentration data for each sampling location and Figure 8 provides the indoor air TCE concentration distribution across the building.

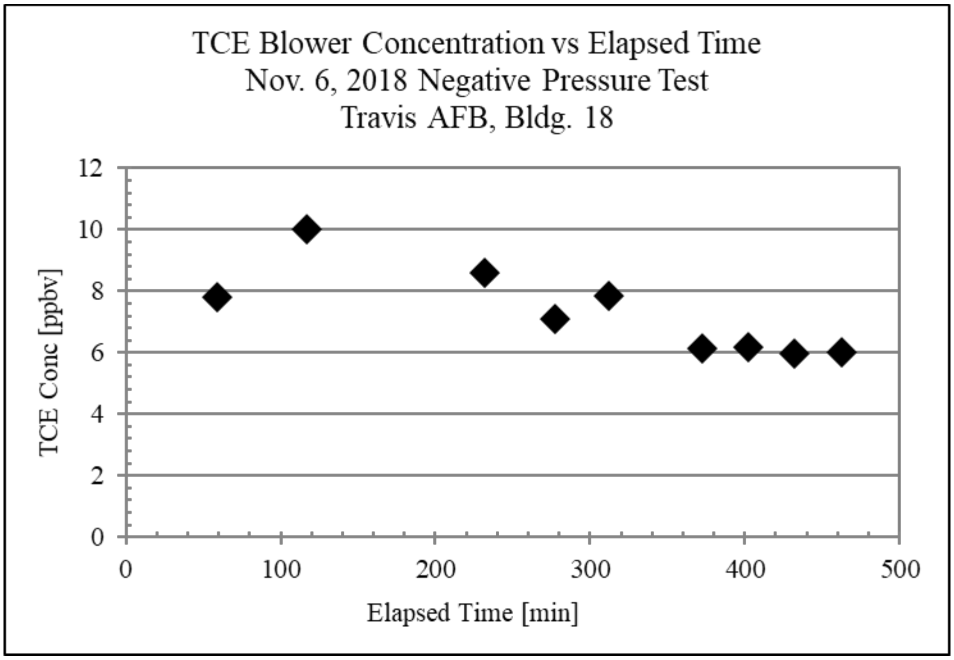


Figure 7. TCE concentration in air at blower intake vs. elapsed time during negative pressure testing.

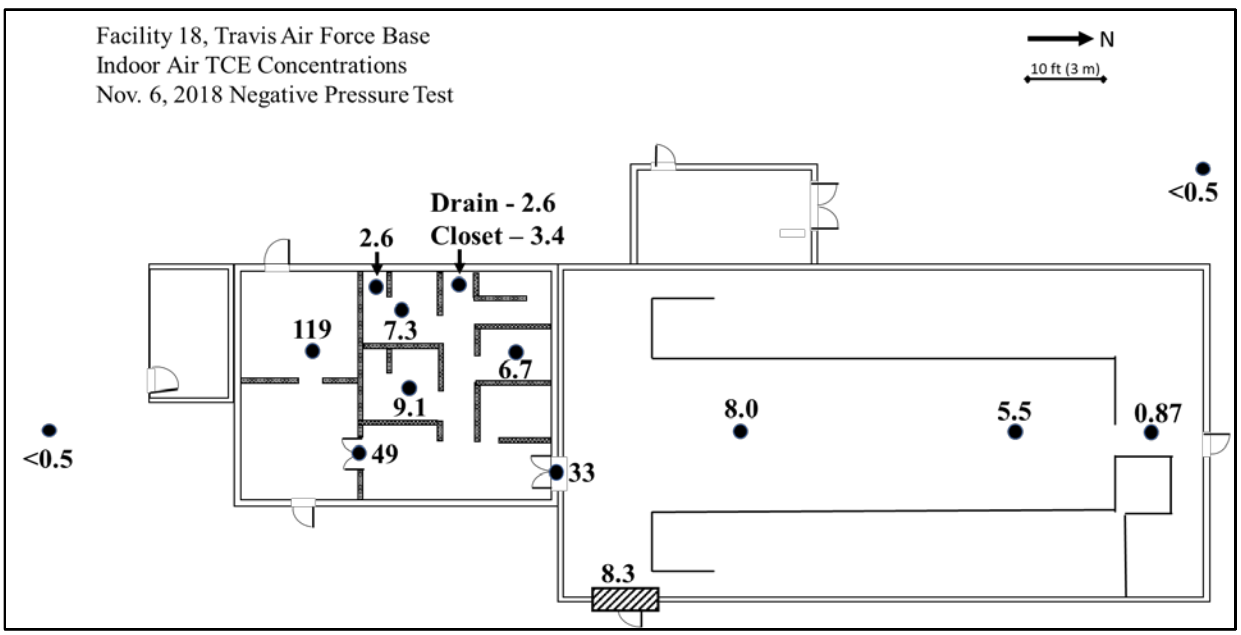


Figure 8. TCE concentration map for Nov. 6, 2018 negative pressure test.

Table 1. CVOC analytical results for Nov. 6, 2018 negative pressure testing.

Location	Analyte Concentration (ppb_v)[1]							
	Grab Samples							TD tube
	TCE	c 1,2-DCE	t 1,2-DCE	1,1-DCA	PCE	1,2-DCA	1,1,1-TCA	TCE[2]
Blower	8.34	ND	0.13	2.47	0.15	ND	ND	6.4
Blower dup	7.59	ND	ND	2.36	0.08	ND	0.03	---
Main W	5.54	ND	ND	1.72	0.07	ND	ND	---
Main E	8.00	ND	ND	2.62	0.08	ND	ND	---
Off 1	119	ND	ND	54	0.59	ND	ND	---
Off 2 door	49	ND	ND	20.4	0.34	ND	ND	---
Off Main Door	33	ND	ND	13.6	0.21	ND	ND	---
Bathroom	6.67	ND	ND	1.90	0.11	ND	ND	---
Shower 1	7.27	ND	ND	2.59	0.07	ND	ND	---
Shower 2	9.13	ND	ND	3.79	0.13	ND	ND	---
Janitor	3.44	ND	ND	0.857	0.06	ND	ND	---
Sump	0.87	ND	ND	0.16	0.05	ND	ND	---
Shower 1 drain	2.56	ND	ND	0.17	0.08	0.41	0.06	---
Janitor drain	2.60	ND	ND	0.24	0.08	0.30	ND	---
Ambient NW 0947	0.37	ND	ND	ND	0.33	ND	ND	---
Ambient SE 0947	0.34	ND	ND	ND	0.26	ND	ND	---
Ambient NW 1240	0.49	ND	ND	ND	0.01	ND	ND	---
Ambient SE 1240	0.26	ND	ND	ND	0.07	ND	ND	---
Ambient NW 1419	0.32	ND	ND	ND	0.10	ND	ND	---
Ambient SE 1419	0.28	ND	ND	ND	0.06	ND	ND	---
Ambient NW 1715	0.39	ND	ND	0.09	0.06	ND	0.03	---
Ambient SE 1715	0.90	ND	ND	ND	ND	ND	ND	---

ND - Non-detectable
1-Calibration range of 0.5 to 20 ppbv. Highlighted concentrations were out of range and estimated.
2-Average of 4 TD tubes collected, with TCE conc. ranging from 5.6 to 7.9 ppbv.

Ambient outdoor air samples showed detectable concentrations that were less than the calibration range of 0.5 ppb_v for all samples except one, which showed 0.9 ppb_v. The final grab sample TCE concentration at the blower intake was 8.34 ppb_v, and the final average TD tube concentration was 6.4 ppb_v. The maximum area specific concentration for TCE was 119 ppb_v.

Both blower intake and area specific indoor air samples indicated TCE concentrations well in excess of the EPA screening levels of 0.08 ppb_v for residential and 0.65 ppb_v for industrial (USEPA, 2015/2020). These concentrations are indicative of a complete VI pathway per the definition provided in the Introduction. Based on this result, a positive pressure CPM test was necessary to determine if that signature was solely from vapor intrusion or whether there was one or more indoor air sources that could, at least in part, contribute to those concentrations.

Positive Pressure Testing, Nov. 7, 2018

For positive pressure testing, the same blower-door configuration was used as that used for the negative pressure test. Blower operation was initiated and blower speed was adjusted to achieve a flowrate of approximately 4050 cfm. Operational conditions for blower operation were as follows:

- Flowrate: 3980 cfm average
- Indoor vs. outdoor differential pressure: 16.4 Pa average
- Duration of positive pressure testing: 320 min.
- Building air exchange rate: ~30 min per volume
- Number of building air exchanges: >10 exchanges

Figure 9 provides a time series graphic of flowrate and differential pressure.

Three (3) ambient outdoor air samples were collected from the same two locations (southeast and northwest) outside the building as were used during negative pressure testing. Samples were collected at 90 min, 270 min, and 420 min after the test started.

After approximately seven air exchanges and prior to cessation of the positive pressure condition, indoor air samples were collected at those locations shown in Figure 10.

Analytical Results – Positive Pressure Testing

Table 2 provides CVOC analyte concentrations for indoor area specific and ambient outdoor sampling locations. In addition, Figure 11 provides the indoor air TCE concentration distribution based on those results.

All ambient outdoor air sample concentrations showed detectable concentrations, ranging from non-detectable to 0.13 ppb_v. Indoor air concentrations ranged from <0.1 ppb_v to 0.96 ppb_v, indicating there was evidence of one or more low-level indoor air sources.

4.2 **Air Sampling Under Passive Building Pressure Conditions**

Natural Building Pressure Conditions

As previously indicated, indoor air sampling under natural building pressure conditions was performed both prior to and subsequent to pressure testing. The sampling methods included were as follows:

- 21-day timed interval TD tube sampling and 24-h MTS-32 TD tube sampling was performed for the 22 day period prior to CPM testing; and
- 18-day timed interval TD tube sampling, 24-h MTS-32 TD tube sampling, and passive sampling was performed for the 18 day period following the CPM testing.

Sampling locations and the types of sampling performed at each location are shown in Figure 12.

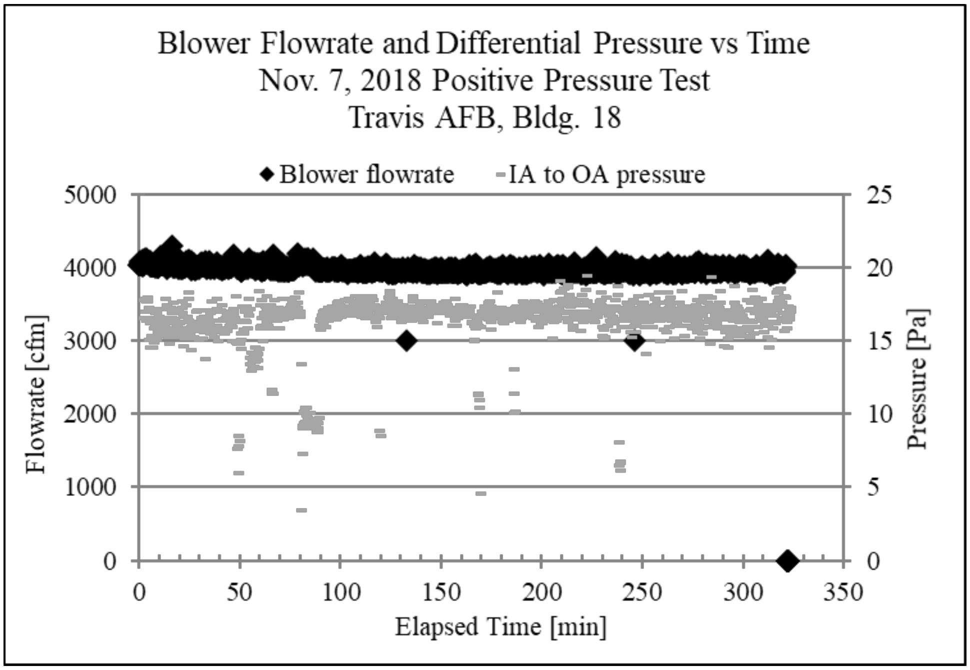


Figure 9. Real-time indoor to outdoor pressure differential and blower flowrate monitoring results for the positive pressure testing. The test started at t = 0 min. Differential pressure outliers increased scatter is typically associated with wind gusts and/or increasing wind speed.

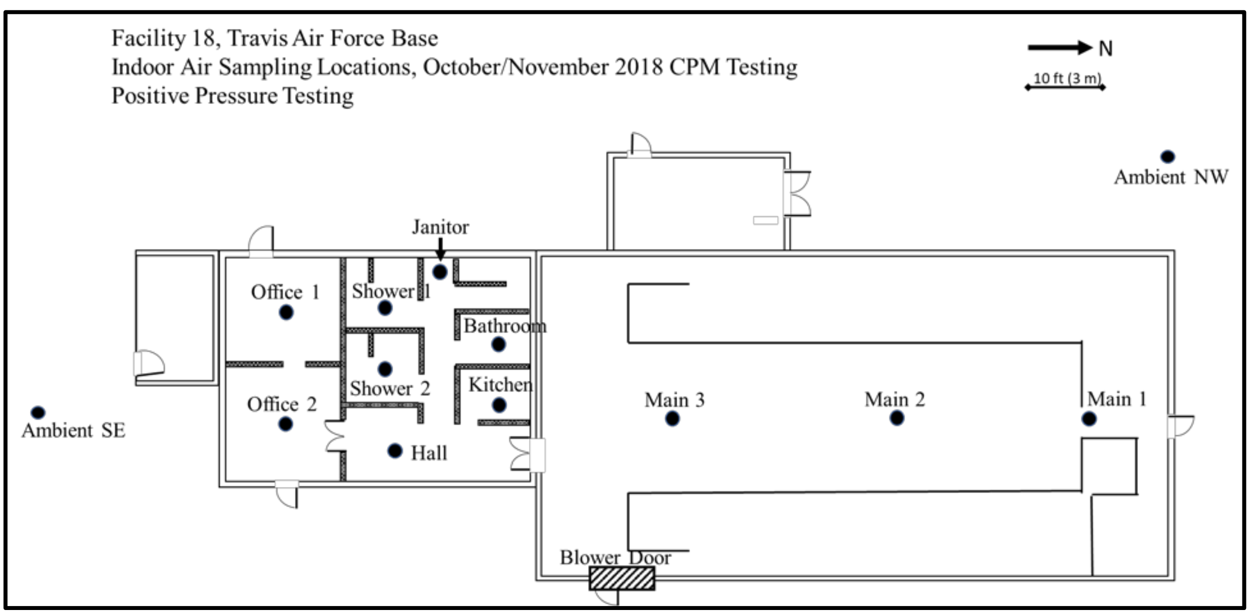


Figure 10. Sampling location map for indoor air grab samples during positive pressure testing.

Table 2. CVOC analytical results for Nov. 7, 2018 positive pressure testing.

Location	Analyte Concentration (ppb_v)[1]						
	TCE	c 1,2-DCE	t 1,2-DCE	1,1-DCA	PCE	1,2-DCA	1,1,1-TCA
Main1	0.112	ND	ND	0.017	0.005	0.010	ND
Main2	0.070	ND	ND	0.011	0.005	0.012	ND
Main3	0.072	ND	ND	0.011	0.005	0.013	ND
Kitchen	0.124	ND	ND	0.020	0.006	0.013	ND
Hall	0.147	ND	ND	0.032	0.006	0.012	0.003
Bath	0.216	ND	ND	0.048	0.007	0.013	0.003
Shower1	0.303	ND	ND	0.075	0.007	0.013	0.004
Shower2	0.267	ND	ND	0.075	0.007	0.013	ND
Janitor	0.220	ND	ND	0.051	0.007	0.013	ND
Office1	0.955	ND	ND	0.186	0.014	0.015	0.004
Office2	0.369	ND	ND	0.079	0.008	0.013	0.003
Ambient SE 0900	0.134	ND	ND	0.018	0.015	0.019	0.005
Ambient NW 0900	0.029	ND	ND	ND	0.006	0.013	ND
Ambient SE 1500	0.082	ND	ND	0.012	0.007	0.016	0.006
Ambient NW 1500	0.050	ND	ND	ND	0.009	0.013	ND
Ambient SE 1730	0.080	0.013	ND	0.014	0.006	0.013	0.003
Ambient NW 1730	ND	ND	ND	0.011	ND	ND	0.038

ND - Non-detectable
1-Calibration limit of 0.1 to 10 ppbv. Highlighted concentrations were out of range and estimated.

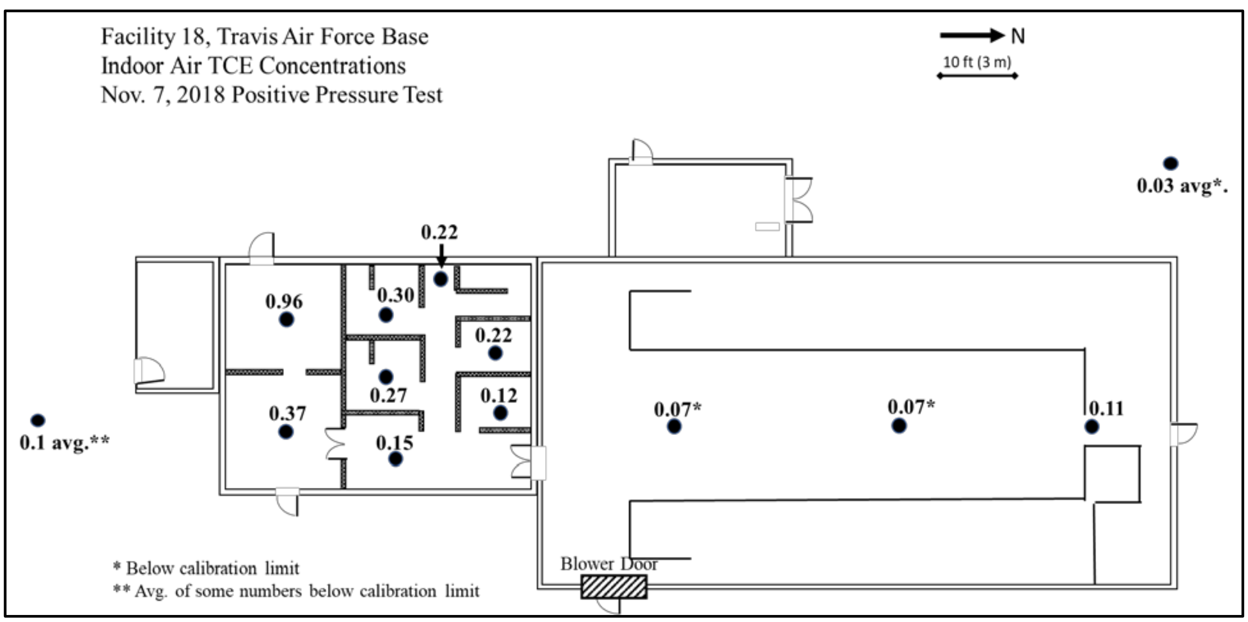


Figure 11. Indoor air TCE concentration distribution for indoor air grab samples during positive pressure testing.

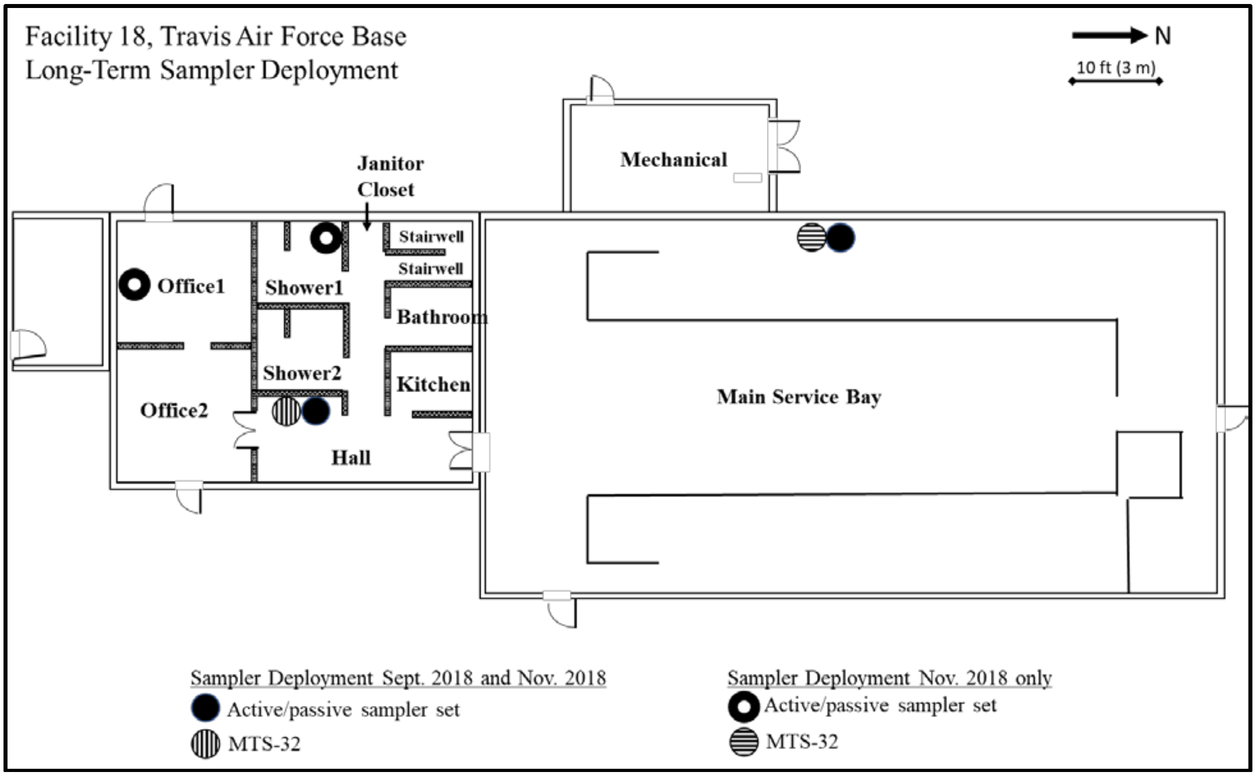


Figure 12. Passive building pressure condition sample locations and type of sampling.

Air sampling results for background sampling under natural building pressure conditions are attached in Appendices 18A and 18B for active TD tube and passive sampler results, respectively, and are shown in Table 3 with a focus on TCE and c 1,2-DCE, the dominant analytes detected in lab analyses. Time series graphics for average daily concentrations from MTS-32 TD tube sampling for the Hall and Main service bay are shown in Figures 13 and 14, respectively.

5. CPM DEMONSTRATION SUMMARY

Negative Pressure CPM Testing Summary

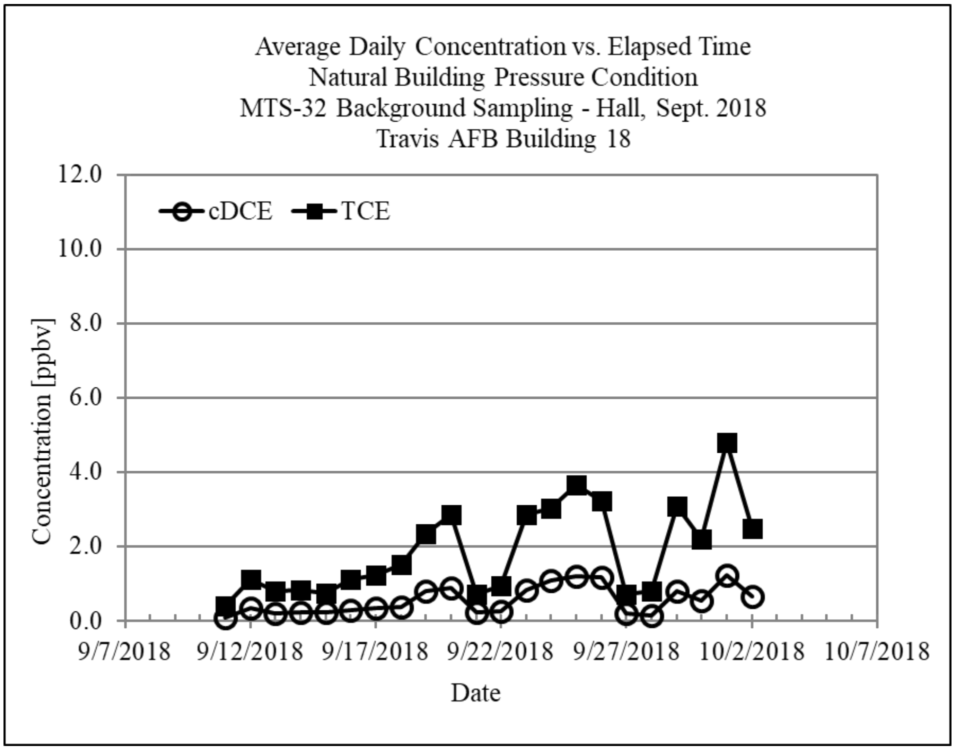
The final TCE test concentration for negative pressure testing was 8.34 ppb_v at the blower intake for a composite building concentration, and area specific concentrations as high as 119 ppb_v.

Both blower intake and area specific indoor air samples indicated TCE concentrations well in excess of the EPA screening levels of 0.08 ppb_v for residential and 0.65 ppb_v for industrial (USEPA, 2015/2020). These concentrations are indicative of a complete VI pathway per the definition provided in the Introduction. Based on those results, a positive pressure CPM test was necessary to rule out indoor air sources.

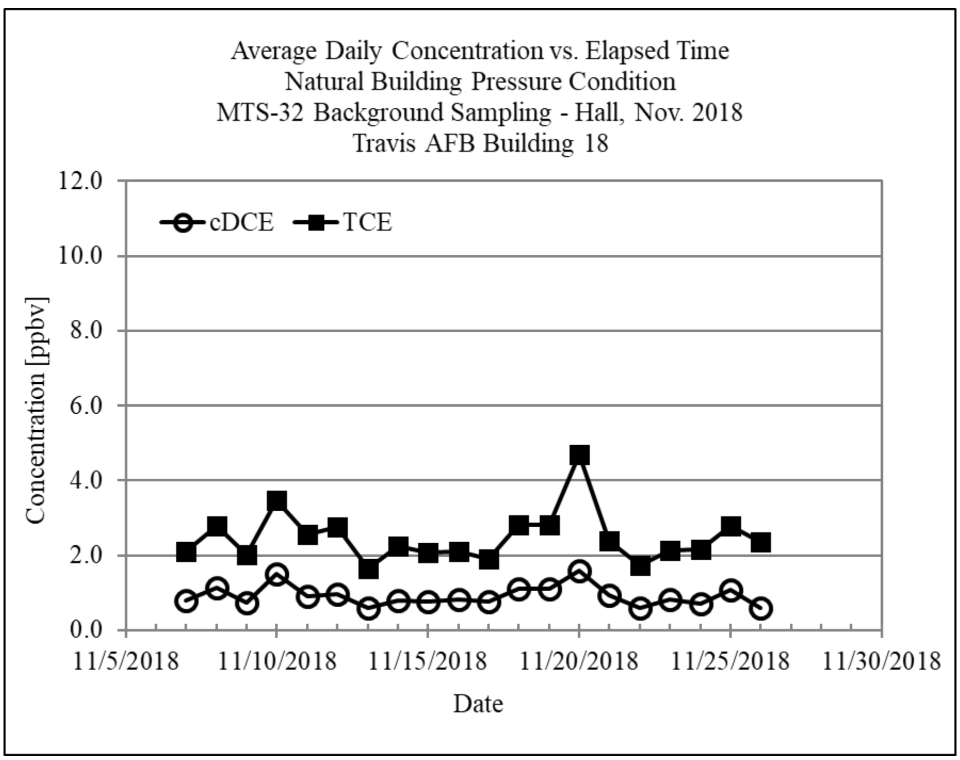
Table 3. Long-Term Air Sampling Results for Natural Building Pressure Condition Background Sampling, Facility 18, Travis Air Force Base, California.

Location	Event	Sampling Method	Sample Type	TCE Conc (ppb_v)	cis 1,2 DCE Conc (ppb_v)	Breakthrough?
Hall	Sept 2018	Long-term TD tube	TD1	0.28	1.0	*1
			TD2	0.27	1.13	*1
		MTS-32 TD tube autosampling	MTS-32 Avg	1.88	0.6	*1
			MTS-32 Max	4.81	1.2	*1
			MTS-32 Min	0.41	0.1	*1
	Nov 2018	Long-term TD tube	TD1	15.1	5.38	*2
			TD2	16.8	6.40	*2
			Beacon TD	6.55	1.75	No
		Passive sampling	Beacon Passive	6.12	0.94	Not Applicable
		MTS-32 TD tube autosampling	MTS-32 Avg	6.03	2.3	*2
			MTS-32 Max	10.3	3.6	*2
			MTS-32 Min	1.44	0.2	*2
Main	Sept 2018	Long-term TD tube	TD1	No data *3	No data *3	*1
			TD2	No data *3	No data *3	*1
	Nov 2018	Long-term TD tube	TD1	6.48	2.58	*2
			TD2	6.19	2.16	*2
			Beacon TD	2.24	0.4	No
		Passive sampling	Beacon Passive	2.56	0.55	Not Applicable
		MTS-32 TD tube autosampling	MTS-32 Avg	2.48	0.9	*2
			MTS-32 Max	4.69	1.6	*2
			MTS-32 Min	1.66	0.6	*2
Office1	Nov 2018	Long-term TD tube	TD1	53.4	18.4	*2
			TD2	55.1	20.0	*2
			Beacon TD	11.4*4	3.47*4	*2
		Passive sampling	Beacon Passive	31.0	9.24	Not Applicable
Shower1	Nov 2018	Long-term TD tube	TD1	16.9	6.51	*2
			TD2	14.5	6.12	*2
			Beacon TD	7.26	2.03	No
		Passive sampling	Beacon Passive	8.01	1.54	Not Applicable

*1 – No breakthrough backup tube possible. Based on contaminant concentration and volume of sample, breakthrough was not likely
*2 - Based on Beacon breakthrough sample results, no breakthrough occurred
*3 - These samples were run only to determine what contaminants might be present in bldg. No quantitative data available.
*4 – Data is biased low because of analytical recollection failure and should be disregarded.



(a) Hall prior to pressure testing (Sept.)



(b) Hall post pressure testing (Nov.)

Figure 13. Average daily indoor air concentrations from 24-h MTS-32 TD tube auto-sampling for background vapor concentrations under natural building pressure conditions in the Hall, (a) prior to CPM testing in Sept. and (b) post CPM testing in Nov.

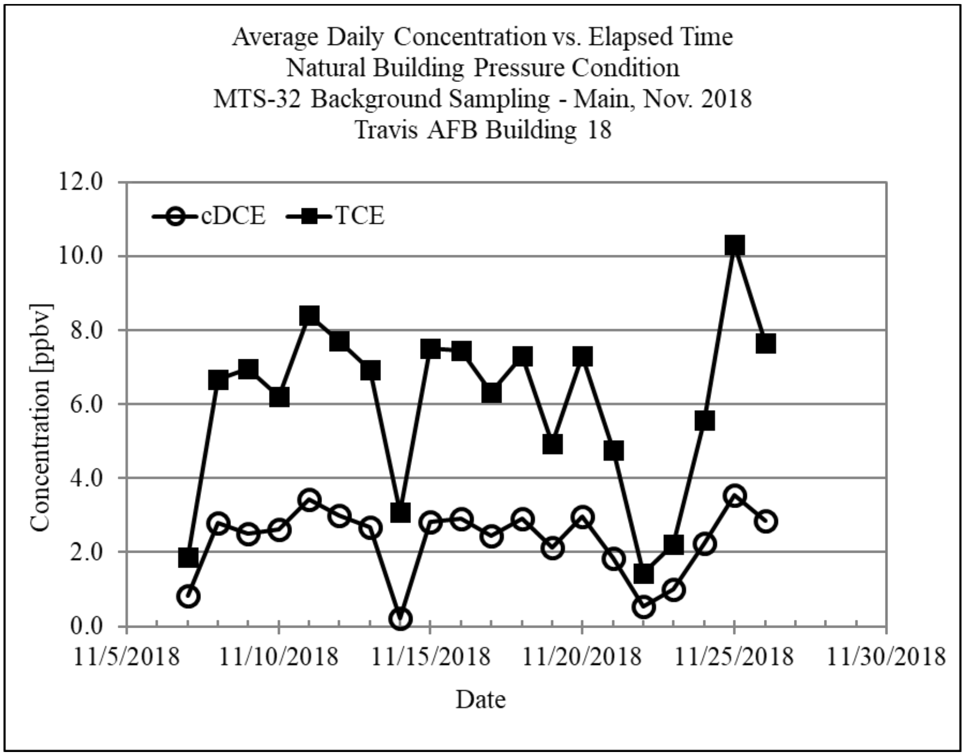


Figure 14. Average daily indoor air concentrations from 24-h MTS-32 TD tube auto-sampling for background vapor concentrations under natural building pressure conditions in the Main service bay, post CPM testing, Nov. 2018.

Positive Pressure CPM Testing Summary

Indoor air concentrations during positive pressure testing were detectable at concentrations above ambient outdoor concentrations, yet well below concentrations detected during negative pressure testing. As such, there was a complete VI pathway.

Regarding the low level detects during positive pressure testing, given the presence of a complete VI pathway and historic sub-slab vapor concentrations of 508,000 ppb_v (CH2MHILL, 2010), it is possible that the indoor air concentrations noted were a result of off gassing concrete and/or equipment that has been stored in a facility with VI.

Background Sampling Under Passive Building Pressure Conditions Summary

Results of background air sampling under passive building pressure conditions indicated that TCE was present in indoor air well in excess of the EPA screening levels of 0.08 ppb_v for residential and 0.65 ppb_v for industrial (USEPA, 2015/2020). Based on this data, there was a complete VI pathway present.

6. **CPM DEMONSTRATION CONCLUSIONS**

As stated in the Introduction, a complete VI pathway was defined as vapor intrusion with indoor vapor contaminant concentrations in excess of a regulatory limit or action level. Based on this definition and indoor air TCE concentrations during CPM testing that were well in excess of USEPA standards, there was a complete VI pathway for Building 18. This result was corroborated with more traditional active and passive sampling techniques within the building under natural pressure conditions.

Area specific indoor air TCE concentrations during negative pressure testing ranged from 0.9 to 119 ppb_v, the highest concentrations of which were noted in the southern portion of the building. This indicated the southern portion of the building was the dominant area for VI, which correlated with:

- the location of the bioreactor and groundwater plume source off the southern end of the building (see Fig. 1); and
- historic sub slab air sampling data which indicated vapor concentrations of 508,000 ppb_v (CH2MHILL, 2010) beneath the southern end of the building.

Field results, however, did not provide any clear information as to the specific pathway, nor was there a significant effort to define the pathway(s). Pathways could include cracks/joints in the concrete slab, or utility conduits such as sewer drains and/or subsurface utility corridors. In general, concentration data suggested that the showers, janitor closet with sink, and bathroom could be contributory, but the primary pathway was likely associated with the back corner office (Office 1). However, that room was covered with equipment/supplies and the only exposed floor was tiled and showed no suggestions of a pathway.

7. **REFERENCES**

CH2M Hill, 2013. Travis Air Force Base Environmental Restoration Program, Final Vapor Intrusion Assessment Update. Memorandum to the Dept. of the Air Force, 60th Civil Engineering Squadron.

2016 Annual GRISR, 2017. Limited reference - partial document received from Travis Air Force Base Environmental Restoration, 2016_Annual_GRISR_21Apr2017_document.

USEPA, 2020. Indoor Air Unit Conversion. Online Tools for Site Assessment Calculation website: https://www3.epa.gov/ceampubl/learn2model/part-two/onsite/ia_unit_conversion.html

USEPA, 2015. Regional Screening Level (RSL) Summary Table June 2015 (revised) https://archive.epa.gov/region9/superfund/web/pdf/master_sl_table_run_june2015_rev.pdf

USEPA, 2020. Regional Screening Level (RSL) Summary Table (TR=1E-06, HQ=1) May 2020 (corrected). https://semspub.epa.gov/work/HQ/200043.pdf

Appendix 18A
Background Indoor Air Sampling - Active TD Tube Results
Analytical Report

(Only sample IDs with a prefix of “Tr 18”
are related to Travis AFB, Bldg. 18)

BEACON ENVIRONMENTAL SERVICES, INC.

The Leaders in Air Surveys and Vapor Intrusion Monitoring

Arizona State University
660 South College Avenue, Room 507
Tempe, AZ 85281
Attn: Paul Dahlen

Air Samples -- Analytical Report

Date: June 17, 2020
Beacon Project No. 4459.1A

Project Reference:	Beale and Travis AFB
Sampling Date:	November 2 through 8, 2018
Samples Received:	December 11, 2018
Analyses Completed:	December 13, 2018

Results for the following samples are included in this data package:

Sample ID	Matrix	Analysis
BTheaterStageL	Air	TO-17
BtheaterStageL_B_Up	Air	TO-17
BTheaterLobby	Air	TO-17
BtheaterLobby_B_Up	Air	TO-17
BTheaterWRR	Air	TO-17
BTheaterWRR_B_Up	Air	TO-17
BTheaterStageWRR	Air	TO-17
BTheaterStageWRR_B_Up	Air	TO-17
Tr18Main	Air	TO-17
Tr18Main_B_Up	Air	TO-17
Tr18Hall	Air	TO-17
Tr18Hall_B_Up	Air	TO-17
Tr18SEOffice	Air	TO-17
Tr18SEOffice_B_Up	Air	TO-17
Tr18Shower1	Air	TO-17
Tr18Shower1_B_Up	Air	TO-17
BCACCafe	Air	TO-17
BCACCafe_B_Up	Air	TO-17
BCACBallR	Air	TO-17
BCACBallR_B_Up	Air	TO-17
BCACConf	Air	TO-17
BCACConf_B_Up	Air	TO-17
BCACOff	Air	TO-17
BCACOff_B_Up	Air	TO-17
BCACMRR	Air	TO-17
BCACMRR_B_Up	Air	TO-17
BCACWelcCtrOffR	Air	TO-17
BCACWelcCtrOffR_B_Up	Air	TO-17
BCACRec	Air	TO-17
BCACRec_B_Up	Air	TO-17

Sample Collection

Beacon Environmental provided Arizona State University with thermally conditioned multi-bed stainless steel tubes to target a custom list of analytes. Air was drawn through each tube and the resulting mass of target analytes captured on each sampler was reported as a concentration.

U. S. EPA Method TO-17

All samples were analyzed for a custom target compound list following U.S. EPA Method TO-17. The analytical results are reported in micrograms per meter cubed ($\mu g/m^3$) and ppbv based on the measured mass and volume of gas sampled.

Reporting Limits (RLs) for EPA Method TO-17

The lowest point in the calibration curve and the limit of quantitation (LOQ) is 10 nanograms (ng), which is the RL; however, when reporting concentration data the values are provided in $\mu g/m^3$ and ppbv. The RLs represent a baseline above which results exceed laboratory-determined limits of precision and accuracy.

Calibration Verification

The initial laboratory control sample (LCS) also serves as the calibration verification and values for the analytes were all within ±30% of the true values as defined by the initial five-point calibration and met the requirements specified in Beacon Environmental's Quality Manual. Both the LCS and the laboratory control duplicate (LCSD) are spiked at 50 ng and percentage of recovery is calculated and reported. Acceptance criteria for surrogate and analyte recoveries are 70 to 130 percent; all surrogates and analytes were within the acceptance criteria.

Internal Standards and Surrogates

Internal standards and surrogates are spiked on each field and QC sample at 100 ng and 50 ng, respectively, and the percentage of recovery is calculated. Acceptance criteria for internal standards are 60 to 140 percent and surrogate recoveries are 70 to 130 percent; all internal standards and surrogates were within the acceptance criteria.

Blank Contamination

No targeted compounds above the limit of detection (LOD) for each compound were observed in the Laboratory Method Blanks.

Discussion

Thirty (30) samples were collected following U.S. EPA Method TO-17. Sampling start and stop times, and total sampling volume can be found in the Chain of Custody (**Attachment 1**).

Dilutions were required for multiple samples, to bring the detected concentrations of reported compounds into the calibration range of the GC/MSD instrument. The LOQs of the diluted sample results are higher and noted in **Table 1**.

Demonstrated Linear Range of the GC-MS Instrumentation (EPA Method TO-17)

An initial five-point calibration is performed on the instrumentation from 10 to 200 ng per analyte.

Attachments:

-1- Chain of Custody

ALL DATA MEET REQUIREMENTS AS SPECIFIED IN THE BEACON ENVIRONMENTAL SERVICES, INC. QUALITY MANUAL AND THE RESULTS RELATE ONLY TO THE SAMPLES REPORTED. BEACON ENVIRONMENTAL SERVICES IS ACCREDITED TO ISO/IEC 17025:2005, AND THE WORK PERFORMED WAS IN ACCORDANCE WITH ISO/IEC 17025 REQUIREMENTS. THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY. RELEASE OF THE DATA HAS BEEN AUTHORIZED BY THE LABORATORY DIRECTOR OR HIS SIGNEE, AS VERIFIED BY THE FOLLOWING SIGNATURES:

Steven C. Thornley
Laboratory Director

Date: June 17, 2020

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LCS_1078673_181212

Analysis	Lab FileID
initial	K18121202
1st Dilution	
2nd Dilution	
3rd Dilution	

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**102%**	%REC	70-130	12/12/18 12:47	K18121202
trans-1,2-Dichloroethene	156-60-5	**103%**	%REC	70-130	12/12/18 12:47	K18121202
1,1-Dichloroethane	75-34-3	**102%**	%REC	70-130	12/12/18 12:47	K18121202
cis-1,2-Dichloroethene	156-59-2	**107%**	%REC	70-130	12/12/18 12:47	K18121202
Chloroform	67-66-3	**105%**	%REC	70-130	12/12/18 12:47	K18121202
1,2-Dichloroethane	107-06-2	**110%**	%REC	70-130	12/12/18 12:47	K18121202
1,1,1-Trichloroethane	71-55-6	**108%**	%REC	70-130	12/12/18 12:47	K18121202
Trichloroethene	79-01-6	**112%**	%REC	70-130	12/12/18 12:47	K18121202
Bromodichloromethane	75-27-4	**113%**	%REC	70-130	12/12/18 12:47	K18121202
Dibromochloromethane	124-48-1	**109%**	%REC	70-130	12/12/18 12:47	K18121202
Tetrachloroethene	127-18-4	**96%**	%REC	70-130	12/12/18 12:47	K18121202
Bromoform	75-25-2	**109%**	%REC	70-130	12/12/18 12:47	K18121202

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LB_1078524_181212

Client:	Analysis	Lab FileID
Arizon State University	initial	K18121203
660 South College Avenue, Room 507	1st Dilution	
Tempe, AZ 85281	2nd Dilution	
ph: 480-385-9671	3rd Dilution	

COMPOUNDS	CAS#						
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 13:07	K18121203
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 13:07	K18121203
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 13:07	K18121203
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 13:07	K18121203
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 13:07	K18121203
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 13:07	K18121203
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/12/18 13:07	K18121203
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 13:07	K18121203
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 13:07	K18121203
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 13:07	K18121203
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 13:07	K18121203
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 13:07	K18121203

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: **LCSD_1078697_181212**

Client:	Analysis	Lab File ID
Arizon State University	**initial**	K18121204
660 South College Avenue, Room 507	1st Dilution	
Tempe, AZ 85281	2nd Dilution	
ph: 480-385-9671	3rd Dilution	

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**91%**	%REC	70-130	12/12/18 13:27	K18121204
trans-1,2-Dichloroethene	156-60-5	**95%**	%REC	70-130	12/12/18 13:27	K18121204
1,1-Dichloroethane	75-34-3	**98%**	%REC	70-130	12/12/18 13:27	K18121204
cis-1,2-Dichloroethene	156-59-2	**101%**	%REC	70-130	12/12/18 13:27	K18121204
Chloroform	67-66-3	**102%**	%REC	70-130	12/12/18 13:27	K18121204
1,2-Dichloroethane	107-06-2	**107%**	%REC	70-130	12/12/18 13:27	K18121204
1,1,1-Trichloroethane	71-55-6	**103%**	%REC	70-130	12/12/18 13:27	K18121204
Trichloroethene	79-01-6	**111%**	%REC	70-130	12/12/18 13:27	K18121204
Bromodichloromethane	75-27-4	**112%**	%REC	70-130	12/12/18 13:27	K18121204
Dibromochloromethane	124-48-1	**111%**	%REC	70-130	12/12/18 13:27	K18121204
Tetrachloroethene	127-18-4	**100%**	%REC	70-130	12/12/18 13:27	K18121204
Bromoform	75-25-2	**111%**	%REC	70-130	12/12/18 13:27	K18121204

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterStageL
Lab Sample ID:	1078601
Sample Collection Time:	11/26/18 3:13 PM
Sample Volume in Liters:	155.72
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121205	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 13:51	K18121205
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 13:51	K18121205
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 13:51	K18121205
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 13:51	K18121205
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 13:51	K18121205
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 13:51	K18121205
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 13:51	K18121205
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 13:51	K18121205
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 13:51	K18121205
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 13:51	K18121205
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 13:51	K18121205
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 13:51	K18121205

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterStageL_B_up
Lab Sample ID:	1078544
Sample Collection Time:	11/26/18 3:13 PM
Sample Volume in Liters:	155.72
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121206	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 14:16	K18121206
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 14:16	K18121206
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 14:16	K18121206
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 14:16	K18121206
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 14:16	K18121206
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 14:16	K18121206
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 14:16	K18121206
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 14:16	K18121206
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 14:16	K18121206
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 14:16	K18121206
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 14:16	K18121206
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 14:16	K18121206

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterLobby
Lab Sample ID:	1078895
Sample Collection Time:	11/26/18 2:55 PM
Sample Volume in Liters:	156.31
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121207	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 14:40	K18121207
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 14:40	K18121207
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 14:40	K18121207
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 14:40	K18121207
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 14:40	K18121207
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 14:40	K18121207
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 14:40	K18121207
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 14:40	K18121207
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 14:40	K18121207
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 14:40	K18121207
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 14:40	K18121207
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 14:40	K18121207

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BTheaterLobby_B_up
Lab Sample ID: 1078651
Sample Collection Time: 11/26/18 2:55 PM
Sample Volume in Liters: 156.31
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121208	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 15:05	K18121208
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 15:05	K18121208
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 15:05	K18121208
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 15:05	K18121208
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 15:05	K18121208
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 15:05	K18121208
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 15:05	K18121208
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 15:05	K18121208
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 15:05	K18121208
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 15:05	K18121208
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 15:05	K18121208
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 15:05	K18121208

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterWRR
Lab Sample ID:	1078606
Sample Collection Time:	11/26/18 3:07 PM
Sample Volume in Liters:	138.05
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121209	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 15:29	K18121209
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 15:29	K18121209
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 15:29	K18121209
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 15:29	K18121209
Chloroform	67-66-3	**0.09**	0.1	**0.02**	0.01	12/12/18 15:29	K18121209
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 15:29	K18121209
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 15:29	K18121209
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 15:29	K18121209
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 15:29	K18121209
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 15:29	K18121209
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 15:29	K18121209
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 15:29	K18121209

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BTheaterWRR_B_up
Lab Sample ID: 1078803
Sample Collection Time: 11/26/18 3:07 PM
Sample Volume in Liters: 138.05
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121210	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 15:53	K18121210
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 15:53	K18121210
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 15:53	K18121210
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 15:53	K18121210
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 15:53	K18121210
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 15:53	K18121210
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 15:53	K18121210
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 15:53	K18121210
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 15:53	K18121210
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 15:53	K18121210
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 15:53	K18121210
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 15:53	K18121210

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Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121211	1
1st Dilution		
2nd Dilution		
3rd Dilution		

Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BTheaterStageWRR
Lab Sample ID: 1078556
Sample Collection Time: 11/26/18 3:18 PM
Sample Volume in Liters: 161.68
Date Received: 12/11/2018

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 16:17	K18121211
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 16:17	K18121211
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 16:17	K18121211
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 16:17	K18121211
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 16:17	K18121211
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 16:17	K18121211
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 16:17	K18121211
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 16:17	K18121211
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 16:17	K18121211
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 16:17	K18121211
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 16:17	K18121211
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 16:17	K18121211

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BTheaterStageWRR_B_up
Lab Sample ID: 1078769
Sample Collection Time: 11/26/18 3:18 PM
Sample Volume in Liters: 161.68
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab FileID	Dilution Factor
initial	K18121212	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 16:42	K18121212
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 16:42	K18121212
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 16:42	K18121212
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 16:42	K18121212
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 16:42	K18121212
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 16:42	K18121212
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 16:42	K18121212
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 16:42	K18121212
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 16:42	K18121212
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 16:42	K18121212
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 16:42	K18121212
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 16:42	K18121212

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: Tr18Main
Lab Sample ID: 1078557
Sample Collection Time: 11/27/18 4:36 PM
Sample Volume in Liters: 65.64
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121213	1
1st Dilution	K18121305	8.49
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.2	U	0.04	12/12/18 17:06	K18121213
trans-1,2-Dichloroethene	156-60-5	U	0.2	U	0.04	12/12/18 17:06	K18121213
1,1-Dichloroethane	75-34-3	U	0.2	U	0.04	12/12/18 17:06	K18121213
cis-1,2-Dichloroethene	156-59-2	**1.6**	0.2	**0.4**	0.04	12/12/18 17:06	K18121213
Chloroform	67-66-3	U	0.2	U	0.03	12/12/18 17:06	K18121213
1,2-Dichloroethane	107-06-2	U	0.2	U	0.04	12/12/18 17:06	K18121213
1,1,1-Trichloroethane	71-55-6	U	0.2	U	0.03	12/12/18 17:06	K18121213
Trichloroethene	79-01-6	**12.05 D**	1.3	**2.24 D**	0.24	12/13/18 11:03	K18121305
Bromodichloromethane	75-27-4	U	0.2	U	0.02	12/12/18 17:06	K18121213
Dibromochloromethane	124-48-1	U	0.2	U	0.02	12/12/18 17:06	K18121213
Tetrachloroethene	127-18-4	U	0.2	U	0.02	12/12/18 17:06	K18121213
Bromoform	75-25-2	U	0.2	U	0.01	12/12/18 17:06	K18121213

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18Main_B_up
Lab Sample ID:	1078647
Sample Collection Time:	11/27/18 4:36 PM
Sample Volume in Liters:	65.64
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121214	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.2	U	0.04	12/12/18 17:30	K18121214
trans-1,2-Dichloroethene	156-60-5	U	0.2	U	0.04	12/12/18 17:30	K18121214
1,1-Dichloroethane	75-34-3	U	0.2	U	0.04	12/12/18 17:30	K18121214
cis-1,2-Dichloroethene	156-59-2	U	0.2	U	0.04	12/12/18 17:30	K18121214
Chloroform	67-66-3	U	0.2	U	0.03	12/12/18 17:30	K18121214
1,2-Dichloroethane	107-06-2	U	0.2	U	0.04	12/12/18 17:30	K18121214
1,1,1-Trichloroethane	71-55-6	U	0.2	U	0.03	12/12/18 17:30	K18121214
Trichloroethene	79-01-6	U	0.2	U	0.03	12/12/18 17:30	K18121214
Bromodichloromethane	75-27-4	U	0.2	U	0.02	12/12/18 17:30	K18121214
Dibromochloromethane	124-48-1	U	0.2	U	0.02	12/12/18 17:30	K18121214
Tetrachloroethene	127-18-4	U	0.2	U	0.02	12/12/18 17:30	K18121214
Bromoform	75-25-2	U	0.2	U	0.01	12/12/18 17:30	K18121214

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18Hall
Lab Sample ID:	1078637
Sample Collection Time:	11/27/18 4:21 PM
Sample Volume in Liters:	68.60
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121215	1
1st Dilution	K18121306	8.5
2nd Dilution	K18121309	42.8
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.04	12/12/18 17:55	K18121215
trans-1,2-Dichloroethene	156-60-5	**0.19**	0.1	**0.05**	0.04	12/12/18 17:55	K18121215
1,1-Dichloroethane	75-34-3	U	0.1	U	0.04	12/12/18 17:55	K18121215
cis-1,2-Dichloroethene	156-59-2	**6.95 D**	1.2	**1.75 D**	0.31	12/13/18 11:26	K18121306
Chloroform	67-66-3	U	0.1	U	0.03	12/12/18 17:55	K18121215
1,2-Dichloroethane	107-06-2	U	0.1	U	0.04	12/12/18 17:55	K18121215
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.03	12/12/18 17:55	K18121215
Trichloroethene	79-01-6	**35.21 D**	6.2	**6.55 D**	1.16	12/13/18 12:46	K18121309
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/12/18 17:55	K18121215
Dibromochloromethane	124-48-1	U	0.1	U	0.02	12/12/18 17:55	K18121215
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/12/18 17:55	K18121215
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 17:55	K18121215

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18Hall_B_up
Lab Sample ID:	1078511
Sample Collection Time:	11/27/18 4:21 PM
Sample Volume in Liters:	68.60
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121216	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.04	12/12/18 18:19	K18121216
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.04	12/12/18 18:19	K18121216
1,1-Dichloroethane	75-34-3	U	0.1	U	0.04	12/12/18 18:19	K18121216
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.04	12/12/18 18:19	K18121216
Chloroform	67-66-3	U	0.1	U	0.03	12/12/18 18:19	K18121216
1,2-Dichloroethane	107-06-2	U	0.1	U	0.04	12/12/18 18:19	K18121216
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.03	12/12/18 18:19	K18121216
Trichloroethene	79-01-6	U	0.1	U	0.03	12/12/18 18:19	K18121216
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/12/18 18:19	K18121216
Dibromochloromethane	124-48-1	U	0.1	U	0.02	12/12/18 18:19	K18121216
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/12/18 18:19	K18121216
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 18:19	K18121216

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18SEOffice
Lab Sample ID:	1078558
Sample Collection Time:	11/27/18 4:21 PM
Sample Volume in Liters:	56.66
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121217	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.2	U	0.04	12/12/18 18:46	K18121217
trans-1,2-Dichloroethene	156-60-5	**0.65**	0.2	**0.16**	0.04	12/12/18 18:46	K18121217
1,1-Dichloroethane	75-34-3	U	0.2	U	0.04	12/12/18 18:46	K18121217
cis-1,2-Dichloroethene	156-59-2	**13.75 E**	0.2	**3.47 E**	0.04	12/12/18 18:46	K18121217
Chloroform	67-66-3	U	0.2	U	0.04	12/12/18 18:46	K18121217
1,2-Dichloroethane	107-06-2	U	0.2	U	0.04	12/12/18 18:46	K18121217
1,1,1-Trichloroethane	71-55-6	U	0.2	U	0.03	12/12/18 18:46	K18121217
Trichloroethene	79-01-6	**61.03 E**	0.2	**11.36 E**	0.03	12/12/18 18:46	K18121217
Bromodichloromethane	75-27-4	U	0.2	U	0.03	12/12/18 18:46	K18121217
Dibromochloromethane	124-48-1	U	0.2	U	0.02	12/12/18 18:46	K18121217
Tetrachloroethene	127-18-4	**0.24**	0.2	**0.04**	0.03	12/12/18 18:46	K18121217
Bromoform	75-25-2	U	0.2	U	0.02	12/12/18 18:46	K18121217

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: Tr18SEOffice_B_up
Lab Sample ID: 1078666
Sample Collection Time: 11/27/18 4:21 PM
Sample Volume in Liters: 56.66
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121218	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.2	U	0.04	12/12/18 19:10	K18121218
trans-1,2-Dichloroethene	156-60-5	U	0.2	U	0.04	12/12/18 19:10	K18121218
1,1-Dichloroethane	75-34-3	U	0.2	U	0.04	12/12/18 19:10	K18121218
cis-1,2-Dichloroethene	156-59-2	U	0.2	U	0.04	12/12/18 19:10	K18121218
Chloroform	67-66-3	U	0.2	U	0.04	12/12/18 19:10	K18121218
1,2-Dichloroethane	107-06-2	U	0.2	U	0.04	12/12/18 19:10	K18121218
1,1,1-Trichloroethane	71-55-6	U	0.2	U	0.03	12/12/18 19:10	K18121218
Trichloroethene	79-01-6	U	0.2	U	0.03	12/12/18 19:10	K18121218
Bromodichloromethane	75-27-4	U	0.2	U	0.03	12/12/18 19:10	K18121218
Dibromochloromethane	124-48-1	U	0.2	U	0.02	12/12/18 19:10	K18121218
Tetrachloroethene	127-18-4	U	0.2	U	0.03	12/12/18 19:10	K18121218
Bromoform	75-25-2	U	0.2	U	0.02	12/12/18 19:10	K18121218

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18Shower1
Lab Sample ID:	1078519
Sample Collection Time:	11/27/18 4:41 PM
Sample Volume in Liters:	72.13
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121219	1
1st Dilution	K18121308	8.5
2nd Dilution	K18121310	42.8
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/12/18 19:35	K18121219
trans-1,2-Dichloroethene	156-60-5	**0.17**	0.1	**0.04**	0.03	12/12/18 19:35	K18121219
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/12/18 19:35	K18121219
cis-1,2-Dichloroethene	156-59-2	**8.06 D**	1.2	**2.03 D**	0.30	12/13/18 12:13	K18121308
Chloroform	67-66-3	**0.15**	0.1	**0.03**	0.03	12/12/18 19:35	K18121219
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/12/18 19:35	K18121219
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.03	12/12/18 19:35	K18121219
Trichloroethene	79-01-6	**39.04 D**	5.9	**7.26 D**	1.10	12/13/18 13:09	K18121310
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/12/18 19:35	K18121219
Dibromochloromethane	124-48-1	U	0.1	U	0.02	12/12/18 19:35	K18121219
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/12/18 19:35	K18121219
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 19:35	K18121219

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: Tr18Shower1_B_up
Lab Sample ID: 1078536
Sample Collection Time: 11/27/18 4:41 PM
Sample Volume in Liters: 72.13
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121220	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/12/18 19:59	K18121220
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.03	12/12/18 19:59	K18121220
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/12/18 19:59	K18121220
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.03	12/12/18 19:59	K18121220
Chloroform	67-66-3	U	0.1	U	0.03	12/12/18 19:59	K18121220
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/12/18 19:59	K18121220
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.03	12/12/18 19:59	K18121220
Trichloroethene	79-01-6	U	0.1	U	0.03	12/12/18 19:59	K18121220
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/12/18 19:59	K18121220
Dibromochloromethane	124-48-1	U	0.1	U	0.02	12/12/18 19:59	K18121220
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/12/18 19:59	K18121220
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 19:59	K18121220

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACCafe
Lab Sample ID:	1078661
Sample Collection Time:	11/26/18 4:18 PM
Sample Volume in Liters:	122.20
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121221	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 20:24	K18121221
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 20:24	K18121221
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 20:24	K18121221
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 20:24	K18121221
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 20:24	K18121221
1,2-Dichloroethane	107-06-2	**0.17**	0.1	**0.04**	0.02	12/12/18 20:24	K18121221
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 20:24	K18121221
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 20:24	K18121221
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 20:24	K18121221
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 20:24	K18121221
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 20:24	K18121221
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 20:24	K18121221

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Beacon Job Number: 4459.1A
Analysis Method: TO17
Matrix: Air
Client ID/Field Sampling Location: BCACCafe_B_up
Lab Sample ID: 1078610
Sample Collection Time: 11/26/18 4:18 PM
Sample Volume in Liters: 122.20
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121222	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 20:48	K18121222
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 20:48	K18121222
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 20:48	K18121222
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 20:48	K18121222
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 20:48	K18121222
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 20:48	K18121222
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 20:48	K18121222
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 20:48	K18121222
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 20:48	K18121222
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 20:48	K18121222
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 20:48	K18121222
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 20:48	K18121222

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACBallR
Lab Sample ID:	1078639
Sample Collection Time:	11/26/18 3:46 PM
Sample Volume in Liters:	112.72
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121223	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 21:13	K18121223
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 21:13	K18121223
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 21:13	K18121223
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 21:13	K18121223
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 21:13	K18121223
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 21:13	K18121223
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/12/18 21:13	K18121223
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 21:13	K18121223
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 21:13	K18121223
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 21:13	K18121223
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 21:13	K18121223
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 21:13	K18121223

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACBallR_B_up
Lab Sample ID:	1078687
Sample Collection Time:	11/26/18 3:46 PM
Sample Volume in Liters:	112.72
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121224	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 21:37	K18121224
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 21:37	K18121224
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 21:37	K18121224
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 21:37	K18121224
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 21:37	K18121224
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 21:37	K18121224
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/12/18 21:37	K18121224
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 21:37	K18121224
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 21:37	K18121224
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 21:37	K18121224
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 21:37	K18121224
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 21:37	K18121224

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: CL_LCS_1078733_181212

	Analysis	Lab FileID
Client:	initial	K18121225
Arizon State University	1st Dilution	
660 South College Avenue, Room 507	2nd Dilution	
Tempe, AZ 85281	3rd Dilution	
ph: 480-385-9671		

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**81%**	%REC	50-150	12/12/18 21:57	K18121225
trans-1,2-Dichloroethene	156-60-5	**96%**	%REC	50-150	12/12/18 21:57	K18121225
1,1-Dichloroethane	75-34-3	**100%**	%REC	50-150	12/12/18 21:57	K18121225
cis-1,2-Dichloroethene	156-59-2	**101%**	%REC	50-150	12/12/18 21:57	K18121225
Chloroform	67-66-3	**100%**	%REC	50-150	12/12/18 21:57	K18121225
1,2-Dichloroethane	107-06-2	**98%**	%REC	50-150	12/12/18 21:57	K18121225
1,1,1-Trichloroethane	71-55-6	**111%**	%REC	50-150	12/12/18 21:57	K18121225
Trichloroethene	79-01-6	**110%**	%REC	50-150	12/12/18 21:57	K18121225
Bromodichloromethane	75-27-4	**103%**	%REC	50-150	12/12/18 21:57	K18121225
Dibromochloromethane	124-48-1	**98%**	%REC	50-150	12/12/18 21:57	K18121225
Tetrachloroethene	127-18-4	**94%**	%REC	50-150	12/12/18 21:57	K18121225
Bromoform	75-25-2	**109%**	%REC	50-150	12/12/18 21:57	K18121225

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LCS_1078851_181213

Client:	Analysis	Lab FileID
	initial	K18121313
Arizon State University	1st Dilution	
660 South College Avenue, Room 507	2nd Dilution	
Tempe, AZ 85281	3rd Dilution	
ph: 480-385-9671		

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**109%**	%REC	70-130	12/13/18 16:35	K18121313
trans-1,2-Dichloroethene	156-60-5	**103%**	%REC	70-130	12/13/18 16:35	K18121313
1,1-Dichloroethane	75-34-3	**106%**	%REC	70-130	12/13/18 16:35	K18121313
cis-1,2-Dichloroethene	156-59-2	**109%**	%REC	70-130	12/13/18 16:35	K18121313
Chloroform	67-66-3	**105%**	%REC	70-130	12/13/18 16:35	K18121313
1,2-Dichloroethane	107-06-2	**106%**	%REC	70-130	12/13/18 16:35	K18121313
1,1,1-Trichloroethane	71-55-6	**112%**	%REC	70-130	12/13/18 16:35	K18121313
Trichloroethene	79-01-6	**111%**	%REC	70-130	12/13/18 16:35	K18121313
Bromodichloromethane	75-27-4	**105%**	%REC	70-130	12/13/18 16:35	K18121313
Dibromochloromethane	124-48-1	**101%**	%REC	70-130	12/13/18 16:35	K18121313
Tetrachloroethene	127-18-4	**105%**	%REC	70-130	12/13/18 16:35	K18121313
Bromoform	75-25-2	**100%**	%REC	70-130	12/13/18 16:35	K18121313

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LB_1078571_181213

Analysis	Lab FileID
initial	K18121314
1st Dilution	
2nd Dilution	
3rd Dilution	

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

COMPOUNDS	CAS#						
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/13/18 16:55	K18121314
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.03	12/13/18 16:55	K18121314
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/13/18 16:55	K18121314
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.03	12/13/18 16:55	K18121314
Chloroform	67-66-3	U	0.1	U	0.03	12/13/18 16:55	K18121314
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/13/18 16:55	K18121314
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 16:55	K18121314
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 16:55	K18121314
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/13/18 16:55	K18121314
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 16:55	K18121314
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/13/18 16:55	K18121314
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 16:55	K18121314

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LCSD_1078816_181213

Client:	Analysis	Lab File ID
Arizon State University	**initial**	K18121315
660 South College Avenue, Room 507	1st Dilution	
Tempe, AZ 85281	2nd Dilution	
ph: 480-385-9671	3rd Dilution	

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**103%**	%REC	70-130	12/13/18 17:15	K18121315
trans-1,2-Dichloroethene	156-60-5	**110%**	%REC	70-130	12/13/18 17:15	K18121315
1,1-Dichloroethane	75-34-3	**111%**	%REC	70-130	12/13/18 17:15	K18121315
cis-1,2-Dichloroethene	156-59-2	**113%**	%REC	70-130	12/13/18 17:15	K18121315
Chloroform	67-66-3	**111%**	%REC	70-130	12/13/18 17:15	K18121315
1,2-Dichloroethane	107-06-2	**112%**	%REC	70-130	12/13/18 17:15	K18121315
1,1,1-Trichloroethane	71-55-6	**111%**	%REC	70-130	12/13/18 17:15	K18121315
Trichloroethene	79-01-6	**116%**	%REC	70-130	12/13/18 17:15	K18121315
Bromodichloromethane	75-27-4	**114%**	%REC	70-130	12/13/18 17:15	K18121315
Dibromochloromethane	124-48-1	**107%**	%REC	70-130	12/13/18 17:15	K18121315
Tetrachloroethene	127-18-4	**101%**	%REC	70-130	12/13/18 17:15	K18121315
Bromoform	75-25-2	**105%**	%REC	70-130	12/13/18 17:15	K18121315

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BCACConf
Lab Sample ID: 1078562
Sample Collection Time: 11/26/18 4:36 PM
Sample Volume in Liters: 115.77
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121316	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 17:40	K18121316
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 17:40	K18121316
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 17:40	K18121316
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 17:40	K18121316
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 17:40	K18121316
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 17:40	K18121316
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 17:40	K18121316
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 17:40	K18121316
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 17:40	K18121316
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 17:40	K18121316
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 17:40	K18121316
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 17:40	K18121316

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACConf_B_up
Lab Sample ID:	1078546
Sample Collection Time:	11/26/18 4:36 PM
Sample Volume in Liters:	115.77
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121317	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 18:04	K18121317
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 18:04	K18121317
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 18:04	K18121317
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 18:04	K18121317
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 18:04	K18121317
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 18:04	K18121317
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 18:04	K18121317
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 18:04	K18121317
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 18:04	K18121317
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 18:04	K18121317
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 18:04	K18121317
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 18:04	K18121317

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACOff
Lab Sample ID:	1078892
Sample Collection Time:	11/26/18 4:09 PM
Sample Volume in Liters:	112.85
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121318	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 18:29	K18121318
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 18:29	K18121318
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 18:29	K18121318
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 18:29	K18121318
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 18:29	K18121318
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 18:29	K18121318
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 18:29	K18121318
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 18:29	K18121318
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 18:29	K18121318
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 18:29	K18121318
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 18:29	K18121318
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 18:29	K18121318

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACOff_B_up
Lab Sample ID:	1078504
Sample Collection Time:	11/26/18 4:09 PM
Sample Volume in Liters:	112.85
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121319	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 18:53	K18121319
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 18:53	K18121319
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 18:53	K18121319
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 18:53	K18121319
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 18:53	K18121319
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 18:53	K18121319
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 18:53	K18121319
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 18:53	K18121319
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 18:53	K18121319
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 18:53	K18121319
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 18:53	K18121319
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 18:53	K18121319

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

nvironmental Services, Inc.
A Commerce Road Suite 1
orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACMRR
Lab Sample ID:	1078804
Sample Collection Time:	11/26/18 4:17 PM
Sample Volume in Liters:	106.18
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121320	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 19:18	K18121320
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 19:18	K18121320
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 19:18	K18121320
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 19:18	K18121320
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 19:18	K18121320
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 19:18	K18121320
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 19:18	K18121320
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 19:18	K18121320
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 19:18	K18121320
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 19:18	K18121320
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 19:18	K18121320
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 19:18	K18121320

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nvironmental Services, Inc.
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orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BCACMRR_B_up
Lab Sample ID: 1078608
Sample Collection Time: 11/26/18 4:17 PM
Sample Volume in Liters: 106.18
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121321	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 19:42	K18121321
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 19:42	K18121321
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 19:42	K18121321
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 19:42	K18121321
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 19:42	K18121321
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 19:42	K18121321
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 19:42	K18121321
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 19:42	K18121321
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 19:42	K18121321
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 19:42	K18121321
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 19:42	K18121321
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 19:42	K18121321

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

nvironmental Services, Inc.
A Commerce Road Suite 1
orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BCACWelcCtrOffR
Lab Sample ID: 1078898
Sample Collection Time: 11/26/18 4:32 PM
Sample Volume in Liters: 134.11
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121322	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 20:07	K18121322
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 20:07	K18121322
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 20:07	K18121322
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 20:07	K18121322
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 20:07	K18121322
1,2-Dichloroethane	107-06-2	**0.36**	0.1	**0.09**	0.02	12/13/18 20:07	K18121322
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/13/18 20:07	K18121322
Trichloroethene	79-01-6	U	0.1	U	0.01	12/13/18 20:07	K18121322
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 20:07	K18121322
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 20:07	K18121322
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 20:07	K18121322
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 20:07	K18121322

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nvironmental Services, Inc.
A Commerce Road Suite 1
orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BCACWelcCtrOffR_B_up
Lab Sample ID: 1078835
Sample Collection Time: 11/26/18 4:32 PM
Sample Volume in Liters: 134.11
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab FileID	Dilution Factor
initial	K18121323	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 20:31	K18121323
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 20:31	K18121323
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 20:31	K18121323
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 20:31	K18121323
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 20:31	K18121323
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 20:31	K18121323
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/13/18 20:31	K18121323
Trichloroethene	79-01-6	U	0.1	U	0.01	12/13/18 20:31	K18121323
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 20:31	K18121323
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 20:31	K18121323
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 20:31	K18121323
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 20:31	K18121323

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed

nvironmental Services, Inc.
A Commerce Road Suite 1
orest Hill, MD 21050 USA
ph:410-838-8780
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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACRec
Lab Sample ID:	1078765
Sample Collection Time:	11/26/18 4:26 PM
Sample Volume in Liters:	81.68
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121324	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/13/18 20:56	K18121324
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.03	12/13/18 20:56	K18121324
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/13/18 20:56	K18121324
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.03	12/13/18 20:56	K18121324
Chloroform	67-66-3	U	0.1	U	0.03	12/13/18 20:56	K18121324
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/13/18 20:56	K18121324
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 20:56	K18121324
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 20:56	K18121324
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/13/18 20:56	K18121324
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 20:56	K18121324
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/13/18 20:56	K18121324
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 20:56	K18121324

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nvironmental Services, Inc.
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orest Hill, MD 21050 USA
ph:410-838-8780
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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACRec_B_up
Lab Sample ID:	1078672
Sample Collection Time:	11/26/18 4:26 PM
Sample Volume in Liters:	81.68
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121325	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/13/18 21:20	K18121325
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.03	12/13/18 21:20	K18121325
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/13/18 21:20	K18121325
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.03	12/13/18 21:20	K18121325
Chloroform	67-66-3	U	0.1	U	0.03	12/13/18 21:20	K18121325
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/13/18 21:20	K18121325
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 21:20	K18121325
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 21:20	K18121325
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/13/18 21:20	K18121325
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 21:20	K18121325
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/13/18 21:20	K18121325
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 21:20	K18121325

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nvironmental Services, Inc.
A Commerce Road Suite 1
orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number:
Analysis Method: TO17
Matrix: QC

Lab Sample ID: CL_LCS_1078865_181213

Client:	Analysis	Lab FileID
Arizon State University	initial	K18121329
660 South College Avenue, Room 507	1st Dilution	
Tempe, AZ 85281	2nd Dilution	
ph: 480-385-9671	3rd Dilution	

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**78%**	%REC	50-150	12/13/18 22:41	K18121329
trans-1,2-Dichloroethene	156-60-5	**92%**	%REC	50-150	12/13/18 22:41	K18121329
1,1-Dichloroethane	75-34-3	**101%**	%REC	50-150	12/13/18 22:41	K18121329
cis-1,2-Dichloroethene	156-59-2	**98%**	%REC	50-150	12/13/18 22:41	K18121329
Chloroform	67-66-3	**99%**	%REC	50-150	12/13/18 22:41	K18121329
1,2-Dichloroethane	107-06-2	**97%**	%REC	50-150	12/13/18 22:41	K18121329
1,1,1-Trichloroethane	71-55-6	**115%**	%REC	50-150	12/13/18 22:41	K18121329
Trichloroethene	79-01-6	**103%**	%REC	50-150	12/13/18 22:41	K18121329
Bromodichloromethane	75-27-4	**100%**	%REC	50-150	12/13/18 22:41	K18121329
Dibromochloromethane	124-48-1	**101%**	%REC	50-150	12/13/18 22:41	K18121329
Tetrachloroethene	127-18-4	**96%**	%REC	50-150	12/13/18 22:41	K18121329
Bromoform	75-25-2	**106%**	%REC	50-150	12/13/18 22:41	K18121329

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

Attachment 1

Chain of Custody

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1. Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Manager: Paul Dahlen	BEACON Project No.: 4459
Company:	ASU SSEBE	Phone: 480-727-2960	Client PO No.
Address:	POB 873005	Project Name: Beale AFB	Analysis Turnaround Time
City/State/Zip:	Tempe AZ 85287	Location: Theater	✓ Normal
Phone:	480-727-2960	Sampler Name(s): Paul Dahlen	Rush (Specify): ____ days

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	Analysis: TO-17	Analysis: 8260B	Analysis: TICs	Matrix: Indoor/Ambient Air	Matrix: Soil Gas
BTheater-StageL	1078601	2	11/2/18	0925	11/26/18	1513	40.61	39.66	155.72				✓	
BTheater-StageL BUA	1078544	2	"	"	"	"	"	"	"				✓	
BTheater-Lobby	1078895	6	11/2/18	1030	11/26/18	1455	40.59	40.13	156.31				✓	
ATheater-Lobby BUA	1078651	6	"	"	"	"	"	"	"				✓	
BTheater-WRR	1078606	9	11/5/18	0831	11/26/18	1507	35.80	35.49	138.05				✓	
BTheater-WRR BUA	1078803	9	"	"	"	"	"	"	"				✓	
BTheater-StageWRR	1078556	11	11/2/18	0946	11/26/18	1518	41.48	42.01	161.68				✓	
BTheater-StageWRR BUP	1078769	11	"	"	"	"	"	"	"				✓	

Ambient Conditions When Sampling

	Temperature (F)	Barometric Pressure (mmHg)	Date
Start	70		
Stop			

Pump(s) Calibration and Flow Rate Check:

Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Pre-Survey			
Post-Survey			

Special Notes/Instructions:

Relinquished by: (signature) Paul Dahlen	Date/Time: 12/10/18 1300	Received by: (signature) Courier	Date/Time:
Relinquished by: (signature)	Date/Time:	Received by: (signature) Steven Thornley	Date/Time: 12.11.18 / 1500
Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	Fedex	✓		Yes No None	

Beacon Project 4459 1A -- Page 43 of 46

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1. Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Information		BEACON Project No.: 4459	
Company:	ASU SSEBE	Project Manager:	Paul Dahlen	Client PO No.	
Address:	POB 873005	Phone:	480-727-2960	Analysis Turnaround Time	
City/State/Zip:	Tempe AZ 85287	Project Name:	Travis	✓ Normal	
Phone:	480-727-2960	Location:	Bldg 18	Rush (Specify): ____ days	
		Sampler Name(s):	Paul Dahlen		

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	TO-17	8260B	TICs	Indoor/Ambient Air	Soil Gas
Tr18 Main	1078557	5	11/7/18	1558	11/27/18	1636	41.60	40.20	65.64				✓	
Tr18 Main B/A	1078647	5	↓	1558	↓	1636	"	"	"				✓	
Tr18 Hall	1078637	3	↓	1614	↓	1621	42.93	42.82	68.60				✓	
Tr18 Hall B/A	1078511	3	↓	1614	↓	1621	"	"	"				✓	
Tr18 SE Office	1078558	13	↓	1614	↓	1621	35.82	35.00	56.66				✓	
Tr18 SE Office B/A	1078666	13	↓	1614	↓	1621	"	"	"				✓	
Tr18 Shower 1	1078519	14	↓	1625	↓	1641	45.53	44.35	72.13				✓	
Tr18 Shower 1 B/A	1078536	14	↓	1625	↓	1641	"	"	"				✓	

Ambient Conditions When Sampling

	Temperature (F)	Barometric Pressure (mmHg)	Date
Start	68		
Stop			

Pump(s) Calibration and Flow Rate Check:

Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Pre-Survey			
Post-Survey			

Special Notes/Instructions: See SS for additional sampling data

Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:
Paul Dahlen	12/10/18 1300	Courier	
		Steven Thornley	12.11.18/1500

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	Fedex	✓		Yes No None	

Beacon Project 4459-A - Page 44 of 46

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1. Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information	Project information	
Company: ASU SSEBE	Project Manager: Paul Dahlen	BEACON Project No.: 4459
Address: PO B 873005	Phone: 480-727-2960	Client PO No.
City/State/Zip: Tempe AZ 85287	Project Name: Beale AFB	Analysis Turnaround Time: ✓ Normal
Phone: 480-727-2960	Location: CAC	Rush (Specify): ____ days
	Sampler Name(s): Paul Dahlen	

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	TO-17	8260B	TICs	Indoor/Ambient Air	Soil Gas
BCAC Cafe	1078661	10	11/8/18	1747	11/26/18	1618	43.44	41.57	122.20				✓	
BCAC Cafe B dup	1078610	10		"		"	"	"	"				✓	
BCAC Ball R	1078639	8		1606		1546	39.93	38.24	112.72				✓	
BCAC Ball R B dup	1078687	8		"		"	"	"	"				✓	
BCAC Conf	1078562	4		1635		1636	40.52	39.82	115.77				✓	
BCAC Conf B dup	1078546	4		"		"	"	"	"				✓	
BCAC Off	1078892	6		1716		1609	39.82	38.63	112.85				✓	
BCAC Off B dup	1078504	6		"		"	"	"	"				✓	
BCAC MRR	1078804	7		1826		1617	37.57	36.58	106.18				✓	
BCAC MRR B dup	1078608	7	↓	"	↓	"	"	"	"				✓	

Ambient Conditions When Sampling

	Temperature (F)	Barometric Pressure (mmHg)	Date
Start	71		
Stop			

Pump(s) Calibration and Flow Rate Check:

Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Pre-Survey			
Post-Survey			

Special Notes/Instructions:

Relinquished by: (signature) Paul Dahlen	Date/Time: 12/10/18 1300	Received by: (signature) Courier	Date/Time:
Relinquished by: (signature)	Date/Time:	Received by: (signature) Steven Thornley	Date/Time: 12.11.18 / 1500
Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	Fedex	✓		Yes No None	

Beacon Project 4459 IA – Page 45 of 46

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1. Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Manager: Paul Dahlen	BEACON Project No.: 4459
Company:	ASU SSEBE	Phone: 480-727-2960	Client PO No.
Address:	POB 873005	Project Name: Beale AFB	Analysis Turnaround Time: Normal ✓
City/State/Zip:	Tempe AZ 85287	Location: CAC	Rush (Specify): ____ days
Phone:	480-727-2960	Sampler Name(s): Paul Dahlen	

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	TO-17	8260B	TICs	Indoor/Ambient Air	Soil Gas
BCACWelcCtrOffR	1078898	3	11/8/18	1807	11/26/18	1632	46.14	47.48	134.11				✓	
BCACWelcCtrOffR Dup	1078835	3	↓	"	↓	"	"	"	"				✓	
BCACRec	1078765	12	↓	1847	↓	1626	31.44	25.58	81.68				✓	
BCACRec Bp	1078672	12	↓	"	↓	"	"	"	"				✓	

Ambient Conditions When Sampling

	Temperature (F)	Barometric Pressure (mmHg)	Date
Start	71		
Stop			

Pump(s) Calibration and Flow Rate Check:

Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Pre-Survey			
Post-Survey			

Special Notes/Instructions:

Relinquished by: (signature) Paul Dahlen	Date/Time: 12/10/18 1300	Received by: (signature) Gurier	Date/Time:
Relinquished by: (signature)	Date/Time:	Received by: (signature) Steven Thornley	Date/Time: 12.11.18 / 1500
Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	Fedex	✓		Yes No None	

Beacon Project 4459 1A -- Page 46 of 46

Appendix 18B
Background Indoor Air Sampling – Passive Air Sampler
Analytical Report

(Only sample IDs 17-20 with a prefix of "TR 18"
are related to Travis AFB, Bldg. 18)

BEACON ENVIRONMENTAL SERVICES, INC.

The Leaders in Soil Gas Surveys and Vapor Intrusion Monitoring

Arizona State University
660 South College Avenue, Room 507
Tempe, AZ 85281
Attn: Paul Dahlen

Air Samples -- Analytical Report

Date: January 8, 2019
Beacon Project No. 4459.1B

Project Reference:	Beale and Travis AFB
Sampling Period:	November 2 through 26, 2018
Samples Received:	December 11, 2018
Analyses Completed:	December 14, 2018

Results for the following indoor and ambient air samples are included in this data package:

Sample ID	Location	Matrix	Analysis
1	B Theater lobby	Air	TO-17
2	B Theater WRR	Air	TO-17
3	B Theater Stage WRR	Air	TO-17
4	B Theater Stage L	Air	TO-17
5	B Theater R	Air	TO-17
6	B CAC Ball L	Air	TO-17
7	B CAC Café	Air	TO-17
8	B CAC MRR	Air	TO-17
9	B CAC Ball R	Air	TO-17
10	B CAC Welc Ctr Off R	Air	TO-17
11	B CAC Conf	Air	TO-17
12	B CAC Office	Air	TO-17
13	B CAC Lobby	Air	TO-17
14	B CAC Rec	Air	TO-17
15	B CAC Pizzeria	Air	TO-17
16	B CAC Music	Air	TO-17
17	TR 18 Main	Air	TO-17
18	TR 18 Hall	Air	TO-17
19	TR 18 SE Office	Air	TO-17
20	TR 18 Shower 1	Air	TO-17

Sample Collection

Beacon Environmental provided thermally conditioned Beacon Samplers to target a select list of compounds, with analyses following U.S. EPA Method TO-17. These passive diffusion samples (PDS) were exposed to air for approximately three weeks and the resulting mass of target analytes captured on each sampler was reported as a concentration following procedures detailed in ISO 16017-2, *Indoor, ambient and workplace air-Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography-Part 2: Diffusive sampling.*

U. S. EPA Method TO-17

All samples were analyzed for a custom target compound list following U.S. EPA Method TO-17.

2203A Commerce Road, Suite 1, Forest Hill, MD 21050 USA 410-838-8780 •P 410-838-8740 •F BEACON-USA.COM

The analytical results are reported in **Table 1**, with results reported in micrograms per cubic meter ($\mu g/m^3$) and ppbv using the following equations.

$$C = \frac{1000 \times M \times d}{U \times t} \qquad C_{ppbv} = C \text{ x } \frac{24.45}{MW}$$

where:	C	=	concentration ($\mu g/m^3$)
	C_{ppbv}	=	concentration (ppbv)
	M	=	mass (ng)
	d	=	dilution factor
	U	=	uptake rate (ml/min),
	t	=	sampling time (minutes)
	MW	=	molecular weight

The following table provides uptake rates for the compounds reported in this investigation.

Compound	Uptake Rate
1,1-Dichloroethene	0.32
trans-1,2-Dichloroethene	0.42
1,1-Dichloroethane	0.80
cis-1,2-Dichloroethene	0.52
Chloroform	0.34
1,2-Dichloroethane	0.54
1,1,1-Trichloroethane	0.98
Trichloroethene	0.33
Bromodichloromethane	0.40
Dibromochloromethane	0.35
Tetrachloroethene	0.39
Bromoform	0.32

Practical Quantification Levels (PQL) for EPA Method TO-17

The lowest point in the calibration curve and the limit of quantitation (LOQ) is 10 nanograms (ng), and the limit of detection (LOD) is 5 ng. The concentration data in **Table 1** are provided in micrograms per meter cubed ($\mu g/m^3$) and parts per billion by volume (ppbv), and the LOQs are additionally based on the sample collection times, the uptake rates, and the dilution factors.

Calibration Verification

The continuing calibration verification (CCV) values for the analytes were all within ±30% of the true values as defined by the initial five-point calibration and met the requirements specified in Beacon Environmental's Quality Manual.

Internal Standards and Surrogates

Internal standards and surrogates are spiked at 100 ng and 50 ng, respectively, and percentage of recovery is calculated. Acceptance criteria for internal standards are 60 to 140 percent and surrogate recoveries are 70 to 130 percent; all internal standards and surrogates were within the acceptance criteria.

Blank Contamination

No targeted compounds above the LOD for each compound were observed in the Laboratory Method Blanks (LB 181214). For comparison to field sample results, the longest sampling time was used to calculate the LOQs for the blank.

Laboratory Control Samples

Laboratory control samples are spiked at 50 ng and percentage of recovery is calculated and reported. Acceptance criteria for surrogate and analytes recoveries are 70 to 130 percent; all surrogates and analytes were within the acceptance criteria.

Discussion

Twenty (20) indoor air samples were received by Beacon Environmental on December 12, 2018. Sampling start and end times and dates can be found in the Chain of Custody (**Attachment 1**).

Dilutions were required for three (3) samples (18, 19, and 20), which had high levels of cis-1,2-d ichloroethene and/or trichloroethene. Dilutions were performed for these samples to bring the detected concentrations of those compounds into the calibration range of the GC/MSD instrument, as noted in **Table 1**.

Demonstrated Linear Range of the GC-MS Instrumentation (EPA Method TO-17)

An initial six-point calibration is performed on the instrumentation from 5 to 200 ng per analyte.

<u>Attachments:</u>

-1- Chain of Custody

ALL DATA MEET REQUIREMENTS AS SPECIFIED IN THE BEACON ENVIRONMENTAL SERVICES, INC. QUALITY ASSURANCE PROJECT PLAN AND THE RESULTS RELATE ONLY TO THE SAMPLES REPORTED. BEACON ENVIRONMENTAL SERVICES IS ACCREDITED TO ISO/IEC 17025:2005, AND THE WORK PERFORMED WAS IN ACCORDANCE WITH ISO/IEC 17025:2005 REQUIREMENTS. THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY. RELEASE OF THE DATA CONTAINED IN THIS DATA PACKAGE HAS BEEN AUTHORIZED BY THE LABORATORY DIRECTOR OR HIS SIGNEE, AS VERIFIED BY THE FOLLOWING SIGNATURES:

Steven C. Thornley — Patti J. Riggs — Date: January 8, 2018

Steven C. Thornley
Laboratory Director

Patti J. Riggs
Quality Manager

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

COMPOUNDS	CAS						
Client Sample ID:		LCS_181214	LB_181214	LCSD_181214	1	2	3
Project Number:					4459.1B	4459.1B	4459.1B
Lab File ID:		K18121402	K18121403	K18121404	K18121405	K18121406	K18121407
Received Date:					12/11/2018	12/11/2018	12/11/2018
Analysis Date:		12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018
Analysis Time:		10:20	10:40	11:01	12:08	12:35	13:02
Matrix:					Air	Air	Air
Units:		%Recovery	ug/m3	%Recovery	ug/m3	ug/m3	ug/m3
1,1-Dichloroethene	75-35-4	**104%**	<0.91	**102%**	<0.91	<1.03	<0.91
trans-1,2-Dichloroethene	156-60-5	**109%**	<0.68	**106%**	<0.68	<0.77	<0.68
1,1-Dichloroethane	75-34-3	**109%**	<0.36	**107%**	<0.36	<0.41	<0.36
cis-1,2-Dichloroethene	156-59-2	**113%**	<0.55	**109%**	<0.55	<0.63	<0.55
Chloroform	67-66-3	**112%**	<0.84	**107%**	<0.84	<0.95	<0.84
1,2-Dichloroethane	107-06-2	**117%**	<0.53	**112%**	<0.54	<0.61	<0.53
1,1,1-Trichloroethane	71-55-6	**110%**	<0.29	**103%**	<0.29	<0.33	<0.29
Trichloroethene	79-01-6	**120%**	<0.88	**117%**	<0.88	<1.00	<0.88
Bromodichloromethane	123-91-1	**120%**	<0.72	**113%**	<0.73	<0.83	<0.73
Dibromochloromethane	106-93-4	**119%**	<0.82	**116%**	<0.82	<0.93	<0.82
Tetrachloroethene	127-18-4	**110%**	<0.73	**109%**	<0.73	<0.83	<0.73
Bromoform	108-38-3	**114%**	<0.90	**116%**	<0.90	<1.03	<0.90

Reporting limit is limit of quantitation (LOQ). E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

Client Sample ID:		4	5	6	7	8	9
Project Number:		4459.1B	4459.1B	4459.1B	4459.1B	4459.1B	4459.1B
Lab File ID:		K18121408	K18121409	K18121410	K18121411	K18121412	K18121413
Received Date:		12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018
Analysis Date:		12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018
Analysis Time:		13:28	13:55	14:36	15:03	15:30	15:56
Matrix:		Air	Air	Air	Air	Air	Air
Units:		ug/m3	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
COMPOUNDS	CAS						
1,1-Dichloroethene	75-35-4	<0.91	<0.91	<1.22	<1.22	<1.23	<1.22
trans-1,2-Dichloroethene	156-60-5	<0.68	<0.68	<0.92	<0.92	<0.92	<0.92
1,1-Dichloroethane	75-34-3	<0.36	<0.36	<0.48	<0.48	<0.48	<0.48
cis-1,2-Dichloroethene	156-59-2	<0.55	<0.55	<0.75	<0.75	<0.75	<0.75
Chloroform	67-66-3	<0.84	<0.84	<1.13	<1.13	<1.13	<1.13
1,2-Dichloroethane	107-06-2	<0.53	<0.53	<0.72	<0.72	<0.72	<0.72
1,1,1-Trichloroethane	71-55-6	<0.29	<0.29	<0.40	<0.40	<0.40	<0.40
Trichloroethene	79-01-6	<0.88	<0.88	<1.19	<1.19	<1.19	<1.19
Bromodichloromethane	123-91-1	<0.72	<0.72	<0.98	<0.98	<0.98	<0.98
Dibromochloromethane	106-93-4	<0.82	<0.82	<1.10	<1.10	<1.11	<1.10
Tetrachloroethene	127-18-4	<0.73	<0.73	<0.98	<0.99	<0.99	<0.98
Bromoform	108-38-3	<0.90	<0.90	<1.21	<1.22	<1.22	<1.21

Reporting limit is limit of quantitation (LOQ). E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

Client Sample ID:		10	11	12	13	14	15
Project Number:		4459.1B	4459.1B	4459.1B	4459.1B	4459.1B	4459.1B
Lab File ID:		K18121414	K18121415	K18121416	K18121417	K18121418	K18121705
Received Date:		12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018
Analysis Date:		12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/17/2018
Analysis Time:		16:23	16:50	17:17	17:44	18:11	10:39
Matrix:		Air	Air	Air	Air	Air	Air
Units:		ug/m3	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
COMPOUNDS	CAS						
1,1-Dichloroethene	75-35-4	<1.22	<1.22	<1.22	<1.23	<1.23	<1.23
trans-1,2-Dichloroethene	156-60-5	<0.92	<0.91	<0.92	<0.92	<0.92	<0.92
1,1-Dichloroethane	75-34-3	<0.48	<0.48	<0.48	<0.48	<0.48	<0.48
cis-1,2-Dichloroethene	156-59-2	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75
Chloroform	67-66-3	<1.13	<1.13	<1.13	<1.14	<1.13	<1.14
1,2-Dichloroethane	107-06-2	**0.94**	<0.72	<0.72	<0.73	<0.72	<0.72
1,1,1-Trichloroethane	71-55-6	<0.40	<0.39	<0.40	<0.40	<0.40	<0.40
Trichloroethene	79-01-6	<1.19	<1.18	<1.19	<1.20	<1.19	<1.19
Bromodichloromethane	123-91-1	<0.98	<0.98	<0.98	<0.99	<0.98	<0.98
Dibromochloromethane	106-93-4	<1.10	<1.10	<1.10	<1.11	<1.11	<1.11
Tetrachloroethene	127-18-4	<0.99	<0.98	<0.98	<0.99	<0.99	<0.99
Bromoform	108-38-3	<1.22	<1.21	<1.22	<1.22	<1.22	<1.22

Reporting limit is limit of quantitation (LOQ). E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

Client Sample ID:		16	17	18	19	20	CL_LCS_181214
Project Number:		4459.1B	4459.1B	4459.1B	4459.1B	4459.1B	
Lab File ID:		K18121420	K18121706	K18121422	K18121423	K18121424	K18121425
Received Date:		12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018	
Analysis Date:		12/14/2018	12/17/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018
Analysis Time:		19:05	11:06	19:59	20:28	20:55	21:16
Matrix:		Air	Air	Air	Air	Air	
Units:		ug/m3	ug/m3	ug/m3	ug/m3	ug/m3	%Recovery
COMPOUNDS	CAS						
1,1-Dichloroethene	75-35-4	<1.23	<1.10	<1.10	<1.10	<1.10	**90%**
trans-1,2-Dichloroethene	156-60-5	<0.92	<0.82	<0.82	**1.51**	<0.82	**88%**
1,1-Dichloroethane	75-34-3	<0.48	<0.43	<0.43	<0.43	<0.43	**107%**
cis-1,2-Dichloroethene	156-59-2	<0.75	**2.2**	**3.75**	**36.76D**	**6.12**	**99%**
Chloroform	67-66-3	<1.14	<1.01	<1.01	<1.01	<1.01	**106%**
1,2-Dichloroethane	107-06-2	<0.72	<0.65	<0.65	<0.65	<0.65	**100%**
1,1,1-Trichloroethane	71-55-6	<0.40	<0.35	<0.36	<0.36	<0.36	**122%**
Trichloroethene	79-01-6	<1.19	**13.78**	**33.01D**	**167.05D**	**43.20D**	**109%**
Bromodichloromethane	123-91-1	<0.98	<0.88	<0.88	<0.88	<0.88	**110%**
Dibromochloromethane	106-93-4	<1.11	<0.99	<0.99	<0.99	<0.99	**107%**
Tetrachloroethene	127-18-4	<0.99	<0.88	<0.88	**0.97**	<0.88	**98%**
Bromoform	108-38-3	<1.22	<1.09	<1.09	<1.09	<1.09	**120%**

Reporting limit is limit of quantitation (LOQ). E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Attachment 1

Chain of Custody

Beacon Environmental Services, Inc.

CHAIN-OF-CUSTODY PASSIVE DIFFUSION SAMPLES

2203A Commerce Road, Suite 1
Forest Hill, MD 21050
410-838-8780 / fax: 410-838-8740

Client Contact Information	Project Information	BEACON Project Information
Company: ASU SSEBE	Project Manager: Paul Dahlen	BEACON Project No.: 4459
Address: POB 873005	Phone: 480-727-2960	Client PO No.
City/State/Zip: Tempe AZ 85287	Project Name: Beale AFB	Analysis Turnaround Time: [x] Normal
Phone: 480-727-2960	Location: Theater	[ ] Rush (Specify): ____ days
	Sampler Name(s): Paul Dahlen	NIST traceable Thermometer ID:

Location ID	Tube/Sample number	Start Date (mm/dd/yy)	Start Time (24 hr)	Stop Date (mm/dd/yy)	Stop Time (24 hr)	Interior Temp. (F)	Notes	TO-17	8260C	TICs	Indoor/Ambient Air	Soil Gas
1	BTheaterLobby	11/2/18	1030	11/26/18	1455	70	34825 min				✓	
2	BTheater WRR	11/5/18	0831	11/26/18	1507	↓	30636 min				✓	
3	BTheater Stage WRR	11/2/18	0946	11/26/18	1518	↓	34892 min				✓	
4	BTheater Stage L	11/2/18	0925	11/26/18	1513	↓	34908 min				✓	
5	BTheater R	11/5/18	0852	11/26/18	1505	↓	30613 min				✓	
[crossed out, initialed 12.11.18]												

Special Instructions/Notes:

Relinquished by (signature)	Date/Time	Received by (signature)	Date/Time
Paul Dahlen	12/10/18 1300	Courier	
		Steven Thornley	12.11.18 / 1500

Lab Use Only	Courier Name	Shipment Condition	Custody Seal Intact	Custody Seal Number
	Fedex	✓	Yes No (None)	

Page ____ of ____

Beacon Project 4459.1B -- Page 9 of 12

Beacon Environmental Services, Inc.

CHAIN-OF-CUSTODY PASSIVE DIFFUSION SAMPLES

2203A Commerce Road, Suite 1
Forest Hill, MD 21050
410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Information			
Company:	ASU SSEBE	Project Manager:	Paul Dahlen	BEACON Project No.:	4459
Address:	PO B 873005	Phone:	480-727-2960	Client PO No.	
City/State/Zip:	Tempe AZ 85287	Project Name:	Beale AFB	Analysis Turnaround Time	☑ Normal
Phone:	480-727-2960	Location:	CAC		☐ Rush (Specify): ____ days
		Sampler Name(s):	Paul Dahlen	NIST traceable Thermometer ID:	

Location ID	Tube/Sample number	Start Time Date (mm/dd/yy)	Start Time Time (24 hr)	Stop Time Date (mm/dd/yy)	Stop Time Time (24 hr)	Interior Temp. (F)	Notes	Analysis: TO-17	Analysis: 8260C	Analysis: TICs	Matrix: Indoor/Ambient Air	Matrix: Soil Gas
6	BCAC Ball L	11/8/18	1616	11/26/18	1546	71	25890 min				✓	
7	BCAC Cafe	11/8/18	1747	11/26/18	1618	↓	25831 min				✓	
8	BCAC MRR	11/8/18	1826	11/26/18	1617	↓	25791 min				✓	
9	BCAC Ball R	11/8/18	1606	11/26/18	1546	↓	25900 min				✓	
10	BCAC WeldCtr Off R	11/8/18	1807	11/26/18	1632	↓	25825 min				✓	
11	BCAC Conf	11/8/18	1635	11/26/18	1636	↓	25921 min				✓	

Special Instructions/Notes:

Relinquished by: (signature)	Paul Dahlen	Date/Time: 12/10/18 1300	Received by: (signature) Guien	Date/Time:	
Relinquished by: (signature)		Date/Time:	Received by: (signature) Steven Thornley	Date/Time: 12.11.18/1500	
Relinquished by: (signature)		Date/Time:	Received by: (signature)	Date/Time:	

Lab Use Only	Courier Name	Shipment Condition	Custody Seal Intact	Custody Seal Number
	Fedex	✓	Yes No (None)	

Page ____ of ____

Beacon Project 4459.1B -- Page 10 of 12

Beacon Environmental Services, Inc.

CHAIN-OF-CUSTODY PASSIVE DIFFUSION SAMPLES

2203A Commerce Road, Suite 1
Forest Hill, MD 21050
410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Manager: Paul Dahlen	BEACON Project No.: 4459
Company: ASU SSEBE		Phone: 480-727-2960	Client PO No.
Address: POB 873005		Project Name: Beale AFB	Analysis Turnaround Time
City/State/Zip: Tempe AZ 85287		Location: CAC	☒ Normal
Phone: 480-727-2960		Sampler Name(s): Paul Dahlen	☐ Rush (Specify): ____ days
			NIST traceable Thermometer ID:

Location ID	Tube/Sample number	Start Date (mm/dd/yy)	Start Time (24 hr)	Stop Date (mm/dd/yy)	Stop Time (24 hr)	Interior Temp. (F)	Notes	TO-17	8260C	TICs	Indoor/Ambient Air	Soil Gas
12	BCAC Office	11/8/18	1716	11/26/18	1609	71	25853 min				✓	
13	BCAC Lobby	11/8/18	1918	11/26/18	1515	↓	25677 min				✓	
14	BCAC Rec	11/8/18	1847	11/26/18	1626	↓	25779 min				✓	
15	BCAC Pizzeria	11/8/18	1913	11/26/18	1558	↓	25725 min				✓	
16	BCAC Music	11/8/18	1905	11/26/18	1600	↓	25732 min				✓	
	PD											

Special Instructions/Notes:

Relinquished by: (signature) Paul Dahlen	Date/Time: 12/10/18 1300	Received by: (signature) Courier	Date/Time:
Relinquished by: (signature)	Date/Time:	Received by: (signature) Steven Thornley	Date/Time: 12.11.18/1500
Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:

Lab Use Only	Courier Name	Shipment Condition	Custody Seal Intact	Custody Seal Number
	Fedex	✓	Yes No (None)	

Page ____ of ____

Beacon Project 4459.1B -- Page 11 of 12

Industrial Scale Controlled Pressure Method Test Demonstration for Vapor Intrusion Pathway Assessment – ESTCP ER#201501

Building 2474, Theatre
Beale Air Force Base, California

Arizona State University SSEBE, Oct 12, 2020

8. INTRODUCTION

1.2 BACKGROUND

Controlled pressure method (CPM) testing for vapor intrusion (VI) pathway assessment was developed to evaluate the maximum VI related impact to a structure in a short period of time. Its use has been studied in various Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) funded projects (ER#200707, ER#1686, and ER#201501). In the most recent project, ER#201501, CPM testing has been included as one of a suite of tools to more expediently and confidently define the presence of vapor intrusion pathways in structures.

During CPM testing, the controlled negative pressurization of a test structure induces a worst-case vapor intrusion scenario. Assessment of exhaust air contaminant concentrations provides an estimate of the average indoor air concentration, while area specific samples define local responses to this worst-case scenario. By creating that worst-case VI scenario, CPM testing is most effectively used to identify and rule out structures where VI impacts are non-existent (e.g. test concentrations are less than or equal to ambient outdoor concentrations) and/or of no regulatory concern. If, however, contaminant concentrations approach or are in excess of a regulatory concern during negative pressure testing, positive pressure testing, which suppresses VI, should then be used to rule out (or identify) indoor air source(s). If VI impacts are confirmed, concentrations will either be high enough to define the immediate need for mitigation, or alternatively, should be used as a line of evidence in a multiple lines of evidence approach to define risk.

Use of CPM testing as the primary tool for VI assessment is effective since it recognizes that:

- multiple VI pathways can exist, including:
  - the traditional "*soil VI*" conceptualization (source → through soil → through foundation to indoor air); and
  - "*pipe flow VI*" from sources such as land drains and sanitary sewers.
- the VI pathways discussed above may be present, but not discernible by traditional site characterization; and
- VI concentrations vary both spatially and temporally.

ESTCP project ER#201501 included the demonstration of the CPM test protocol in both residential- and industrial-scale buildings. In brief the CPM Test Guidelines (ER201501 Final Rpt. Appendix D) use negative- and positive-pressure testing of the structure as follows:

- Negative pressure testing of a structure was used to induce a worst-case VI scenario. During negative pressure testing, after a minimum of nine building air exchanges, air quality was tested at the blower intake/exhaust and if of interest, throughout the structure. If concentrations during negative pressurization were less than ambient outdoor concentrations or regulatory concerns, then the VI impact was considered minimal or non-existent and testing would be complete. If, however, concentrations exceeded ambient outdoor concentrations and were of regulatory concern, then VI impacts could be a concern. At this point, a positive pressure test was necessary to rule out indoor air sources.
- Positive pressure testing was used to identify the presence/impact of an indoor air source(s). During positive pressure testing, VI was suppressed, and after a minimum of four building air exchanges air quality was tested throughout the structure. If no contaminant was present in the building, then only VI was present. If, however, contaminants were detected in indoor air, that indicated an indoor air source was present that would require removal followed by additional CPM testing.

This document presents the results of the industrial-scale CPM demonstration at the Beale Air Force Base Theatre, Bldg. 2474, Beale Air Force Base, California. The objectives of this demonstration were to: a) demonstrate the controlled pressure method in an industrial-scale building; b) perform an extended-term post-CPM test air-quality assessment to determine if the CPM test would lead to the same/similar decision as standard air-quality testing; and c) improve current CPM protocols based on knowledge gained from the demonstration.

9. SITE DESCRIPTION

2.1 BEALE AIR FORCE BASE AND BUILDINGS 2474, 2425, AND 24176

Beale Air Force Base (AFB) lies within Yuba County in Northern California, approximately 40 miles north of Sacramento and 13 miles east of Marysville (Fig. 1; CH2MHill, 2016). It covers approximately 23,000 acres.

Beale AFB began as Camp Beale, an Army installation, at the onset of World War II. During that war, the Base served as an armored division and later as infantry division training base. The Base was transferred to the Air Force in 1948 and served primarily as a training base for aviation engineers. In 1965, it became a Strategic Reconnaissance Wing and since 1981 has been the 9th Reconnaissance Wing under Air Combat Command.

The generalized geology/hydrogeology of Beale AFB consists of unconsolidated sedimentary deposits, underlain by consolidated sedimentary bedrock, further underlain by crystalline metamorphic bedrock. Groundwater occurs primarily in the unconsolidated sedimentary deposits. Depth-to-water is approximately 40 ft below ground surface in the area of interest and groundwater flow direction is generally to the south/southwest.

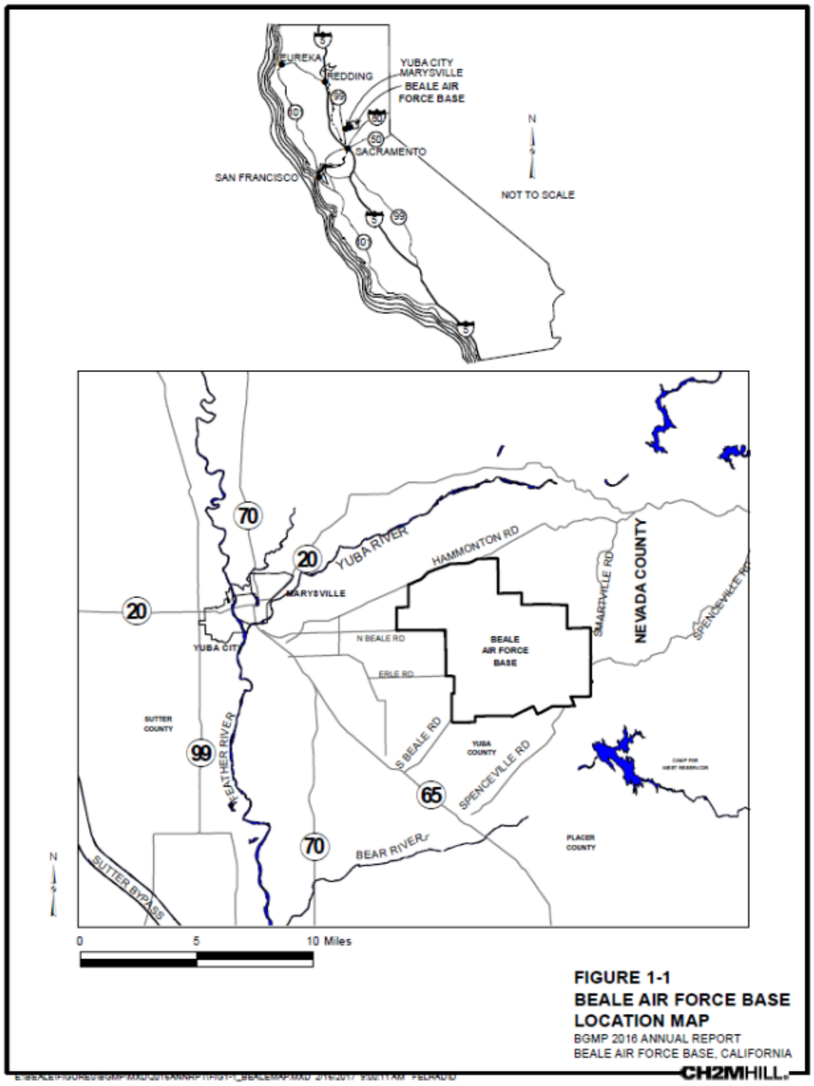

Figure 1. Location Map for Beale Air Force Base, California.

Site CG041 is part of the Cantonment Remedial Investigation and was established by the Air Force in 2013 to separate groundwater responses from soil responses and address base-wide groundwater as a single site. It currently consists of groundwater plumes underlying 11 soil sites. Pertinent to this study is Plume GC041-039, a dilute chlorinated solvent plume that trends to the south/southwest in-line with groundwater flow and contains TCE concentrations currently ranging to approximately 110 µg/L.

Per a 2018 Record of Decision (ROD; USAF, 2018), an additional industrial/commercial Land Use Control for new buildings was to be implemented within the bounds of Plume CG041-039 to address risk assessment issues. The ROD identified three buildings that were within plume boundaries that required air sampling to assess vapor intrusion risk and confirm current use; 2474 (Theatre), 2425 (Community Activities Center; CAC), and 24176 (dormitory building B, the southern building of a two building dorm complex). Those buildings are shown in Figure 2, which provides a location map in addition to an overlay of the 2016 TCE plume delineation. General attributes of those buildings are shown in Table 1.

Based on the ROD requirement for a vapor intrusion assessment, buildings 2474, 2425, and 24176 were selected for CPM demonstration testing.

Table 1. Attributes of Beale AFB buildings 2474, 2425, and 24176.

Location	Bldg. Use	Size (ft2)	Occupancy	History of VI	Comment
Bldg. 2474	Theatre	10.3K	Occupied	Unknown Never tested	Bldgs. overlie a dilute TCE groundwater plume (5-110 ug/L) ROD indicated that VI testing was required for these facilities
Bldg. 2425	Community Activities Center	20.5K	Occupied		
Bldg. 24176	Dormitory	13.6K	Occupied		

2.1 Beale Theatre, Building 2474

Building 2474, the Theatre, is the focus of this report (Fig. 3). Originally built in the mid-1970s, the structure was renovated in the mid-2000s and has continuously served as a movie and performance theatre. The brick structure was built on grade and is approximately 10,300 square feet, the floorplan for which is shown in Figure 4. The front, 2-story portion of the theatre houses the lobby, restrooms, theatre office, concession sales area and storeroom, janitorial storerooms, and projection room (upstairs). The main body of the theatre includes the auditorium, performance stage, restrooms, janitorial closet, and two storerooms. Mechanical is also present in the rear portion of the building with an outside entrance. The building volume was estimated at 250,000 ft^3 for test purposes.

10.CPM TEST BUILDING PRESSURE CONTROL, AIR SAMPLING, AND ANALYTICAL METHODS

3.1 Building Pressure Control

The CPM demonstration followed early versions of the CPM Test Guidelines (SOP; see Main Report Appendix D) with some modification to account for size and construction of the building and to incorporate knowledge gained from prior industrial-scale tests.

Building pressure control was managed with either a Retrotec 1000 or 6000 blower door system (Retrotec, WA). This system included the following:

- Variable speed blower (blower): Blower was operated using the DM32 digital blower control (Retrotec, WA). Blower flowrate was managed via blower speed and intake shrouds that control the cross-sectional area of intake.

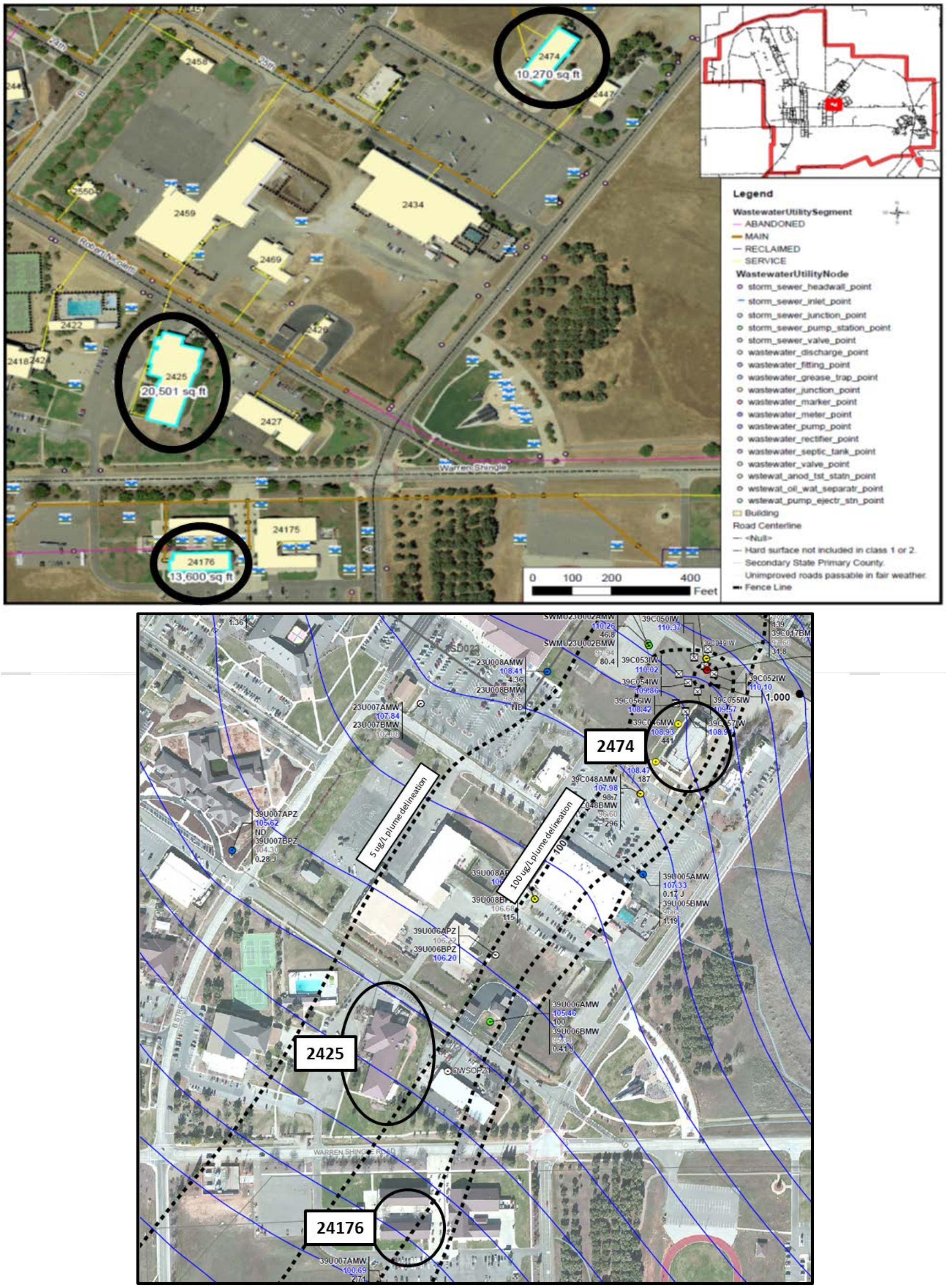

Figure 2. Location map for buildings 2474, 2425, and 24176, and their locations relative to a 2016 TCE plume delineation.

Figure 3. Beale Air Force Base Building 2474 (Theatre).

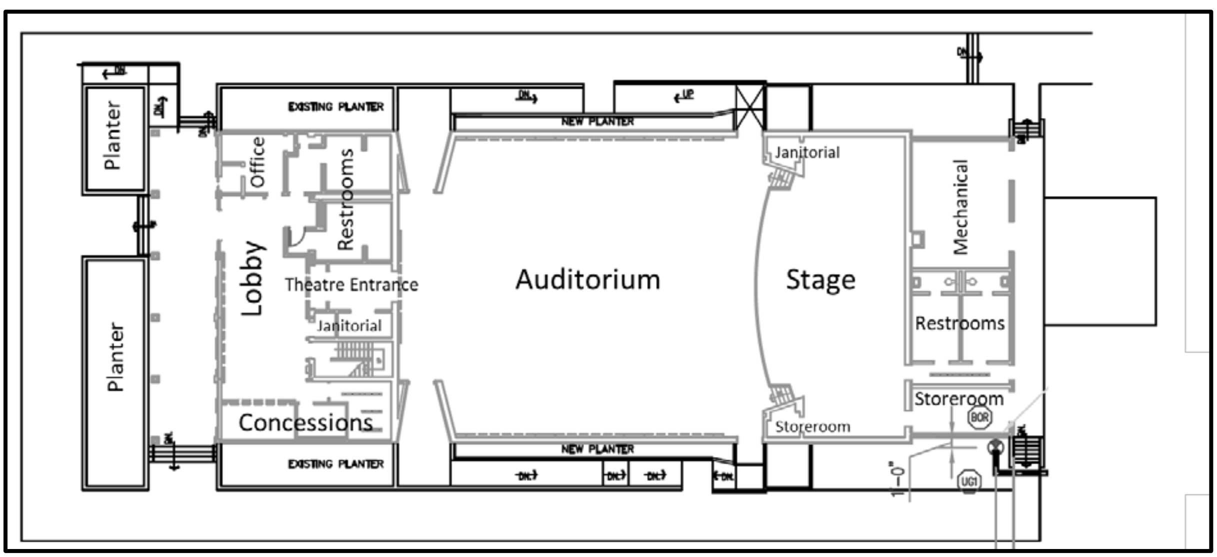

Figure 4. Beale Air Force Base Building 2474 (Theatre) Floorplan.

- ➢ DM32 digital blower controller and pressure monitor: The DM32 (Figure 5) measured and recorded 1) indoor vs. outdoor pressure differential and 2) blower flowrate as determined by a fan shroud vs. reference pressure differential. Data logging included, but was not limited to time, date, blower flowrate, and differential pressure. Data was recorded on user defined intervals of 30 seconds.
- ➢ In this demonstration, the indoor to outdoor pressure differential was measured between a single indoor pressure port and a composite outdoor pressure reference. The outdoor reference included pressure ports from four (4) aspects of the building, manifolded together for a single outdoor reference point. The composite outdoor pressure reference provided a more stable and reliable outdoor reference by minimizing short-term pressure fluctuations from wind loading or turbulence generated by building faces.
- ➢ Adjustable frame with blower door cloth (blower door): The "blower door" included an adjustable frame and cover cloth with a cutout for the blower. The blower door was installed in a man-door doorframe. Figure 5 shows a blower door with a blower in place.

3.2 Air Sampling and Analytical Procedure

CPM test air sampling included both indoor air and ambient outdoor samples, both of which utilized grab sampling. Indoor air sampling was specific to the type of test performed: Negative pressure CPM testing required a blower intake sample (functionally a composite of indoor air) for building concentration, and optional area specific samples. Final samples for negative pressure testing should be performed after a minimum of nine (9) building air exchanges. Positive pressure CPM testing required area specific sampling, and sampling should proceed after a minimum of four (4) building air exchanges. To eliminate spatial variations during sampling and to ensure greater sample consistency, air mixing was employed in the sampling area using fans (e.g. box/floor fans).

Ambient outdoor sampling was performed to determine the baseline concentration of analytes and was representative of the air quality of air drawn into the structure during pressure testing.

Figure 5. Retrotec DM32 with display (left) and blower door with blower (right).

Long term, indoor air sampling utilized long-term thermal desorption tube sampling techniques and/or passive sampler technology.

Air sampling and associated analytical was performed using the following methods:

- Grab Sampling: Grab Sampling with Tedlar bags and a vacuum sampler was used to collect indoor and ambient outdoor air samples during CPM testing. These samples were analyzed on-site and analytical results were obtained the same day of sample collection.

  

  On-site grab sample analyses were performed using an SRI 8610C gas chromatograph (SRI, CA) equipped with a sorbent concentrator and a dry electrolytic conductivity detector (DELCD). The DELCD was well suited for analytical due to its selective nature for only chlorinated and brominated compounds.

  The GC-DELCD system was calibrated before negative and positive pressure testing. Calibration concentrations ranged from 0.01 to 10 ppb_v for both negative and positive pressure testing. Calibration standards were prepared by dilution in clean Tedlar bags using Zero-air and a custom chlorinated compound calibration gas stock (Scotty Analyzed Gases).

  For on-site analytical, a suite of chlorinated volatile organic hydrocarbons (CVOCs) based on trichloroethene and its daughter products was of interest. Those that responded well to the DELCD detector used for chromatography were as follows:

  - Trichloroethene (TCE)
  - 1,1 Dichloroethene (1,1-DCE)
  - 1,2 Dichloroethane (1,2-DCA)
  - 1,1,1 Trichloroethane (1,1,1-TCA)
  - 1,1,2 Trichloroethane (1,1,2-TCA)
  - Tetrachloroethene (PCE)

- Thermal Desorption (TD) tube sampling: TD tube sampling involved actively pulling air through a multi-bed, sorbent packed tube at a controlled flowrate. The flowrate and duration of collection determined the volume of air sampled. The averaged air concentration was calculated using the absorbed VOC mass and the total sample volume.

  Long-term TD tube sampling was performed as follows:

  - 24-day, timed interval sampling: 24-day, timed interval sample collection used a single Sensidyne Gilian LFS-113 (Sendsidyne, FL) pump in constant pressure mode to provide a continuous pressure source to a manifold with restrictor orifices to control flowrates for multiple tubes. The active sampling time was timer controlled to reduce collection volume to prevent TD tube sorbent saturation if indoor air concentrations were high. Active sampling was performed for 10-minute intervals every 1.5 hours throughout the sampling period, a total of 160 minutes per day. See Figure 6 for sampler photo.

    Sample integrity was maintained using Markes Difflok caps (Markes International, United Kingdom). In addition, to ensure that contaminant breakthrough did not occur, for each tube set, a backup TD tube was placed downstream of one of the tubes and was analyzed for the presence of contaminant. All backup TD tubes returned non-detect for VOCs.

Sampling flowrates were measured prior-to and subsequent-to sampling using the Gilian Gilibrator-2 calibrator (Sensidyne, FL). The difference between two measures were less than 6% for all tube samples.

A single TD tube and the backup TD tube both supplied by Beacon Environmental Services, were shipped back to them for analysis. Other tubes deployed were from ASU and used for research purposes, the results for which will not be addressed in this report.

- Passive Sampling: ***Passive samplers*** were deployed for continuous, long-term sampling for a 24 day period. Passive samplers used were the Beacon Sampler (Beacon Environmental Services, MD) and were sent to Beacon Environmental Services for analysis.

While results for all analytes will be reported, the analyte of interest for discussion purposes will be TCE. TCE is the analyte of interest since this building resides over a TCE contaminant plume, and because of its low regulatory limit, TCE is frequently a focal point and regulatory driver.

11.CPM TEST DEMONSTRATION AND RESULTS

The goal of this CPM demonstration was not to perform a formal VI risk assessment, but rather, validate CPM testing for VI pathway assessment. Therefore, in addition to CPM testing, post-CPM testing indoor air sampling was performed and was used to characterize background indoor air concentrations to provide a point of comparison for the CPM test results.

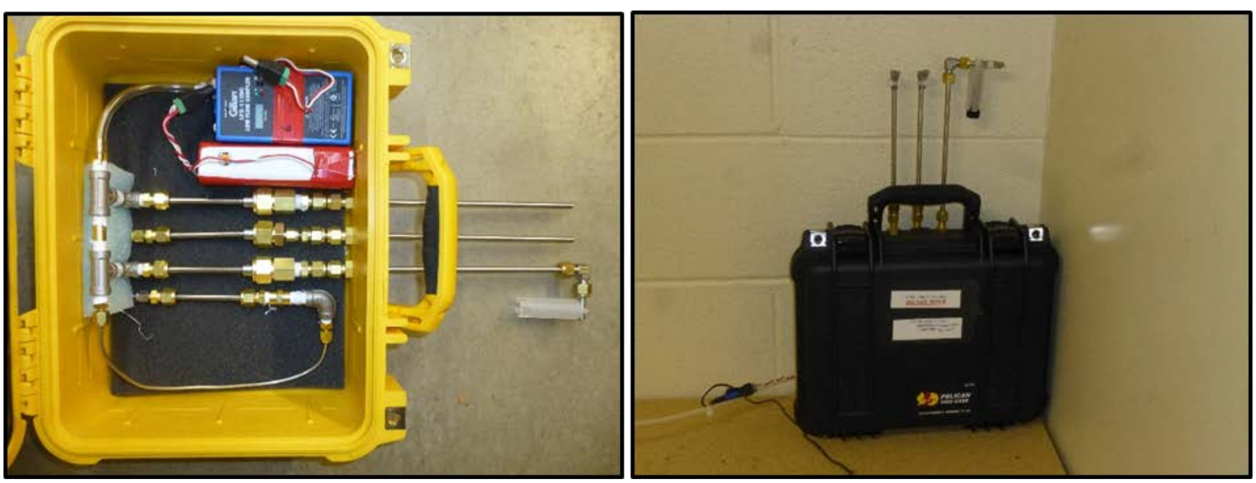

Figure 6. Active TD tube and Passive sampler deployment with passive sampler, TD tube active samplers in triplicate with a single tube for breakthrough assessment, pump, and timer.

The demonstration proceeded as follows:

- Sept. 6, 2018: CPM negative pressure pre-test. Preliminary test to determine concentration ranges and equipment/instrumentation needs for full test.
- Oct. 29, 2018: CPM Demonstration. Negative pressure test 1. Sampling included ***Grab sampling with on-site analytical***.
- Oct. 30, 2018: CPM Demonstration. Positive pressure testing. Sampling included ***Grab sampling with on-site analytical***.
- Nov. 1, 2018: CPM Demonstration. Negative pressure test 2. Sampling included ***Grab sampling with on-site analytical***.
- Nov. 2 – Nov. 26, 2018: Background indoor air sampling. Sampling included long-term ***TD tube sampling*** and ***Passive sampling***.

The Sept. 6 pretest involved a brief negative pressure test to determine what blower equipment would be needed for a full test and to determine approximate analyte concentration ranges for calibration of on-site analytical equipment that would be used during the full test. Due to the informal nature of the test, test results will not be reported.

4.1 CPM Demonstration

CPM testing was performed over a three-day period as described above; negative pressure test 1 on Oct. 29, positive pressure testing on Oct. 30, and negative pressure test 2 on Nov. 1. For all tests, the blower-door/blower was installed in the man-door along the northwestern wall of the building at the back of the theatre auditorium. Figures 7 and 8 show the blower installation location and installation, respectively.

Initially, an approximate magnitude 10 Pa pressure differential was intended for testing, and negative pressure test 1 was based on that differential. The blower flowrate for that test was determined by adjusting blower speed to achieve the desired indoor-to-outdoor differential pressure. This blower speed was then used for positive pressure testing also. However, windy conditions during the positive pressure test resulted in highly variable differential pressures, including periods of negative pressure. As such, the flowrate was doubled to maintain a positively pressured condition within the structure, increasing the differential pressure to approximately +16 Pa. On Nov. 1, a second negative pressure test (negative pressure test 2) was repeated at the higher magnitude 16 Pa differential pressure.

Air sampling during negative pressure test 1 focused on blower intake and ambient outdoor sampling. Blower intake concentrations, functionally a composite of indoor air, were monitored throughout the test to determine if concentration equilibrium had been reached. Ambient outdoor air sampling was performed in two locations to determine the baseline concentration of analytes drawn into the building.

Air sampling during positive pressure testing and negative pressure test 2 included indoor area specific and ambient outdoor locations. Indoor area specific sampling was performed during positive pressure testing as defined by the SOP. Indoor area specific sampling for negative

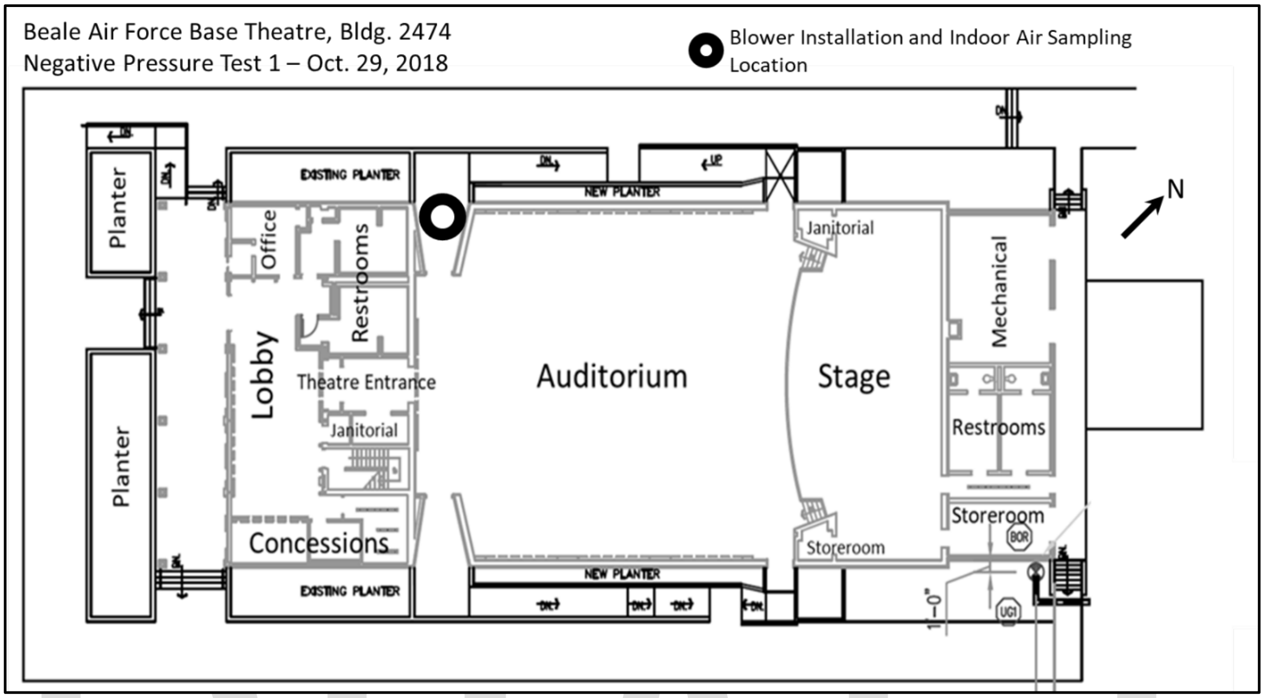

Figure 7. Oct. 29 negative pressure test 1 blower installation and air sampling location, Beale AFB Theatre, Building 2474.

Figure 8. Blower door installation and the use of floor fans to facilitate air mixing near the blower intake sampling area.

pressure test 2 was performed as a point of interest to gain information on area specific response. Ambient outdoor air sampling was performed at the same two locations used for negative pressure test 1 and was used to determine the baseline concentration of analytes drawn into the building.

4.1.1 CPM Demonstration – Negative Pressure Test 1, Oct. 29, 2018

A single blower was used for pressure control and was operated at a constant speed to maintain as uniform a flowrate as possible. Flowrate for negative pressure testing was determined by adjusting the blower speed to achieve an indoor-to-outdoor differential pressure of approximately -10 Pa. Operational conditions were as follows:

- Flowrate: 3440 cfm average
- Approximate indoor vs. outdoor differential pressure: –10 Pa with great variability
- Duration of negative pressure testing: 585 min.
- Air turnover rate: ~73 min per building volume
- Building volume air exchanges: ~8 exchanges

Figure 9 provides a time series graphic of flowrate and differential pressure. Note that outliers or increasing data spread in either flowrate or differential pressure are typically related to increasing outdoor wind speed or gusting winds: Wind activity can affect both indoor and outdoor pressures and can generate erratic outdoor pressure references, both of which can affect the overall differential pressure across the building envelope.

Eight (8) blower intake grab samples were collected throughout negative pressure testing to determine if/when concentration equilibrium was achieved. Samples were collected at a defined location 1-2 ft from the blower intake as a cumulative representation of building air quality. Figure 10 provides a graphic of blower intake TCE concentration vs. elapsed time. Based on this graphic, equilibrium concentration was not achieved nor had the nine (9) air exchanges. However, due to limited time and because test concentrations were consistently less than 0.020 ppbv, the test was considered complete at eight (8) air exchanges. The final blower intake sample was collected at 583 minutes and was considered the final test concentration for this negative pressure test.

For negative pressure test 1, no area-specific samples were collected. At this point in CPM protocol development, it was not believed that additional samples from locations throughout the test structure would provide substantive benefit.

<u>Analytical Results – Negative Pressure Test 1</u>

Table 2 shows CVOC analyte concentrations for this event.

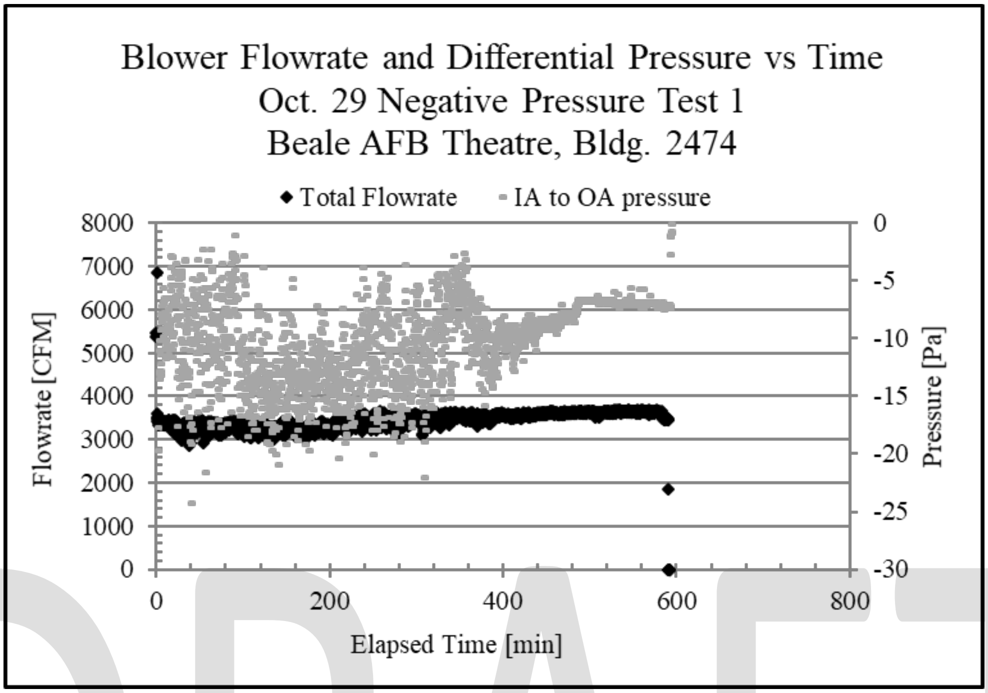

Figure 9. Blower flowrate and differential pressure vs time, Oct. 29 negative pressure test 1. Beale AFB Theatre, Bldg. 2474.

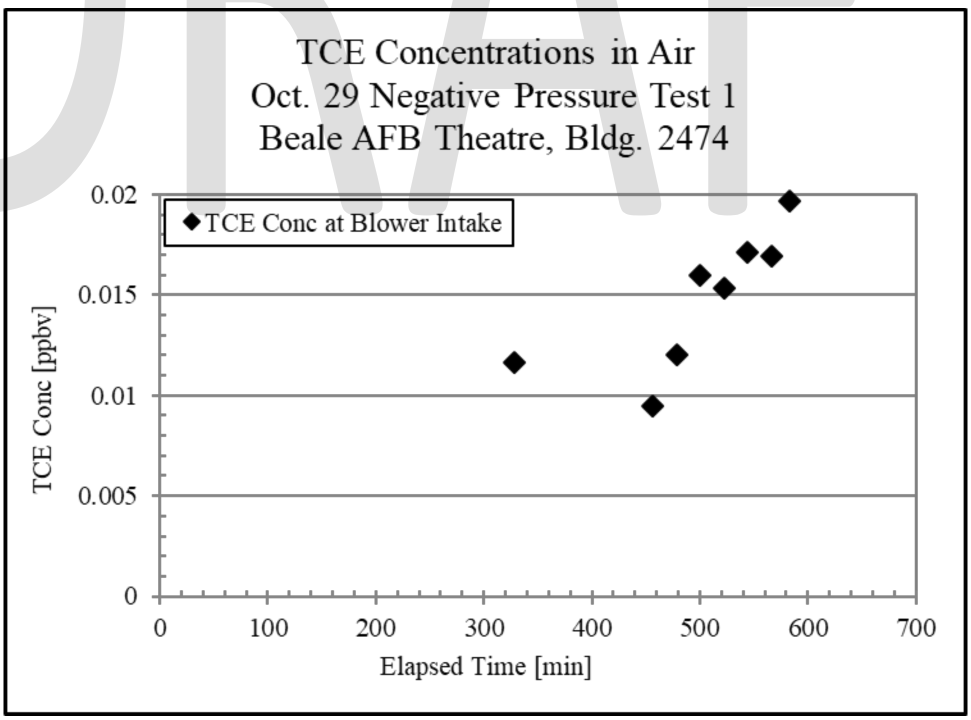

Figure 10. TCE Air Concentrations at the blower intake, Oct. 29 negative pressure test 1. Beale AFB Theatre, Bldg. 2474.

Table 2. Indoor and ambient outdoor air sampling results for Oct. 29 negative pressure test 1.

Location	Elapsed Time (min)	Analyte Concentration in Air (ppbv)					
		TCE[1]	1,1- DCE[1]	1,2- DCA[1]	1,1,1-TCA[1]	1,1,2-TCA[2]	PCE[2]
Ambient Outdoor SE	325	0.002*	0.028	0.021	0.005*	0.012	0.009*
Ambient Outdoor NW	325	0.001*	0.025	0.019	0.005*	0.009*	0.006*
Ambient Outdoor SE	435	0.001*	0.024	0.018	0.005*	0.015	0.005*
Ambient Outdoor NW	435	0.001*	0.023	0.019	0.005*	0.011	0.007*
Ambient Outdoor SE	540	0.001*	0.023	0.019	0.005*	0.016	0.006*
Ambient Outdoor NW	540	0.002*	0.024	0.020	0.005*	0.013	0.007*
Blower intake	583	0.020	0.025	0.025	0.007*	0.012	0.013
Blower intake dup	583	0.019	0.027	0.028	0.007*	0.012	0.016

1 - Calibration limit of 0.01 ppbv. Highlighted concentrations were detectable and estimated.
2 - Calibration limit of 0.05 ppbv. Highlighted concentrations were detectable and estimated.

Indoor air concentrations for TCE were somewhat elevated, but definitively less than the EPA action level of 0.08 ppbv (USEPA, 2015/2020). In addition, other analytes, when adjusted for ambient outdoor concentrations, were all less than both the residential and industrial screening levels. As such, there was no complete VI pathway for the Theatre as per the definition provided in the Introduction. Based on this result, no positive pressure CPM test would be necessary and the CPM test would be complete. However, for demonstration purposes, a positive pressure test was performed.

4.1.2 CPM Demonstration – Positive Pressure Testing, Oct. 30, 2018

A single blower was used for pressure control and was initially operated at approximately the same blower speed as the negative pressure test. Operational conditions for this first stage of positive pressure testing were as follows:

- Flowrate: 3640 cfm m^3/min average
- Indoor vs. outdoor differential pressure: +5.9 Pa average. Initially, the pressure differential was approximately +7 Pa, but as the test proceeded, the pressure differential became progressively more variable due to high wind speeds and it was not possible to maintain a positive indoor-outdoor pressure differential.
- Duration of positive pressure testing at this flowrate: 432 min.
- Air turnover rate: ~69 min per building volume
- Building volume air exchanges: ~6 exchanges

Figure 11 provides a time series graphic of flowrate and differential pressure. Of note is that with increasing wind speeds during the test, both the differential pressures and the blower flowrate become more erratic, including periods of negative pressurization.

In response to the inadequately pressurized condition, the blower flowrate was approximately doubled to increase the differential pressure at 433 minutes. Following the increase, the operational conditions were as follows:

- Flowrate: 7340 cfm average
- Indoor vs. outdoor differential pressure: +16.3 Pa average
- Duration of positive pressure testing at this flowrate: 210 min.
- Air turnover rate: ~34 min per building volume
- Building volume air exchanges: ~6 exchanges

Blower flowrate and differential pressure vs time for those new conditions is also shown in Figure 11.

After a minimum four air exchanges and prior to cessation of the increased pressure condition, grab sampling was performed in 20 area specific locations. Those locations along with their analytical designations are shown in Table 3, the locations for which are shown in Figure 12.

In addition, three (3) ambient outdoor air grab samples were collected from two (2) locations (southeast (SE) and northwest (NW)) outside the building at 70 min, 190 min, and 275 min elapsed time. Those samples provided a baseline concentration for air quality and was representative of air that was drawn into the building during pressure testing.

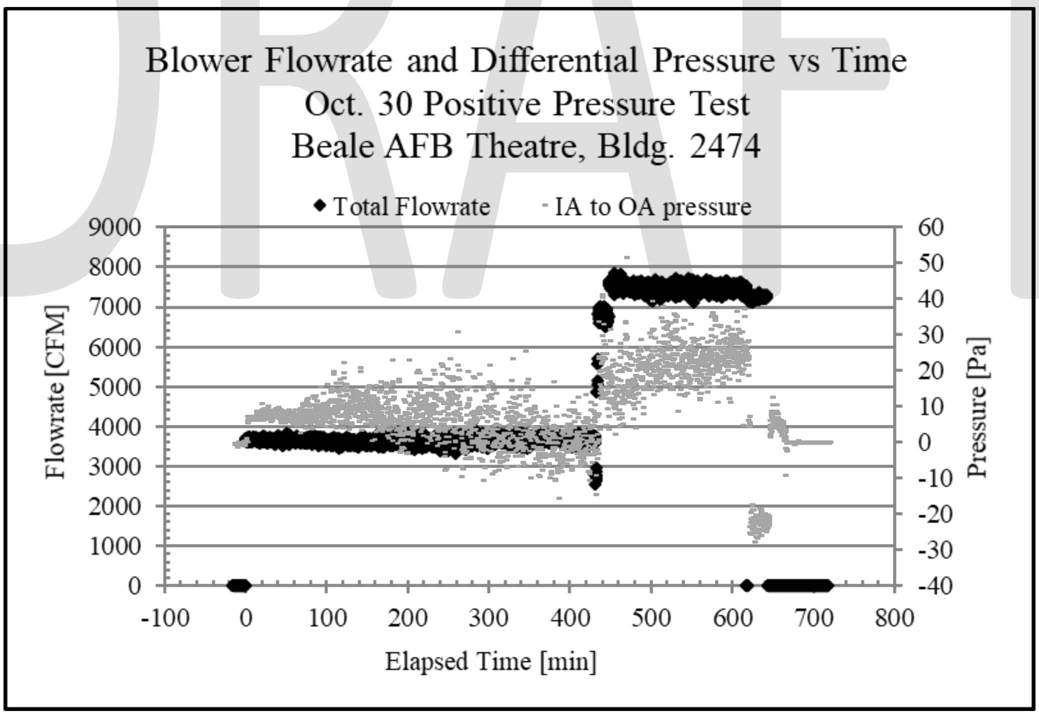

Figure 11. Blower flowrate and differential pressure vs time, Oct. 30 positive pressure test. Beale AFB Theatre, Bldg. 2474.

Table 3. Area specific sampling locations and analytical designations for Oct. 30 positive pressure testing.

Theatre Location	Designation	Theatre Location	Designation
Theatre left	Th L	Stage left janitorial closet	St L Jan
Theatre right	Th R	Projection room, upstairs	Proj
Stage left	St L	Lobby janitor closet 1	Jan 1
Stage right	St R	Lobby janitor closet 2 with sink	Jan 2 Sink
Backstage left	BSt L	Concession storeroom	Conc Stor
Backstage right	BSt R	Concession	Conc
Stage storeroom	St Stor	Lobby	Lob
Stage women’s restroom	St WRR	Office	Off
Stage men’s restroom	St MRR	Lobby women’s restroom	WRR
Stage right storeroom	St Stor R	Lobby men’s restroom	MRR

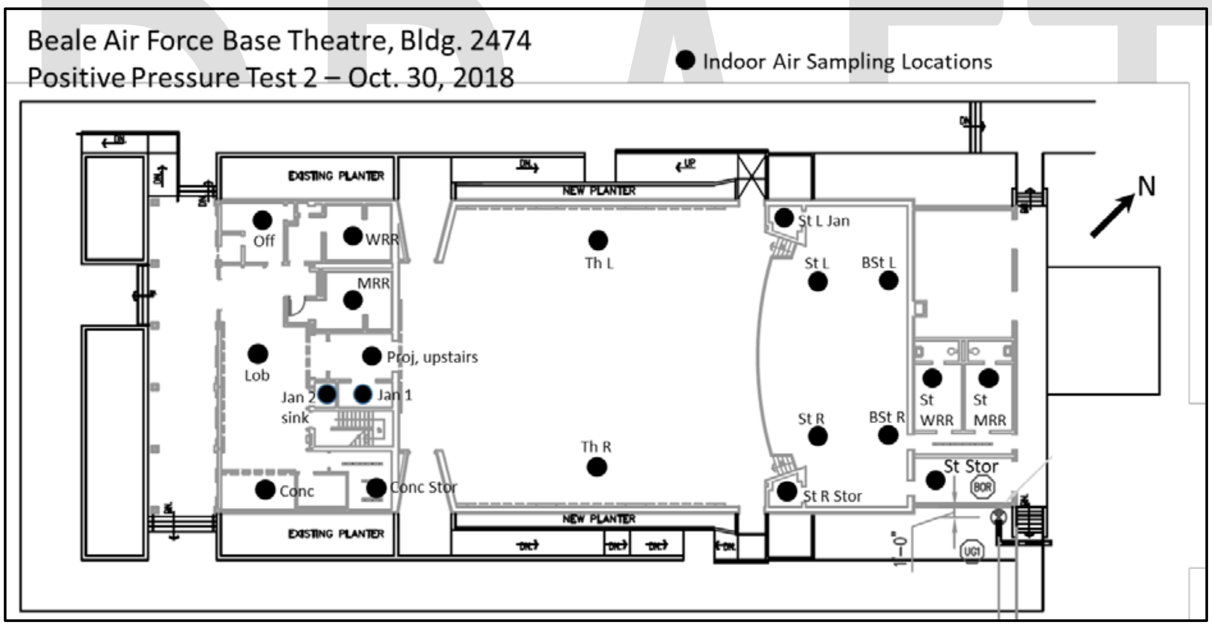

Figure 12. Oct. 30 positive pressure test air sampling locations, Beale AFB Theatre, Bldg. 2474.

Analytical Results – Positive Pressure Test

Tables 4 and 5 show positive pressure CVOC analyte concentrations for indoor air and ambient outdoor air, respectively. All locations showed TCE indoor air concentrations less than 0.01 ppbv, and other analytes, when adjusted for ambient outdoor concentrations, were all less than both the residential and industrial screening levels. This indicated that there were no indoor air sources of concern.

Table 4. Indoor air sampling results for Oct. 30 positive pressure testing.

Theatre Location	Analyte Concentration in Air (ppbv)					
	TCE[1]	1,1-DCE[1]	1,2-DCA[1]	1.1.1-TCA[1]	1,1,2-TCA[1]	PCE[1]
Th L	0.001	0.021	0.018	0.003	0.002	0.005
Th R	0.001	0.019	0.017	0.003	0.002	0.005
St L	0.002	0.019	0.018	0.003	0.002	0.005
St R	0.002	0.020	0.019	0.003	0.003	0.006
BSt L	0.002	0.020	0.019	0.003	0.003	0.006
BSt R	ND	0.020	0.017	0.004	0.006	0.009
St Stor	0.001	0.021	0.020	0.005	0.007	0.058
St WRR	0.002	0.021	0.019	0.004	0.007	0.009
St MRR	0.001	0.021	0.019	0.004	0.008	0.008
St Stor R	0.001	0.021	0.019	0.005	0.009	0.006
St Stor L	0.003	0.021	0.023	0.004	0.007	0.006
Proj	0.004	0.028	0.024	0.006	0.010	0.008
Jan1	0.002	0.021	0.021	0.004	0.009	0.007
Jan2 Sink	0.002	0.021	0.023	0.005	0.009	0.009
Conc Stor	0.004	0.023	0.025	0.005	0.009	0.008
Conc	0.005	0.025	0.025	0.005	0.009	0.009
Lob	0.005	0.022	0.028	0.005	0.009	0.009
Off	0.005	0.022	0.027	0.006	0.009	0.008
WRR	0.005	0.022	0.026	0.005	0.009	0.009
MRR	0.010	0.022	0.026	0.005	0.009	0.006
MRR dup	0.008	0.022	0.026	0.005	0.009	0.010

ND - Non-detectable
1 - Calibration limit of 0.01 ppbv. Highlighted concentrations were detectable and estimated.

Table 5. Ambient outdoor air sampling results for Oct. 30 positive pressure testing.

Location	Elapsed Time (min)	Analyte Concentration in Air (ppbv)					
		TCE[1]	1,1-DCE[1]	1,2 –DCA[1]	1,1,1-TCA[1]	1,1,2-TCA[1]	PCE[1]
A-SE	70	0.002	0.022	0.019	0.005	0.001	0.007
A-NW	70	0.001	0.022	0.019	0.004	0.001	0.008
A-SE	190	ND	0.022	0.018	0.004	ND	0.011
A-NW	190	0.001	0.022	0.020	0.004	0.001	0.009
A-SE	275	ND	0.020	0.018	0.003	0.008	0.009
A-NW	275	ND	0.021	0.018	0.003	0.007	0.007

ND - Non-detectable
1 - Calibration limit of 0.01 ppbv. Highlighted concentrations were detectable and estimated.

4.1.3 CPM Demonstration – Negative Pressure Test 2, Nov. 1, 2018

Since sampling for the positive pressure test was conducted at a flowrate approximately twice that of negative pressure test 1, a second negative pressure test was performed on Nov. 1 using a flowrate approximately equivalent to that of the positive pressure test.

A single blower was used for pressure control and was operated at a constant speed to maintain as uniform a flowrate as possible. Flowrate for negative pressure test 2 was facilitated by adjusting the blower speed to achieve a flowrate of approximately 7350 cfm. Resultant operational conditions were as follows:

- Flowrate: 7480 cfm average
- Approximate indoor vs. outdoor differential pressure: –22 Pa with variability
- Duration of negative pressure testing: 764 min.
- Air turnover rate: ~33 min per building volume
- Building volume air exchanges: ~22 exchanges

Figure 13 provides a time series graphic of flowrate and differential pressure. The changes in flowrate and differential pressure (IA to OA pressure) during the test cannot be explained.

Twelve (12) blower intake grab samples were collected throughout negative pressure testing to determine concentration equilibrium. Samples were collected at a defined location 1-2 ft from the blower intake as a cumulative representation of building air quality. Figure 14 provides a graphic of blower intake TCE concentration vs. elapsed time. Based on this graphic, an equilibrium concentration was approximately achieved at 200 minutes or 7 indoor air exchanges. However, due to unknown pressure disturbances between 250 and 600 minutes (see Fig. 13), the TCE concentration dropped and regained equilibrium at 600 minutes or 20 indoor air exchanges.

Prior to cessation of the pressurized condition, grab sampling was performed at the blower. In addition, based on earlier TCE detects during negative pressurization, 12 additional area specific locations were also sampled. Those sampling locations with analytical designations for each are shown in Table 6 and in Figure 15.

In addition, three (3) ambient outdoor air grab samples were collected from two (2) locations (southeast (SE) and northwest (NW) side) outside the building. Those samples provided a baseline concentration for air quality and was representative of air that was drawn into the building during pressure testing. Samples were collected at 325 min, 435 min, and 540 min after the test started.

<u>Analytical Results – Negative Pressure Test 2</u>

Tables 7 and 8 show CVOC analyte concentrations for ambient outdoor and indoor air, respectively. Indoor air TCE concentrations for all locations were well below the EPA action level of 0.08 ppbv (USEPA, 2015/2020). In addition, other analytes when adjusted for ambient outdoor concentrations were all less than both the residential and industrial screening levels. As such, for this increased pressure, there was still no complete VI pathway for the Theatre as per the definition provided in the Introduction.

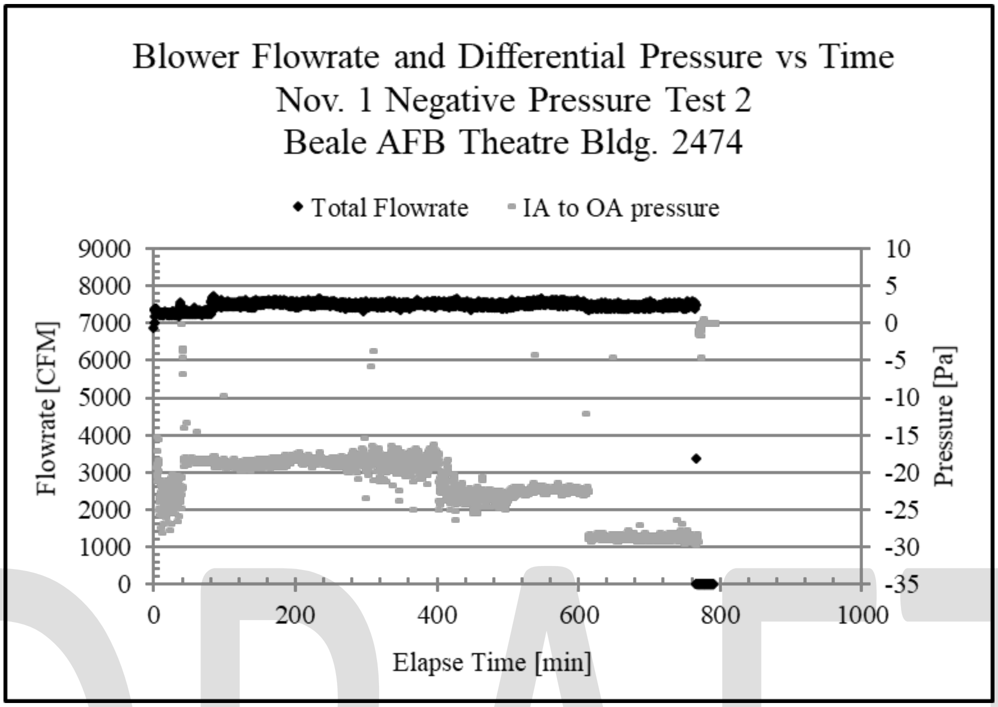

Figure 13. Blower flowrate and differential pressure vs time, Nov. 1 negative pressure test 2. Beale AFB Theatre, Bldg. 2474.

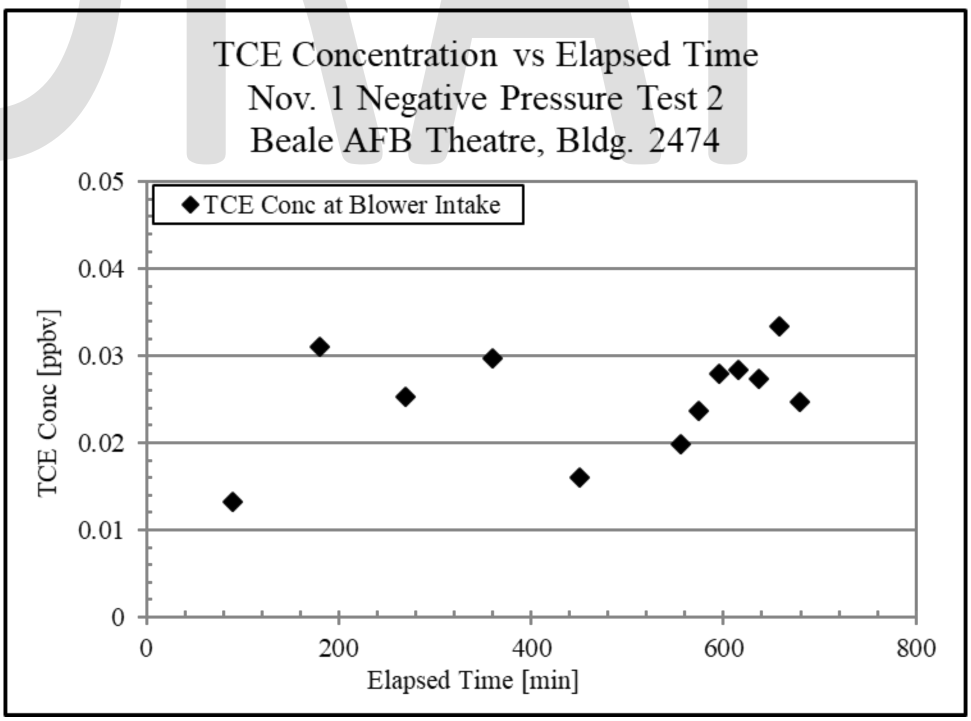

Figure 14. TCE air concentrations at the blower intake, Nov. 1 negative pressure test 2. Beale AFB Theatre, Bldg. 2474.

Table 6. Area specific sampling locations and analytical designations for Nov. 1 negative pressure test 2.

Theatre Location	Designation	Theatre Location	Designation
Blower	Blower	Stage men's restroom	St MRR
Concession storeroom	Conc Stor	Stage women's restroom	St WRR
Concession desk	Conc Desk	Stage restroom door	St RRdoor
Office	Off	Stage storage room	St Stor
Lobby women's restroom	WRR	Stage left	St L
Lobby men's restroom	MRR	Stage right	St R
Theatre entrance	Th Entrance		

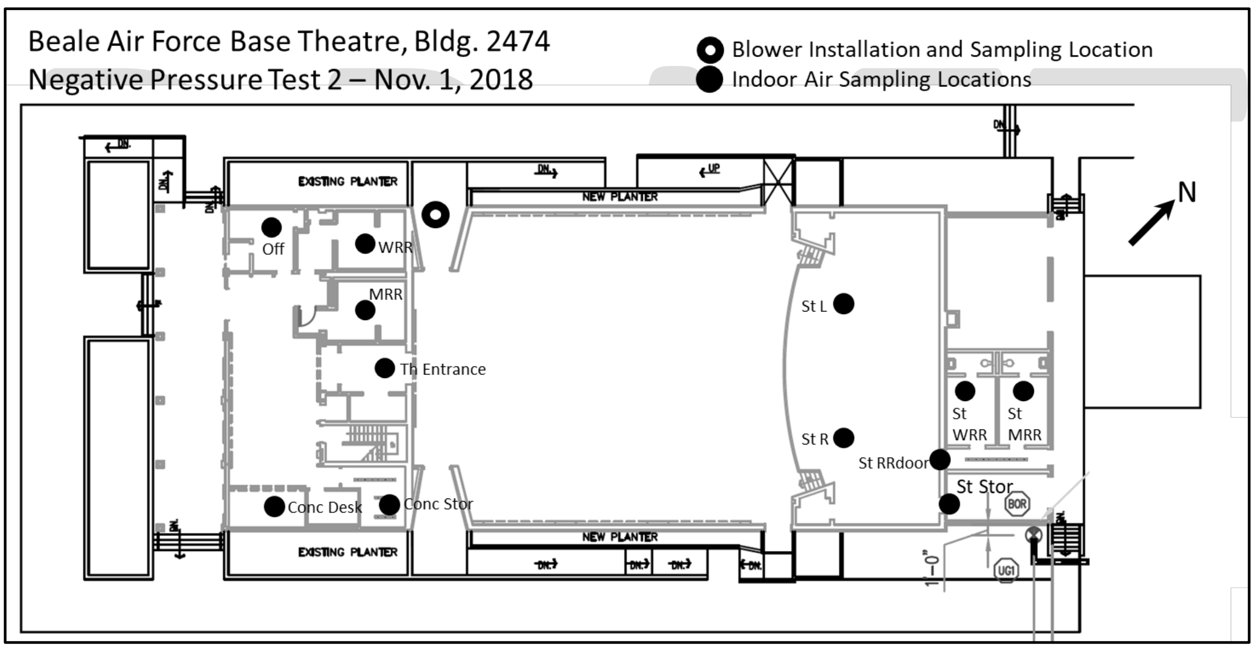

Figure 15. Nov. 1 negative pressure test 2 blower installation and air sampling locations. Beale AFB Theatre, Building 2474.

Table 7. Ambient outdoor air sampling results for Nov. 1 negative pressure test 2.

Location	Elapsed Time (min)	Analyte Concentration in Air (ppbv)					
		TCE[1]	1,1-DCE[1]	1,2-DCA[1]	1,1,1-TCA[1]	1,1,2-TCA[1]	PCE[1]
A-SE	90	ND	0.030	0.024	0.005*	ND	0.008*
A-NW	90	ND	0.031	0.024	0.005*	ND	0.008*
A-SE	360	ND	0.029	0.023	0.005*	ND	0.007*
A-NW	360	ND	0.023	0.022	0.004*	ND	0.007*

ND - Non-detectable
1 - Calibration limit of 0.01 ppbv. Highlighted concentrations were detectable and estimated.

Table 8. Indoor air sampling results for Nov. 1 negative pressure test 2.

Location	Analyte Concentration in Air (ppbv)					
	TCE[1]	1,1-DCE[1]	1,2-DCA[1]	1,1,1-TCA[1]	1,1,2-TCA[1]	PCE[1]
Blower	0.015	0.027	0.031	0.007*	0.006*	0.013
Conc Stor	0.003*	0.028	0.029	0.005*	ND	0.006*
Conc Desk	0.009*	0.027	0.026	0.005*	0.005*	0.007*
Off	0.010	0.034	0.029	0.007*	0.005*	0.008*
WRR	0.003*	0.026	0.029	0.006*	0.005*	0.008*
MRR	0.005*	0.026	0.030	0.007*	0.007*	0.009*
MRR dup	0.008*	0.025	0.024	0.005*	0.006*	0.007*
Th Entrance	ND	0.026	0.025	0.005*	0.006*	0.007*
St MRR	ND	0.024	0.025	0.006*	0.008*	0.009*
St WRR	ND	0.026	0.026	0.006*	0.007*	0.009*
St RRdoor	ND	0.026	0.025	0.006*	0.007*	0.010
St RRdoor dup	0.009*	0.028	0.031	0.006*	0.006*	0.009*
St Stor	0.004*	0.027	0.030	0.007*	0.008*	0.042
St L	0.016	0.027	0.028	0.006*	0.016	0.015
St R	0.018	0.027	0.028	0.006*	0.007*	0.015
St R dup	0.015	0.027	0.030	0.007*	0.007*	0.015

ND - Non-detectable
1 - Calibration limit of 0.01 ppbv. Highlighted concentrations were detectable and estimated.

4.2 Background Indoor Air Sampling

Background indoor air sampling was performed Nov. 2 – Nov. 26, 2018. Sampling included long-term TD tube sampling and Passive sampling. Sampling locations for this event are shown in Figure 16.

Laboratory analytical results for TD tube and passive sampling of background indoor air conditions are shown in Table 9 and are attached in the Appendices 2474A and 2474B for active TD tube and passive sampler results, respectively. The elevated detection limits for the passive air sampling is related to sampler characteristics, deployment time, and analytical.

Results indicated concentrations that were less than the quantitation limit for all analytes in all locations.

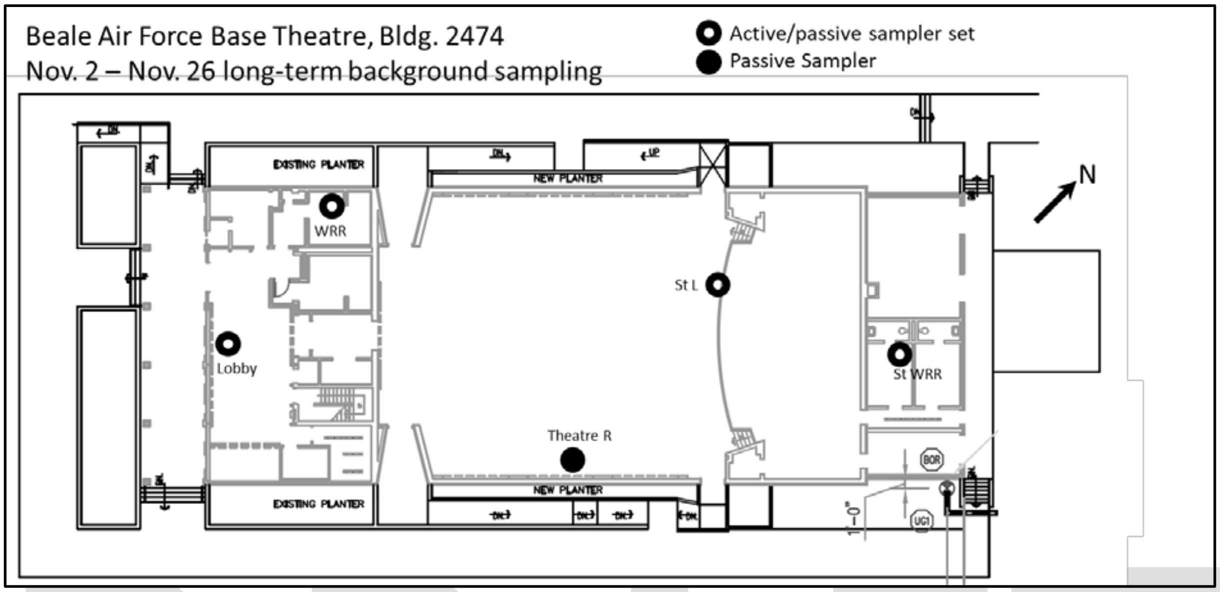

Figure 16. Nov. 2 through Nov. 26 long-term active/passive sampling locations. Beale AFB Theatre, Building 2474.

12.CPM DEMONSTRATION SUMMARY

Summary of CPM Negative Pressure Test 1

As indicated previously, negative pressure testing induced a worst-case-scenario for vapor intrusion. As such, the concentrations noted during the test were likely worst-case-scenario concentrations.

With only eight (8) building air exchanges, the optimum number of nine (9) air exchanges had not been met. In addition, per Figure 10, concentration equilibrium had not been realized. However, since the test had been underway for almost 10 hours and time was limited, eight (8) air exchanges had been achieved, and the range of TCE concentrations at the blower were between 0.01 ppbv and 0.02 ppbv, it was not believed that more significant concentration changes would be encountered with another air exchange. As such, the test was deemed complete.

The approximate indoor air TCE concentration collected at the blower intake was 0.02 ppbv for negative pressure test 1. This concentration was above ambient outdoor concentrations, however, it was well below the EPA action level of 0.08 ppbv (USEPA, 2015/2020). In addition, other analytes, when adjusted for ambient outdoor concentrations, were all less than both the EPA residential and industrial screening levels. As such, there was no complete VI pathway for the Theatre as per the definition provided in the Introduction.

Table 9. Laboratory analytical results for Nov. 2 through Nov. 26 active TD tube and passive sampling during natural building pressure conditions, Bldg. 2474.

Analyte	Analyte Concentration in Air[1]									
	Lobby		WRR		St WRR		Stage L		Theatre R	
	Active TD[2] Tube (ppbv)	Passive[2] (ug/m3 : ppbv)	Active TD[2] Tube (ppbv)	Passive[2] (ug/m3 : ppbv)	Active TD[2] Tube (ppbv)	Passive[2] (ug/m3 : ppbv)	Active TD[2] Tube (ppbv)	Passive[2] (ug/m3 : ppbv)	Active TD Tube (ppbv)	Passive[2] (ug/m3 : ppbv)
1,1-DCE	<0.02	<0.91 : <0.23	<0.02	<1.03 : <0.26	<0.02	<0.91 : <0.23	<0.02	<0.91 : <0.23	---	<0.91 : <0.23
trans-1,2-DCE	<0.02	<0.68 : <0.17	<0.02	<0.77 : <0.19	<0.02	<0.68 : <0.17	<0.02	<0.68 : <0.17	---	<0.68 : <0.17
1,1-DCA	<0.02	<0.36 : <0.09	<0.02	<0.41 : <0.10	<0.02	<0.36 : <0.09	<0.02	<0.36 : <0.09	---	<0.36 : <0.09
cis-1,2-DCE	<0.02	<0.55 : <0.14	<0.02	<0.63 : <0.16	<0.02	<0.55 : <0.14	<0.02	<0.55 : <0.14	---	<0.55 : <0.14
1,2-DCA	<0.02	<0.54 : <0.13	<0.02	<0.61 : <0.15	<0.02	<0.53 : <0.13	<0.02	<0.53 : <0.13	---	<0.53 : <0.11
1,1,1-TCA	<0.01	<0.29 : <0.05	<0.01	<0.33 : <0.06	<0.01	<0.29 : <0.05	<0.01	<0.29 : <0.05	---	<0.29 : <0.05
TCE	<0.01	<0.88 : <0.16	<0.01	<1.00 : <0.18	<0.01	<0.88 : <0.16	<0.01	<0.88 : <0.16	---	<0.88 : <0.16
PCE	<0.01	<0.73 : <0.11	<0.01	<0.83 : <0.12	<0.01	<0.73 : <0.11	<0.01	<0.73 : <0.11	---	<0.73 : <0.11
Bromodichloromethane	<0.01	<0.73 : <0.11	<0.01	<0.83 : <0.12	<0.01	<0.73 : <0.11	<0.01	<0.73 : <0.11	---	<0.73 : <0.11
Dibromochloromethane	<0.01	<0.82 : <0.10[3]	<0.01	<0.93 : <0.11[3]	<0.01	<0.82 : <0.10[3]	<0.01	<0.82 : <0.10[3]	---	<0.82 : <0.10[3]

1-For concentrations noted as "<", concentrations were non-detectable or less than the limits of quantitation shown.
2-Concentrations reported in ug/m3 and converted to ppbv using the EPA Indoor Air Unit Conversion, Online Tools for Site Assessment Calculation (USEPA, 2020).
3-Concentration reported in ug/m3 and converted to ppbv using the Eurofins Unit Conversion Calculator (Eurofins, 2020).

At that juncture, no positive pressure CPM test was necessary. However, for completeness of demonstration, a positive pressure test was performed.

Summary of CPM Positive Pressure Testing

As stated previously, positive pressure testing was initially conducted at approximately the same blower flowrate as negative pressure test 1. However, due to erratic pressure differentials and the failure to maintain a positively pressured condition for the duration of the test resulting from high wind conditions, the blower flowrate was roughly doubled to increase the positive pressure.

After meeting the minimum condition of four air exchanges at the elevated flowrate and differential pressure condition, location specific sampling was performed.

Results indicated that no indoor air sources of consequence were present within the building.

Summary of CPM Negative Pressure Test 2

Based on the increased pressure and flowrate used during positive pressure testing, a second negative pressure test was conducted at the same elevated flowrate that was used for sampling during the positive pressure test. Concentration equilibrium was met prior to sampling and area specific sampling was performed in addition to blower intake sampling.

Negative pressure test 2 indicated that the approximate averaged indoor air TCE concentration collected at the blower intake was 0.015 ppbv and the highest area specific concentration was 0.018 ppbv. These concentrations were above ambient outdoor concentrations, but again well below the EPA action level of 0.08 ppbv in a worst-case scenario. In addition, other analytes when adjusted for ambient outdoor concentrations were all less than both the residential and industrial screening levels. As such, for this increased pressure, there was still no complete VI pathway for the Theatre as per the definition provided in the Introduction.

Summary of Background Sampling Under Natural Building Pressure Conditions

No analytes of interest were detected in the background sampling of Building 2474 under natural building pressure conditions. These results indicate that there is no vapor intrusion impact, or more specifically, there was no complete vapor intrusion pathway. These results corroborated the results of CPM testing which also indicated that there was no complete vapor intrusion pathway.

13. ADDITIONAL SAMPLING TO DEFINE THE APPARENT LOW LEVEL TCE DETECTIONS

In both negative and positive pressure CPM tests, apparent low level concentrations of TCE up to 0.02 ppbv were detected (see Tables 2, 5, and 7). While these concentrations did not alter the determination that there was no complete VI pathway, additional sampling was performed to understand the origins of those apparent TCE concentrations.

Of particular note was the apparent detection of TCE when sampling MRR during positive pressure testing. Given that positive pressure testing was designed to identify indoor air sources and none were obvious, other explanations for those detects were considered. Since grab sampling in the MRR was performed adjacent to a urinal which flushed a couple of times during sampling, the primary consideration was that the water flush played a part in that signature. Based on this premise, additional air samples were collected during subsequent pressure testing. Locations of focus included water sources, drains, and the sewer manhole closest to the facility, locations for which are shown in Figure 17.

Sample analysis indicated that all additional samples showed apparent TCE concentrations of 0.01 ppbv or greater. In particular, a sample collected directly in front of a flushing urinal in MRR showed an apparent concentration in excess of 2 ppbv, which seemed quite implausible. As such, co-elution of a compound other than TCE was considered.

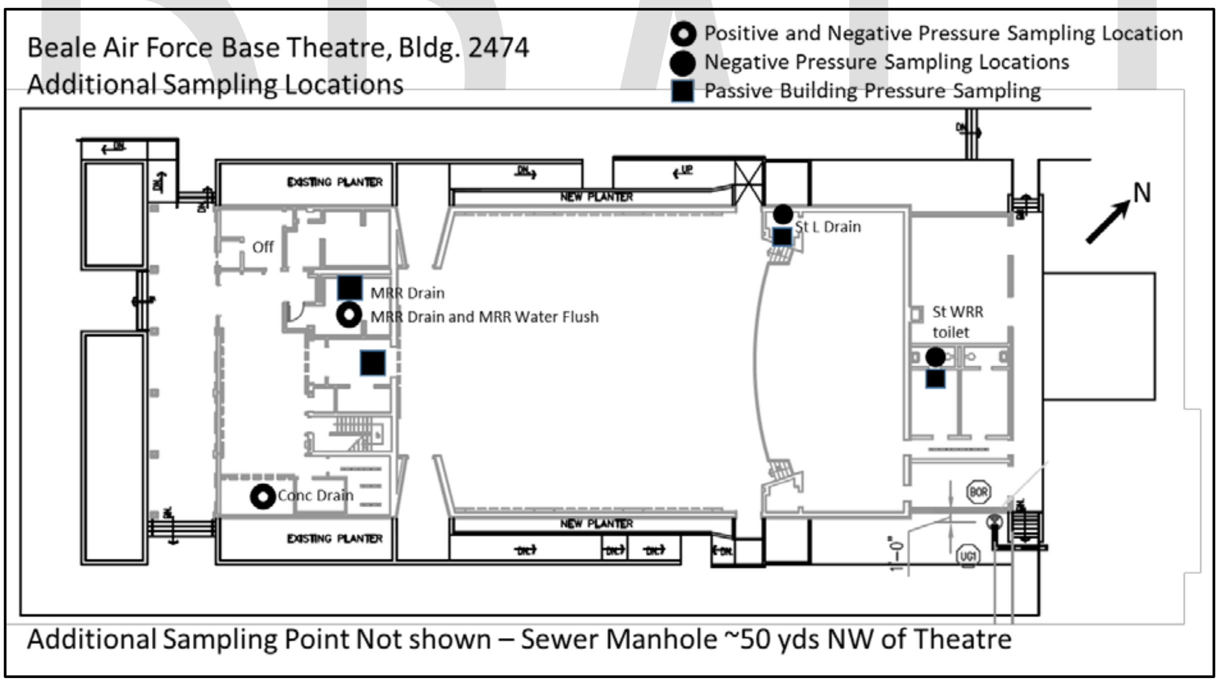

Figure 17. Additional sampling locations to determine origins of apparent TCE detections. Beale AFB Theatre, Building 2474.

During GC analysis, when a different compound has the same retention time as a calibrated compound and is detected, it is called co-elution. When a compound co-elutes, there is an assumption that the resultant peak is a detection of the calibrated compound alone. It was possible that there was a compound present in the water that was co-eluting with TCE.

Investigations to clarify the issue included a GCMS headspace analysis of potable tap water. The sample was analyzed for TCE and unknown compounds at ASU via two GCMS methods, one looking specifically for TCE using the ion specific mode of analysis, the other looking for any compound using the scan mode of analysis. Under ion specific mode for TCE, there was no detection. However, under scan mode, a very large peak with almost the same retention time as TCE was identified with 90% confidence as bromodichloromethane, a disinfection by-product of chlorination during water treatment. Since the presence of a disinfection by-product in tap water, drains, and the sewer was highly plausible, it was determined that apparent TCE detects were in fact bromodichloromethane. However, it is recommended that the base conduct sampling of both tap water and sewer gas to verify those findings.

14.CPM DEMONSTRATION CONCLUSIONS

As stated in the Introduction, a complete VI pathway was defined as vapor intrusion with indoor vapor contaminant concentrations in excess of a regulatory limit or action level. Based on this definition, CPM testing indicated that there was no complete VI pathway for the Building 2474, the Theatre. This result was corroborated with more traditional active and passive sampling techniques within the building under passive pressure conditions.

15.REFERENCES

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USEPA, 2020. Regional Screening Level (RSL) Summary Table (TR=1E-06, HQ=1) May 2020 (corrected). https://semspub.epa.gov/work/HQ/200043.pdf

Appendix 2474A
Background Indoor Air Sampling - Active TD Tube Results
Analytical Report

(Only sample IDs prefix of “B Theatre”
are related to the Beale Theatre, Bldg. 2474)

BEACON ENVIRONMENTAL SERVICES, INC.

The Leaders in Air Surveys and Vapor Intrusion Monitoring

Arizona State University
660 South College Avenue, Room 507
Tempe, AZ 85281
Attn: Paul Dahlen

Air Samples -- Analytical Report

Date: June 17, 2020
Beacon Project No. 4459.1A

Project Reference:	Beale and Travis AFB
Sampling Date:	November 2 through 8, 2018
Samples Received:	December 11, 2018
Analyses Completed:	December 13, 2018

Results for the following samples are included in this data package:

Sample ID	Matrix	Analysis
BTheaterStageL	Air	TO-17
BtheaterStageL_B_Up	Air	TO-17
BTheaterLobby	Air	TO-17
BtheaterLobby_B_Up	Air	TO-17
BTheaterWRR	Air	TO-17
BTheaterWRR_B_Up	Air	TO-17
BTheaterStageWRR	Air	TO-17
BTheaterStageWRR_B_Up	Air	TO-17
Tr18Main	Air	TO-17
Tr18Main_B_Up	Air	TO-17
Tr18Hall	Air	TO-17
Tr18Hall_B_Up	Air	TO-17
Tr18SEOffice	Air	TO-17
Tr18SEOffice_B_Up	Air	TO-17
Tr18Shower1	Air	TO-17
Tr18Shower1_B_Up	Air	TO-17
BCACCafe	Air	TO-17
BCACCafe_B_Up	Air	TO-17
BCACBallR	Air	TO-17
BCACBallR_B_Up	Air	TO-17
BCACConf	Air	TO-17
BCACConf_B_Up	Air	TO-17
BCACOff	Air	TO-17
BCACOff_B_Up	Air	TO-17
BCACMRR	Air	TO-17
BCACMRR_B_Up	Air	TO-17
BCACWelcCtrOffR	Air	TO-17
BCACWelcCtrOffR_B_Up	Air	TO-17
BCACRec	Air	TO-17
BCACRec_B_Up	Air	TO-17

Sample Collection

Beacon Environmental provided Arizona State University with thermally conditioned multi-bed stainless steel tubes to target a custom list of analytes. Air was drawn through each tube and the resulting mass of target analytes captured on each sampler was reported as a concentration.

U. S. EPA Method TO-17

All samples were analyzed for a custom target compound list following U.S. EPA Method TO-17. The analytical results are reported in micrograms per meter cubed ($\mu g/m^3$) and ppbv based on the measured mass and volume of gas sampled.

Reporting Limits (RLs) for EPA Method TO-17

The lowest point in the calibration curve and the limit of quantitation (LOQ) is 10 nanograms (ng), which is the RL; however, when reporting concentration data the values are provided in $\mu g/m^3$ and ppbv. The RLs represent a baseline above which results exceed laboratory-determined limits of precision and accuracy.

Calibration Verification

The initial laboratory control sample (LCS) also serves as the calibration verification and values for the analytes were all within ±30% of the true values as defined by the initial five-point calibration and met the requirements specified in Beacon Environmental's Quality Manual. Both the LCS and the laboratory control duplicate (LCSD) are spiked at 50 ng and percentage of recovery is calculated and reported. Acceptance criteria for surrogate and analyte recoveries are 70 to 130 percent; all surrogates and analytes were within the acceptance criteria.

Internal Standards and Surrogates

Internal standards and surrogates are spiked on each field and QC sample at 100 ng and 50 ng, respectively, and the percentage of recovery is calculated. Acceptance criteria for internal standards are 60 to 140 percent and surrogate recoveries are 70 to 130 percent; all internal standards and surrogates were within the acceptance criteria.

Blank Contamination

No targeted compounds above the limit of detection (LOD) for each compound were observed in the Laboratory Method Blanks.

Discussion

Thirty (30) samples were collected following U.S. EPA Method TO-17. Sampling start and stop times, and total sampling volume can be found in the Chain of Custody (**Attachment 1**).

Dilutions were required for multiple samples, to bring the detected concentrations of reported compounds into the calibration range of the GC/MSD instrument. The LOQs of the diluted sample results are higher and noted in **Table 1**.

Demonstrated Linear Range of the GC-MS Instrumentation (EPA Method TO-17)

An initial five-point calibration is performed on the instrumentation from 10 to 200 ng per analyte.

Attachments:

-1- Chain of Custody

ALL DATA MEET REQUIREMENTS AS SPECIFIED IN THE BEACON ENVIRONMENTAL SERVICES, INC. QUALITY MANUAL AND THE RESULTS RELATE ONLY TO THE SAMPLES REPORTED. BEACON ENVIRONMENTAL SERVICES IS ACCREDITED TO ISO/IEC 17025:2005, AND THE WORK PERFORMED WAS IN ACCORDANCE WITH ISO/IEC 17025 REQUIREMENTS. THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY. RELEASE OF THE DATA HAS BEEN AUTHORIZED BY THE LABORATORY DIRECTOR OR HIS SIGNEE, AS VERIFIED BY THE FOLLOWING SIGNATURES:

Steven C. Thornley
Laboratory Director

Date: June 17, 2020

nvironmental Services, Inc.
A Commerce Road Suite 1
orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LCS_1078673_181212

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID
initial	K18121202
1st Dilution	
2nd Dilution	
3rd Dilution	

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**102%**	%REC	70-130	12/12/18 12:47	K18121202
trans-1,2-Dichloroethene	156-60-5	**103%**	%REC	70-130	12/12/18 12:47	K18121202
1,1-Dichloroethane	75-34-3	**102%**	%REC	70-130	12/12/18 12:47	K18121202
cis-1,2-Dichloroethene	156-59-2	**107%**	%REC	70-130	12/12/18 12:47	K18121202
Chloroform	67-66-3	**105%**	%REC	70-130	12/12/18 12:47	K18121202
1,2-Dichloroethane	107-06-2	**110%**	%REC	70-130	12/12/18 12:47	K18121202
1,1,1-Trichloroethane	71-55-6	**108%**	%REC	70-130	12/12/18 12:47	K18121202
Trichloroethene	79-01-6	**112%**	%REC	70-130	12/12/18 12:47	K18121202
Bromodichloromethane	75-27-4	**113%**	%REC	70-130	12/12/18 12:47	K18121202
Dibromochloromethane	124-48-1	**109%**	%REC	70-130	12/12/18 12:47	K18121202
Tetrachloroethene	127-18-4	**96%**	%REC	70-130	12/12/18 12:47	K18121202
Bromoform	75-25-2	**109%**	%REC	70-130	12/12/18 12:47	K18121202

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

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orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LB_1078524_181212

Analysis	Lab FileID
initial	K18121203
1st Dilution	
2nd Dilution	
3rd Dilution	

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

COMPOUNDS	CAS#						
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 13:07	K18121203
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 13:07	K18121203
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 13:07	K18121203
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 13:07	K18121203
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 13:07	K18121203
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 13:07	K18121203
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/12/18 13:07	K18121203
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 13:07	K18121203
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 13:07	K18121203
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 13:07	K18121203
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 13:07	K18121203
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 13:07	K18121203

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: **LCSD_1078697_181212**

	Analysis	Lab File ID
Client:	**initial**	K18121204
Arizon State University	1st Dilution	
660 South College Avenue, Room 507	2nd Dilution	
Tempe, AZ 85281	3rd Dilution	
ph: 480-385-9671		

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**91%**	%REC	70-130	12/12/18 13:27	K18121204
trans-1,2-Dichloroethene	156-60-5	**95%**	%REC	70-130	12/12/18 13:27	K18121204
1,1-Dichloroethane	75-34-3	**98%**	%REC	70-130	12/12/18 13:27	K18121204
cis-1,2-Dichloroethene	156-59-2	**101%**	%REC	70-130	12/12/18 13:27	K18121204
Chloroform	67-66-3	**102%**	%REC	70-130	12/12/18 13:27	K18121204
1,2-Dichloroethane	107-06-2	**107%**	%REC	70-130	12/12/18 13:27	K18121204
1,1,1-Trichloroethane	71-55-6	**103%**	%REC	70-130	12/12/18 13:27	K18121204
Trichloroethene	79-01-6	**111%**	%REC	70-130	12/12/18 13:27	K18121204
Bromodichloromethane	75-27-4	**112%**	%REC	70-130	12/12/18 13:27	K18121204
Dibromochloromethane	124-48-1	**111%**	%REC	70-130	12/12/18 13:27	K18121204
Tetrachloroethene	127-18-4	**100%**	%REC	70-130	12/12/18 13:27	K18121204
Bromoform	75-25-2	**111%**	%REC	70-130	12/12/18 13:27	K18121204

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterStageL
Lab Sample ID:	1078601
Sample Collection Time:	11/26/18 3:13 PM
Sample Volume in Liters:	155.72
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121205	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 13:51	K18121205
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 13:51	K18121205
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 13:51	K18121205
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 13:51	K18121205
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 13:51	K18121205
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 13:51	K18121205
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 13:51	K18121205
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 13:51	K18121205
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 13:51	K18121205
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 13:51	K18121205
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 13:51	K18121205
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 13:51	K18121205

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterStageL_B_up
Lab Sample ID:	1078544
Sample Collection Time:	11/26/18 3:13 PM
Sample Volume in Liters:	155.72
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121206	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 14:16	K18121206
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 14:16	K18121206
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 14:16	K18121206
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 14:16	K18121206
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 14:16	K18121206
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 14:16	K18121206
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 14:16	K18121206
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 14:16	K18121206
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 14:16	K18121206
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 14:16	K18121206
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 14:16	K18121206
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 14:16	K18121206

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterLobby
Lab Sample ID:	1078895
Sample Collection Time:	11/26/18 2:55 PM
Sample Volume in Liters:	156.31
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121207	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 14:40	K18121207
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 14:40	K18121207
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 14:40	K18121207
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 14:40	K18121207
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 14:40	K18121207
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 14:40	K18121207
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 14:40	K18121207
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 14:40	K18121207
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 14:40	K18121207
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 14:40	K18121207
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 14:40	K18121207
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 14:40	K18121207

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BTheaterLobby_B_up
Lab Sample ID: 1078651
Sample Collection Time: 11/26/18 2:55 PM
Sample Volume in Liters: 156.31
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121208	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 15:05	K18121208
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 15:05	K18121208
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 15:05	K18121208
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 15:05	K18121208
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 15:05	K18121208
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 15:05	K18121208
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 15:05	K18121208
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 15:05	K18121208
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 15:05	K18121208
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 15:05	K18121208
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 15:05	K18121208
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 15:05	K18121208

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterWRR
Lab Sample ID:	1078606
Sample Collection Time:	11/26/18 3:07 PM
Sample Volume in Liters:	138.05
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121209	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 15:29	K18121209
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 15:29	K18121209
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 15:29	K18121209
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 15:29	K18121209
Chloroform	67-66-3	**0.09**	0.1	**0.02**	0.01	12/12/18 15:29	K18121209
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 15:29	K18121209
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 15:29	K18121209
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 15:29	K18121209
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 15:29	K18121209
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 15:29	K18121209
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 15:29	K18121209
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 15:29	K18121209

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterWRR_B_up
Lab Sample ID:	1078803
Sample Collection Time:	11/26/18 3:07 PM
Sample Volume in Liters:	138.05
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121210	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 15:53	K18121210
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 15:53	K18121210
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 15:53	K18121210
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 15:53	K18121210
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 15:53	K18121210
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 15:53	K18121210
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 15:53	K18121210
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 15:53	K18121210
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 15:53	K18121210
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 15:53	K18121210
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 15:53	K18121210
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 15:53	K18121210

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterStageWRR
Lab Sample ID:	1078556
Sample Collection Time:	11/26/18 3:18 PM
Sample Volume in Liters:	161.68
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121211	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 16:17	K18121211
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 16:17	K18121211
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 16:17	K18121211
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 16:17	K18121211
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 16:17	K18121211
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 16:17	K18121211
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 16:17	K18121211
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 16:17	K18121211
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 16:17	K18121211
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 16:17	K18121211
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 16:17	K18121211
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 16:17	K18121211

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BTheaterStageWRR_B_up
Lab Sample ID: 1078769
Sample Collection Time: 11/26/18 3:18 PM
Sample Volume in Liters: 161.68
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab FileID	Dilution Factor
initial	K18121212	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 16:42	K18121212
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 16:42	K18121212
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 16:42	K18121212
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 16:42	K18121212
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 16:42	K18121212
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 16:42	K18121212
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 16:42	K18121212
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 16:42	K18121212
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 16:42	K18121212
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 16:42	K18121212
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 16:42	K18121212
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 16:42	K18121212

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18Main
Lab Sample ID:	1078557
Sample Collection Time:	11/27/18 4:36 PM
Sample Volume in Liters:	65.64
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121213	1
1st Dilution	K18121305	8.49
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.2	U	0.04	12/12/18 17:06	K18121213
trans-1,2-Dichloroethene	156-60-5	U	0.2	U	0.04	12/12/18 17:06	K18121213
1,1-Dichloroethane	75-34-3	U	0.2	U	0.04	12/12/18 17:06	K18121213
cis-1,2-Dichloroethene	156-59-2	**1.6**	0.2	**0.4**	0.04	12/12/18 17:06	K18121213
Chloroform	67-66-3	U	0.2	U	0.03	12/12/18 17:06	K18121213
1,2-Dichloroethane	107-06-2	U	0.2	U	0.04	12/12/18 17:06	K18121213
1,1,1-Trichloroethane	71-55-6	U	0.2	U	0.03	12/12/18 17:06	K18121213
Trichloroethene	79-01-6	**12.05 D**	1.3	**2.24 D**	0.24	12/13/18 11:03	K18121305
Bromodichloromethane	75-27-4	U	0.2	U	0.02	12/12/18 17:06	K18121213
Dibromochloromethane	124-48-1	U	0.2	U	0.02	12/12/18 17:06	K18121213
Tetrachloroethene	127-18-4	U	0.2	U	0.02	12/12/18 17:06	K18121213
Bromoform	75-25-2	U	0.2	U	0.01	12/12/18 17:06	K18121213

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Beacon Job Number: 4459.1A
Analysis Method: TO17
Matrix: Air
Client ID/Field Sampling Location: Tr18Main_B_up
Lab Sample ID: 1078647
Sample Collection Time: 11/27/18 4:36 PM
Sample Volume in Liters: 65.64
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121214	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.2	U	0.04	12/12/18 17:30	K18121214
trans-1,2-Dichloroethene	156-60-5	U	0.2	U	0.04	12/12/18 17:30	K18121214
1,1-Dichloroethane	75-34-3	U	0.2	U	0.04	12/12/18 17:30	K18121214
cis-1,2-Dichloroethene	156-59-2	U	0.2	U	0.04	12/12/18 17:30	K18121214
Chloroform	67-66-3	U	0.2	U	0.03	12/12/18 17:30	K18121214
1,2-Dichloroethane	107-06-2	U	0.2	U	0.04	12/12/18 17:30	K18121214
1,1,1-Trichloroethane	71-55-6	U	0.2	U	0.03	12/12/18 17:30	K18121214
Trichloroethene	79-01-6	U	0.2	U	0.03	12/12/18 17:30	K18121214
Bromodichloromethane	75-27-4	U	0.2	U	0.02	12/12/18 17:30	K18121214
Dibromochloromethane	124-48-1	U	0.2	U	0.02	12/12/18 17:30	K18121214
Tetrachloroethene	127-18-4	U	0.2	U	0.02	12/12/18 17:30	K18121214
Bromoform	75-25-2	U	0.2	U	0.01	12/12/18 17:30	K18121214

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18Hall
Lab Sample ID:	1078637
Sample Collection Time:	11/27/18 4:21 PM
Sample Volume in Liters:	68.60
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121215	1
1st Dilution	K18121306	8.5
2nd Dilution	K18121309	42.8
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.04	12/12/18 17:55	K18121215
trans-1,2-Dichloroethene	156-60-5	**0.19**	0.1	**0.05**	0.04	12/12/18 17:55	K18121215
1,1-Dichloroethane	75-34-3	U	0.1	U	0.04	12/12/18 17:55	K18121215
cis-1,2-Dichloroethene	156-59-2	**6.95 D**	1.2	**1.75 D**	0.31	12/13/18 11:26	K18121306
Chloroform	67-66-3	U	0.1	U	0.03	12/12/18 17:55	K18121215
1,2-Dichloroethane	107-06-2	U	0.1	U	0.04	12/12/18 17:55	K18121215
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.03	12/12/18 17:55	K18121215
Trichloroethene	79-01-6	**35.21 D**	6.2	**6.55 D**	1.16	12/13/18 12:46	K18121309
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/12/18 17:55	K18121215
Dibromochloromethane	124-48-1	U	0.1	U	0.02	12/12/18 17:55	K18121215
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/12/18 17:55	K18121215
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 17:55	K18121215

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18Hall_B_up
Lab Sample ID:	1078511
Sample Collection Time:	11/27/18 4:21 PM
Sample Volume in Liters:	68.60
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121216	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.04	12/12/18 18:19	K18121216
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.04	12/12/18 18:19	K18121216
1,1-Dichloroethane	75-34-3	U	0.1	U	0.04	12/12/18 18:19	K18121216
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.04	12/12/18 18:19	K18121216
Chloroform	67-66-3	U	0.1	U	0.03	12/12/18 18:19	K18121216
1,2-Dichloroethane	107-06-2	U	0.1	U	0.04	12/12/18 18:19	K18121216
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.03	12/12/18 18:19	K18121216
Trichloroethene	79-01-6	U	0.1	U	0.03	12/12/18 18:19	K18121216
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/12/18 18:19	K18121216
Dibromochloromethane	124-48-1	U	0.1	U	0.02	12/12/18 18:19	K18121216
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/12/18 18:19	K18121216
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 18:19	K18121216

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18SEOffice
Lab Sample ID:	1078558
Sample Collection Time:	11/27/18 4:21 PM
Sample Volume in Liters:	56.66
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121217	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.2	U	0.04	12/12/18 18:46	K18121217
trans-1,2-Dichloroethene	156-60-5	**0.65**	0.2	**0.16**	0.04	12/12/18 18:46	K18121217
1,1-Dichloroethane	75-34-3	U	0.2	U	0.04	12/12/18 18:46	K18121217
cis-1,2-Dichloroethene	156-59-2	**13.75 E**	0.2	**3.47 E**	0.04	12/12/18 18:46	K18121217
Chloroform	67-66-3	U	0.2	U	0.04	12/12/18 18:46	K18121217
1,2-Dichloroethane	107-06-2	U	0.2	U	0.04	12/12/18 18:46	K18121217
1,1,1-Trichloroethane	71-55-6	U	0.2	U	0.03	12/12/18 18:46	K18121217
Trichloroethene	79-01-6	**61.03 E**	0.2	**11.36 E**	0.03	12/12/18 18:46	K18121217
Bromodichloromethane	75-27-4	U	0.2	U	0.03	12/12/18 18:46	K18121217
Dibromochloromethane	124-48-1	U	0.2	U	0.02	12/12/18 18:46	K18121217
Tetrachloroethene	127-18-4	**0.24**	0.2	**0.04**	0.03	12/12/18 18:46	K18121217
Bromoform	75-25-2	U	0.2	U	0.02	12/12/18 18:46	K18121217

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18SEOffice_B_up
Lab Sample ID:	1078666
Sample Collection Time:	11/27/18 4:21 PM
Sample Volume in Liters:	56.66
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121218	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.2	U	0.04	12/12/18 19:10	K18121218
trans-1,2-Dichloroethene	156-60-5	U	0.2	U	0.04	12/12/18 19:10	K18121218
1,1-Dichloroethane	75-34-3	U	0.2	U	0.04	12/12/18 19:10	K18121218
cis-1,2-Dichloroethene	156-59-2	U	0.2	U	0.04	12/12/18 19:10	K18121218
Chloroform	67-66-3	U	0.2	U	0.04	12/12/18 19:10	K18121218
1,2-Dichloroethane	107-06-2	U	0.2	U	0.04	12/12/18 19:10	K18121218
1,1,1-Trichloroethane	71-55-6	U	0.2	U	0.03	12/12/18 19:10	K18121218
Trichloroethene	79-01-6	U	0.2	U	0.03	12/12/18 19:10	K18121218
Bromodichloromethane	75-27-4	U	0.2	U	0.03	12/12/18 19:10	K18121218
Dibromochloromethane	124-48-1	U	0.2	U	0.02	12/12/18 19:10	K18121218
Tetrachloroethene	127-18-4	U	0.2	U	0.03	12/12/18 19:10	K18121218
Bromoform	75-25-2	U	0.2	U	0.02	12/12/18 19:10	K18121218

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18Shower1
Lab Sample ID:	1078519
Sample Collection Time:	11/27/18 4:41 PM
Sample Volume in Liters:	72.13
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121219	1
1st Dilution	K18121308	8.5
2nd Dilution	K18121310	42.8
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/12/18 19:35	K18121219
trans-1,2-Dichloroethene	156-60-5	**0.17**	0.1	**0.04**	0.03	12/12/18 19:35	K18121219
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/12/18 19:35	K18121219
cis-1,2-Dichloroethene	156-59-2	**8.06 D**	1.2	**2.03 D**	0.30	12/13/18 12:13	K18121308
Chloroform	67-66-3	**0.15**	0.1	**0.03**	0.03	12/12/18 19:35	K18121219
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/12/18 19:35	K18121219
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.03	12/12/18 19:35	K18121219
Trichloroethene	79-01-6	**39.04 D**	5.9	**7.26 D**	1.10	12/13/18 13:09	K18121310
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/12/18 19:35	K18121219
Dibromochloromethane	124-48-1	U	0.1	U	0.02	12/12/18 19:35	K18121219
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/12/18 19:35	K18121219
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 19:35	K18121219

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18Shower1_B_up
Lab Sample ID:	1078536
Sample Collection Time:	11/27/18 4:41 PM
Sample Volume in Liters:	72.13
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121220	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/12/18 19:59	K18121220
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.03	12/12/18 19:59	K18121220
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/12/18 19:59	K18121220
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.03	12/12/18 19:59	K18121220
Chloroform	67-66-3	U	0.1	U	0.03	12/12/18 19:59	K18121220
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/12/18 19:59	K18121220
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.03	12/12/18 19:59	K18121220
Trichloroethene	79-01-6	U	0.1	U	0.03	12/12/18 19:59	K18121220
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/12/18 19:59	K18121220
Dibromochloromethane	124-48-1	U	0.1	U	0.02	12/12/18 19:59	K18121220
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/12/18 19:59	K18121220
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 19:59	K18121220

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BCACCafe
Lab Sample ID: 1078661
Sample Collection Time: 11/26/18 4:18 PM
Sample Volume in Liters: 122.20
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121221	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 20:24	K18121221
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 20:24	K18121221
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 20:24	K18121221
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 20:24	K18121221
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 20:24	K18121221
1,2-Dichloroethane	107-06-2	**0.17**	0.1	**0.04**	0.02	12/12/18 20:24	K18121221
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 20:24	K18121221
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 20:24	K18121221
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 20:24	K18121221
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 20:24	K18121221
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 20:24	K18121221
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 20:24	K18121221

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACCafe_B_up
Lab Sample ID:	1078610
Sample Collection Time:	11/26/18 4:18 PM
Sample Volume in Liters:	122.20
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121222	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 20:48	K18121222
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 20:48	K18121222
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 20:48	K18121222
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 20:48	K18121222
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 20:48	K18121222
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 20:48	K18121222
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 20:48	K18121222
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 20:48	K18121222
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 20:48	K18121222
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 20:48	K18121222
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 20:48	K18121222
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 20:48	K18121222

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACBallR
Lab Sample ID:	1078639
Sample Collection Time:	11/26/18 3:46 PM
Sample Volume in Liters:	112.72
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121223	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 21:13	K18121223
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 21:13	K18121223
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 21:13	K18121223
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 21:13	K18121223
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 21:13	K18121223
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 21:13	K18121223
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/12/18 21:13	K18121223
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 21:13	K18121223
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 21:13	K18121223
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 21:13	K18121223
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 21:13	K18121223
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 21:13	K18121223

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACBallR_B_up
Lab Sample ID:	1078687
Sample Collection Time:	11/26/18 3:46 PM
Sample Volume in Liters:	112.72
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	**Lab File ID**	**Dilution Factor**
initial	K18121224	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 21:37	K18121224
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 21:37	K18121224
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 21:37	K18121224
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 21:37	K18121224
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 21:37	K18121224
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 21:37	K18121224
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/12/18 21:37	K18121224
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 21:37	K18121224
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 21:37	K18121224
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 21:37	K18121224
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 21:37	K18121224
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 21:37	K18121224

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: CL_LCS_1078733_181212

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab FileID
initial	K18121225
1st Dilution	
2nd Dilution	
3rd Dilution	

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**81%**	%REC	50-150	12/12/18 21:57	K18121225
trans-1,2-Dichloroethene	156-60-5	**96%**	%REC	50-150	12/12/18 21:57	K18121225
1,1-Dichloroethane	75-34-3	**100%**	%REC	50-150	12/12/18 21:57	K18121225
cis-1,2-Dichloroethene	156-59-2	**101%**	%REC	50-150	12/12/18 21:57	K18121225
Chloroform	67-66-3	**100%**	%REC	50-150	12/12/18 21:57	K18121225
1,2-Dichloroethane	107-06-2	**98%**	%REC	50-150	12/12/18 21:57	K18121225
1,1,1-Trichloroethane	71-55-6	**111%**	%REC	50-150	12/12/18 21:57	K18121225
Trichloroethene	79-01-6	**110%**	%REC	50-150	12/12/18 21:57	K18121225
Bromodichloromethane	75-27-4	**103%**	%REC	50-150	12/12/18 21:57	K18121225
Dibromochloromethane	124-48-1	**98%**	%REC	50-150	12/12/18 21:57	K18121225
Tetrachloroethene	127-18-4	**94%**	%REC	50-150	12/12/18 21:57	K18121225
Bromoform	75-25-2	**109%**	%REC	50-150	12/12/18 21:57	K18121225

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LCS_1078851_181213

Client:	Analysis	Lab FileID
Arizon State University	**initial**	K18121313
660 South College Avenue, Room 507	1st Dilution	
Tempe, AZ 85281	2nd Dilution	
ph: 480-385-9671	3rd Dilution	

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**109%**	%REC	70-130	12/13/18 16:35	K18121313
trans-1,2-Dichloroethene	156-60-5	**103%**	%REC	70-130	12/13/18 16:35	K18121313
1,1-Dichloroethane	75-34-3	**106%**	%REC	70-130	12/13/18 16:35	K18121313
cis-1,2-Dichloroethene	156-59-2	**109%**	%REC	70-130	12/13/18 16:35	K18121313
Chloroform	67-66-3	**105%**	%REC	70-130	12/13/18 16:35	K18121313
1,2-Dichloroethane	107-06-2	**106%**	%REC	70-130	12/13/18 16:35	K18121313
1,1,1-Trichloroethane	71-55-6	**112%**	%REC	70-130	12/13/18 16:35	K18121313
Trichloroethene	79-01-6	**111%**	%REC	70-130	12/13/18 16:35	K18121313
Bromodichloromethane	75-27-4	**105%**	%REC	70-130	12/13/18 16:35	K18121313
Dibromochloromethane	124-48-1	**101%**	%REC	70-130	12/13/18 16:35	K18121313
Tetrachloroethene	127-18-4	**105%**	%REC	70-130	12/13/18 16:35	K18121313
Bromoform	75-25-2	**100%**	%REC	70-130	12/13/18 16:35	K18121313

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LB_1078571_181213

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab FileID
initial	K18121314
1st Dilution	
2nd Dilution	
3rd Dilution	

COMPOUNDS	CAS#						
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/13/18 16:55	K18121314
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.03	12/13/18 16:55	K18121314
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/13/18 16:55	K18121314
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.03	12/13/18 16:55	K18121314
Chloroform	67-66-3	U	0.1	U	0.03	12/13/18 16:55	K18121314
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/13/18 16:55	K18121314
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 16:55	K18121314
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 16:55	K18121314
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/13/18 16:55	K18121314
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 16:55	K18121314
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/13/18 16:55	K18121314
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 16:55	K18121314

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LCSD_1078816_181213

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID
initial	K18121315
1st Dilution	
2nd Dilution	
3rd Dilution	

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**103%**	%REC	70-130	12/13/18 17:15	K18121315
trans-1,2-Dichloroethene	156-60-5	**110%**	%REC	70-130	12/13/18 17:15	K18121315
1,1-Dichloroethane	75-34-3	**111%**	%REC	70-130	12/13/18 17:15	K18121315
cis-1,2-Dichloroethene	156-59-2	**113%**	%REC	70-130	12/13/18 17:15	K18121315
Chloroform	67-66-3	**111%**	%REC	70-130	12/13/18 17:15	K18121315
1,2-Dichloroethane	107-06-2	**112%**	%REC	70-130	12/13/18 17:15	K18121315
1,1,1-Trichloroethane	71-55-6	**111%**	%REC	70-130	12/13/18 17:15	K18121315
Trichloroethene	79-01-6	**116%**	%REC	70-130	12/13/18 17:15	K18121315
Bromodichloromethane	75-27-4	**114%**	%REC	70-130	12/13/18 17:15	K18121315
Dibromochloromethane	124-48-1	**107%**	%REC	70-130	12/13/18 17:15	K18121315
Tetrachloroethene	127-18-4	**101%**	%REC	70-130	12/13/18 17:15	K18121315
Bromoform	75-25-2	**105%**	%REC	70-130	12/13/18 17:15	K18121315

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACConf
Lab Sample ID:	1078562
Sample Collection Time:	11/26/18 4:36 PM
Sample Volume in Liters:	115.77
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121316	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 17:40	K18121316
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 17:40	K18121316
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 17:40	K18121316
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 17:40	K18121316
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 17:40	K18121316
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 17:40	K18121316
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 17:40	K18121316
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 17:40	K18121316
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 17:40	K18121316
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 17:40	K18121316
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 17:40	K18121316
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 17:40	K18121316

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACConf_B_up
Lab Sample ID:	1078546
Sample Collection Time:	11/26/18 4:36 PM
Sample Volume in Liters:	115.77
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121317	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 18:04	K18121317
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 18:04	K18121317
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 18:04	K18121317
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 18:04	K18121317
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 18:04	K18121317
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 18:04	K18121317
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 18:04	K18121317
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 18:04	K18121317
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 18:04	K18121317
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 18:04	K18121317
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 18:04	K18121317
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 18:04	K18121317

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACOff
Lab Sample ID:	1078892
Sample Collection Time:	11/26/18 4:09 PM
Sample Volume in Liters:	112.85
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121318	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 18:29	K18121318
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 18:29	K18121318
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 18:29	K18121318
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 18:29	K18121318
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 18:29	K18121318
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 18:29	K18121318
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 18:29	K18121318
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 18:29	K18121318
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 18:29	K18121318
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 18:29	K18121318
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 18:29	K18121318
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 18:29	K18121318

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACOff_B_up
Lab Sample ID:	1078504
Sample Collection Time:	11/26/18 4:09 PM
Sample Volume in Liters:	112.85
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121319	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 18:53	K18121319
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 18:53	K18121319
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 18:53	K18121319
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 18:53	K18121319
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 18:53	K18121319
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 18:53	K18121319
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 18:53	K18121319
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 18:53	K18121319
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 18:53	K18121319
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 18:53	K18121319
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 18:53	K18121319
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 18:53	K18121319

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACMRR
Lab Sample ID:	1078804
Sample Collection Time:	11/26/18 4:17 PM
Sample Volume in Liters:	106.18
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121320	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 19:18	K18121320
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 19:18	K18121320
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 19:18	K18121320
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 19:18	K18121320
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 19:18	K18121320
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 19:18	K18121320
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 19:18	K18121320
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 19:18	K18121320
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 19:18	K18121320
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 19:18	K18121320
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 19:18	K18121320
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 19:18	K18121320

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

nvironmental Services, Inc.
A Commerce Road Suite 1
orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4459.1A
Analysis Method: TO17
Matrix: Air
Client ID/Field Sampling Location: BCACMRR_B_up
Lab Sample ID: 1078608
Sample Collection Time: 11/26/18 4:17 PM
Sample Volume in Liters: 106.18
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121321	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 19:42	K18121321
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 19:42	K18121321
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 19:42	K18121321
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 19:42	K18121321
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 19:42	K18121321
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 19:42	K18121321
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 19:42	K18121321
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 19:42	K18121321
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 19:42	K18121321
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 19:42	K18121321
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 19:42	K18121321
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 19:42	K18121321

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

nvironmental Services, Inc.
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orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACWelcCtrOffR
Lab Sample ID:	1078898
Sample Collection Time:	11/26/18 4:32 PM
Sample Volume in Liters:	134.11
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121322	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 20:07	K18121322
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 20:07	K18121322
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 20:07	K18121322
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 20:07	K18121322
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 20:07	K18121322
1,2-Dichloroethane	107-06-2	**0.36**	0.1	**0.09**	0.02	12/13/18 20:07	K18121322
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/13/18 20:07	K18121322
Trichloroethene	79-01-6	U	0.1	U	0.01	12/13/18 20:07	K18121322
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 20:07	K18121322
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 20:07	K18121322
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 20:07	K18121322
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 20:07	K18121322

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

nvironmental Services, Inc.
A Commerce Road Suite 1
orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4459.1A
Analysis Method: TO17
Matrix: Air
Client ID/Field Sampling Location: BCACWelcCtrOffR_B_up
Lab Sample ID: 1078835
Sample Collection Time: 11/26/18 4:32 PM
Sample Volume in Liters: 134.11
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab FileID	Dilution Factor
initial	K18121323	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 20:31	K18121323
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 20:31	K18121323
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 20:31	K18121323
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 20:31	K18121323
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 20:31	K18121323
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 20:31	K18121323
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/13/18 20:31	K18121323
Trichloroethene	79-01-6	U	0.1	U	0.01	12/13/18 20:31	K18121323
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 20:31	K18121323
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 20:31	K18121323
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 20:31	K18121323
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 20:31	K18121323

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

nvironmental Services, Inc.
A Commerce Road Suite 1
orest Hill, MD 21050 USA
ph:410-838-8780
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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACRec
Lab Sample ID:	1078765
Sample Collection Time:	11/26/18 4:26 PM
Sample Volume in Liters:	81.68
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121324	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/13/18 20:56	K18121324
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.03	12/13/18 20:56	K18121324
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/13/18 20:56	K18121324
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.03	12/13/18 20:56	K18121324
Chloroform	67-66-3	U	0.1	U	0.03	12/13/18 20:56	K18121324
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/13/18 20:56	K18121324
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 20:56	K18121324
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 20:56	K18121324
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/13/18 20:56	K18121324
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 20:56	K18121324
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/13/18 20:56	K18121324
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 20:56	K18121324

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

nvironmental Services, Inc.
A Commerce Road Suite 1
orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4459.1A
Analysis Method: TO17
Matrix: Air
Client ID/Field Sampling Location: BCACRec_B_up
Lab Sample ID: 1078672
Sample Collection Time: 11/26/18 4:26 PM
Sample Volume in Liters: 81.68
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121325	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/13/18 21:20	K18121325
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.03	12/13/18 21:20	K18121325
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/13/18 21:20	K18121325
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.03	12/13/18 21:20	K18121325
Chloroform	67-66-3	U	0.1	U	0.03	12/13/18 21:20	K18121325
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/13/18 21:20	K18121325
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 21:20	K18121325
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 21:20	K18121325
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/13/18 21:20	K18121325
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 21:20	K18121325
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/13/18 21:20	K18121325
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 21:20	K18121325

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

nvironmental Services, Inc.
A Commerce Road Suite 1
orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number:
Analysis Method TO17
Matrix: QC

Lab Sample ID: CL_LCS_1078865_181213

Client:	Analysis	Lab FileID
	initial	K18121329
Arizon State University	1st Dilution	
660 South College Avenue, Room 507	2nd Dilution	
Tempe, AZ 85281	3rd Dilution	
ph: 480-385-9671		

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**78%**	%REC	50-150	12/13/18 22:41	K18121329
trans-1,2-Dichloroethene	156-60-5	**92%**	%REC	50-150	12/13/18 22:41	K18121329
1,1-Dichloroethane	75-34-3	**101%**	%REC	50-150	12/13/18 22:41	K18121329
cis-1,2-Dichloroethene	156-59-2	**98%**	%REC	50-150	12/13/18 22:41	K18121329
Chloroform	67-66-3	**99%**	%REC	50-150	12/13/18 22:41	K18121329
1,2-Dichloroethane	107-06-2	**97%**	%REC	50-150	12/13/18 22:41	K18121329
1,1,1-Trichloroethane	71-55-6	**115%**	%REC	50-150	12/13/18 22:41	K18121329
Trichloroethene	79-01-6	**103%**	%REC	50-150	12/13/18 22:41	K18121329
Bromodichloromethane	75-27-4	**100%**	%REC	50-150	12/13/18 22:41	K18121329
Dibromochloromethane	124-48-1	**101%**	%REC	50-150	12/13/18 22:41	K18121329
Tetrachloroethene	127-18-4	**96%**	%REC	50-150	12/13/18 22:41	K18121329
Bromoform	75-25-2	**106%**	%REC	50-150	12/13/18 22:41	K18121329

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

Attachment 1

Chain of Custody

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1, Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Manager:	Paul Dahlen	BEACON Project No.: 4459	
Company:	ASU SSEBE	Phone:	480-727-2960	Client PO No.	
Address:	PO B 873005	Project Name:	Beale AFB	Analysis Turnaround Time	
City/State/Zip:	Tempe AZ 85287	Location:	Theater	✓ Normal	
Phone:	480-727-2960	Sampler Name(s):	Paul Dahlen	Rush (Specify): ____ days	

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	TO-17	8260B	TICs	Indoor/Ambient Air	Soil Gas
BTheater-StageL	1078601	2	11/2/18	0925	11/26/18	1573	40.61	39.66	155.72				✓	
BTheater-StageL BUA	1078544	2	''	''	[illegible] ''	''	''	''	''				✓	
BTheater Lobby	1078895	6	11/2/18	1030	11/26/18	1455	40.59	40.13	156.31				✓	
ATheater Lobby BUA	1078651	6	''	''	''	''	''	''	''				✓	
BTheater-WRR	1078606	9	11/5/18	0831	11/26/18	1507	35.80	35.49	138.05				✓	
BTheater-WRR BUA	1078803	9	''	''	''	''	''	''	''				✓	
BTheater-StageWRR	1078556	11	11/2/18	0946	11/26/18	1518	41.48	42.01	161.68				✓	
BTheater-StageWRR BUA	1078769	11	''	''	''	''	''	''	''				✓	

Ambient Conditions When Sampling

	Temperature (F)	Barometric Pressure (mmHg)	Date
Start	70		
Stop			

Pump(s) Calibration and Flow Rate Check:

Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Pre-Survey			
Post-Survey			

Special Notes/Instructions:

Relinquished by: (signature)	Paul Dahlen	Date/Time: 12/10/18 1300	Received by: (signature)	Courier	Date/Time:
Relinquished by: (signature)		Date/Time:	Received by: (signature)	Steven Thornley	Date/Time: 12.11.18 / 1500
Relinquished by: (signature)		Date/Time:	Received by: (signature)		Date/Time:

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	Fedex	✓		Yes No None	

Beacon Project 4459, 1A -- Page 43 of 46

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1. Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Manager: Paul Dahlen	BEACON Project No.: 4459
Company: ASU SSEBE		Phone: 480-727-2960	Client PO No.
Address: POB 873005		Project Name: Travis	Analysis Turnaround Time
City/State/Zip: Tempe AZ 85287		Location: Bldg 18	Normal ✓
Phone: 480-727-2960		Sampler Name(s): Paul Dahlen	Rush (Specify): ____ days

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	TO-17	8260B	TICs	Indoor/Ambient Air	Soil Gas
Tr 18 Main	1078557	5	11/7/18	1558	11/27/18	1636	41.60	40.20	65.64				✓	
Tr 18 Main B/UP	1078647	5	↓	1558	↓	1636	"	"	"				✓	
Tr 18 Hall	1078637	3	↓	1614	↓	1621	42.93	42.82	68.60				✓	
Tr 18 Hall B/UP	1078511	3	↓	1614	↓	1621	"	"	"				✓	
Tr 18 SEOffice	1078558	13	↓	1614	↓	1621	35.82	35.00	56.66				✓	
Tr 18 SEOffice B/UP	1078666	13	↓	1614	↓	1621	"	"	"				✓	
Tr 18 Shower 1	1078519	14	↓	1625	↓	1641	45.53	44.35	72.13				✓	
Tr 18 Shower 1 B/UP	1078536	14	↓	1625	↓	1641	"	"	"				✓	

Ambient Conditions When Sampling				Pump(s) Calibration and Flow Rate Check:			
	Temperature (F)	Barometric Pressure (mmHg)	Date	Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Start	68			Pre-Survey			
Stop				Post-Survey			

Special Notes/Instructions: See SS for additional sampling data

Relinquished by: (signature) Paul Dahlen	Date/Time: 12/10/18 1300	Received by: (signature) Courier	Date/Time:
Relinquished by: (signature)	Date/Time:	Received by: (signature) Steven Thowley	Date/Time: 12.11.18/1500
Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	Fedex	✓		Yes No None	

Beacon Project 4459 JA - Page 44 of 46

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1. Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information		
Company: ASU SSEBE	Project Manager: Paul Dahlen	BEACON Project No.: 4459
Address: PO B 873005	Phone: 480-727-2960	Client PO No.
City/State/Zip: Tempe AZ 85287	Project Name: Beale AFB	Analysis Turnaround Time: Normal ✓
Phone: 480-727-2960	Location: CAC	
	Sampler Name(s): Paul Dahlen	Rush (Specify): ____ days

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	TO-17	8260B	TICs	Indoor/Ambient Air	Soil Gas
BCACCafe	1078661	10	11/8/18	~~1660~~ 1347	11/26/18	~~1546~~ 1618	43.44	41.57	122.20				✓	
BCACCafe B/Dup	1078610	10	↓	"	↓	"	"	"	"				✓	
BCACBallR	1078639	8	↓	1606	↓	1546	39.93	38.24	112.72				✓	
BCACBallR B/Dup	1078687	8	↓	"	↓	"	"	"	"				✓	
BCACConf	1078562	4	↓	1635	↓	1636	40.52	39.82	115.77				✓	
BCACConf B/Dup	1078546	4	↓	"	↓	"	"	"	"				✓	
BCACOff	1078892	6	↓	1716	↓	1609	39.82	38.63	112.85				✓	
BCACOff B/Dup	1078504	6	↓	"	↓	"	"	"	"				✓	
BCACMRR	1078804	7	↓	1826	↓	1617	37.57	36.58	106.18				✓	
BCACMRR B/Dup	1078608	7	↓	"	↓	"	"	"	"				✓	

Ambient Conditions When Sampling

	Temperature (F)	Barometric Pressure (mmHg)	Date
Start	71		
Stop			

Pump(s) Calibration and Flow Rate Check:

Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Pre-Survey			
Post-Survey			

Special Notes/Instructions:

Relinquished by: (signature) Paul Dahlen	Date/Time: 12/10/18 1300	Received by: (signature) Courier	Date/Time:
Relinquished by: (signature)	Date/Time:	Received by: (signature) Steven Thornley	Date/Time: 12.11.18 / 1500
Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	Fedex	✓		Yes No None	

Beacon Project 4459 IA -- Page 45 of 46

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1. Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information

Company: ASU SSEBE
Address: POB 873005
City/State/Zip: Tempe AZ 85287
Phone: 480-727-2960

Project Manager: Paul Dahlen
Phone: 480-727-2960
Project Name: Beale AFB
Location: CAC
Sampler Name(s): Paul Dahlen

BEACON Project No.: 4459
Client PO No.

Analysis Turnaround Time

Normal ✓
Rush (Specify): _____ days

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	TO-17	8260B	TICs	Indoor/Ambient Air	Soil Gas
BCACWelcCtrOffR	1078898	3	11/8/18	1807	11/26/18	1632	46.14	47.48	134.11				✓	
BCACWelcCtrOffR Dup	1078835	3	↓	"	↓	"	"	"	"				✓	
BCACRec	1078765	12	↓	1847	↓	1626	31.44	25.58	81.68				✓	
BCACRec Bp	1078672	12	↓	"	↓	"	"	"	"				✓	

Ambient Conditions When Sampling

	Temperature (F)	Barometric Pressure (mmHg)	Date
Start	71		
Stop			

Pump(s) Calibration and Flow Rate Check:

Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Pre-Survey			
Post-Survey			

Special Notes/Instructions:

Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:
Paul Dahlen	12/10/18 1300	Gurres	
		Steven Homley	12.11.18 / 1500

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	Fedex	✓		Yes No None	

Beacon Project 4459 IA -- Page 46 of 46

Appendix 2474B
Background Indoor Air Sampling – Passive Air Sampler Analytical Report

(Only sample IDs 1-5 with a prefix of “B Theatre”
are related to the Beale Theatre, Bldg. 2474)

BEACON ENVIRONMENTAL
SERVICES, INC.

The Leaders in Soil Gas Surveys
and Vapor Intrusion Monitoring

Arizona State University
660 South College Avenue, Room 507
Tempe, AZ 85281
Attn: Paul Dahlen

Air Samples -- Analytical Report

Date: January 8, 2019
Beacon Project No. 4459.1B

Project Reference:	Beale and Travis AFB
Sampling Period:	November 2 through 26, 2018
Samples Received:	December 11, 2018
Analyses Completed:	December 14, 2018

Results for the following indoor and ambient air samples are included in this data package:

Sample ID	Location	Matrix	Analysis
1	B Theater lobby	Air	TO-17
2	B Theater WRR	Air	TO-17
3	B Theater Stage WRR	Air	TO-17
4	B Theater Stage L	Air	TO-17
5	B Theater R	Air	TO-17
6	B CAC Ball L	Air	TO-17
7	B CAC Café	Air	TO-17
8	B CAC MRR	Air	TO-17
9	B CAC Ball R	Air	TO-17
10	B CAC Welc Ctr Off R	Air	TO-17
11	B CAC Conf	Air	TO-17
12	B CAC Office	Air	TO-17
13	B CAC Lobby	Air	TO-17
14	B CAC Rec	Air	TO-17
15	B CAC Pizzeria	Air	TO-17
16	B CAC Music	Air	TO-17
17	TR 18 Main	Air	TO-17
18	TR 18 Hall	Air	TO-17
19	TR 18 SE Office	Air	TO-17
20	TR 18 Shower 1	Air	TO-17

Sample Collection
Beacon Environmental provided thermally conditioned Beacon Samplers to target a select list of compounds, with analyses following U.S. EPA Method TO-17. These passive diffusion samples (PDS) were exposed to air for approximately three weeks and the resulting mass of target analytes captured on each sampler was reported as a concentration following procedures detailed in ISO 16017-2, *Indoor, ambient and workplace air-Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography-Part 2: Diffusive sampling.*

U. S. EPA Method TO-17
All samples were analyzed for a custom target compound list following U.S. EPA Method TO-17.

2203A Commerce Road, Suite 1, Forest Hill, MD 21050 USA 410-838-8780 •P 410-838-8740 •F BEACON-USA.COM

The analytical results are reported in **Table 1**, with results reported in micrograms per cubic meter (µg/m^3) and ppbv using the following equations.

$$C = \frac{1000 \times M \times d}{U \times t} \qquad C_{ppbv} = C \text{ x } \frac{24.45}{MW}$$

where:

C	=	concentration (µg/m^3)
C_{ppbv}	=	concentration (ppbv)
M	=	mass (ng)
d	=	dilution factor
U	=	uptake rate (ml/min),
t	=	sampling time (minutes)
MW	=	molecular weight

The following table provides uptake rates for the compounds reported in this investigation.

Compound	Uptake Rate
1,1-Dichloroethene	0.32
trans-1,2-Dichloroethene	0.42
1,1-Dichloroethane	0.80
cis-1,2-Dichloroethene	0.52
Chloroform	0.34
1,2-Dichloroethane	0.54
1,1,1-Trichloroethane	0.98
Trichloroethene	0.33
Bromodichloromethane	0.40
Dibromochloromethane	0.35
Tetrachloroethene	0.39
Bromoform	0.32

Practical Quantification Levels (PQL) for EPA Method TO-17

The lowest point in the calibration curve and the limit of quantitation (LOQ) is 10 nanograms (ng), and the limit of detection (LOD) is 5 ng. The concentration data in **Table 1** are provided in micrograms per meter cubed (µg/m^3) and parts per billion by volume (ppbv), and the LOQs are additionally based on the sample collection times, the uptake rates, and the dilution factors.

Calibration Verification

The continuing calibration verification (CCV) values for the analytes were all within ±30% of the true values as defined by the initial five-point calibration and met the requirements specified in Beacon Environmental's Quality Manual.

Internal Standards and Surrogates

Internal standards and surrogates are spiked at 100 ng and 50 ng, respectively, and percentage of recovery is calculated. Acceptance criteria for internal standards are 60 to 140 percent and surrogate recoveries are 70 to 130 percent; all internal standards and surrogates were within the acceptance criteria.

Blank Contamination

No targeted compounds above the LOD for each compound were observed in the Laboratory Method Blanks (LB 181214). For comparison to field sample results, the longest sampling time was used to calculate the LOQs for the blank.

Laboratory Control Samples

Laboratory control samples are spiked at 50 ng and percentage of recovery is calculated and reported. Acceptance criteria for surrogate and analytes recoveries are 70 to 130 percent; all surrogates and analytes were within the acceptance criteria.

Discussion

Twenty (20) indoor air samples were received by Beacon Environmental on December 12, 2018. Sampling start and end times and dates can be found in the Chain of Custody (**Attachment 1**).

Dilutions were required for three (3) samples (18, 19, and 20), which had high levels of cis-1,2-d ichloroethene and/or trichloroethene. Dilutions were performed for these samples to bring the detected concentrations of those compounds into the calibration range of the GC/MSD instrument, as noted in **Table 1**.

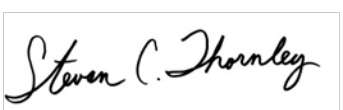
Demonstrated Linear Range of the GC-MS Instrumentation (EPA Method TO-17)

An initial six-point calibration is performed on the instrumentation from 5 to 200 ng per analyte.

<u>**Attachments:**</u>

-1- Chain of Custody

ALL DATA MEET REQUIREMENTS AS SPECIFIED IN THE BEACON ENVIRONMENTAL SERVICES, INC. QUALITY ASSURANCE PROJECT PLAN AND THE RESULTS RELATE ONLY TO THE SAMPLES REPORTED. BEACON ENVIRONMENTAL SERVICES IS ACCREDITED TO ISO/IEC 17025:2005, AND THE WORK PERFORMED WAS IN ACCORDANCE WITH ISO/IEC 17025:2005 REQUIREMENTS. THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY. RELEASE OF THE DATA CONTAINED IN THIS DATA PACKAGE HAS BEEN AUTHORIZED BY THE LABORATORY DIRECTOR OR HIS SIGNEE, AS VERIFIED BY THE FOLLOWING SIGNATURES:



Steven C. Thornley
Laboratory Director

Patti J. Riggs
Quality Manager

Date: January 8, 2018

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

Client Sample ID:		LCS_181214	LB_181214	LCSD_181214	1	2	3
Project Number:					4459.1B	4459.1B	4459.1B
Lab File ID:		K18121402	K18121403	K18121404	K18121405	K18121406	K18121407
Received Date:					12/11/2018	12/11/2018	12/11/2018
Analysis Date:		12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018
Analysis Time:		10:20	10:40	11:01	12:08	12:35	13:02
Matrix:					Air	Air	Air
Units:		%Recovery	ug/m3	%Recovery	ug/m3	ug/m3	ug/m3
COMPOUNDS	CAS						
1,1-Dichloroethene	75-35-4	**104%**	<0.91	**102%**	<0.91	<1.03	<0.91
trans-1,2-Dichloroethene	156-60-5	**109%**	<0.68	**106%**	<0.68	<0.77	<0.68
1,1-Dichloroethane	75-34-3	**109%**	<0.36	**107%**	<0.36	<0.41	<0.36
cis-1,2-Dichloroethene	156-59-2	**113%**	<0.55	**109%**	<0.55	<0.63	<0.55
Chloroform	67-66-3	**112%**	<0.84	**107%**	<0.84	<0.95	<0.84
1,2-Dichloroethane	107-06-2	**117%**	<0.53	**112%**	<0.54	<0.61	<0.53
1,1,1-Trichloroethane	71-55-6	**110%**	<0.29	**103%**	<0.29	<0.33	<0.29
Trichloroethene	79-01-6	**120%**	<0.88	**117%**	<0.88	<1.00	<0.88
Bromodichloromethane	123-91-1	**120%**	<0.72	**113%**	<0.73	<0.83	<0.73
Dibromochloromethane	106-93-4	**119%**	<0.82	**116%**	<0.82	<0.93	<0.82
Tetrachloroethene	127-18-4	**110%**	<0.73	**109%**	<0.73	<0.83	<0.73
Bromoform	108-38-3	**114%**	<0.90	**116%**	<0.90	<1.03	<0.90

Reporting limit is limit of quantitation (LOQ). E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

Client Sample ID:		4	5	6	7	8	9
Project Number:		4459.1B	4459.1B	4459.1B	4459.1B	4459.1B	4459.1B
Lab File ID:		K18121408	K18121409	K18121410	K18121411	K18121412	K18121413
Received Date:		12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018
Analysis Date:		12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018
Analysis Time:		13:28	13:55	14:36	15:03	15:30	15:56
Matrix:		Air	Air	Air	Air	Air	Air
Units:		ug/m3	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
COMPOUNDS	CAS						
1,1-Dichloroethene	75-35-4	<0.91	<0.91	<1.22	<1.22	<1.23	<1.22
trans-1,2-Dichloroethene	156-60-5	<0.68	<0.68	<0.92	<0.92	<0.92	<0.92
1,1-Dichloroethane	75-34-3	<0.36	<0.36	<0.48	<0.48	<0.48	<0.48
cis-1,2-Dichloroethene	156-59-2	<0.55	<0.55	<0.75	<0.75	<0.75	<0.75
Chloroform	67-66-3	<0.84	<0.84	<1.13	<1.13	<1.13	<1.13
1,2-Dichloroethane	107-06-2	<0.53	<0.53	<0.72	<0.72	<0.72	<0.72
1,1,1-Trichloroethane	71-55-6	<0.29	<0.29	<0.40	<0.40	<0.40	<0.40
Trichloroethene	79-01-6	<0.88	<0.88	<1.19	<1.19	<1.19	<1.19
Bromodichloromethane	123-91-1	<0.72	<0.72	<0.98	<0.98	<0.98	<0.98
Dibromochloromethane	106-93-4	<0.82	<0.82	<1.10	<1.10	<1.11	<1.10
Tetrachloroethene	127-18-4	<0.73	<0.73	<0.98	<0.99	<0.99	<0.98
Bromoform	108-38-3	<0.90	<0.90	<1.21	<1.22	<1.22	<1.21

Reporting limit is limit of quantitation (LOQ). E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

Client Sample ID:		10	11	12	13	14	15
Project Number:		4459.1B	4459.1B	4459.1B	4459.1B	4459.1B	4459.1B
Lab File ID:		K18121414	K18121415	K18121416	K18121417	K18121418	K18121705
Received Date:		12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018
Analysis Date:		12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/17/2018
Analysis Time:		16:23	16:50	17:17	17:44	18:11	10:39
Matrix:		Air	Air	Air	Air	Air	Air
Units:		ug/m3	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
COMPOUNDS	CAS						
1,1-Dichloroethene	75-35-4	<1.22	<1.22	<1.22	<1.23	<1.23	<1.23
trans-1,2-Dichloroethene	156-60-5	<0.92	<0.91	<0.92	<0.92	<0.92	<0.92
1,1-Dichloroethane	75-34-3	<0.48	<0.48	<0.48	<0.48	<0.48	<0.48
cis-1,2-Dichloroethene	156-59-2	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75
Chloroform	67-66-3	<1.13	<1.13	<1.13	<1.14	<1.13	<1.14
1,2-Dichloroethane	107-06-2	**0.94**	<0.72	<0.72	<0.73	<0.72	<0.72
1,1,1-Trichloroethane	71-55-6	<0.40	<0.39	<0.40	<0.40	<0.40	<0.40
Trichloroethene	79-01-6	<1.19	<1.18	<1.19	<1.20	<1.19	<1.19
Bromodichloromethane	123-91-1	<0.98	<0.98	<0.98	<0.99	<0.98	<0.98
Dibromochloromethane	106-93-4	<1.10	<1.10	<1.10	<1.11	<1.11	<1.11
Tetrachloroethene	127-18-4	<0.99	<0.98	<0.98	<0.99	<0.99	<0.99
Bromoform	108-38-3	<1.22	<1.21	<1.22	<1.22	<1.22	<1.22

Reporting limit is limit of quantitation (LOQ). E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

	Client Sample ID:	16	17	18	19	20	CL_LCS_181214
	Project Number:	4459.1B	4459.1B	4459.1B	4459.1B	4459.1B	
	Lab File ID:	K18121420	K18121706	K18121422	K18121423	K18121424	K18121425
	Received Date:	12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018	
	Analysis Date:	12/14/2018	12/17/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018
	Analysis Time:	19:05	11:06	19:59	20:28	20:55	21:16
	Matrix:	Air	Air	Air	Air	Air	
	Units:	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3	%Recovery
COMPOUNDS	CAS						
1,1-Dichloroethene	75-35-4	<1.23	<1.10	<1.10	<1.10	<1.10	**90%**
trans-1,2-Dichloroethene	156-60-5	<0.92	<0.82	<0.82	**1.51**	<0.82	**88%**
1,1-Dichloroethane	75-34-3	<0.48	<0.43	<0.43	<0.43	<0.43	**107%**
cis-1,2-Dichloroethene	156-59-2	<0.75	**2.2**	**3.75**	**36.76 D**	**6.12**	**99%**
Chloroform	67-66-3	<1.14	<1.01	<1.01	<1.01	<1.01	**106%**
1,2-Dichloroethane	107-06-2	<0.72	<0.65	<0.65	<0.65	<0.65	**100%**
1,1,1-Trichloroethane	71-55-6	<0.40	<0.35	<0.36	<0.36	<0.36	**122%**
Trichloroethene	79-01-6	<1.19	**13.78**	**33.01 D**	**167.05 D**	**43.20 D**	**109%**
Bromodichloromethane	123-91-1	<0.98	<0.88	<0.88	<0.88	<0.88	**110%**
Dibromochloromethane	106-93-4	<1.11	<0.99	<0.99	<0.99	<0.99	**107%**
Tetrachloroethene	127-18-4	<0.99	<0.88	<0.88	**0.97**	<0.88	**98%**
Bromoform	108-38-3	<1.22	<1.09	<1.09	<1.09	<1.09	**120%**

Reporting limit is limit of quantitation (LOQ). E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Attachment 1

Chain of Custody

Beacon Environmental Services, Inc.

CHAIN-OF-CUSTODY PASSIVE DIFFUSION SAMPLES

2203A Commerce Road, Suite 1
Forest Hill, MD 21050
410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Information		
Company:	ASU SSEBE	Project Manager:	Paul Dahlen	BEACON Project No.: 4459
Address:	POB 873005	Phone:	480-727-2960	Client PO No.
City/State/Zip:	Tempe AZ 85287	Project Name:	Beale AFB	Analysis Turnaround Time: ☒ Normal ☐ Rush (Specify): ____ days
Phone:	480-727-2960	Location:	CAC	NIST traceable Thermometer ID:
		Sampler Name(s):	Paul Dahlen	

Location ID	Tube/Sample number	Start Time Date (mm/dd/yy)	Start Time Time (24 hr)	Stop Time Date (mm/dd/yy)	Stop Time Time (24 hr)	Interior Temp. (F)	Notes	TO-17	8260C	TICs	Indoor/Ambient Air	Soil Gas
12	BCAC Office	11/8/18	1716	11/26/18	1609	71	25853 min				✓	
13	BCAC Lobby	11/8/18	1918	11/26/18	1515	↓	25677 min				✓	
14	BCAC Rec	11/8/18	1847	11/26/18	1626	↓	25779 min				✓	
15	BCAC Arzeria	11/8/18	1913	11/26/18	1558	↓	25725 min				✓	
16	BCAC Music	11/8/18	1905	11/26/18	1600	↓	25732 min				✓	
—	(crossed out)											

Special Instructions/Notes:

Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:
Paul Dahlen	12/10/18 1300	Courier	
		Steven Thornley	12.11.18/1500

Lab Use Only	Courier Name	Shipment Condition	Custody Seal Intact	Custody Seal Number
	Fedex	✓	Yes No (None)	

Page ____ of ____

Beacon Project 4459.1B -- Page 11 of 12

Beacon Environmental Services, Inc.

2203A Commerce Road, Suite 1
Forest Hill, MD 21050
410-838-8780 / fax: 410-838-8740

CHAIN-OF-CUSTODY PASSIVE DIFFUSION SAMPLES

Client Contact Information			
Company: ASU SSEBE	Project Manager: Paul Dahlen	BEACON Project No.: 4459	
Address: POB 873005	Phone: 480-727-2960	Client PO No.	
City/State/Zip: Tempe AZ 85287	Project Name: Beale AFB	Analysis Turnaround Time	
Phone: 480-727-2960	Location: Theater	☒ Normal	
	Sampler Name(s): Paul Dahlen	☐ Rush (Specify): ______ days	
		NIST traceable Thermometer ID:	

Location ID	Tube/Sample number	Start Date (mm/dd/yy)	Start Time (24 hr)	Stop Date (mm/dd/yy)	Stop Time (24 hr)	Interior Temp. (F)	Notes	Analysis: TO-17	Analysis: 8260C	Analysis: TICs	Matrix: Indoor/Ambient Air	Matrix: Soil Gas
1	BTheater Lobby	11/2/18	1030	11/26/18	1455	70	34825 min				✓	
2	BTheater WRR	11/5/18	0831	11/26/18	1507	↓	30636 min				✓	
3	BTheater Stage WRR	11/2/18	0946	11/26/18	1518	↓	34892 min				✓	
4	BTheater Stage L	11/2/18	0925	11/26/18	1513	↓	34908 min				✓	
5	BTheater R	11/5/18	0852	11/26/18	1505	↓	30613 min				✓	
(crossed out) 12.11.18												

Special Instructions/Notes:

Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:
Paul Dahlen	12/10/18 1300	Courier	
		Steven Thornley	12.11.18/1500

Lab Use Only	Courier Name	Shipment Condition	Custody Seal Intact	Custody Seal Number
	Fedex	✓	Yes No (None)	

Page ____ of ____

Beacon Project 4459.1B -- Page 9 of 12

Beacon Environmental Services, Inc.

CHAIN-OF-CUSTODY PASSIVE DIFFUSION SAMPLES

2203A Commerce Road, Suite 1
Forest Hill, MD 21050
410-838-8780 / fax: 410-838-8740

Client Contact Information		
Company: ASU SSEBE	Project Manager: Paul Dahlen	BEACON Project No.: 4459
Address: POB 873005	Phone: 480-727-2960	Client PO No.
City/State/Zip: Tempe AZ 85287	Project Name: Beale AFB	Analysis Turnaround Time: ☑ Normal
Phone: 480-727-2960	Location: CAC	☐ Rush (Specify): ______ days
	Sampler Name(s): Paul Dahlen	NIST traceable Thermometer ID:

Location ID	Tube/Sample number	Start Date (mm/dd/yy)	Start Time (24 hr)	Stop Date (mm/dd/yy)	Stop Time (24 hr)	Interior Temp. (F)	Notes	TO-17	8260C	TICs	Indoor/Ambient Air	Soil Gas
6	BCAC Ball L	11/8/18	1616	11/26/18	1546	71	25890 min				✓	
7	BCAC Cafe	11/8/18	1747	11/26/18	1618	↓	25831 min				✓	
8	BCAC MRR	11/8/18	1826	11/26/18	1617	↓	25791 min				✓	
9	BCAC Ball R	11/8/18	1606	11/26/18	1546	↓	25900 min				✓	
10	BCAC WeldCtr Off R	11/8/18	1807	11/26/18	1632	↓	25825 min				✓	
11	BCAC Cont	11/8/18	1635	11/26/18	1636	↓	25921 min				✓	

Special Instructions/Notes:

Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:
Paul Dahlen	12/10/18 1300	Courier	
		Steven Thorley	12.11.18/1500

Lab Use Only	Courier Name	Shipment Condition	Custody Seal Intact	Custody Seal Number
	Fedex	✓	Yes No (None)	

Page ____ of ____

Beacon Project 4459.1B -- Page 10 of 12

Industrial Scale Controlled Pressure Method Test Demonstration for Vapor Intrusion Pathway Assessment – ESTCP ER#201501

Building 2425, Community Activity Center (CAC)
Beale Air Force Base, California

Arizona State University SSEBE, Oct. 12, 2020

16. INTRODUCTION

1.3 BACKGROUND

Controlled pressure method (CPM) testing for vapor intrusion (VI) pathway assessment was developed to evaluate the maximum VI related impact to a structure in a short period of time. Its use has been studied in various Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) funded projects (ER#200707, ER#1686, and ER#201501). In the most recent project, ER#201501, CPM testing has been included as one of a suite of tools to more expediently and confidently define the presence of vapor intrusion pathways in structures.

During CPM testing, the controlled negative pressurization of a test structure induces a worst-case vapor intrusion scenario. Assessment of exhaust air contaminant concentrations provides an estimate of the average indoor air concentration, while area specific samples define local responses to this worst-case scenario. By creating that worst-case VI scenario, CPM testing is most effectively used to identify and rule out structures where VI impacts are non-existent (e.g. test concentrations are less than or equal to ambient outdoor concentrations) and/or of no regulatory concern. If, however, contaminant concentrations approach or are in excess of a regulatory concern during negative pressure testing, positive pressure testing, which suppresses VI, should then be used to rule out (or identify) indoor air source(s). If VI impacts are confirmed, concentrations will either be high enough to define the immediate need for mitigation, or alternatively, should be used as a line of evidence in a multiple lines of evidence approach to define risk.

Use of CPM testing as the primary tool for VI assessment is effective since it recognizes that:

- multiple VI pathways can exist, including:
  - the traditional "*soil VI*" conceptualization (source → through soil → through foundation to indoor air); and
  - "*pipe flow VI*" from sources such as land drains and sanitary sewers.
- the VI pathways discussed above may be present, but not discernible by traditional site characterization; and
- VI concentrations vary both spatially and temporally.

ESTCP project ER#201501 included the demonstration of the CPM test protocol in both residential- and industrial-scale buildings. In brief, the CPM Test Guidelines (ER201501 Final Rpt. Appendix D) use negative- and positive-pressure testing of the structure as follows:

- Negative pressure testing of a structure was used to induce a worst-case VI scenario. During negative pressure testing, after a minimum of nine building air exchanges, air quality was tested at the blower intake/exhaust and if of interest, throughout the structure. If concentrations during negative pressurization were less than ambient outdoor concentrations or regulatory concerns, then the VI impact was considered minimal or non-existent and testing would be complete. If, however, concentrations exceeded ambient outdoor concentrations and were of regulatory concern, then VI impacts could be a concern. At this point, a positive pressure test was necessary to rule out indoor air sources.

- Positive pressure testing was used to identify the presence/impact of an indoor air source(s). During positive pressure testing, VI was suppressed, and after a minimum of four building air exchanges air quality was tested throughout the structure. If no contaminant was present in the building, then only VI was present. If, however, contaminants were detected in indoor air, that indicated an indoor air source was present that would require removal followed by additional CPM testing.

This document presents the results of the industrial-scale CPM demonstration at the Beale Air Force Base Community Activity Center (CAC), Bldg. 2425, Beale Air Force Base, California. The objectives of this demonstration were to: a) demonstrate the controlled pressure method in an industrial-scale building; b) perform an extended-term post-CPM test air-quality assessment to determine if the CPM test would lead to the same/similar decision as standard air-quality testing; and c) improve current CPM protocols based on knowledge gained from the demonstration.

17. SITE DESCRIPTION

2.1 BEALE AIR FORCE BASE AND BUILDINGS 2474, 2425, AND 24176

Beale Air Force Base (AFB) lies within Yuba County in Northern California, approximately 40 miles north of Sacramento and 13 miles east of Marysville (Fig. 1; CH2MHill, 2016). It covers approximately 23,000 acres.

Beale AFB began as Camp Beale, an Army installation, at the onset of World War II. During that war, the Base served as an armored division and later as infantry division training base. The Base was transferred to the Air Force in 1948 and served primarily as a training base for aviation engineers. In 1965, it became a Strategic Reconnaissance Wing and since 1981 has been the 9th Reconnaissance Wing under Air Combat Command.

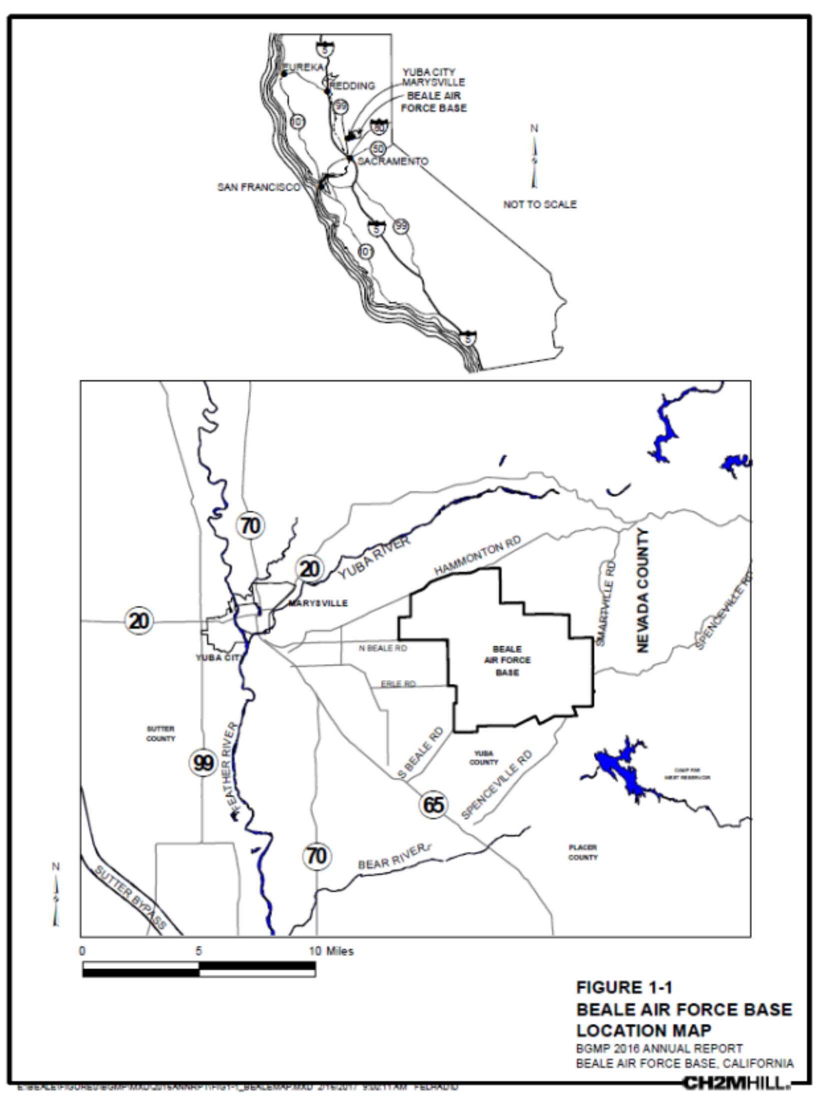


Figure 1. Location Map for Beale Air Force Base, California.

The generalized geology/hydrogeology of Beale AFB consists of unconsolidated sedimentary deposits, underlain by consolidated sedimentary bedrock, further underlain by crystalline metamorphic bedrock. Groundwater occurs primarily in the unconsolidated sedimentary deposits. Depth-to-water is approximately 40 ft below ground surface in the area of interest and groundwater flow direction is generally to the south/southwest.

Site CG041 is part of the Cantonment Remedial Investigation and was established by the Air Force in 2013 to separate groundwater responses from soil responses and address base-wide groundwater as a single site. It currently consists of groundwater plumes underlying 11 soil sites. Pertinent to this study is Plume GC041-039, a dilute chlorinated solvent plume that trends to the south/southwest in-line with groundwater flow and contains TCE concentrations currently ranging to approximately 110 µg/L.

Per a 2018 Record of Decision (ROD; USAF, 2018), an additional industrial/commercial Land Use Control for new buildings was to be implemented within the bounds of Plume CG041-039 to address risk assessment issues. The ROD identified three buildings that were within plume boundaries that required air sampling to assess vapor intrusion risk and confirm current use; 2474 (Theatre), 2425 (Community Activities Center; CAC), and 24176 (dormitory building B, the southern building of a two building dorm complex). Those buildings are shown in Figure 2, which provides a location map in addition to an overlay of the 2016 TCE plume delineation. General attributes of those buildings are shown in Table 1.

Based on the ROD requirement for a vapor intrusion assessment, buildings 2474, 2425, and 24176 were selected for CPM demonstration testing.

Table 1. Attributes of Beale AFB buildings 2474, 2425, and 24176.

Location	Bldg. Use	Size (ft2)	Occupancy	History of VI	Comment
Bldg. 2474	Theatre	10.3K	Occupied	Unknown Never tested	Bldgs. overlie a dilute TCE groundwater plume (5-110 ug/L) ROD indicated that VI testing was required for these facilities
Bldg. 2425	Community Activities Center	20.5K	Occupied		
Bldg. 24176	Dormitory	13.6K	Occupied		

2.1 BEALE COMMUNITY ACTIVITIES CENTER, BUILDING 2425

Building 2425, the Community Activities Center (CAC), is the focus of this report (Fig. 3). Originally built in the early-1950s, it served as the Airmen's Club. The structure was renovated in the mid-1970s and again the mid 1990s, and is currently serving as the Community Activity Center. The brick structure was built on grade and is approximately 20,500 square feet. It includes the main lobby and office, a large auditorium, the Beale Welcome Center including offices and lounge, a conference room, lounges, recreation room, kids activity room, and the Runway Pizzeria. Mechanical was also present in the rear portion of the building with an outside entrance. The floorplan for the CAC is shown in Figure 4. The building volume was estimated at 410,000 ft^3 for test purposes.

18. CPM TEST BUILDING PRESSURE CONTROL, AIR SAMPLING, AND ANALYTICAL METHODS

3.1 BUILDING PRESSURE CONTROL

The CPM demonstration followed early versions of the CPM Test Guidelines (SOP; see Main Report Appendix D) with some modification to account for size and construction of the building and to incorporate knowledge gained from prior industrial-scale tests.

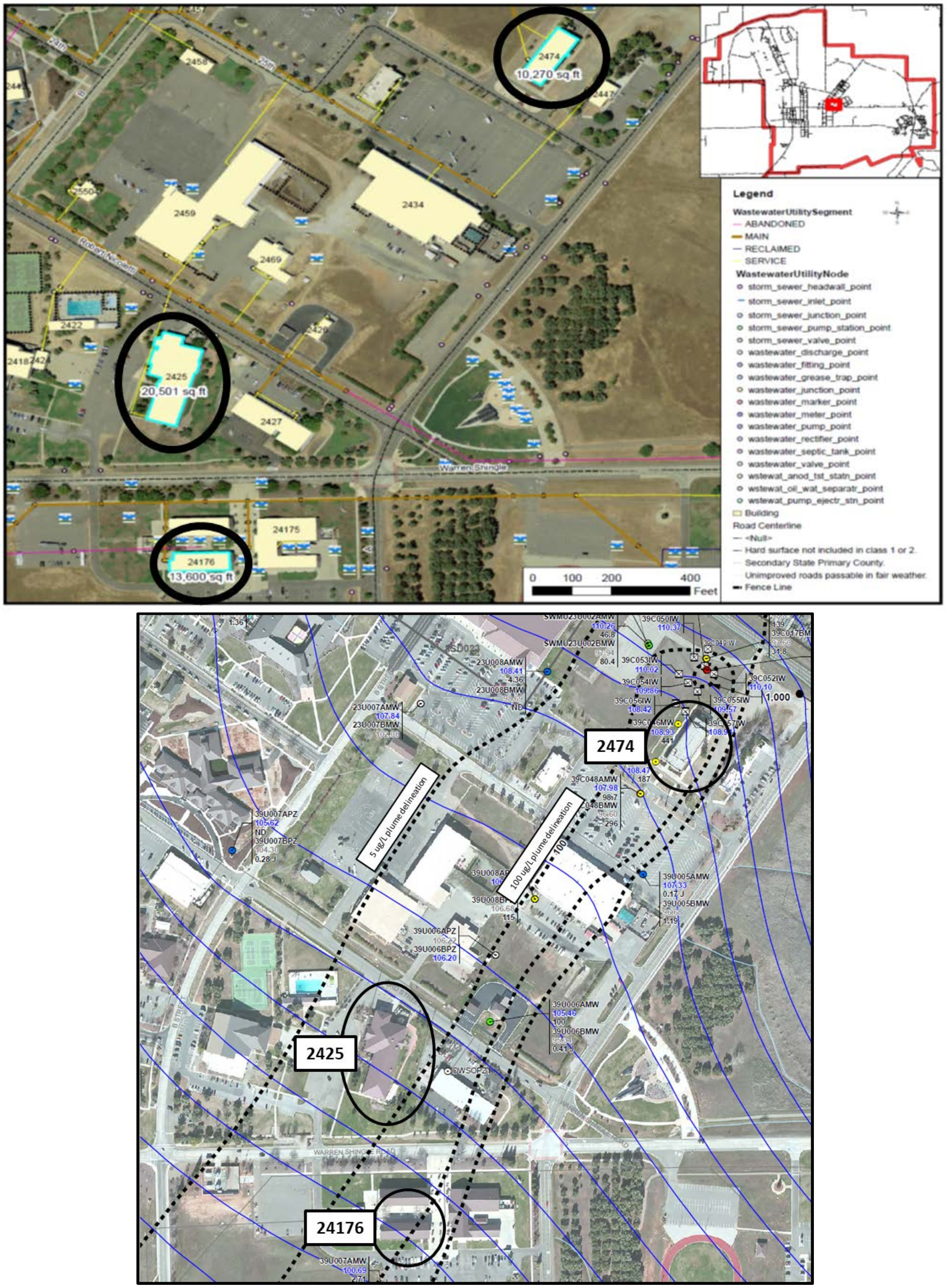


Figure 2. Location map for buildings 2474, 2425, and 24176, and their locations relative to a 2016 TCE plume delineation.

Figure 3. Beale AFB Community Activity Center (CAC), Building 2425. (Picture from the Beale Force Support Squadron website at http://www.bealefss.com/community-center/).

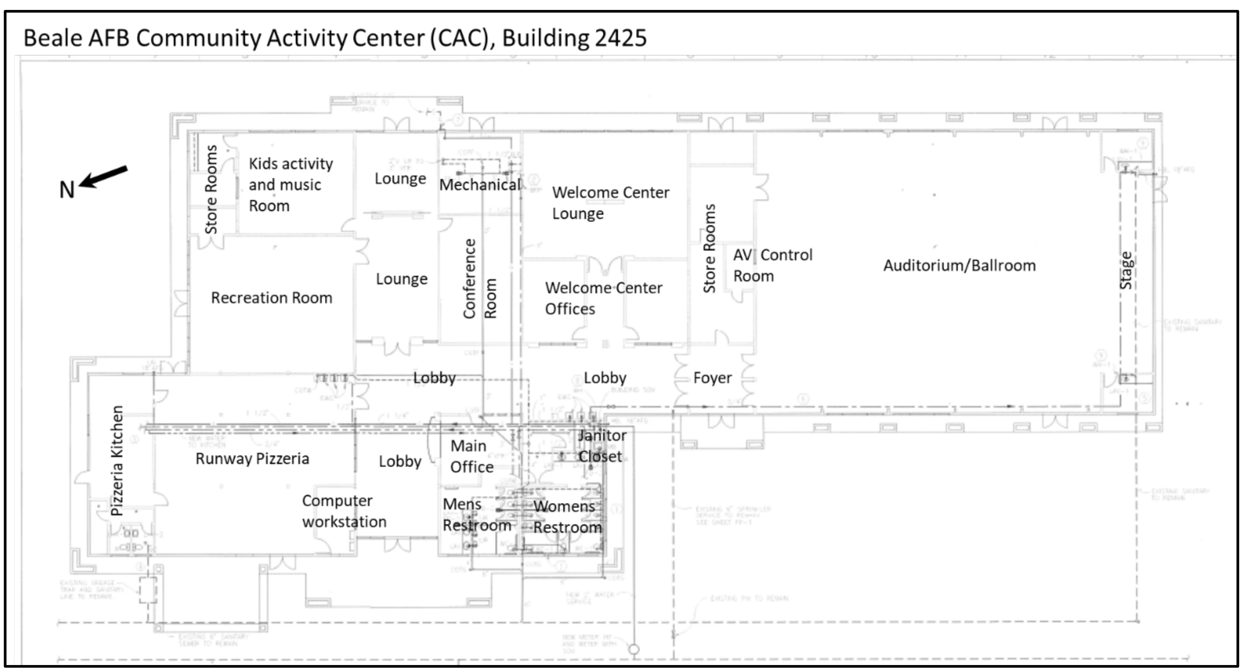


Figure 4. Beale Air Force Base Community Activity Center (Bldg. 2425) floorplan.

Building pressure control was managed using both Retrotec 1000 and 6000 blower door systems (Retrotec, WA). This system included the following:

- Variable speed blower (blower): Blower was operated using the DM32 digital blower control (Retrotec, WA). Blower flowrate was managed via blower speed and intake shrouds that control the cross-sectional area of intake.
- DM32 digital blower controller and pressure monitor: The DM32 (Figure 5) measured and recorded 1) indoor vs. outdoor pressure differential and 2) blower flowrate as determined by a fan shroud vs. reference pressure differential. Data logging included, but was not limited to time, date, blower flowrate, and differential pressure. Data was recorded on user defined intervals of 30 seconds.
- In this demonstration, the indoor to outdoor pressure differential was measured between a single indoor pressure port and a composite outdoor pressure reference. The outdoor reference included pressure ports from six (6) aspects of the building, manifolded together for a single outdoor reference point. The composite outdoor pressure reference provided a more stable and reliable outdoor reference by minimizing short-term pressure fluctuations from wind loading or turbulence generated by building faces.
- Adjustable frame with blower door cloth (blower door): The “blower door” included an adjustable frame and cover cloth with a cutout for the blower. The blower door was installed in a man-door doorframe. Figure 5 shows a blower door with a blower in place.

3.2 AIR SAMPLING AND ANALYTICAL PROCEDURE

CPM test air sampling included both indoor air and ambient outdoor samples, both of which utilized grab sampling. Indoor air sampling was specific to the type of test performed: Negative pressure CPM testing required a blower intake sample (functionally a composite of indoor air) for building concentration, and optional area specific samples. Final samples for negative pressure testing should be performed after a minimum of nine (9) building air exchanges.

Figure 5. Retrotec DM32 with display (left) and blower door with blower (right).

Positive pressure CPM testing required area specific sampling, and sampling should proceed after a minimum of four (4) building air exchanges. To eliminate spatial variations during sampling and to ensure greater sample consistency, air mixing was employed in the sampling area using fans (e.g. box/floor fans).

Ambient outdoor sampling was performed to determine the baseline concentration of analytes and was representative of the air quality of air drawn into the structure during pressure testing.

Long term, indoor air sampling utilized long-term thermal desorption tube sampling techniques and/or passive sampler technology.

Air sampling and associated analytical was performed using the following methods:

- Grab Sampling: Grab Sampling with Tedlar bags and a vacuum sampler was used to collect indoor and ambient outdoor air samples during CPM testing. These samples were analyzed on-site and analytical results were obtained the same day of sample collection.

  On-site grab sample analyses were performed using an SRI 8610C gas chromatograph (SRI, CA) equipped with a sorbent concentrator and a dry electrolytic conductivity detector (DELCD). The DELCD was well suited for analytical due to its selective nature for only chlorinated and brominated compounds.

  The GC-DELCD system was calibrated before negative and positive pressure testing. Calibration concentrations ranged from 0.01 to 10 ppb_v for both negative and positive pressure testing. Calibration standards were prepared by dilution in clean Tedlar bags using Zero-air and a custom chlorinated compound calibration gas stock (Scotty Analyzed Gases).

  For on-site analytical, a suite of chlorinated volatile organic hydrocarbons (CVOCs) based on trichloroethene and its daughter products was of interest. Those that responded well to the DELCD detector used for chromatography were as follows:

  - Trichloroethene (TCE)
  - 1,1 Dichloroethene (1,1-DCE)
  - 1,2 Dichloroethane (1,2-DCA)
  - 1,1,1 Trichloroethane (1,1,1-TCA)
  - 1,1,2 Trichloroethane (1,1,2-TCA)
  - Tetrachloroethene (PCE)

- Thermal Desorption (TD) tube sampling: TD tube sampling involved actively pulling air through a multi-bed, sorbent packed tube at a controlled flowrate. The flowrate and duration of collection determined the volume of air sampled. The averaged air concentration was calculated using the absorbed VOC mass and the total sample volume.

  Long-term (18 days) TD tube sampling: Long-term TD tube sampling was performed as follows:

- 18-day, timed interval sampling: 18-day, timed interval sample collection used a single Sensidyne Gilian LFS-113 pump in constant pressure mode to provide a continuous pressure source to a manifold with restrictor orifices to control flowrates for multiple tubes. The active sampling time was timer controlled to reduce collection volume to prevent TD tube sorbent saturation if indoor air concentrations were high. Active sampling was performed for 10-minute intervals every 1.5 hours throughout the sampling period, a total of 160 minutes per day. See Figure 6 for sampler photo.

  Sample integrity was maintained using Markes Difflok caps (Markes International, United Kingdom). In addition, to ensure that contaminant breakthrough did not occur, for each tube set, a backup TD tube was placed downstream of one of the tubes and was analyzed for the presence of contaminant. All backup TD tubes returned non-detect for VOCs.

  Sampling flowrates were measured prior-to and subsequent-to sampling using the Gilian Gilibrator-2 calibrator (Sensidyne, FL). The difference between two measures were less than 6% for all tube samples.

A single TD tube and the backup TD tube both supplied by Beacon Environmental Services, were shipped back to them for analysis. Other tubes deployed were from ASU and used for research purposes, the results for which will not be addressed in this report.

- Passive Sampling: ***Passive samplers*** were deployed for continuous, long-term sampling for an 18 day period. Passive samplers used were the Beacon Sampler (Beacon Environmental Services, MD) and were sent to Beacon Environmental Services for analysis.

While results for all analytes will be reported, the analyte of interest for discussion purposes will be TCE. TCE is the analyte of interest since this building resides over a TCE contaminant plume, and because of its low regulatory limit, TCE is frequently a focal point and regulatory driver.

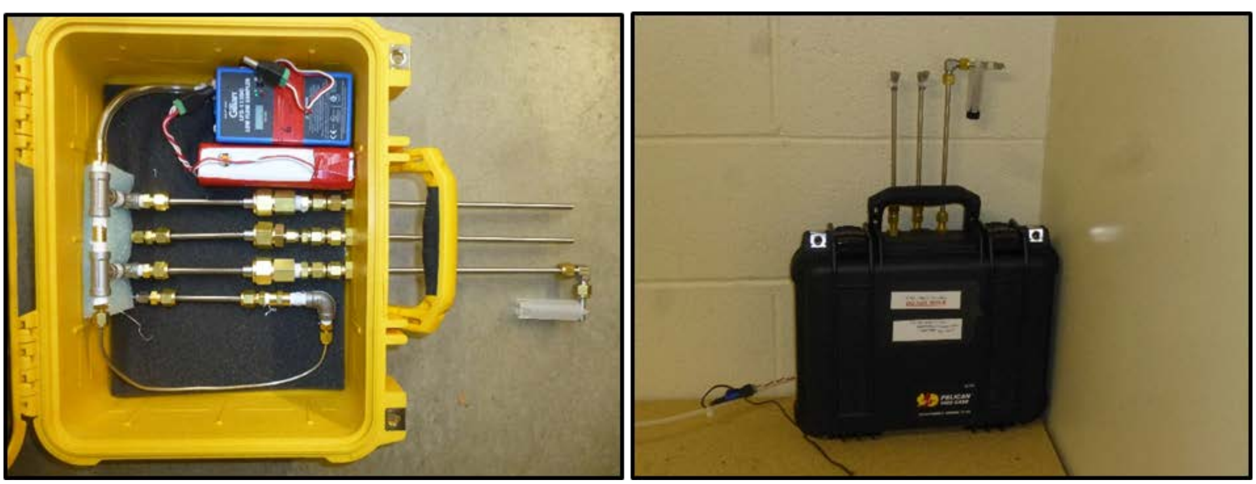


Figure 6. Active TD tube and Passive sampler deployment with passive sampler, TD tube active samplers in triplicate with a single tube for breakthrough assessment, pump, and timer.

19.CPM TEST DEMONSTRATION AND RESULTS

The goal of this CPM demonstration was not to perform a formal VI risk assessment, but rather, validate CPM testing for VI pathway assessment. Therefore, in addition to CPM testing, post-CPM testing indoor air sampling was performed and was used to characterize background indoor air concentrations to provide a point of comparison for the CPM test results.

The demonstration proceeded as follows:

- Sept. 7, 2018: CPM negative pressure pre-test. Preliminary test to determine concentration ranges and instrumentation needs for full test.
- Oct. 27, 2018: CPM Demonstration. Negative pressure testing. Sampling included ***Grab sampling with on-site analytical.***
- Oct. 28, 2018: CPM Demonstration. Positive pressure testing. Sampling included ***Grab sampling with on-site analytical***.
- Nov. 8 – Nov. 26, 2018: Background indoor air sampling. Sampling included long-term ***TD tube sampling*** and ***Passive sampling***.

The Sept. 7 pretest involved a brief negative pressure test to determine what blower equipment would be needed for a full test and to determine approximate analyte concentration ranges for calibration of on-site analytical equipment that would be used during the full test. Due to the informal nature of that test, test results will not be reported.

4.1 CPM DEMONSTRATION

CPM testing was performed over a two-day period as described above; negative pressure testing on Oct. 27 and positive pressure testing on Oct. 28. For each test, the blower-doors/blowers were installed in two (2) exit doorways, the stage exit which held a single blower configuration, and the exit in the southeast corner of the auditorium, which held a two blower configuration. Figure 7 shows a map view of the blower installation locations. Figure 8 shows the blower installations in which the single and double blower configurations are visible.

A magnitude 10 Pa pressure differential was the baseline for a pressure testing. The blower flowrate for this test was determined by adjusting blower speed to achieve the desired indoor-to-outdoor differential pressure. At this point in CPM development, the focus was to maintain the same magnitude of pressure differential for both the negative and positive pressure tests.

Air sampling during negative pressure testing focused on blower intake and ambient outdoor sampling. Blower intake concentrations, functionally a composite of indoor air, were collected during the test to determine when concentration equilibrium was achieved. Ambient outdoor air sampling was performed in two locations to determine the baseline concentration of analytes drawn into the building.

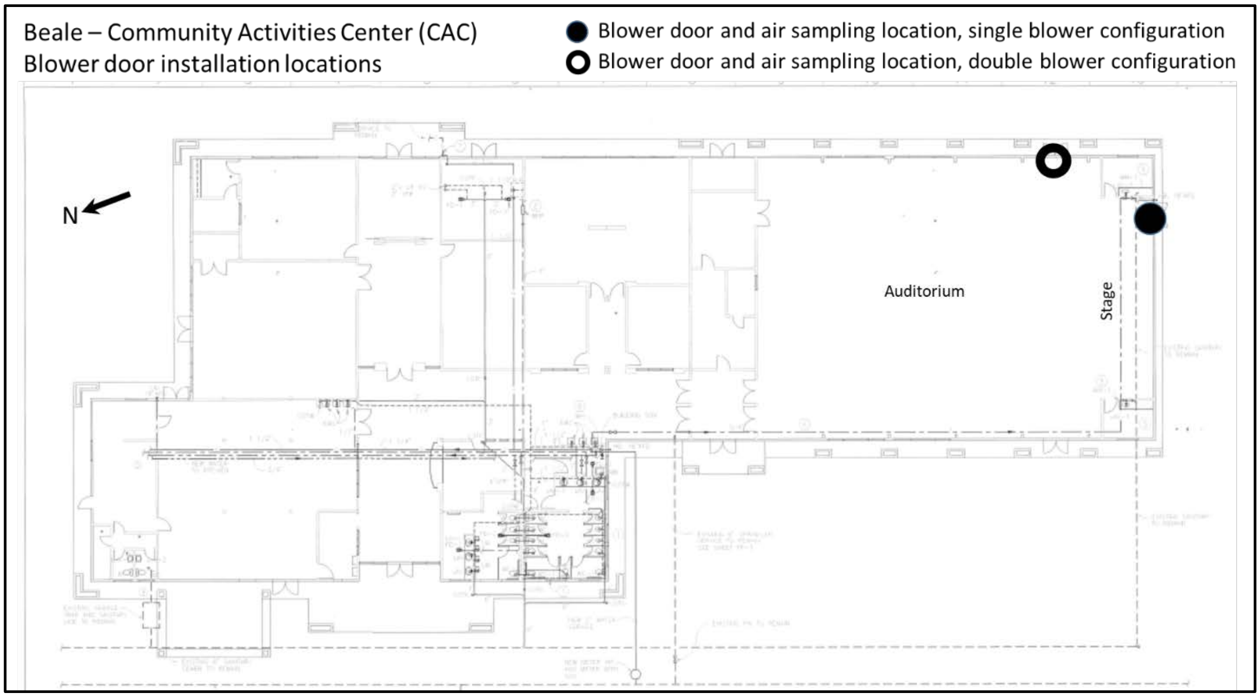


Figure 7. Oct. 27-28 pressure test blower door installations and air sampling locations, Beale AFB Community Activity Center, Building 2425.

Figure 8. Blower door installation and the use of floor fans to facilitate air mixing near the blower intake sampling area.

4.1.1 CPM Demonstration – Negative Pressure Test, Oct. 27, 2018

Three blowers were used for pressure control and were operated at constant speeds to maintain as uniform a flowrate as possible. Flowrate for negative pressure testing was determined by adjusting the blower speeds to achieve an indoor-to-outdoor differential pressure of approximately -10 Pa. Operational conditions with blower-door operation were as follows:

- Flowrate: 19,085 cfm average
- Approximate indoor vs. outdoor differential pressure: –10.3 Pa average
- Duration of negative pressure testing: 470 min.
- Air turnover rate: ~22 min per building volume
- Building volume air exchanges: ~21+ air exchanges

Figure 9 provides a time series graphic of flowrate and differential pressure. Note that outliers in differential pressure are typically related to wind gusts: Wind activity can affect both indoor and outdoor pressures and can generate erratic outdoor pressure references, both of which can affect the overall differential pressure across the building envelope. Also of note is that at 70 minutes elapsed time, it was noticed that an attic door above the stage had opened and from it came a discernible draft. As such, the door was closed and flowrates were adjusted downward to regain the -10 Pa pressure differential. From the graphic, it was evident that this door had opened at startup and was affecting both blower flowrate and differential pressure. Lastly, the increase in flowrate at 310 minutes elapsed time cannot be explained.

Intake grab samples from each blower door were collected throughout negative pressure testing to determine if/when concentration equilibrium was achieved. Samples were collected at a defined location 1-2 ft from the blower intake in the single blower configuration or 3 ft from the blowers at a mid-point between them in the two blower configuration. Jointly, samples reflected a cumulative representation of building air quality. Figure 10 provides a graphic of blower intake TCE concentration vs. elapsed time. Based on this data and limitations on time, While concentration equilibrium was not necessarily achieved, given 21 air exchanges (well in excess of the 9 air exchanges suggested by the SOP), concentrations less than 0.01 ppbv, and time limitations, it was not believed concentrations would not change much and the test was considered complete. The final blower intake samples were collected at 469 minutes.

For this test, no area-specific samples were collected. At this point in CPM protocol development, it was not believed that additional samples from locations throughout the test structure during negative pressurization would provide substantive benefit.

Four (4) rounds of ambient outdoor air grab samples were collected from two (2) locations (east (E) and west (W)) outside the building. Those samples provided a background reference for air quality and was representative of air that was drawn into the building during pressure testing.

<u>Analytical Results – Negative Pressure Test 1</u>

Table 2 shows CVOC analyte concentrations for this event.

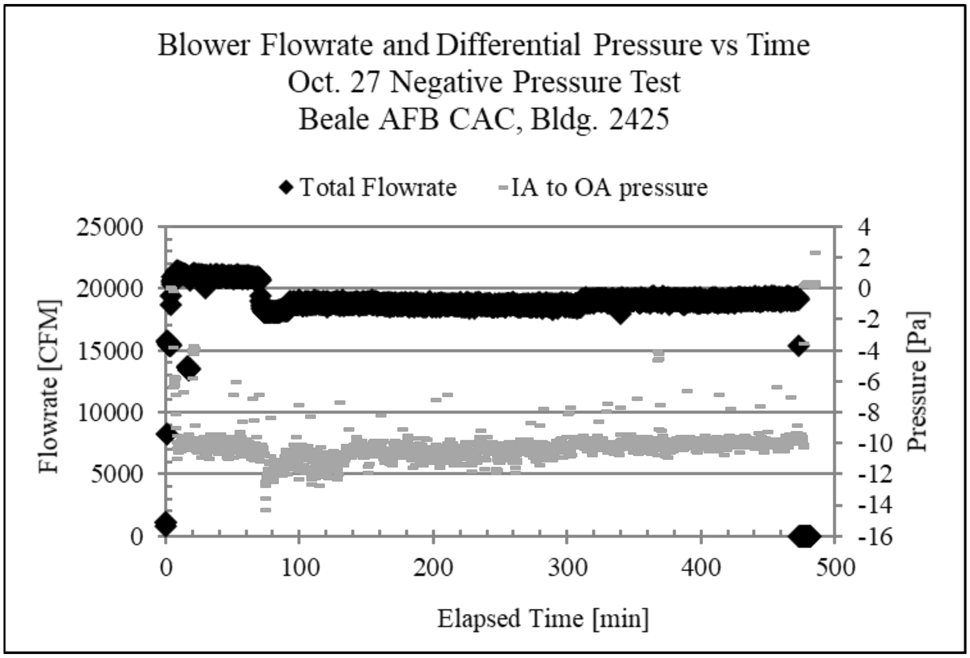


Figure 9. Blower flowrate and differential pressure vs time, Oct. 27 negative pressure test. Beale AFB Community Activity Center, Bldg. 2425.

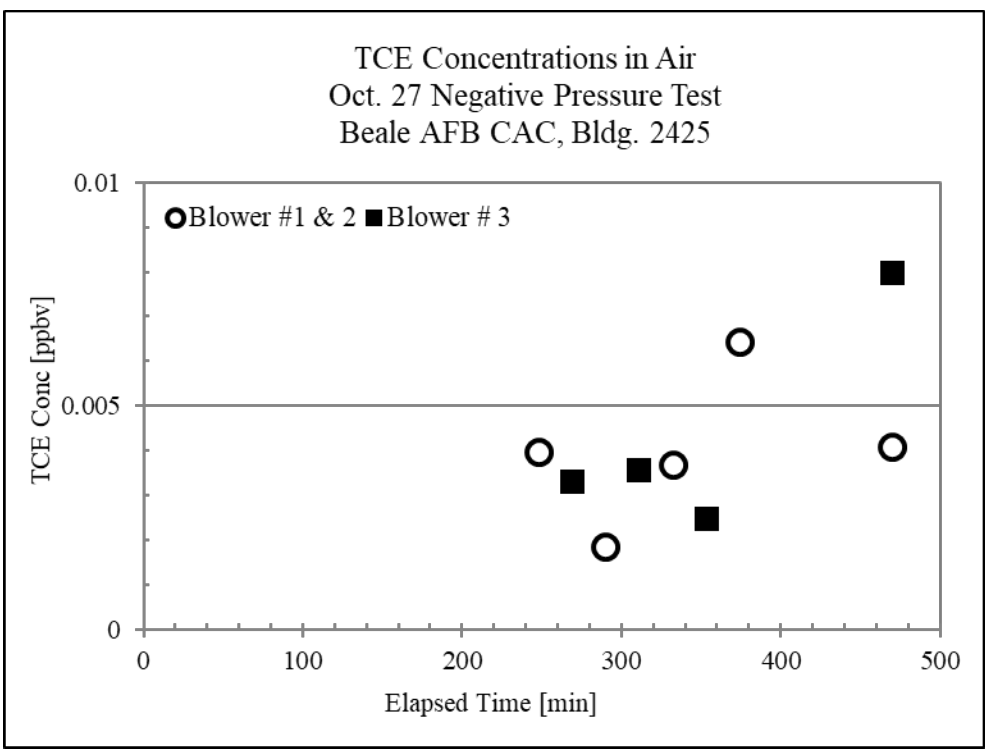


Figure 10. TCE Concentrations in air at the blower intake, Oct. 27 negative pressure test. Beale AFB Community Activity Center, Bldg. 2425.

Table 2. Indoor and ambient outdoor air sampling results for Oct. 27 negative pressure test.

Location	Elapsed Time (min)	Analyte Concentration in Air (ppbv)					
		TCE[1]	1,1- DCE[1]	1,2- DCA[1]	1,1,1-TCA[1]	1,1,2-TCA[3]	PCE[2]
Ambient Outdoor E	230	0.004	0.048	0.018	0.005	ND	0.039
Ambient Outdoor W	230	0.004	0.043	0.020	0.005	ND	0.036
Ambient Outdoor E	380	0.006	0.053	0.023	0.007	ND	0.030
Ambient Outdoor W	380	0.006	0.050	0.026	0.007	0.076	0.036
Ambient Outdoor E	425	0.009	0.047	0.025	0.005	ND	0.034
Ambient Outdoor W	425	0.007	0.046	0.024	0.007	ND	0.030
Ambient Outdoor E	470	0.006	0.054	0.025	ND	ND	0.033
Ambient Outdoor W	470	0.005	0.063	0.025	ND	ND	0.030
Blower intake 1/2	469	0.004	0.055	0.033	ND	ND	0.026
Blower intake 3	469	0.008	0.056	0.033	ND	ND	0.029

ND - Non-detectable
1 - Calibration limit of 0.01 ppbv. Highlighted concentrations were detectable and estimated.
2 - Calibration limit of 0.05 ppbv. Highlighted concentrations were detectable and estimated.
3 - Calibration limit of 0.1 ppbv. Highlighted concentrations were detectable and estimated.

Indoor air concentrations for TCE were equivalent to ambient outdoor concentrations and were less than the EPA screening levels of 0.08 ppbv for residential and 0.65 ppbv for industrial (USEPA, 2015/2020). In addition, other analytes, when adjusted for ambient outdoor concentrations, were all less than both the residential and industrial screening levels. As such, there was no complete VI pathway for the Community Activity Center as per the definition provided in the Introduction. Based on this result, no positive pressure CPM test would be necessary and the CPM test would be complete. However, for demonstration purposes, a positive pressure test was performed.

4.1.2 CPM Demonstration – Positive Pressure Testing, Oct. 28, 2018

For positive pressure testing, the same blower-door configuration was used as was used for the negative pressure test. At this point in CPM development, the blower speed was adjusted to achieve a positive pressure approximately equal in magnitude to the negative pressure test. Operational conditions for blower operation were as follows:

- Flowrate: 18,400 cfm average
- Indoor vs. outdoor differential pressure: +10.5 Pa average.
- Duration of positive pressure testing at this flowrate: 395 min.
- Air turnover rate: ~22.5 min per building volume
- Building volume air exchanges: 17+ air exchanges

Figure 11 provides a time series graphic of flowrate and differential pressure.

Prior to cessation of the positive pressure condition, grab sampling was performed in 18 area specific locations. Those locations along with their analytical designations are shown in Table 3, the locations for which are shown in Figure 12.

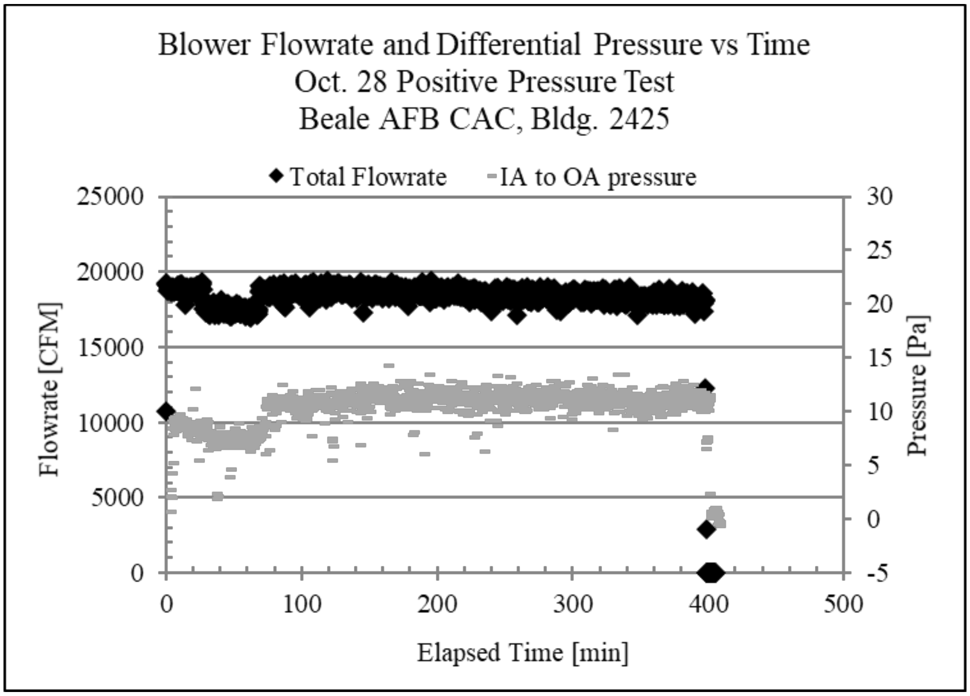


Figure 11. Blower flowrate and differential pressure vs time, Oct. 28 positive pressure test. Beale AFB Community Activity Center, Bldg. 2425.

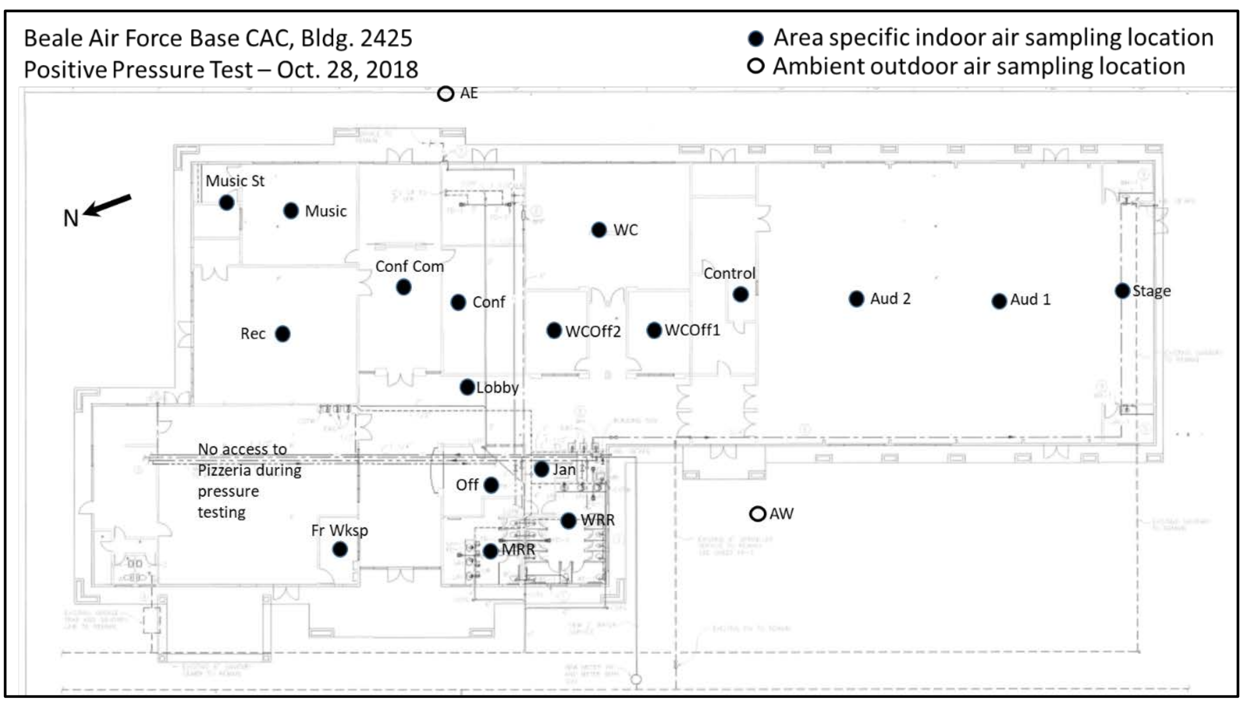


Figure 12. Air sampling locations, Oct. 28 positive pressure test, Beale AFB Community Activity Center, Bldg. 2425.

Table 3. Area specific sampling locations and analytical designations for Oct. 28 positive pressure test.

CAC Location	Designation		CAC Location	Designation
Music storeroom	Music St		Women's restroom	WRR
Music room	Music		Janitorial closet	Jan
Recreation room	Rec		Foyer	Foyer
Conference common area	Conf Com		Welcome Ctr. office 1	WCOff1
Conference room	Conf		Welcome Ctr. office 2	WCOff2
Lobby	Lobby		Welcome Ctr. lounge	WC
Front workspace	Frt Wksp		Auditorium 1	Aud1
Office	Office		Auditorium 2	Aud2
Men's restroom	MRR		Auditorium sound control room	Control

In addition, eight (8) ambient outdoor air grab samples were collected from two (2) locations, one east (AE) and one west (AW) of the building at 75 min, 150 min, 210 min, and 330 min after the test started. Those samples provided a baseline concentration for air quality and was representative of air that was drawn into the building during pressure testing.

<u>Analytical Results – Positive Pressure Test</u>

Tables 4 and 5 show CVOC analyte concentrations for indoor area specific locations and ambient outdoor locations, respectively.

When adjusted for background concentration as necessary, results indicated that there were no indoor air sources of concern.

4.2 BACKGROUND INDOOR AIR SAMPLING

Background indoor air sampling was performed Nov. 8 – Nov. 26, 2018. Sampling included long-term TD tube sampling and Passive sampling. Sampling locations for that event are shown in Figure 13.

Laboratory analytical results for TD tube and passive sampling of background indoor air conditions are shown in Table 6 and are attached in Appendices 2425A and 2425B for active TD tube and passive sampler results, respectively. The elevated detection limits for the passive air sampling is related to sampler characteristics, deployment time, and analytical.

With the exception of 1,2-DCA detections in WelCtrOffR and the Cafe, all concentrations were less than the quantitation limit for that analysis. While the 1,2-DCA concentrations in the WelCtrOffR and Café are in excess of the EPA indoor air standard for both residential and commercial, the detects are isolated and there is no indication of a larger vapor intrusion problem. Based on these results, there appears to be no complete vapor intrusion pathway in the Community Activity Center. This finding corroborates CPM test results.

Table 4. Indoor air sampling results for Oct. 28 positive pressure testing.

CAC Location	Analyte Concentration in Air (ppbv)					
	TCE[1]	1,1-DCE[1]	1,2-DCA[1]	1.1.1-TCA[1]	1,1,2-TCA[2]	PCE[2]
Aud 1	0.023	0.032	0.033	0.007	0.010	0.019
Aud 2	0.008	0.032	0.033	ND	ND	0.019
Control	0.011	0.032	0.035	ND	ND	0.014
M RR	0.002	0.032	0.027	ND	ND	0.020
W RR	0.006	0.033	0.025	ND	ND	0.019
Jan	0.006	0.033	0.036	ND	ND	0.049
Stage	0.006	0.034	0.034	ND	ND	0.052
WC Off1	0.009	0.038	0.131	ND	ND	0.011
WC Off2	0.006	0.037	0.059	ND	ND	0.011
WC	0.006	0.049	0.074	ND	0.003	0.027
WC dup	0.006	0.048	0.075	ND	ND	0.033
Off	0.006	0.040	0.055	0.008	ND	0.008
Fr Wksp	0.006	0.038	0.036	0.007	ND	0.028
Rec	0.006	0.038	0.042	0.007	ND	0.025
Music	0.006	0.038	0.037	0.007	ND	0.023
Music St	ND	0.039	0.024	0.005	ND	0.015
Conf	ND	0.039	0.029	0.006	ND	0.026
Conf Com	ND	0.042	0.027	0.006	ND	0.025
Lobby	0.002	0.040	0.027	0.006	ND	0.025
Conf Com Dup	ND	0.040	0.030	0.007	ND	0.025

ND - Non-detectable
1 - Calibration limit of 0.01 ppbv. Highlighted concentrations were detectable and estimated.
2 - Calibration limit of 0.05 ppbv. Highlighted concentrations were detectable and estimated.

Table 5. Ambient outdoor air sampling results for Oct. 30 positive pressure testing.

Location	Elapsed Time (min)	Analyte Concentration in Air (ppbv)					
		TCE[1]	1,1-DCE[1]	1,2 –DCA[1]	1,1,1-TCA[1]	1,1,2-TCA[2]	PCE[2]
AE	75	0.012	0.042	0.025	0.008	0.013	0.066
AW	75	0.005	0.040	0.018	0.005	0.009	0.043
AE	150	0.008	0.037	0.025	0.006	0.360	0.019
AW	150	0.011	0.035	0.026	0.003	0.008	0.020
AE	210	0.007	0.033	0.020	0.002	0.007	0.022
AW	210	0.006	0.033	0.027	0.005	0.005	0.017
AE	330	ND	0.039	0.027	0.006	ND	0.026
AW	330	0.004	0.038	0.029	0.007	ND	0.024

ND - Non-detectable
1 - Calibration limit of 0.01 ppbv. Highlighted concentrations were detectable and estimated.
2 - Calibration limit of 0.05 ppbv. Highlighted concentrations were detectable and estimated.

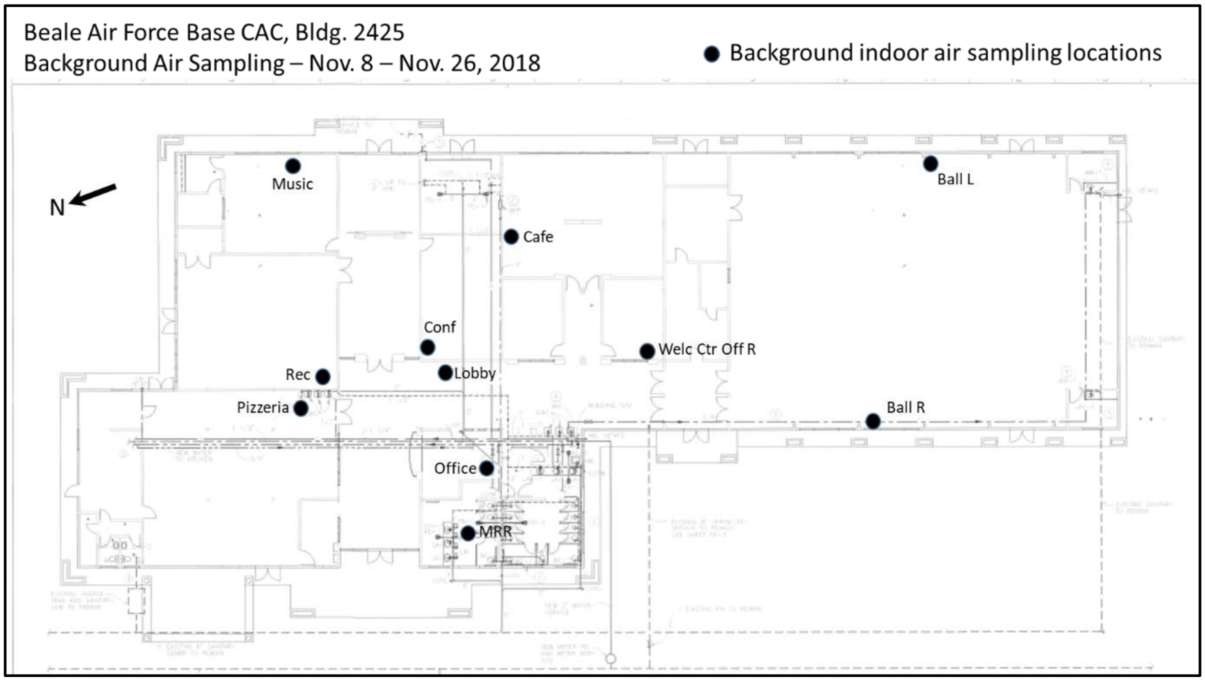


Figure 13. Nov. 8 through Nov. 26 long-term active/passive sampling locations. Beale AFB Community Activity Center, Building 2425.

20.CPM DEMONSTRATION SUMMARY

Summary of CPM Negative Pressure Test 1

As indicated previously, negative pressure testing induces a worst-case-scenario for vapor intrusion. As such, the concentrations noted during the test were likely worst-case-scenario concentrations.

With 21 building air exchanges, the optimum number of 10 air exchanges had been met, although concentration equilibrium had not necessarily been realized. However, since the test had been underway for almost 10 hours, time was limited, and the range of TCE concentration at the blower was less than 0.01 ppbv, it was not believed that more significant concentration changes would be encountered with additional run time. As such, the test was deemed complete.

The negative pressure test indicated that the approximate averaged indoor air TCE concentration collected at the blower intake was less than 0.01 ppbv, a concentration well below the EPA action levels of 0.08 ppbv for residential and 0.65 ppbv for industrial (USEPA, 2015/2020). Based on these results and per the definition forwarded in the Introduction, there was no “complete vapor intrusion pathway.”

Table 6. Laboratory analytical results for Nov. 8 through Nov. 26 active TD tube and passive sampling during natural building pressure conditions, Bldg. 2425.

Location	Sample Type	Units	Analyte Concentration in Air[1]									
			TCE[2]	1,1-DCE[2]	t 1,2-DCE[2]	1,1-DCA[2]	c 1,2-DCE[2]	1,2-DCA[2]	1,1,1-TCA[2]	PCE[2]	Bromodichloro methane[2]	Dibromochloro methane[3]
Ball L	Passive	ug/m3	<1.19	<1.22	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.10
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	---	---	---	---	---	---	---	---	---	---
Ball R	Passive	ug/m3	<1.19	<1.22	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.10
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Cafe	Passive	ug/m3	<1.19	<1.22	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.10
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.02	<0.02	<0.02	<0.02	<0.02	0.04	<0.01	<0.01	<0.01	<0.01
MRR	Passive	ug/m3	<1.19	<1.23	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.11
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Welc Ctr Off R	Passive	ug/m3	<1.19	<1.22	<0.92	<0.48	<0.75	0.94	<0.99	<0.99	<0.98	<1.10
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	0.23	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.01	<0.02	<0.02	<0.02	<0.02	0.09	<0.01	<0.01	<0.01	<0.01
Conf	Passive	ug/m3	<1.18	<1.22	<0.91	<0.48	<0.75	<0.72	<0.98	<0.98	<0.98	<1.10
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Office	Passive	ug/m3	<1.19	<1.22	<0.92	<0.48	<0.75	<0.72	<0.98	<0.98	<0.98	<1.10
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Lobby	Passive	ug/m3	<1.20	<1.23	<0.92	<0.48	<0.75	<0.73	<0.99	<0.99	<0.99	<1.11
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	---	---	---	---	---	---	---	---	---	---
Rec	Passive	ug/m3	<1.19	<1.23	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.11
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	<0.02	<0.03	<0.03	<0.03	<0.03	<0.03	<0.02	<0.02	<0.02	<0.01
Pizzeria	Passive	ug/m3	<1.19	<1.23	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.11
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	---	---	---	---	---	---	---	---	---	---
Music	Passive	ug/m3	<1.19	<1.23	<0.92	<0.48	<0.75	<0.72	<0.99	<0.99	<0.98	<1.11
		ppbv	<0.22	<0.31	<0.23	<0.12	<0.19	<0.18	<0.18	<0.14	<0.15	<0.13
	Active	ppbv	---	---	---	---	---	---	---	---	---	---

1-For concentrations noted as “<”, concentrations were non-detectable or less than the limits of quantitation shown.
2-Passive sampler concentrations reported in ug/m3 and converted to ppbv using the EPA Indoor Air Unit Conversion, Online Tools for Site Assessment Calculation (USEPA, 2020).
3-Passive sampler concentration reported in ug/m3 and converted to ppbv using the Eurofins Unit Conversion Calculator (Eurofins, 2020).

At that juncture, no positive pressure CPM test was necessary. However, for completeness of demonstration, a positive pressure test was performed.

Summary of CPM Positive Pressure Testing

As stated previously, positive pressure testing was conducted at approximately the same magnitude of differential pressure as the negative pressure test. After meeting the minimum condition of four air exchanges at the elevated flowrate and differential pressure condition, location specific sampling was performed.

Results indicated that no indoor air sources of consequence were present within the building.

Summary of Background Sampling Under Natural Building Pressure Conditions

No analytes of interest were detected in the background sampling of Building 2425 under natural building pressure conditions except for isolated detections of 1,2-DCA in the Welcome Center office and the café, both in excess of standard. Due to the isolated nature of those detects within the building and that it was not detected on a broader scale or during pressure testing, it is believed that those might be related to activities in those adjacent areas during the sampling period, but are not indicative of a vapor intrusion problem,

These results indicate that there was no vapor intrusion impact, or more specifically, there was no complete vapor intrusion pathway. These results corroborate the results of CPM testing which also indicated that there was no complete vapor intrusion pathway.

21.CPM DEMONSTRATION CONCLUSIONS

As stated in the Introduction, a complete VI pathway was defined as vapor intrusion with indoor vapor contaminant concentrations in excess of a regulatory limit or action level. Based on this definition, CPM testing indicated that there was no complete VI pathway for Building 2425, the the Community Activity Center. This result was corroborated with more traditional active and passive sampling techniques within the building under passive pressure conditions.

22.REFERENCES

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Appendix 2425A
Background Indoor Air Sampling - Active TD Tube Results
Analytical Report

(Only sample IDs with a prefix of “B CAC”
are related to the Community Activity Center, Bldg. 2425)

The Leaders in Air Surveys
and Vapor Intrusion Monitoring

BEACON ENVIRONMENTAL SERVICES, INC.

Arizona State University
660 South College Avenue, Room 507
Tempe, AZ 85281
Attn: Paul Dahlen

Air Samples -- Analytical Report

Date: June 17, 2020
Beacon Project No. 4459.1A

Project Reference:	Beale and Travis AFB
Sampling Date:	November 2 through 8, 2018
Samples Received:	December 11, 2018
Analyses Completed:	December 13, 2018

Results for the following samples are included in this data package:

Sample ID	Matrix	Analysis
BTheaterStageL	Air	TO-17
BtheaterStageL_B_Up	Air	TO-17
BTheaterLobby	Air	TO-17
BtheaterLobby_B_Up	Air	TO-17
BTheaterWRR	Air	TO-17
BTheaterWRR_B_Up	Air	TO-17
BTheaterStageWRR	Air	TO-17
BTheaterStageWRR_B_Up	Air	TO-17
Tr18Main	Air	TO-17
Tr18Main_B_Up	Air	TO-17
Tr18Hall	Air	TO-17
Tr18Hall_B_Up	Air	TO-17
Tr18SEOffice	Air	TO-17
Tr18SEOffice_B_Up	Air	TO-17
Tr18Shower1	Air	TO-17
Tr18Shower1_B_Up	Air	TO-17
BCACCafe	Air	TO-17
BCACCafe_B_Up	Air	TO-17
BCACBallR	Air	TO-17
BCACBallR_B_Up	Air	TO-17
BCACConf	Air	TO-17
BCACConf_B_Up	Air	TO-17
BCACOff	Air	TO-17
BCACOff_B_Up	Air	TO-17
BCACMRR	Air	TO-17
BCACMRR_B_Up	Air	TO-17
BCACWelcCtrOffR	Air	TO-17
BCACWelcCtrOffR_B_Up	Air	TO-17
BCACRec	Air	TO-17
BCACRec_B_Up	Air	TO-17

Sample Collection

Beacon Environmental provided Arizona State University with thermally conditioned multi-bed stainless steel tubes to target a custom list of analytes. Air was drawn through each tube and the resulting mass of target analytes captured on each sampler was reported as a concentration.

U. S. EPA Method TO-17

All samples were analyzed for a custom target compound list following U.S. EPA Method TO-17. The analytical results are reported in micrograms per meter cubed ($\mu g/m^3$) and ppbv based on the measured mass and volume of gas sampled.

Reporting Limits (RLs) for EPA Method TO-17

The lowest point in the calibration curve and the limit of quantitation (LOQ) is 10 nanograms (ng), which is the RL; however, when reporting concentration data the values are provided in $\mu g/m^3$ and ppbv. The RLs represent a baseline above which results exceed laboratory-determined limits of precision and accuracy.

Calibration Verification

The initial laboratory control sample (LCS) also serves as the calibration verification and values for the analytes were all within ±30% of the true values as defined by the initial five-point calibration and met the requirements specified in Beacon Environmental's Quality Manual. Both the LCS and the laboratory control duplicate (LCSD) are spiked at 50 ng and percentage of recovery is calculated and reported. Acceptance criteria for surrogate and analyte recoveries are 70 to 130 percent; all surrogates and analytes were within the acceptance criteria.

Internal Standards and Surrogates

Internal standards and surrogates are spiked on each field and QC sample at 100 ng and 50 ng, respectively, and the percentage of recovery is calculated. Acceptance criteria for internal standards are 60 to 140 percent and surrogate recoveries are 70 to 130 percent; all internal standards and surrogates were within the acceptance criteria.

Blank Contamination

No targeted compounds above the limit of detection (LOD) for each compound were observed in the Laboratory Method Blanks.

Discussion

Thirty (30) samples were collected following U.S. EPA Method TO-17. Sampling start and stop times, and total sampling volume can be found in the Chain of Custody (**Attachment 1**).

Dilutions were required for multiple samples, to bring the detected concentrations of reported compounds into the calibration range of the GC/MSD instrument. The LOQs of the diluted sample results are higher and noted in **Table 1**.

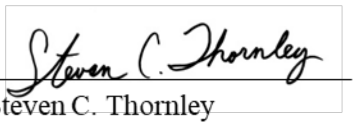
Demonstrated Linear Range of the GC-MS Instrumentation (EPA Method TO-17)

An initial five-point calibration is performed on the instrumentation from 10 to 200 ng per analyte.

Attachments:

-1- Chain of Custody

ALL DATA MEET REQUIREMENTS AS SPECIFIED IN THE BEACON ENVIRONMENTAL SERVICES, INC. QUALITY MANUAL AND THE RESULTS RELATE ONLY TO THE SAMPLES REPORTED. BEACON ENVIRONMENTAL SERVICES IS ACCREDITED TO ISO/IEC 17025:2005, AND THE WORK PERFORMED WAS IN ACCORDANCE WITH ISO/IEC 17025 REQUIREMENTS. THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY. RELEASE OF THE DATA HAS BEEN AUTHORIZED BY THE LABORATORY DIRECTOR OR HIS SIGNEE, AS VERIFIED BY THE FOLLOWING SIGNATURES:



Steven C. Thornley
Laboratory Director

Date: June 17, 2020

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LCS_1078673_181212

Client:	Analysis	Lab FileID
Arizon State University	initial	K18121202
660 South College Avenue, Room 507	1st Dilution	
Tempe, AZ 85281	2nd Dilution	
ph: 480-385-9671	3rd Dilution	

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**102%**	%REC	70-130	12/12/18 12:47	K18121202
trans-1,2-Dichloroethene	156-60-5	**103%**	%REC	70-130	12/12/18 12:47	K18121202
1,1-Dichloroethane	75-34-3	**102%**	%REC	70-130	12/12/18 12:47	K18121202
cis-1,2-Dichloroethene	156-59-2	**107%**	%REC	70-130	12/12/18 12:47	K18121202
Chloroform	67-66-3	**105%**	%REC	70-130	12/12/18 12:47	K18121202
1,2-Dichloroethane	107-06-2	**110%**	%REC	70-130	12/12/18 12:47	K18121202
1,1,1-Trichloroethane	71-55-6	**108%**	%REC	70-130	12/12/18 12:47	K18121202
Trichloroethene	79-01-6	**112%**	%REC	70-130	12/12/18 12:47	K18121202
Bromodichloromethane	75-27-4	**113%**	%REC	70-130	12/12/18 12:47	K18121202
Dibromochloromethane	124-48-1	**109%**	%REC	70-130	12/12/18 12:47	K18121202
Tetrachloroethene	127-18-4	**96%**	%REC	70-130	12/12/18 12:47	K18121202
Bromoform	75-25-2	**109%**	%REC	70-130	12/12/18 12:47	K18121202

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LB_1078524_181212

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab FileID
initial	K18121203
1st Dilution	
2nd Dilution	
3rd Dilution	

COMPOUNDS	CAS#						
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 13:07	K18121203
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 13:07	K18121203
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 13:07	K18121203
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 13:07	K18121203
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 13:07	K18121203
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 13:07	K18121203
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/12/18 13:07	K18121203
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 13:07	K18121203
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 13:07	K18121203
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 13:07	K18121203
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 13:07	K18121203
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 13:07	K18121203

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: **LCSD_1078697_181212**

	Analysis	**Lab File ID**
Client:	**initial**	K18121204
Arizon State University	1st Dilution	
660 South College Avenue, Room 507	2nd Dilution	
Tempe, AZ 85281	3rd Dilution	
ph: 480-385-9671		

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**91%**	%REC	70-130	12/12/18 13:27	K18121204
trans-1,2-Dichloroethene	156-60-5	**95%**	%REC	70-130	12/12/18 13:27	K18121204
1,1-Dichloroethane	75-34-3	**98%**	%REC	70-130	12/12/18 13:27	K18121204
cis-1,2-Dichloroethene	156-59-2	**101%**	%REC	70-130	12/12/18 13:27	K18121204
Chloroform	67-66-3	**102%**	%REC	70-130	12/12/18 13:27	K18121204
1,2-Dichloroethane	107-06-2	**107%**	%REC	70-130	12/12/18 13:27	K18121204
1,1,1-Trichloroethane	71-55-6	**103%**	%REC	70-130	12/12/18 13:27	K18121204
Trichloroethene	79-01-6	**111%**	%REC	70-130	12/12/18 13:27	K18121204
Bromodichloromethane	75-27-4	**112%**	%REC	70-130	12/12/18 13:27	K18121204
Dibromochloromethane	124-48-1	**111%**	%REC	70-130	12/12/18 13:27	K18121204
Tetrachloroethene	127-18-4	**100%**	%REC	70-130	12/12/18 13:27	K18121204
Bromoform	75-25-2	**111%**	%REC	70-130	12/12/18 13:27	K18121204

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BTheaterStageL
Lab Sample ID: 1078601
Sample Collection Time: 11/26/18 3:13 PM
Sample Volume in Liters: 155.72
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121205	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 13:51	K18121205
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 13:51	K18121205
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 13:51	K18121205
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 13:51	K18121205
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 13:51	K18121205
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 13:51	K18121205
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 13:51	K18121205
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 13:51	K18121205
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 13:51	K18121205
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 13:51	K18121205
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 13:51	K18121205
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 13:51	K18121205

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterStageL_B_up
Lab Sample ID:	1078544
Sample Collection Time:	11/26/18 3:13 PM
Sample Volume in Liters:	155.72
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121206	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 14:16	K18121206
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 14:16	K18121206
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 14:16	K18121206
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 14:16	K18121206
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 14:16	K18121206
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 14:16	K18121206
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 14:16	K18121206
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 14:16	K18121206
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 14:16	K18121206
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 14:16	K18121206
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 14:16	K18121206
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 14:16	K18121206

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterLobby
Lab Sample ID:	1078895
Sample Collection Time:	11/26/18 2:55 PM
Sample Volume in Liters:	156.31
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121207	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 14:40	K18121207
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 14:40	K18121207
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 14:40	K18121207
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 14:40	K18121207
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 14:40	K18121207
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 14:40	K18121207
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 14:40	K18121207
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 14:40	K18121207
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 14:40	K18121207
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 14:40	K18121207
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 14:40	K18121207
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 14:40	K18121207

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BTheaterLobby_B_up
Lab Sample ID: 1078651
Sample Collection Time: 11/26/18 2:55 PM
Sample Volume in Liters: 156.31
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121208	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 15:05	K18121208
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 15:05	K18121208
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 15:05	K18121208
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 15:05	K18121208
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 15:05	K18121208
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 15:05	K18121208
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 15:05	K18121208
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 15:05	K18121208
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 15:05	K18121208
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 15:05	K18121208
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 15:05	K18121208
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 15:05	K18121208

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterWRR
Lab Sample ID:	1078606
Sample Collection Time:	11/26/18 3:07 PM
Sample Volume in Liters:	138.05
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121209	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 15:29	K18121209
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 15:29	K18121209
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 15:29	K18121209
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 15:29	K18121209
Chloroform	67-66-3	**0.09**	0.1	**0.02**	0.01	12/12/18 15:29	K18121209
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 15:29	K18121209
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 15:29	K18121209
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 15:29	K18121209
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 15:29	K18121209
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 15:29	K18121209
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 15:29	K18121209
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 15:29	K18121209

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BTheaterWRR_B_up
Lab Sample ID: 1078803
Sample Collection Time: 11/26/18 3:07 PM
Sample Volume in Liters: 138.05
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121210	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 15:53	K18121210
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 15:53	K18121210
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 15:53	K18121210
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 15:53	K18121210
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 15:53	K18121210
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 15:53	K18121210
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 15:53	K18121210
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 15:53	K18121210
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 15:53	K18121210
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 15:53	K18121210
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 15:53	K18121210
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 15:53	K18121210

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BTheaterStageWRR
Lab Sample ID:	1078556
Sample Collection Time:	11/26/18 3:18 PM
Sample Volume in Liters:	161.68
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121211	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 16:17	K18121211
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 16:17	K18121211
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 16:17	K18121211
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 16:17	K18121211
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 16:17	K18121211
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 16:17	K18121211
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 16:17	K18121211
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 16:17	K18121211
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 16:17	K18121211
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 16:17	K18121211
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 16:17	K18121211
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 16:17	K18121211

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BTheaterStageWRR_B_up
Lab Sample ID: 1078769
Sample Collection Time: 11/26/18 3:18 PM
Sample Volume in Liters: 161.68
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab FileID	Dilution Factor
initial	K18121212	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 16:42	K18121212
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 16:42	K18121212
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 16:42	K18121212
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 16:42	K18121212
Chloroform	67-66-3	U	0.1	U	0.01	12/12/18 16:42	K18121212
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 16:42	K18121212
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 16:42	K18121212
Trichloroethene	79-01-6	U	0.1	U	0.01	12/12/18 16:42	K18121212
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 16:42	K18121212
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 16:42	K18121212
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 16:42	K18121212
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 16:42	K18121212

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18Main
Lab Sample ID:	1078557
Sample Collection Time:	11/27/18 4:36 PM
Sample Volume in Liters:	65.64
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121213	1
1st Dilution	K18121305	8.49
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.2	U	0.04	12/12/18 17:06	K18121213
trans-1,2-Dichloroethene	156-60-5	U	0.2	U	0.04	12/12/18 17:06	K18121213
1,1-Dichloroethane	75-34-3	U	0.2	U	0.04	12/12/18 17:06	K18121213
cis-1,2-Dichloroethene	156-59-2	**1.6**	0.2	**0.4**	0.04	12/12/18 17:06	K18121213
Chloroform	67-66-3	U	0.2	U	0.03	12/12/18 17:06	K18121213
1,2-Dichloroethane	107-06-2	U	0.2	U	0.04	12/12/18 17:06	K18121213
1,1,1-Trichloroethane	71-55-6	U	0.2	U	0.03	12/12/18 17:06	K18121213
Trichloroethene	79-01-6	**12.05 D**	1.3	**2.24 D**	0.24	12/13/18 11:03	K18121305
Bromodichloromethane	75-27-4	U	0.2	U	0.02	12/12/18 17:06	K18121213
Dibromochloromethane	124-48-1	U	0.2	U	0.02	12/12/18 17:06	K18121213
Tetrachloroethene	127-18-4	U	0.2	U	0.02	12/12/18 17:06	K18121213
Bromoform	75-25-2	U	0.2	U	0.01	12/12/18 17:06	K18121213

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Beacon Job Number: 4459.1A
Analysis Method: TO17
Matrix: Air
Client ID/Field Sampling Location: Tr18Main_B_up
Lab Sample ID: 1078647
Sample Collection Time: 11/27/18 4:36 PM
Sample Volume in Liters: 65.64
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121214	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.2	U	0.04	12/12/18 17:30	K18121214
trans-1,2-Dichloroethene	156-60-5	U	0.2	U	0.04	12/12/18 17:30	K18121214
1,1-Dichloroethane	75-34-3	U	0.2	U	0.04	12/12/18 17:30	K18121214
cis-1,2-Dichloroethene	156-59-2	U	0.2	U	0.04	12/12/18 17:30	K18121214
Chloroform	67-66-3	U	0.2	U	0.03	12/12/18 17:30	K18121214
1,2-Dichloroethane	107-06-2	U	0.2	U	0.04	12/12/18 17:30	K18121214
1,1,1-Trichloroethane	71-55-6	U	0.2	U	0.03	12/12/18 17:30	K18121214
Trichloroethene	79-01-6	U	0.2	U	0.03	12/12/18 17:30	K18121214
Bromodichloromethane	75-27-4	U	0.2	U	0.02	12/12/18 17:30	K18121214
Dibromochloromethane	124-48-1	U	0.2	U	0.02	12/12/18 17:30	K18121214
Tetrachloroethene	127-18-4	U	0.2	U	0.02	12/12/18 17:30	K18121214
Bromoform	75-25-2	U	0.2	U	0.01	12/12/18 17:30	K18121214

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18Hall
Lab Sample ID:	1078637
Sample Collection Time:	11/27/18 4:21 PM
Sample Volume in Liters:	68.60
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121215	1
1st Dilution	K18121306	8.5
2nd Dilution	K18121309	42.8
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.04	12/12/18 17:55	K18121215
trans-1,2-Dichloroethene	156-60-5	**0.19**	0.1	**0.05**	0.04	12/12/18 17:55	K18121215
1,1-Dichloroethane	75-34-3	U	0.1	U	0.04	12/12/18 17:55	K18121215
cis-1,2-Dichloroethene	156-59-2	**6.95 D**	1.2	**1.75 D**	0.31	12/13/18 11:26	K18121306
Chloroform	67-66-3	U	0.1	U	0.03	12/12/18 17:55	K18121215
1,2-Dichloroethane	107-06-2	U	0.1	U	0.04	12/12/18 17:55	K18121215
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.03	12/12/18 17:55	K18121215
Trichloroethene	79-01-6	**35.21 D**	6.2	**6.55 D**	1.16	12/13/18 12:46	K18121309
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/12/18 17:55	K18121215
Dibromochloromethane	124-48-1	U	0.1	U	0.02	12/12/18 17:55	K18121215
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/12/18 17:55	K18121215
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 17:55	K18121215

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18Hall_B_up
Lab Sample ID:	1078511
Sample Collection Time:	11/27/18 4:21 PM
Sample Volume in Liters:	68.60
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121216	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.04	12/12/18 18:19	K18121216
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.04	12/12/18 18:19	K18121216
1,1-Dichloroethane	75-34-3	U	0.1	U	0.04	12/12/18 18:19	K18121216
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.04	12/12/18 18:19	K18121216
Chloroform	67-66-3	U	0.1	U	0.03	12/12/18 18:19	K18121216
1,2-Dichloroethane	107-06-2	U	0.1	U	0.04	12/12/18 18:19	K18121216
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.03	12/12/18 18:19	K18121216
Trichloroethene	79-01-6	U	0.1	U	0.03	12/12/18 18:19	K18121216
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/12/18 18:19	K18121216
Dibromochloromethane	124-48-1	U	0.1	U	0.02	12/12/18 18:19	K18121216
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/12/18 18:19	K18121216
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 18:19	K18121216

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18SEOffice
Lab Sample ID:	1078558
Sample Collection Time:	11/27/18 4:21 PM
Sample Volume in Liters:	56.66
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121217	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.2	U	0.04	12/12/18 18:46	K18121217
trans-1,2-Dichloroethene	156-60-5	**0.65**	0.2	**0.16**	0.04	12/12/18 18:46	K18121217
1,1-Dichloroethane	75-34-3	U	0.2	U	0.04	12/12/18 18:46	K18121217
cis-1,2-Dichloroethene	156-59-2	**13.75 E**	0.2	**3.47 E**	0.04	12/12/18 18:46	K18121217
Chloroform	67-66-3	U	0.2	U	0.04	12/12/18 18:46	K18121217
1,2-Dichloroethane	107-06-2	U	0.2	U	0.04	12/12/18 18:46	K18121217
1,1,1-Trichloroethane	71-55-6	U	0.2	U	0.03	12/12/18 18:46	K18121217
Trichloroethene	79-01-6	**61.03 E**	0.2	**11.36 E**	0.03	12/12/18 18:46	K18121217
Bromodichloromethane	75-27-4	U	0.2	U	0.03	12/12/18 18:46	K18121217
Dibromochloromethane	124-48-1	U	0.2	U	0.02	12/12/18 18:46	K18121217
Tetrachloroethene	127-18-4	**0.24**	0.2	**0.04**	0.03	12/12/18 18:46	K18121217
Bromoform	75-25-2	U	0.2	U	0.02	12/12/18 18:46	K18121217

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	Tr18SEOffice_B_up
Lab Sample ID:	1078666
Sample Collection Time:	11/27/18 4:21 PM
Sample Volume in Liters:	56.66
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121218	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.2	U	0.04	12/12/18 19:10	K18121218
trans-1,2-Dichloroethene	156-60-5	U	0.2	U	0.04	12/12/18 19:10	K18121218
1,1-Dichloroethane	75-34-3	U	0.2	U	0.04	12/12/18 19:10	K18121218
cis-1,2-Dichloroethene	156-59-2	U	0.2	U	0.04	12/12/18 19:10	K18121218
Chloroform	67-66-3	U	0.2	U	0.04	12/12/18 19:10	K18121218
1,2-Dichloroethane	107-06-2	U	0.2	U	0.04	12/12/18 19:10	K18121218
1,1,1-Trichloroethane	71-55-6	U	0.2	U	0.03	12/12/18 19:10	K18121218
Trichloroethene	79-01-6	U	0.2	U	0.03	12/12/18 19:10	K18121218
Bromodichloromethane	75-27-4	U	0.2	U	0.03	12/12/18 19:10	K18121218
Dibromochloromethane	124-48-1	U	0.2	U	0.02	12/12/18 19:10	K18121218
Tetrachloroethene	127-18-4	U	0.2	U	0.03	12/12/18 19:10	K18121218
Bromoform	75-25-2	U	0.2	U	0.02	12/12/18 19:10	K18121218

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: Tr18Shower1
Lab Sample ID: 1078519
Sample Collection Time: 11/27/18 4:41 PM
Sample Volume in Liters: 72.13
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121219	1
1st Dilution	K18121308	8.5
2nd Dilution	K18121310	42.8
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/12/18 19:35	K18121219
trans-1,2-Dichloroethene	156-60-5	**0.17**	0.1	**0.04**	0.03	12/12/18 19:35	K18121219
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/12/18 19:35	K18121219
cis-1,2-Dichloroethene	156-59-2	**8.06 D**	1.2	**2.03 D**	0.30	12/13/18 12:13	K18121308
Chloroform	67-66-3	**0.15**	0.1	**0.03**	0.03	12/12/18 19:35	K18121219
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/12/18 19:35	K18121219
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.03	12/12/18 19:35	K18121219
Trichloroethene	79-01-6	**39.04 D**	5.9	**7.26 D**	1.10	12/13/18 13:09	K18121310
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/12/18 19:35	K18121219
Dibromochloromethane	124-48-1	U	0.1	U	0.02	12/12/18 19:35	K18121219
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/12/18 19:35	K18121219
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 19:35	K18121219

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Beacon Job Number: 4459.1A
Analysis Method: TO17
Matrix: Air
Client ID/Field Sampling Location: Tr18Shower1_B_up
Lab Sample ID: 1078536
Sample Collection Time: 11/27/18 4:41 PM
Sample Volume in Liters: 72.13
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121220	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/12/18 19:59	K18121220
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.03	12/12/18 19:59	K18121220
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/12/18 19:59	K18121220
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.03	12/12/18 19:59	K18121220
Chloroform	67-66-3	U	0.1	U	0.03	12/12/18 19:59	K18121220
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/12/18 19:59	K18121220
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.03	12/12/18 19:59	K18121220
Trichloroethene	79-01-6	U	0.1	U	0.03	12/12/18 19:59	K18121220
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/12/18 19:59	K18121220
Dibromochloromethane	124-48-1	U	0.1	U	0.02	12/12/18 19:59	K18121220
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/12/18 19:59	K18121220
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 19:59	K18121220

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACCafe
Lab Sample ID:	1078661
Sample Collection Time:	11/26/18 4:18 PM
Sample Volume in Liters:	122.20
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121221	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 20:24	K18121221
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 20:24	K18121221
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 20:24	K18121221
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 20:24	K18121221
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 20:24	K18121221
1,2-Dichloroethane	107-06-2	**0.17**	0.1	**0.04**	0.02	12/12/18 20:24	K18121221
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 20:24	K18121221
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 20:24	K18121221
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 20:24	K18121221
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 20:24	K18121221
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 20:24	K18121221
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 20:24	K18121221

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACCafe_B_up
Lab Sample ID:	1078610
Sample Collection Time:	11/26/18 4:18 PM
Sample Volume in Liters:	122.20
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121222	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 20:48	K18121222
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 20:48	K18121222
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 20:48	K18121222
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 20:48	K18121222
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 20:48	K18121222
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 20:48	K18121222
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/12/18 20:48	K18121222
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 20:48	K18121222
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 20:48	K18121222
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 20:48	K18121222
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 20:48	K18121222
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 20:48	K18121222

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACBallR
Lab Sample ID:	1078639
Sample Collection Time:	11/26/18 3:46 PM
Sample Volume in Liters:	112.72
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121223	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 21:13	K18121223
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 21:13	K18121223
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 21:13	K18121223
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 21:13	K18121223
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 21:13	K18121223
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 21:13	K18121223
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/12/18 21:13	K18121223
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 21:13	K18121223
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 21:13	K18121223
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 21:13	K18121223
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 21:13	K18121223
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 21:13	K18121223

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACBallR_B_up
Lab Sample ID:	1078687
Sample Collection Time:	11/26/18 3:46 PM
Sample Volume in Liters:	112.72
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121224	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/12/18 21:37	K18121224
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/12/18 21:37	K18121224
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/12/18 21:37	K18121224
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/12/18 21:37	K18121224
Chloroform	67-66-3	U	0.1	U	0.02	12/12/18 21:37	K18121224
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/12/18 21:37	K18121224
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/12/18 21:37	K18121224
Trichloroethene	79-01-6	U	0.1	U	0.02	12/12/18 21:37	K18121224
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/12/18 21:37	K18121224
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/12/18 21:37	K18121224
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/12/18 21:37	K18121224
Bromoform	75-25-2	U	0.1	U	0.01	12/12/18 21:37	K18121224

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: CL_LCS_1078733_181212

	Analysis	Lab FileID
Client:	**initial**	K18121225
Arizon State University	1st Dilution	
660 South College Avenue, Room 507	2nd Dilution	
Tempe, AZ 85281	3rd Dilution	
ph: 480-385-9671		

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**81%**	%REC	50-150	12/12/18 21:57	K18121225
trans-1,2-Dichloroethene	156-60-5	**96%**	%REC	50-150	12/12/18 21:57	K18121225
1,1-Dichloroethane	75-34-3	**100%**	%REC	50-150	12/12/18 21:57	K18121225
cis-1,2-Dichloroethene	156-59-2	**101%**	%REC	50-150	12/12/18 21:57	K18121225
Chloroform	67-66-3	**100%**	%REC	50-150	12/12/18 21:57	K18121225
1,2-Dichloroethane	107-06-2	**98%**	%REC	50-150	12/12/18 21:57	K18121225
1,1,1-Trichloroethane	71-55-6	**111%**	%REC	50-150	12/12/18 21:57	K18121225
Trichloroethene	79-01-6	**110%**	%REC	50-150	12/12/18 21:57	K18121225
Bromodichloromethane	75-27-4	**103%**	%REC	50-150	12/12/18 21:57	K18121225
Dibromochloromethane	124-48-1	**98%**	%REC	50-150	12/12/18 21:57	K18121225
Tetrachloroethene	127-18-4	**94%**	%REC	50-150	12/12/18 21:57	K18121225
Bromoform	75-25-2	**109%**	%REC	50-150	12/12/18 21:57	K18121225

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LCS_1078851_181213

Client:	Analysis	Lab File ID
Arizon State University	**initial**	K18121313
660 South College Avenue, Room 507	1st Dilution	
Tempe, AZ 85281	2nd Dilution	
ph: 480-385-9671	3rd Dilution	

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**109%**	%REC	70-130	12/13/18 16:35	K18121313
trans-1,2-Dichloroethene	156-60-5	**103%**	%REC	70-130	12/13/18 16:35	K18121313
1,1-Dichloroethane	75-34-3	**106%**	%REC	70-130	12/13/18 16:35	K18121313
cis-1,2-Dichloroethene	156-59-2	**109%**	%REC	70-130	12/13/18 16:35	K18121313
Chloroform	67-66-3	**105%**	%REC	70-130	12/13/18 16:35	K18121313
1,2-Dichloroethane	107-06-2	**106%**	%REC	70-130	12/13/18 16:35	K18121313
1,1,1-Trichloroethane	71-55-6	**112%**	%REC	70-130	12/13/18 16:35	K18121313
Trichloroethene	79-01-6	**111%**	%REC	70-130	12/13/18 16:35	K18121313
Bromodichloromethane	75-27-4	**105%**	%REC	70-130	12/13/18 16:35	K18121313
Dibromochloromethane	124-48-1	**101%**	%REC	70-130	12/13/18 16:35	K18121313
Tetrachloroethene	127-18-4	**105%**	%REC	70-130	12/13/18 16:35	K18121313
Bromoform	75-25-2	**100%**	%REC	70-130	12/13/18 16:35	K18121313

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LB_1078571_181213

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab FileID
initial	K18121314
1st Dilution	
2nd Dilution	
3rd Dilution	

COMPOUNDS	CAS#						
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/13/18 16:55	K18121314
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.03	12/13/18 16:55	K18121314
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/13/18 16:55	K18121314
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.03	12/13/18 16:55	K18121314
Chloroform	67-66-3	U	0.1	U	0.03	12/13/18 16:55	K18121314
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/13/18 16:55	K18121314
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 16:55	K18121314
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 16:55	K18121314
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/13/18 16:55	K18121314
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 16:55	K18121314
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/13/18 16:55	K18121314
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 16:55	K18121314

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: QC

Lab Sample ID: LCSD_1078816_181213

Client:	Analysis	Lab FileID
	initial	K18121315
Arizon State University	1st Dilution	
660 South College Avenue, Room 507	2nd Dilution	
Tempe, AZ 85281	3rd Dilution	
ph: 480-385-9671		

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**103%**	%REC	70-130	12/13/18 17:15	K18121315
trans-1,2-Dichloroethene	156-60-5	**110%**	%REC	70-130	12/13/18 17:15	K18121315
1,1-Dichloroethane	75-34-3	**111%**	%REC	70-130	12/13/18 17:15	K18121315
cis-1,2-Dichloroethene	156-59-2	**113%**	%REC	70-130	12/13/18 17:15	K18121315
Chloroform	67-66-3	**111%**	%REC	70-130	12/13/18 17:15	K18121315
1,2-Dichloroethane	107-06-2	**112%**	%REC	70-130	12/13/18 17:15	K18121315
1,1,1-Trichloroethane	71-55-6	**111%**	%REC	70-130	12/13/18 17:15	K18121315
Trichloroethene	79-01-6	**116%**	%REC	70-130	12/13/18 17:15	K18121315
Bromodichloromethane	75-27-4	**114%**	%REC	70-130	12/13/18 17:15	K18121315
Dibromochloromethane	124-48-1	**107%**	%REC	70-130	12/13/18 17:15	K18121315
Tetrachloroethene	127-18-4	**101%**	%REC	70-130	12/13/18 17:15	K18121315
Bromoform	75-25-2	**105%**	%REC	70-130	12/13/18 17:15	K18121315

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACConf
Lab Sample ID:	1078562
Sample Collection Time:	11/26/18 4:36 PM
Sample Volume in Liters:	115.77
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121316	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 17:40	K18121316
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 17:40	K18121316
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 17:40	K18121316
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 17:40	K18121316
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 17:40	K18121316
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 17:40	K18121316
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 17:40	K18121316
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 17:40	K18121316
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 17:40	K18121316
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 17:40	K18121316
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 17:40	K18121316
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 17:40	K18121316

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACConf_B_up
Lab Sample ID:	1078546
Sample Collection Time:	11/26/18 4:36 PM
Sample Volume in Liters:	115.77
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121317	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 18:04	K18121317
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 18:04	K18121317
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 18:04	K18121317
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 18:04	K18121317
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 18:04	K18121317
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 18:04	K18121317
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 18:04	K18121317
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 18:04	K18121317
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 18:04	K18121317
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 18:04	K18121317
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 18:04	K18121317
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 18:04	K18121317

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACOff
Lab Sample ID:	1078892
Sample Collection Time:	11/26/18 4:09 PM
Sample Volume in Liters:	112.85
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121318	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 18:29	K18121318
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 18:29	K18121318
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 18:29	K18121318
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 18:29	K18121318
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 18:29	K18121318
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 18:29	K18121318
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 18:29	K18121318
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 18:29	K18121318
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 18:29	K18121318
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 18:29	K18121318
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 18:29	K18121318
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 18:29	K18121318

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACOff_B_up
Lab Sample ID:	1078504
Sample Collection Time:	11/26/18 4:09 PM
Sample Volume in Liters:	112.85
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121319	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 18:53	K18121319
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 18:53	K18121319
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 18:53	K18121319
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 18:53	K18121319
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 18:53	K18121319
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 18:53	K18121319
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 18:53	K18121319
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 18:53	K18121319
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 18:53	K18121319
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 18:53	K18121319
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 18:53	K18121319
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 18:53	K18121319

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACMRR
Lab Sample ID:	1078804
Sample Collection Time:	11/26/18 4:17 PM
Sample Volume in Liters:	106.18
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121320	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 19:18	K18121320
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 19:18	K18121320
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 19:18	K18121320
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 19:18	K18121320
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 19:18	K18121320
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 19:18	K18121320
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 19:18	K18121320
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 19:18	K18121320
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 19:18	K18121320
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 19:18	K18121320
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 19:18	K18121320
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 19:18	K18121320

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACMRR_B_up
Lab Sample ID:	1078608
Sample Collection Time:	11/26/18 4:17 PM
Sample Volume in Liters:	106.18
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121321	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m^3	LOQ ug/m^3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 19:42	K18121321
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 19:42	K18121321
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 19:42	K18121321
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 19:42	K18121321
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 19:42	K18121321
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 19:42	K18121321
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 19:42	K18121321
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 19:42	K18121321
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 19:42	K18121321
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 19:42	K18121321
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 19:42	K18121321
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 19:42	K18121321

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Beacon Job Number: 4459.1A
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: BCACWelcCtrOffR
Lab Sample ID: 1078898
Sample Collection Time: 11/26/18 4:32 PM
Sample Volume in Liters: 134.11
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121322	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 20:07	K18121322
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 20:07	K18121322
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 20:07	K18121322
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 20:07	K18121322
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 20:07	K18121322
1,2-Dichloroethane	107-06-2	**0.36**	0.1	**0.09**	0.02	12/13/18 20:07	K18121322
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/13/18 20:07	K18121322
Trichloroethene	79-01-6	U	0.1	U	0.01	12/13/18 20:07	K18121322
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 20:07	K18121322
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 20:07	K18121322
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 20:07	K18121322
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 20:07	K18121322

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Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACWelcCtrOffR_B_up
Lab Sample ID:	1078835
Sample Collection Time:	11/26/18 4:32 PM
Sample Volume in Liters:	134.11
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab FileID	Dilution Factor
initial	K18121323	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m3	LOQ ug/m3	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	12/13/18 20:31	K18121323
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	12/13/18 20:31	K18121323
1,1-Dichloroethane	75-34-3	U	0.1	U	0.02	12/13/18 20:31	K18121323
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.02	12/13/18 20:31	K18121323
Chloroform	67-66-3	U	0.1	U	0.02	12/13/18 20:31	K18121323
1,2-Dichloroethane	107-06-2	U	0.1	U	0.02	12/13/18 20:31	K18121323
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	12/13/18 20:31	K18121323
Trichloroethene	79-01-6	U	0.1	U	0.01	12/13/18 20:31	K18121323
Bromodichloromethane	75-27-4	U	0.1	U	0.01	12/13/18 20:31	K18121323
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 20:31	K18121323
Tetrachloroethene	127-18-4	U	0.1	U	0.01	12/13/18 20:31	K18121323
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 20:31	K18121323

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Beacon Job Number: 4459.1A
Analysis Method: TO17
Matrix: Air
Client ID/Field Sampling Location: BCACRec
Lab Sample ID: 1078765
Sample Collection Time: 11/26/18 4:26 PM
Sample Volume in Liters: 81.68
Date Received: 12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121324	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/13/18 20:56	K18121324
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.03	12/13/18 20:56	K18121324
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/13/18 20:56	K18121324
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.03	12/13/18 20:56	K18121324
Chloroform	67-66-3	U	0.1	U	0.03	12/13/18 20:56	K18121324
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/13/18 20:56	K18121324
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 20:56	K18121324
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 20:56	K18121324
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/13/18 20:56	K18121324
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 20:56	K18121324
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/13/18 20:56	K18121324
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 20:56	K18121324

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

nvironmental Services, Inc.
A Commerce Road Suite 1
orest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number:	4459.1A
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	BCACRec_B_up
Lab Sample ID:	1078672
Sample Collection Time:	11/26/18 4:26 PM
Sample Volume in Liters:	81.68
Date Received:	12/11/2018

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	K18121325	1
1st Dilution		
2nd Dilution		
3rd Dilution		

COMPOUNDS	CAS#	Results ug/m³	LOQ ug/m³	Results ppbv	LOQ ppbv	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	U	0.1	U	0.03	12/13/18 21:20	K18121325
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.03	12/13/18 21:20	K18121325
1,1-Dichloroethane	75-34-3	U	0.1	U	0.03	12/13/18 21:20	K18121325
cis-1,2-Dichloroethene	156-59-2	U	0.1	U	0.03	12/13/18 21:20	K18121325
Chloroform	67-66-3	U	0.1	U	0.03	12/13/18 21:20	K18121325
1,2-Dichloroethane	107-06-2	U	0.1	U	0.03	12/13/18 21:20	K18121325
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.02	12/13/18 21:20	K18121325
Trichloroethene	79-01-6	U	0.1	U	0.02	12/13/18 21:20	K18121325
Bromodichloromethane	75-27-4	U	0.1	U	0.02	12/13/18 21:20	K18121325
Dibromochloromethane	124-48-1	U	0.1	U	0.01	12/13/18 21:20	K18121325
Tetrachloroethene	127-18-4	U	0.1	U	0.02	12/13/18 21:20	K18121325
Bromoform	75-25-2	U	0.1	U	0.01	12/13/18 21:20	K18121325

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

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orest Hill, MD 21050 USA
ph:410-838-8780
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Beacon Job Number:
Analysis Method TO17
Matrix: QC

Lab Sample ID: CL_LCS_1078865_181213

Analysis	Lab FileID
initial	K18121329
1st Dilution	
2nd Dilution	
3rd Dilution	

Client:
Arizon State University
660 South College Avenue, Room 507
Tempe, AZ 85281
ph: 480-385-9671

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
1,1-Dichloroethene	75-35-4	**78%**	%REC	50-150	12/13/18 22:41	K18121329
trans-1,2-Dichloroethene	156-60-5	**92%**	%REC	50-150	12/13/18 22:41	K18121329
1,1-Dichloroethane	75-34-3	**101%**	%REC	50-150	12/13/18 22:41	K18121329
cis-1,2-Dichloroethene	156-59-2	**98%**	%REC	50-150	12/13/18 22:41	K18121329
Chloroform	67-66-3	**99%**	%REC	50-150	12/13/18 22:41	K18121329
1,2-Dichloroethane	107-06-2	**97%**	%REC	50-150	12/13/18 22:41	K18121329
1,1,1-Trichloroethane	71-55-6	**115%**	%REC	50-150	12/13/18 22:41	K18121329
Trichloroethene	79-01-6	**103%**	%REC	50-150	12/13/18 22:41	K18121329
Bromodichloromethane	75-27-4	**100%**	%REC	50-150	12/13/18 22:41	K18121329
Dibromochloromethane	124-48-1	**101%**	%REC	50-150	12/13/18 22:41	K18121329
Tetrachloroethene	127-18-4	**96%**	%REC	50-150	12/13/18 22:41	K18121329
Bromoform	75-25-2	**106%**	%REC	50-150	12/13/18 22:41	K18121329

U = Not detected or below limit of quantitation (LOQ).; D = Sample dilution performed; E = Measurement exceeded upper calibration range of instrument and sample dilution was not able to be performed.

Attachment 1

Chain of Custody

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1. Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information			
Company: ASU SSEBE	Project Manager: Paul Dahlen	BEACON Project No.: 4459	
Address: POB 873005	Phone: 480-727-2960	Client PO No.	
City/State/Zip: Tempe AZ 85287	Project Name: Beale AFB	Analysis Turnaround Time: Normal ✓	
Phone: 480-727-2960	Location: Theater	Sampler Name(s): Paul Dahlen	Rush (Specify): ____ days

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	TO-17	8260B	TICs	Indoor/Ambient Air	Soil Gas
BTheater-StageL	1078601	2	11/2/18	0925	11/26/18	1573	40.61	39.66	155.72				✓	
BTheater-StageL DUP	1078544	2	"	"	"	"	"	"	"				✓	
BTheater-Lobby	1078895	6	11/2/18	1030	11/26/18	1455	40.59	40.13	156.31				✓	
ATheater-Lobby DUP	1078651	6	"	"	"	"	"	"	"				✓	
BTheater-WRR	1078606	9	11/5/18	0831	11/26/18	1507	35.80	35.49	138.05				✓	
BTheater-WRR DUP	1078803	9	"	"	"	"	"	"	"				✓	
BTheater-StageWRR	1078556	11	11/2/18	0946	11/26/18	1518	41.48	42.01	161.68				✓	
BTheater-StageWRR DUP	1078769	11	"	"	"	"	"	"	"				✓	

Ambient Conditions When Sampling

	Temperature (F)	Barometric Pressure (mmHg)	Date
Start	70		
Stop			

Pump(s) Calibration and Flow Rate Check:

Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Pre-Survey			
Post-Survey			

Special Notes/Instructions:

Relinquished by: (signature) Paul Dahlen	Date/Time: 12/10/18 1300	Received by: (signature) Courier	Date/Time:
Relinquished by: (signature)	Date/Time:	Received by: (signature) Steven Thornley	Date/Time: 12.11.18 / 1500
Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	Fedex	✓		Yes No None	

Beacon Project 4459_1A -- Page 43 of 46

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1. Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Information			
Company:	ASU SSEBE	Project Manager:	Paul Dahlen	BEACON Project No.: 4459	
Address:	POB 873005	Phone:	480-727-2960	Client PO No.	
City/State/Zip:	Tempe AZ 85287	Project Name:	Travis	Analysis Turnaround Time	
Phone:	480-727-2960	Location:	Bldg 18	✓ Normal	
		Sampler Name(s):	Paul Dahlen	Rush (Specify): ____ days	

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	TO-17	8260B	TICs	Indoor/Ambient Air	Soil Gas
Tr18 Main	1078557	5	11/7/18	1558	11/27/18	1636	41.60	40.20	65.64				✓	
Tr18 Main B/UA	1078647	5	↓	1558	↓	1636	"	"	"				✓	
Tr18 Hall	1078637	3	↓	1614	↓	1621	42.93	42.82	68.60				✓	
Tr18 Hall B/UA	1078511	3	↓	1614	↓	1621	"	"	"				✓	
Tr18 SEOffice	1078558	13	↓	1614	↓	1621	35.82	35.00	56.66				✓	
Tr18 SEOffice B/UA	1078666	13	↓	1614	↓	1621	"	"	"				✓	
Tr18 Shower1	1078519	14	↓	1625	↓	1641	45.53	44.35	72.13				✓	
Tr18 Shower1 B/UA	1078536	14	↓	1625	↓	1641	"	"	"				✓	
PD (crossed out)														

Ambient Conditions When Sampling

	Temperature (F)	Barometric Pressure (mmHg)	Date
Start	68		
Stop			

Pump(s) Calibration and Flow Rate Check:

Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Pre-Survey			
Post-Survey			

Special Notes/Instructions: See SS for additional sampling data

Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:
Paul Dahlen	12/10/18 1300	Courier	
		Steven Trowley	12.11.18/1500

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	Fedex	✓		Yes No None	

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1, Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Manager: Paul Dahlen	BEACON Project No.: 4459
Company: ASU SSEBE		Phone: 480-727-2960	Client PO No.
Address: POB 873005		Project Name: Beale AFB	Analysis Turnaround Time
City/State/Zip: Tempe AZ 85287		Location: CAC	✓ Normal
Phone: 480-727-2960		Sampler Name(s): Paul Dahlen	Rush (Specify): _____ days

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	Analysis: TO-17	Analysis: 8260B	Analysis: TICs	Matrix: Indoor/Ambient Air	Matrix: Soil Gas
BCACCafe	1078661	10	11/8/18	~~1606~~ 1347	11/26/18	~~1546~~ 1618	43.44	41.57	122.20				✓	
BCACCafe B/D	1078610	10	↓	"	↓	"	"	"	"				✓	
BCACBallR	1078639	8	↓	1606	↓	1546	39.93	38.24	112.72				✓	
BCACBallR B/D	1078687	8	↓	"	↓	"	"	"	"				✓	
BCACConf	1078562	4	↓	1635	↓	1636	40.52	39.82	115.77				✓	
BCACConf B/D	1078546	4	↓	"	↓	"	"	"	"				✓	
BCACOff	1078892	6	↓	1716	↓	1609	39.82	38.63	112.85				✓	
BCACOff B/D	1078504	6	↓	"	↓	"	"	"	"				✓	
BCACMRR	1078804	7	↓	1826	↓	1617	37.57	36.58	106.18				✓	
BCACMRR B/D	1078608	7	↓	"	↓	"	"	"	"				✓	

Ambient Conditions When Sampling / **Pump(s) Calibration and Flow Rate Check:**

	Temperature (F)	Barometric Pressure (mmHg)	Date	Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Start	71			Pre-Survey			
Stop				Post-Survey			

Special Notes/Instructions:

Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:
Paul Dahlen	12/10/18 1300	Courier	
		Steven Thornley	12.11.18 / 1500

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	Fedex	✓		Yes No None	

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1. Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Manager: Paul Dahlen	BEACON Project No.: 4459
Company: ASU SSEBE		Phone: 480-727-2960	Client PO No.
Address: POB 873005		Project Name: Beale AFB	Analysis Turnaround Time
City/State/Zip: Tempe AZ 85287		Location: CAC	✓ Normal
Phone: 480-727-2960		Sampler Name(s): Paul Dahlen	Rush (Specify): ____ days

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	TO-17	8260B	TICs	Indoor/Ambient Air	Soil Gas
BCACWeleCtrOffR	1078898	3	11/8/18	1807	11/26/18	1632	46.14	47.48	134.11				✓	
BCACWeleCtrOffR Dup	1078835	3	↓	"	↓	"	"	"	"				✓	
BCACRec	1078765	12	↓	1847	↓	1626	31.44	25.58	81.68				✓	
BCACRec B Dup	1078672	12	↓	"	↓	"	"	"	"				✓	

Ambient Conditions When Sampling	Temperature (F)	Barometric Pressure (mmHg)	Date
Start	71		
Stop			

Pump(s) Calibration and Flow Rate Check:

Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Pre-Survey			
Post-Survey			

Special Notes/Instructions:

Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:
Paul Dahlen	12/10/18 1300	Guries	
		Steven Downley	12.11.18 / 1500

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	Fedex	✓		Yes No None	

Beacon Project 4459.1A -- Page 46 of 46

Appendix 2425B
Background Indoor Air Sampling – Passive Air Sampler Analytical Report

(Only sample IDs 6-16 with a prefix of "B CAC"
are related to the Community Activity Center, Bldg. 2425)

BEACON ENVIRONMENTAL SERVICES, INC.

The Leaders in Soil Gas Surveys and Vapor Intrusion Monitoring

Arizona State University
660 South College Avenue, Room 507
Tempe, AZ 85281
Attn: Paul Dahlen

Air Samples -- Analytical Report

Date: January 8, 2019
Beacon Project No. 4459.1B

Project Reference:	Beale and Travis AFB
Sampling Period:	November 2 through 26, 2018
Samples Received:	December 11, 2018
Analyses Completed:	December 14, 2018

Results for the following indoor and ambient air samples are included in this data package:

Sample ID	Location	Matrix	Analysis
1	B Theater lobby	Air	TO-17
2	B Theater WRR	Air	TO-17
3	B Theater Stage WRR	Air	TO-17
4	B Theater Stage L	Air	TO-17
5	B Theater R	Air	TO-17
6	B CAC Ball L	Air	TO-17
7	B CAC Café	Air	TO-17
8	B CAC MRR	Air	TO-17
9	B CAC Ball R	Air	TO-17
10	B CAC Welc Ctr Off R	Air	TO-17
11	B CAC Conf	Air	TO-17
12	B CAC Office	Air	TO-17
13	B CAC Lobby	Air	TO-17
14	B CAC Rec	Air	TO-17
15	B CAC Pizzeria	Air	TO-17
16	B CAC Music	Air	TO-17
17	TR 18 Main	Air	TO-17
18	TR 18 Hall	Air	TO-17
19	TR 18 SE Office	Air	TO-17
20	TR 18 Shower 1	Air	TO-17

Sample Collection

Beacon Environmental provided thermally conditioned Beacon Samplers to target a select list of compounds, with analyses following U.S. EPA Method TO-17. These passive diffusion samples (PDS) were exposed to air for approximately three weeks and the resulting mass of target analytes captured on each sampler was reported as a concentration following procedures detailed in ISO 16017-2, *Indoor, ambient and workplace air-Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography-Part 2: Diffusive sampling.*

U. S. EPA Method TO-17

All samples were analyzed for a custom target compound list following U.S. EPA Method TO-17.

The analytical results are reported in **Table 1**, with results reported in micrograms per cubic meter ($\mu g/m^3$) and ppbv using the following equations.

$$C = \frac{1000 \times M \times d}{U \times t} \qquad C_{ppbv} = C \times \frac{24.45}{MW}$$

where:

C	=	concentration ($\mu g/m^3$)
C_{ppbv}	=	concentration (ppbv)
M	=	mass (ng)
d	=	dilution factor
U	=	uptake rate (ml/min),
t	=	sampling time (minutes)
MW	=	molecular weight

The following table provides uptake rates for the compounds reported in this investigation.

Compound	Uptake Rate
1,1-Dichloroethene	0.32
trans-1,2-Dichloroethene	0.42
1,1-Dichloroethane	0.80
cis-1,2-Dichloroethene	0.52
Chloroform	0.34
1,2-Dichloroethane	0.54
1,1,1-Trichloroethane	0.98
Trichloroethene	0.33
Bromodichloromethane	0.40
Dibromochloromethane	0.35
Tetrachloroethene	0.39
Bromoform	0.32

Practical Quantification Levels (PQL) for EPA Method TO-17

The lowest point in the calibration curve and the limit of quantitation (LOQ) is 10 nanograms (ng), and the limit of detection (LOD) is 5 ng. The concentration data in **Table 1** are provided in micrograms per meter cubed ($\mu g/m^3$) and parts per billion by volume (ppbv), and the LOQs are additionally based on the sample collection times, the uptake rates, and the dilution factors.

Calibration Verification

The continuing calibration verification (CCV) values for the analytes were all within ±30% of the true values as defined by the initial five-point calibration and met the requirements specified in Beacon Environmental's Quality Manual.

Internal Standards and Surrogates

Internal standards and surrogates are spiked at 100 ng and 50 ng, respectively, and percentage of recovery is calculated. Acceptance criteria for internal standards are 60 to 140 percent and surrogate recoveries are 70 to 130 percent; all internal standards and surrogates were within the acceptance criteria.

Blank Contamination
No targeted compounds above the LOD for each compound were observed in the Laboratory Method Blanks (LB 181214). For comparison to field sample results, the longest sampling time was used to calculate the LOQs for the blank.

Laboratory Control Samples
Laboratory control samples are spiked at 50 ng and percentage of recovery is calculated and reported. Acceptance criteria for surrogate and analytes recoveries are 70 to 130 percent; all surrogates and analytes were within the acceptance criteria.

Discussion
Twenty (20) indoor air samples were received by Beacon Environmental on December 12, 2018. Sampling start and end times and dates can be found in the Chain of Custody (**Attachment 1**).

Dilutions were required for three (3) samples (18, 19, and 20), which had high levels of cis-1,2-d ichloroethene and/or trichloroethene. Dilutions were performed for these samples to bring the detected concentrations of those compounds into the calibration range of the GC/MSD instrument, as noted in **Table 1**.

Demonstrated Linear Range of the GC-MS Instrumentation (EPA Method TO-17)
An initial six-point calibration is performed on the instrumentation from 5 to 200 ng per analyte.

<u>Attachments:</u>

-1- Chain of Custody

ALL DATA MEET REQUIREMENTS AS SPECIFIED IN THE BEACON ENVIRONMENTAL SERVICES, INC. QUALITY ASSURANCE PROJECT PLAN AND THE RESULTS RELATE ONLY TO THE SAMPLES REPORTED. BEACON ENVIRONMENTAL SERVICES IS ACCREDITED TO ISO/IEC 17025:2005, AND THE WORK PERFORMED WAS IN ACCORDANCE WITH ISO/IEC 17025:2005 REQUIREMENTS. THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY. RELEASE OF THE DATA CONTAINED IN THIS DATA PACKAGE HAS BEEN AUTHORIZED BY THE LABORATORY DIRECTOR OR HIS SIGNEE, AS VERIFIED BY THE FOLLOWING SIGNATURES:

Steven C. Thornley
Laboratory Director

Patti J. Riggs
Quality Manager

Date: January 8, 2018

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

Client Sample ID:		LCS_181214	LB_181214	LCSD_181214	1	2	3
Project Number:					4459.1B	4459.1B	4459.1B
Lab File ID:		K18121402	K18121403	K18121404	K18121405	K18121406	K18121407
Received Date:					12/11/2018	12/11/2018	12/11/2018
Analysis Date:		12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018
Analysis Time:		10:20	10:40	11:01	12:08	12:35	13:02
Matrix:					Air	Air	Air
Units:		%Recovery	ug/m3	%Recovery	ug/m3	ug/m3	ug/m3
COMPOUNDS	CAS						
1,1-Dichloroethene	75-35-4	**104%**	<0.91	**102%**	<0.91	<1.03	<0.91
trans-1,2-Dichloroethene	156-60-5	**109%**	<0.68	**106%**	<0.68	<0.77	<0.68
1,1-Dichloroethane	75-34-3	**109%**	<0.36	**107%**	<0.36	<0.41	<0.36
cis-1,2-Dichloroethene	156-59-2	**113%**	<0.55	**109%**	<0.55	<0.63	<0.55
Chloroform	67-66-3	**112%**	<0.84	**107%**	<0.84	<0.95	<0.84
1,2-Dichloroethane	107-06-2	**117%**	<0.53	**112%**	<0.54	<0.61	<0.53
1,1,1-Trichloroethane	71-55-6	**110%**	<0.29	**103%**	<0.29	<0.33	<0.29
Trichloroethene	79-01-6	**120%**	<0.88	**117%**	<0.88	<1.00	<0.88
Bromodichloromethane	123-91-1	**120%**	<0.72	**113%**	<0.73	<0.83	<0.73
Dibromochloromethane	106-93-4	**119%**	<0.82	**116%**	<0.82	<0.93	<0.82
Tetrachloroethene	127-18-4	**110%**	<0.73	**109%**	<0.73	<0.83	<0.73
Bromoform	108-38-3	**114%**	<0.90	**116%**	<0.90	<1.03	<0.90

Reporting limit is limit of quantitation (LOQ). E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

Client Sample ID:		4	5	6	7	8	9
Project Number:		4459.1B	4459.1B	4459.1B	4459.1B	4459.1B	4459.1B
Lab File ID:		K18121408	K18121409	K18121410	K18121411	K18121412	K18121413
Received Date:		12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018
Analysis Date:		12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018
Analysis Time:		13:28	13:55	14:36	15:03	15:30	15:56
Matrix:		Air	Air	Air	Air	Air	Air
Units:		ug/m3	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
COMPOUNDS	CAS						
1,1-Dichloroethene	75-35-4	<0.91	<0.91	<1.22	<1.22	<1.23	<1.22
trans-1,2-Dichloroethene	156-60-5	<0.68	<0.68	<0.92	<0.92	<0.92	<0.92
1,1-Dichloroethane	75-34-3	<0.36	<0.36	<0.48	<0.48	<0.48	<0.48
cis-1,2-Dichloroethene	156-59-2	<0.55	<0.55	<0.75	<0.75	<0.75	<0.75
Chloroform	67-66-3	<0.84	<0.84	<1.13	<1.13	<1.13	<1.13
1,2-Dichloroethane	107-06-2	<0.53	<0.53	<0.72	<0.72	<0.72	<0.72
1,1,1-Trichloroethane	71-55-6	<0.29	<0.29	<0.40	<0.40	<0.40	<0.40
Trichloroethene	79-01-6	<0.88	<0.88	<1.19	<1.19	<1.19	<1.19
Bromodichloromethane	123-91-1	<0.72	<0.72	<0.98	<0.98	<0.98	<0.98
Dibromochloromethane	106-93-4	<0.82	<0.82	<1.10	<1.10	<1.11	<1.10
Tetrachloroethene	127-18-4	<0.73	<0.73	<0.98	<0.99	<0.99	<0.98
Bromoform	108-38-3	<0.90	<0.90	<1.21	<1.22	<1.22	<1.21

Reporting limit is limit of quantitation (LOQ). E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

Client Sample ID:		10	11	12	13	14	15
Project Number:		4459.1B	4459.1B	4459.1B	4459.1B	4459.1B	4459.1B
Lab File ID:		K18121414	K18121415	K18121416	K18121417	K18121418	K18121705
Received Date:		12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018
Analysis Date:		12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018	12/17/2018
Analysis Time:		16:23	16:50	17:17	17:44	18:11	10:39
Matrix:		Air	Air	Air	Air	Air	Air
Units:		ug/m3	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
COMPOUNDS	CAS						
1,1-Dichloroethene	75-35-4	<1.22	<1.22	<1.22	<1.23	<1.23	<1.23
trans-1,2-Dichloroethene	156-60-5	<0.92	<0.91	<0.92	<0.92	<0.92	<0.92
1,1-Dichloroethane	75-34-3	<0.48	<0.48	<0.48	<0.48	<0.48	<0.48
cis-1,2-Dichloroethene	156-59-2	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75
Chloroform	67-66-3	<1.13	<1.13	<1.13	<1.14	<1.13	<1.14
1,2-Dichloroethane	107-06-2	**0.94**	<0.72	<0.72	<0.73	<0.72	<0.72
1,1,1-Trichloroethane	71-55-6	<0.40	<0.39	<0.40	<0.40	<0.40	<0.40
Trichloroethene	79-01-6	<1.19	<1.18	<1.19	<1.20	<1.19	<1.19
Bromodichloromethane	123-91-1	<0.98	<0.98	<0.98	<0.99	<0.98	<0.98
Dibromochloromethane	106-93-4	<1.10	<1.10	<1.10	<1.11	<1.11	<1.11
Tetrachloroethene	127-18-4	<0.99	<0.98	<0.98	<0.99	<0.99	<0.99
Bromoform	108-38-3	<1.22	<1.21	<1.22	<1.22	<1.22	<1.22

Reporting limit is limit of quantitation (LOQ). E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

Client Sample ID:		16	17	18	19	20	CL_LCS_181214
Project Number:		4459.1B	4459.1B	4459.1B	4459.1B	4459.1B	
Lab File ID:		K18121420	K18121706	K18121422	K18121423	K18121424	K18121425
Received Date:		12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018	
Analysis Date:		12/14/2018	12/17/2018	12/14/2018	12/14/2018	12/14/2018	12/14/2018
Analysis Time:		19:05	11:06	19:59	20:28	20:55	21:16
Matrix:		Air	Air	Air	Air	Air	
Units:		ug/m3	ug/m3	ug/m3	ug/m3	ug/m3	%Recovery
COMPOUNDS	CAS						
1,1-Dichloroethene	75-35-4	<1.23	<1.10	<1.10	<1.10	<1.10	**90%**
trans-1,2-Dichloroethene	156-60-5	<0.92	<0.82	<0.82	**1.51**	<0.82	**88%**
1,1-Dichloroethane	75-34-3	<0.48	<0.43	<0.43	<0.43	<0.43	**107%**
cis-1,2-Dichloroethene	156-59-2	<0.75	**2.2**	**3.75**	**36.76 D**	**6.12**	**99%**
Chloroform	67-66-3	<1.14	<1.01	<1.01	<1.01	<1.01	**106%**
1,2-Dichloroethane	107-06-2	<0.72	<0.65	<0.65	<0.65	<0.65	**100%**
1,1,1-Trichloroethane	71-55-6	<0.40	<0.35	<0.36	<0.36	<0.36	**122%**
Trichloroethene	79-01-6	<1.19	**13.78**	**33.01 D**	**167.05 D**	**43.20 D**	**109%**
Bromodichloromethane	123-91-1	<0.98	<0.88	<0.88	<0.88	<0.88	**110%**
Dibromochloromethane	106-93-4	<1.11	<0.99	<0.99	<0.99	<0.99	**107%**
Tetrachloroethene	127-18-4	<0.99	<0.88	<0.88	**0.97**	<0.88	**98%**
Bromoform	108-38-3	<1.22	<1.09	<1.09	<1.09	<1.09	**120%**

Reporting limit is limit of quantitation (LOQ). E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Attachment 1

Chain of Custody

Beacon Environmental Services, Inc.

CHAIN-OF-CUSTODY
PASSIVE DIFFUSION SAMPLES

2203A Commerce Road, Suite 1
Forest Hill, MD 21050
410-838-8780 / fax: 410-838-8740

Client Contact Information	Project	Beacon
Company: ASU SSEBE	Project Manager: Paul Dahlen	BEACON Project No.: 4459
Address: POB 873005	Phone: 480-727-2960	Client PO No.
City/State/Zip: Tempe AZ 85287	Project Name: Beale AFB	Analysis Turnaround Time: ☒ Normal
Phone: 480-727-2960	Location: Theater	☐ Rush (Specify): ____ days
	Sampler Name(s): Paul Dahlen	NIST traceable Thermometer ID:

Location ID	Tube/Sample number	Start Date (mm/dd/yy)	Start Time (24 hr)	Stop Date (mm/dd/yy)	Stop Time (24 hr)	Interior Temp. (F)	Notes	TO-17	8260C	TICs	Indoor/Ambient Air	Soil Gas
1	BTheaterLobby	11/2/18	1030	11/26/18	1455	70	34825 min				✓	
2	BTheater WRR	11/5/18	0831	11/26/18	1507	↓	30636 min				✓	
3	BTheater Stage WRR	11/2/18	0946	11/26/18	1518	↓	34892 min				✓	
4	BTheater Stage L	11/2/18	0925	11/26/18	1513	↓	34908 min				✓	
5	BTheater R	11/5/18	0852	11/26/18	1505	↓	30613 min				✓	
[illegible] 12.11.18												

Special Instructions/Notes:

Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:
Paul Dahlen	12/10/18 1300	Courier	
		Steven Thornley	12.11.18/1500

Lab Use Only	Courier Name	Shipment Condition	Custody Seal Intact	Custody Seal Number
	Fedex	✓	Yes No (None)	

Page ____ of ____

Beacon Project 4459.1B -- Page 9 of 12

Beacon Environmental Services, Inc.

CHAIN-OF-CUSTODY
PASSIVE DIFFUSION SAMPLES

2203A Commerce Road, Suite 1
Forest Hill, MD 21050
410-838-8780 / fax: 410-838-8740

Client Contact Information		
Company: ASU SSEBE	Project Manager: Paul Dahlen	BEACON Project No.: 4459
Address: POB 873005	Phone: 480-727-2960	Client PO No.
City/State/Zip: Tempe AZ 85287	Project Name: Beale AFB	Analysis Turnaround Time: ☑ Normal ☐ Rush (Specify): ____ days
Phone: 480-727-2960	Location: CAC	NIST traceable Thermometer ID:
	Sampler Name(s): Paul Dahlen	

Location ID	Tube/Sample number	Start Time Date (mm/dd/yy)	Start Time Time (24 hr)	Stop Time Date (mm/dd/yy)	Stop Time Time (24 hr)	Interior Temp. (F)	Notes	TO-17	8260C	TICs	Indoor/Ambient Air	Soil Gas
6	BCAC Ball L	11/8/18	1616	11/26/18	1546	71	25890 min				✓	
7	BCAC Cafe	11/8/18	1747	11/26/18	1618	↓	25831 min				✓	
8	BCAC MRR	11/8/18	1826	11/26/18	1617	↓	25791 min				✓	
9	BCAC Ball R	11/8/18	1606	11/26/18	1546	↓	25900 min				✓	
10	BCAC WeldCtr Off R	11/8/18	1807	11/26/18	1632	↓	25825 min				✓	
11	BCAC Cont	11/8/18	1635	11/26/18	1636	↓	25921 min				✓	

Special Instructions/Notes:

Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:
Paul Dahlen	12/10/18 1300	Courier	
		Steven Thorley	12.11.18/1500

Lab Use Only	Courier Name	Shipment Condition	Custody Seal Intact	Custody Seal Number
	Fedex	✓	Yes No (None)	

Page ____ of ____

Beacon Project 4459.1B -- Page 10 of 12

Beacon Environmental Services, Inc.

CHAIN-OF-CUSTODY PASSIVE DIFFUSION SAMPLES

2203A Commerce Road, Suite 1
Forest Hill, MD 21050
410-838-8780 / fax: 410-838-8740

Client Contact Information	Project Information	
Company: ASU SSEBE	Project Manager: Paul Dahlen	BEACON Project No.: 4459
Address: PO B 873005	Phone: 480-727-2960	Client PO No.
City/State/Zip: Tempe AZ 85287	Project Name: Beale AFB	Analysis Turnaround Time: [X] Normal
Phone: 480-727-2960	Location: CAC	[ ] Rush (Specify): ____ days
	Sampler Name(s): Paul Dahlen	NIST traceable Thermometer ID:

Location ID	Tube/Sample number	Start Date (mm/dd/yy)	Start Time (24 hr)	Stop Date (mm/dd/yy)	Stop Time (24 hr)	Interior Temp. (F)	Notes	TO-17	8260C	TICs	Indoor/Ambient Air	Soil Gas
12	BCAC Office	11/8/18	1716	11/26/18	1609	71	25853 min				✓	
13	BCAC Lobby	11/8/18	1918	11/26/18	1515	↓	25677 min				✓	
14	BCAC Rec	11/8/18	1847	11/26/18	1626	↓	25779 min				✓	
15	BCAC Azzeria	11/8/18	1913	11/26/18	1558	↓	25725 min				✓	
16	BCAC Music	11/8/18	1908	11/26/18	1600	↓	25732 min				✓	
	PD (struck through)											

Special Instructions/Notes:

Relinquished by (signature)	Date/Time	Received by (signature)	Date/Time
Paul Dahlen	12/10/18 1300	Courier	
		Steven Thornley	12.11.18/1500

Lab Use Only	Courier Name	Shipment Condition	Custody Seal Intact	Custody Seal Number
	Fedex	✓	Yes No (None circled)	

Page ____ of ____

Beacon Project 4459.1B -- Page 11 of 12

Beacon Environmental Services, Inc.

CHAIN-OF-CUSTODY PASSIVE DIFFUSION SAMPLES

2203A Commerce Road, Suite 1
Forest Hill, MD 21050
410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Information		BEACON Project No.: 4459
Company: ASU SSEBE		Project Manager: Paul Dahlen		Client PO No.
Address: POB 873005		Phone: 480-727-2960		Analysis Turnaround Time
City/State/Zip: Tempe AZ 85287		Project Name: Travis AFB		☒ Normal
Phone: 480-727-2960		Location: Bldg 18		☐ Rush (Specify): ____ days
		Sampler Name(s): Paul Dahlen		NIST traceable Thermometer ID:

Location ID	Tube/Sample number	Start Date (mm/dd/yy)	Start Time (24 hr)	Stop Date (mm/dd/yy)	Stop Time (24 hr)	Interior Temp. (F)	Notes	TO-17	8260C	TICs	Indoor/Ambient Air	Soil Gas
17	Tr 18 Main	11/7/18	1555	11/27/18	1636	68	28838 min				✓	
18	Tr 18 Hall	11/7/18	1614	11/27/18	1621	↓	28807 min				✓	
19	Tr 18 SE Office	11/7/18	1614	11/27/18	1621	↓	28807 min				✓	
20	Tr 18 Shower 1	11/7/18	1625	11/27/18	1641	↓	28816 min				✓	

Special Instructions/Notes: Bldg with history of TCE impact ~10 ppbv during depressurization

Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:
[signature]	12/10/18 1300	Courier	
		[signature]	12.11.18/1500

Lab Use Only	Courier Name	Shipment Condition	Custody Seal Intact	Custody Seal Number
	Fedex	✓	Yes No (None)	

Page ____ of ____

Beacon Project 4459.1B -- Page 12 of 12

Industrial Scale Controlled Pressure Method Test Demonstration for Vapor Intrusion Pathway Assessment – ESTCP ER#201501

Building 24176, Dormitory Building B
Beale Air Force Base, California

Arizona State University, Oct. 12, 2020

23. INTRODUCTION

1.4 BACKGROUND

Controlled pressure method (CPM) testing for vapor intrusion (VI) pathway assessment was developed to evaluate the maximum VI related impact to a structure in a short period of time. Its use has been studied in various Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) funded projects (ER#200707, ER#1686, and ER#201501). In the most recent project, ER#201501, CPM testing has been included as one of a suite of tools to more expediently and confidently define the presence of vapor intrusion pathways in structures.

During CPM testing, the controlled negative pressurization of a test structure induces a worst-case vapor intrusion scenario. Assessment of exhaust air contaminant concentrations provides an estimate of the average indoor air concentration, while area specific samples define local responses to this worst-case scenario. By creating that worst-case VI scenario, CPM testing is most effectively used to identify and rule out structures where VI impacts are non-existent (e.g. test concentrations are less than or equal to ambient outdoor concentrations) and/or of no regulatory concern. If, however, contaminant concentrations approach or are in excess of a regulatory concern during negative pressure testing, positive pressure testing, which suppresses VI, should then be used to rule out (or identify) indoor air source(s). If VI impacts are confirmed, concentrations will either be high enough to define the immediate need for mitigation, or alternatively, should be used as a line of evidence in a multiple lines of evidence approach to define risk.

Use of CPM testing as the primary tool for VI assessment is effective since it recognizes that:

- multiple VI pathways can exist, including:
  - the traditional "*soil VI*" conceptualization (source → through soil → through foundation to indoor air); and
  - "*pipe flow VI*" from sources such as land drains and sanitary sewers.
- the VI pathways discussed above may be present, but not discernible by traditional site characterization; and
- VI concentrations vary both spatially and temporally.

ESTCP project ER#201501 included the demonstration of the CPM test protocol in both residential- and industrial-scale buildings. In brief, the CPM Test Guidelines (ER201501 Final Rpt. Appendix D) use negative- and positive-pressure testing of the structure as follows:

- Negative pressure testing of a structure was used to induce a worst-case VI scenario. During negative pressure testing, after a minimum of nine building air exchanges, air quality was tested at the blower intake/exhaust and if of interest, throughout the structure. If concentrations during negative pressurization were less than ambient outdoor concentrations or regulatory concerns, then the VI impact was considered minimal or non-existent and testing would be complete. If, however, concentrations exceeded ambient outdoor concentrations and were of regulatory concern, then VI impacts could be a concern. At this point, a positive pressure test was necessary to rule out indoor air sources.
- Positive pressure testing was used to identify the presence/impact of an indoor air source(s). During positive pressure testing, VI was suppressed, and after a minimum of four building air exchanges air quality was tested throughout the structure. If no contaminant was present in the building, then only VI was present. If, however, contaminants were detected in indoor air, that indicated an indoor air source was present that would require removal followed by additional CPM testing.

This document presents the results of the industrial-scale CPM demonstration at the Beale Air Force Base Dormitory Bldg. B, Bldg. 24176, Beale Air Force Base, California. The objectives of this demonstration were to: a) demonstrate the controlled pressure method in an industrial-scale building; b) perform an extended-term post-CPM test air-quality assessment to determine if the CPM test would lead to the same/similar decision as standard air-quality testing; and c) improve current CPM protocols based on knowledge gained from the demonstration.

24. SITE DESCRIPTION

2.1 BEALE AIR FORCE BASE AND BUILDINGS 2474, 2425, AND 24176

Beale Air Force Base (AFB) lies within Yuba County in Northern California, approximately 40 miles north of Sacramento and 13 miles east of Marysville (Fig. 1; CH2MHill, 2016). It covers approximately 23,000 acres.

Beale AFB began as Camp Beale, an Army installation, at the onset of World War II. During that war, the Base served as an armored division and later as infantry division training base. The Base was transferred to the Air Force in 1948 and served primarily as a training base for aviation engineers. In 1965, it became a Strategic Reconnaissance Wing and since 1981 has been the 9th Reconnaissance Wing under Air Combat Command.

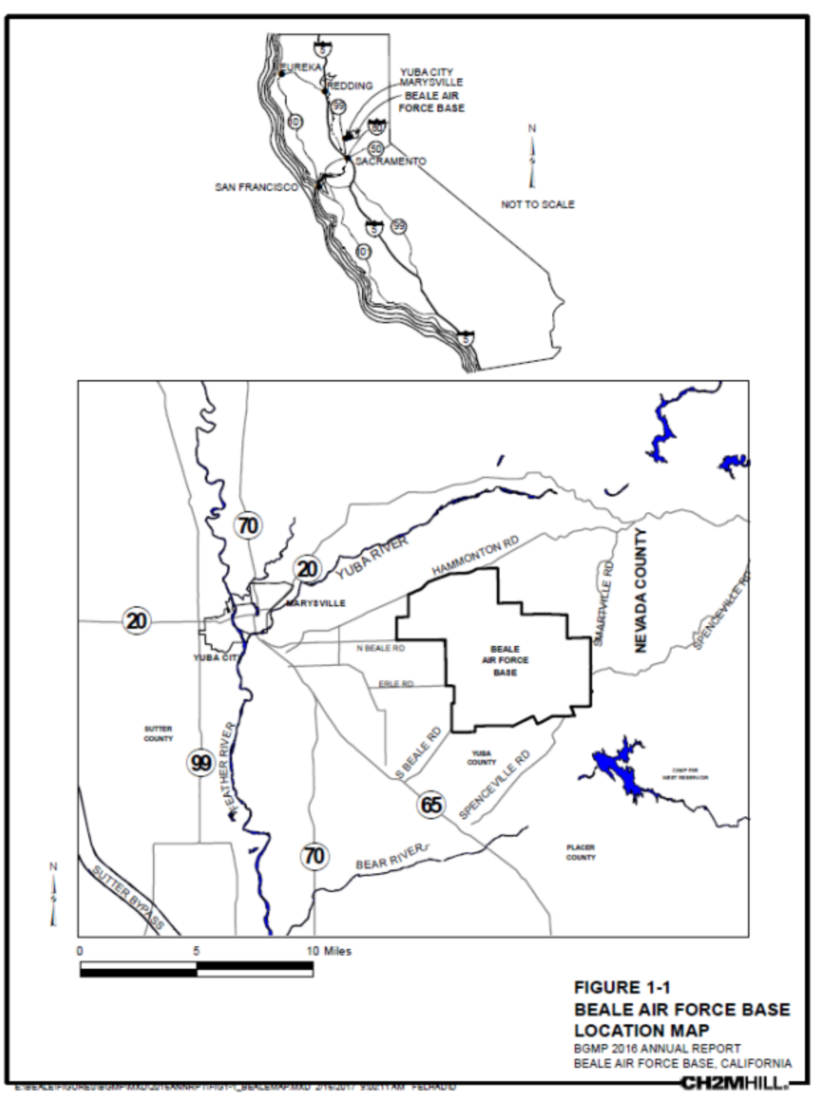

Figure 1. Location Map for Beale Air Force Base, California.

The generalized geology/hydrogeology of Beale AFB consists of unconsolidated sedimentary deposits, underlain by consolidated sedimentary bedrock, further underlain by crystalline metamorphic bedrock. Groundwater occurs primarily in the unconsolidated sedimentary deposits. Depth-to-water is approximately 40 ft below ground surface in the area of interest and groundwater flow direction is generally to the south/southwest.

Site CG041 is part of the Cantonment Remedial Investigation and was established by the Air Force in 2013 to separate groundwater responses from soil responses and address base-wide groundwater as a single site. It currently consists of groundwater plumes underlying 11 soil sites. Pertinent to this study is Plume GC041-039, a dilute chlorinated solvent plume that trends to the south/southwest in-line with groundwater flow and contains TCE concentrations currently ranging to approximately 110 µg/L.

Per a 2018 Record of Decision (ROD; USAF, 2018), an additional industrial/commercial Land Use Control for new buildings was to be implemented within the bounds of Plume CG041-039 to address risk assessment issues. The ROD identified three buildings that were within plume boundaries that required air sampling to assess vapor intrusion risk and confirm current use; 2474 (Theatre), 2425 (Community Activities Center; CAC), and 24176 (dormitory building B, the southern building of a two building dorm complex). Those buildings are shown in Figure 2, which provides a location map in addition to an overlay of the 2016 TCE plume delineation. General attributes of those buildings are shown in Table 1.

Based on the ROD requirement for a vapor intrusion assessment, buildings 2474, 2425, and 24176 were selected for CPM demonstration testing.

Table 1. Attributes of Beale AFB buildings 2474, 2425, and 24176.

Location	Bldg. Use	Size (ft2)	Occupancy	History of VI	Comment
Bldg. 2474	Theatre	10.3K	Occupied	Unknown Never tested	Bldgs. overlie a dilute TCE groundwater plume (5-110 ug/L) ROD indicated that VI testing was required for these facilities
Bldg. 2425	Community Activities Center	20.5K	Occupied		
Bldg. 24176	Dormitory	13.6K	Occupied		

2.1 BUILDING 24176

Building 24176 (dormitory building B), the focus of this report, is the southern building in a two building dormitory complex. The two-story concrete block structure was built on grade and is approximately 13,600 square feet (Figure 3). The ground floor consists of the following independent rooms: 1) eight (8) approximately 400 ft^2 dorm suites, each of which has two rooms with a shared bathroom; 2) a housekeeping room; 3) an electronics storage room; 4) an office suite; and 5) the laundry. The second floor is solely dorm rooms. The ground floor is the floor of primary interest for this study, the floorplan for which is shown in Figure 4. For test purposes, dorm suites were estimated at 4,000 ft^3 each and the building volume at 123,000 ft^3.

25.CPM TEST BUILDING PRESSURE CONTROL, AIR SAMPLING, AND ANALYTICAL METHODS

3.1 BUILDING PRESSURE CONTROL

The CPM demonstration followed early versions of the CPM Test Guidelines (SOP; see Main Report Appendix A) with some modification to account for size and construction of the building and to incorporate knowledge gained from prior industrial-scale tests.

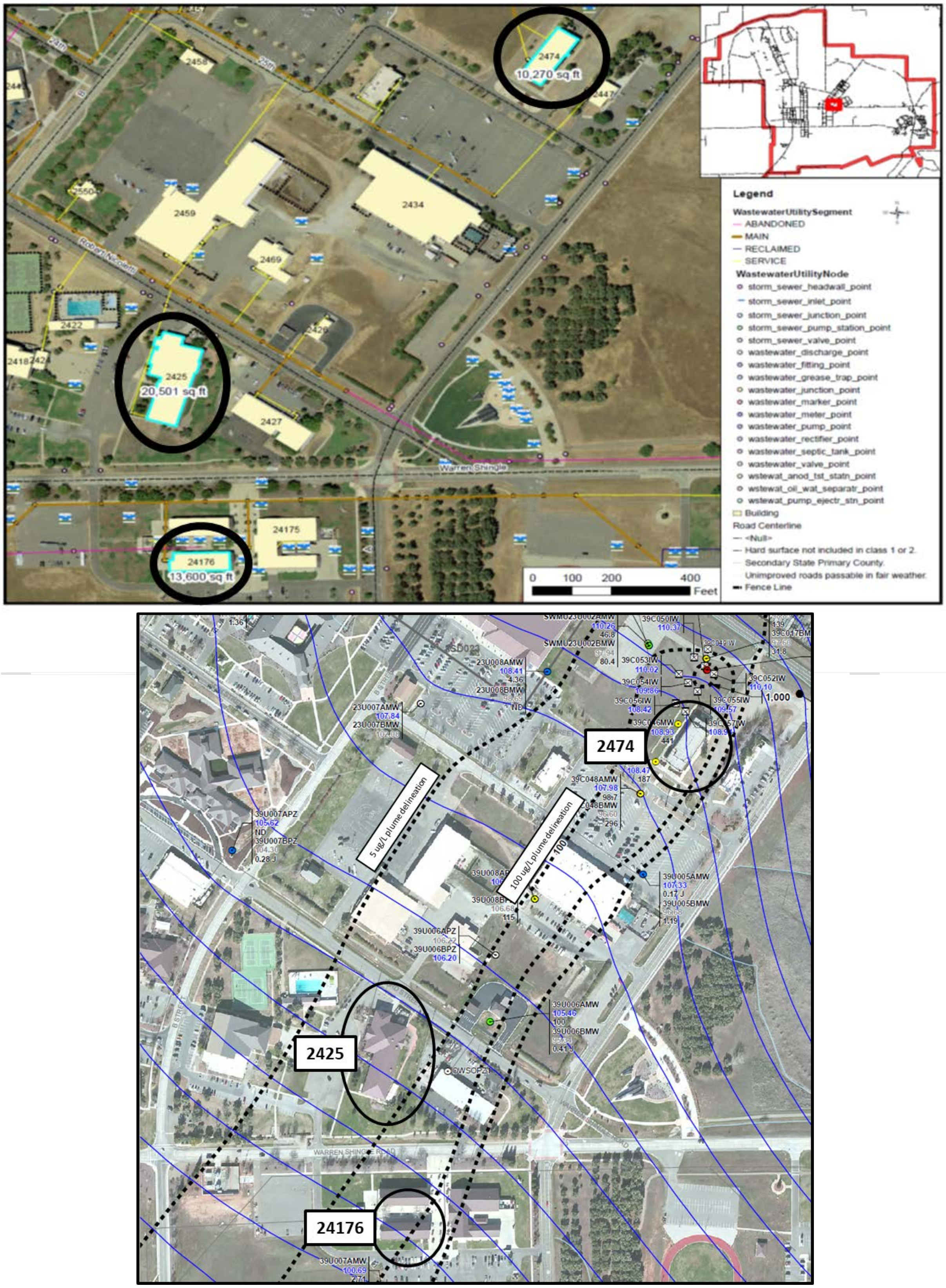

Figure 2. Location map for Buildings 2474, 2425, and 24176, and their locations relative to a 2016 TCE plume delineation.

Figure 3. Beale Air Force Base Building 24176 (Dormitory Building B).

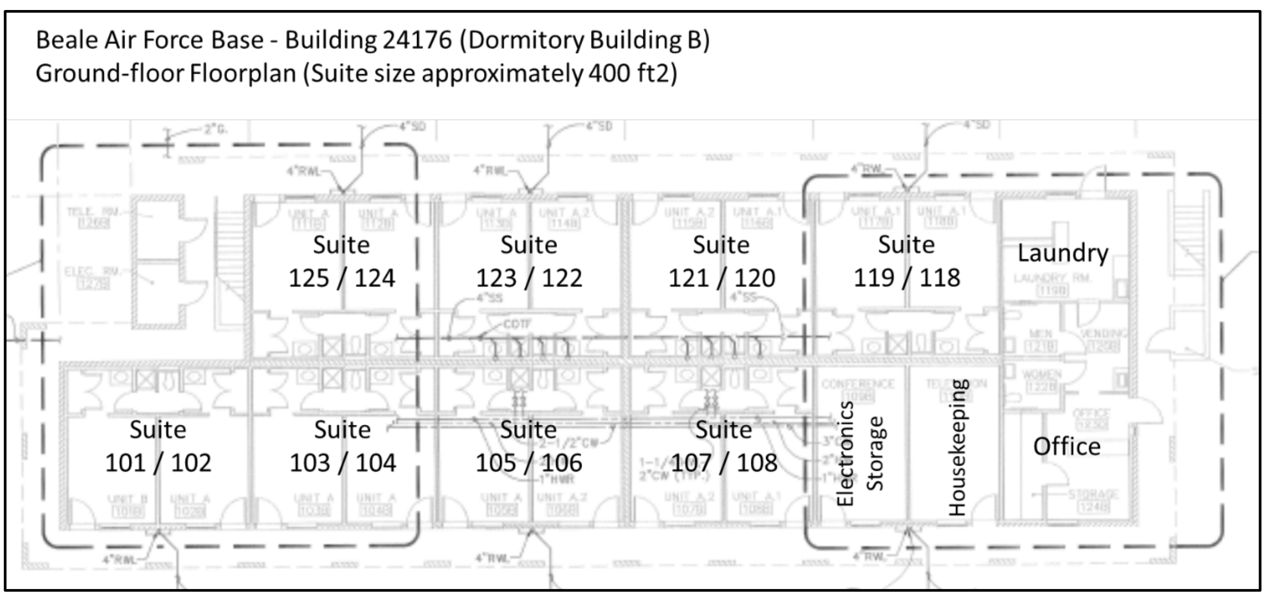

Figure 4. Beale Air Force Base Building 24176 (Dormitory Building B) Ground-floor Floorplan.

Building pressure control was managed with either a Retrotec 1000 or 6000 blower door system (Retrotec, WA). This system included the following:

- Variable speed blower (blower): Blower was operated using the DM32 digital blower control (Retrotec, WA). Blower flowrate was managed via blower speed and intake shrouds that control the cross-sectional area of intake.
- DM32 digital blower controller and pressure monitor: The DM32 (Figure 5) measured and recorded 1) indoor vs. outdoor pressure differential and 2) blower flowrate as determined by a fan shroud vs. reference pressure differential. Data logging included, but was not limited to time, date, blower flowrate, and differential pressure. Data was recorded on user defined intervals of 30 seconds.
- In this demonstration, due to the size and shape of the building, the indoor to outdoor pressure differential was measured between a single indoor pressure port and a single outdoor pressure port adjacent to the suite, but out of the blower exhaust pathway. An outdoor composite pressure reference was not used in this case due to the size and independent nature of the dorm suites.
- Adjustable frame with blower door cloth (blower door): The "blower door" included an adjustable frame and cover cloth with a cutout for the blower. The blower door was installed in a man-door doorframe. Figure 5 shows a blower door with a blower in place.

3.2 AIR SAMPLING AND ANALYTICAL PROCEDURE

CPM test air sampling included both indoor air and ambient outdoor samples, both of which utilized grab sampling. Indoor air sampling was specific to the type of test performed: Negative pressure CPM testing required a blower intake sample (functionally a composite of indoor air) for building concentration, and optional area specific samples. Final samples for negative pressure testing should be performed after a minimum of nine (9) building air exchanges.

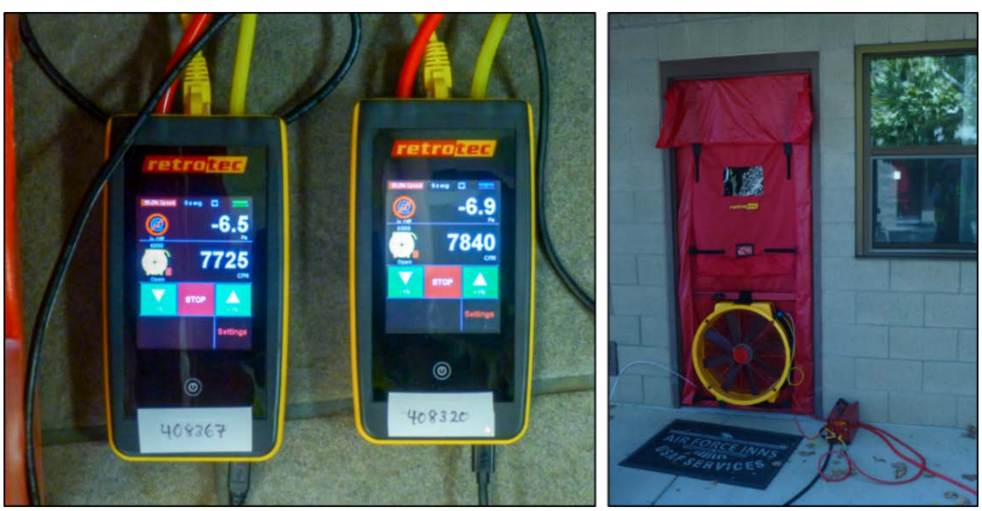

Figure 5. Retrotec DM32 with display (left) and blower door with blower (right).

Positive pressure CPM testing required area specific sampling, and sampling should proceed after a minimum of four (4) building air exchanges. To eliminate spatial variations during sampling and to ensure greater sample consistency, air mixing was employed in the sampling area using fans (e.g. box/floor fans).

Ambient outdoor sampling was performed to determine the baseline concentration of analytes and was representative of the air quality of air drawn into the structure during pressure testing.

Long term, indoor air sampling utilized long-term thermal desorption tube sampling techniques and/or passive sampler technology.

Air sampling and associated analytical was performed using the following methods:

- Grab Sampling: Grab Sampling with Tedlar bags and a vacuum sampler was used to collect indoor and ambient outdoor air samples during CPM testing. These samples were analyzed on-site and analytical results were obtained the same day of sample collection.

  On-site grab sample analyses were performed using an SRI 8610C gas chromatograph (SRI, CA) equipped with a sorbent concentrator and a dry electrolytic conductivity detector (DELCD). The DELCD was well suited for analytical due to its selective nature for only chlorinated and brominated compounds.

  The GC-DELCD system was calibrated before negative and positive pressure testing. Calibration concentrations ranged from 0.01 to 10 ppb_v for both negative and positive pressure testing. Calibration standards were prepared by dilution in clean Tedlar bags using Zero-air and a custom chlorinated compound calibration gas stock (Scotty Analyzed Gases).

  For on-site analytical, a suite of chlorinated volatile organic hydrocarbons (CVOCs) based on Trichloroethene and its daughter products was of interest. Those that responded well to the DELCD detector used for chromatography were as follows:

  - Trichloroethene (TCE)
  - 1,1 Dichloroethene (1,1-DCE)
  - 1,2 Dichloroethane (1,2-DCA)
  - 1,1,1 Trichloroethane (1,1,1-TCA)
  - 1,1,2 Trichloroethane (1,1,2-TCA)
  - Tetrachloroethene (PCE)
- Thermal Desorption (TD) tube sampling: TD tube sampling involved actively pulling air through a multi-bed, sorbent packed tube at a controlled flowrate. The flowrate and duration of collection determined the volume of air sampled. The averaged air concentration was calculated using the absorbed VOC mass and the total sample volume. Long-term (4 days) TD tube sampling: Long-term TD tube sampling was performed as follows:
  - 4-day, timed interval sampling: 4-day, timed interval sample collection used a single Sensidyne Gilian LFS-113 (Sensidyne, FL) pump in constant pressure mode to provide a continuous pressure source to a manifold with restrictor orifices to control flowrates for multiple tubes. The active sampling time was timer controlled to reduce collection volume to prevent TD tube sorbent saturation if indoor air concentrations were high. Active sampling was performed

for 60-minute intervals every 1.5 hours throughout the sampling period, a total of 960 minutes per day. See Figure 6 for sampler photo.
Sample integrity was maintained using Markes Difflok caps (Markes International, United Kingdom). In addition, to ensure that contaminant breakthrough did not occur, for each tube set, a backup TD tube was placed downstream of one of the tubes and was analyzed for the presence of contaminant. All backup TD tubes returned non-detect for VOCs.

Sampling flowrates were measured prior-to and subsequent-to sampling using the Gilian Gilibrator-2 calibrator (Sensidyne, FL). The difference between two measures were less than 6% for all tube samples.

A single TD tube and the backup TD tube both supplied by Beacon Environmental Services, were shipped back to them for analysis. Other tubes deployed were from ASU and used for research purposes, the results for which will not be addressed in this report.

- Passive Sampling: ***Passive samplers*** were deployed for continuous, long-term sampling for the 4 day period. Passive samplers used were the Beacon Sampler (Beacon Environmental Services, MD) and were sent to Beacon Environmental Services for analysis.

While results for all contaminants will be reported, the contaminant of interest for discussion purposes will be TCE. TCE is the contaminant of interest since this building resides over a TCE contaminant plume, and because of its low regulatory limit, TCE is frequently a focal point and regulatory driver.

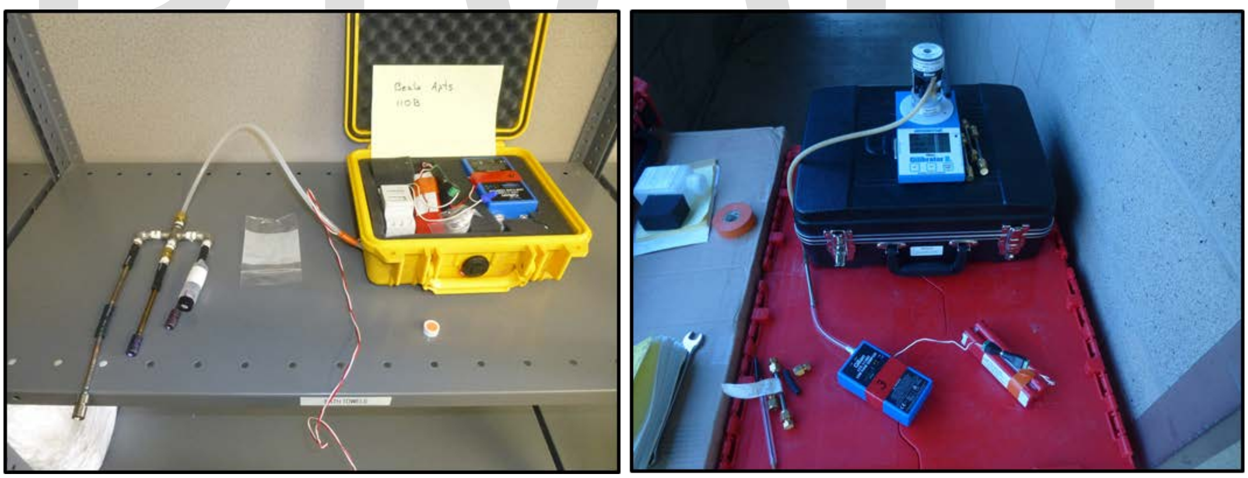

Figure 6. Active TD tube and Passive sampler deployment and Sensidyne Gilibrator II calibrator for sampling pump. Active TD tube and Passive sampler deployment included passive sampler, TD tube active samplers in triplicate with a single tube for breakthrough assessment, pump, and timer.

26.CPM TEST DEMONSTRATION AND RESULTS

The goal of this CPM demonstration was not to perform a formal VI risk assessment, but rather, validate CPM testing for VI pathway assessment. Therefore, in addition to the CPM test, a single four (4) day sampling event using active/passive samplers was performed prior to testing to characterize background indoor air concentrations to provide a point of comparison for the CPM test results.

Testing of the structure focused on the ground floor, as this would likely be the most dominant floor for vapor intrusion impacts. In addition, the building consisted of numerous suites that, through pressure testing, were deemed independent. As such, CPM testing was limited to two suites and the laundry room, while pre-CPM active/passive sampling of the building under passive conditions included a total of four (4) suites, the housekeeping facility, and the laundry room.

The demonstration proceeded as follows:

- Sept. 7, 2018: CPM negative pressure pre-test. Preliminary test to determine concentration ranges and instrumentation needs for full test.
- Sept. 8 – Sept. 12, 2018: Background indoor air sampling of suites B101/102, B105/106, B120/121, B124/125, B110 (Housekeeping), and laundry. Sampling included long-term ***TD tube sampling*** and ***Passive sampling***.
- Nov. 3, 2018: CPM Demonstration. CPM testing of Suite B124/125 and Laundry. Sampling included ***Grab sampling with on-site analytical***.
- Nov. 4, 2018: CPM Demonstration. CPM testing of Suite B103/104. Sampling included ***Grab sampling with on-site analytical***.

The Sept. 7 pretest involved a brief negative pressure test to determine what blower equipment would be needed for a full test and to determine approximate contaminant concentration ranges for calibration of on-site analytical equipment that would be used during the full test. Due to the informal nature of that test, test results will not be reported.

Figure 7 provides locations for both CPM testing and the active/passive long-term sampling.

4.1 CPM DEMONSTRATION

As indicated, CPM testing was performed over a two-day period; both negative and positive pressure testing for each were performed in a single day, with Laundry and Suite B124/125 testing on Nov. 3 and Suite B103/104 testing on Nov. 4.

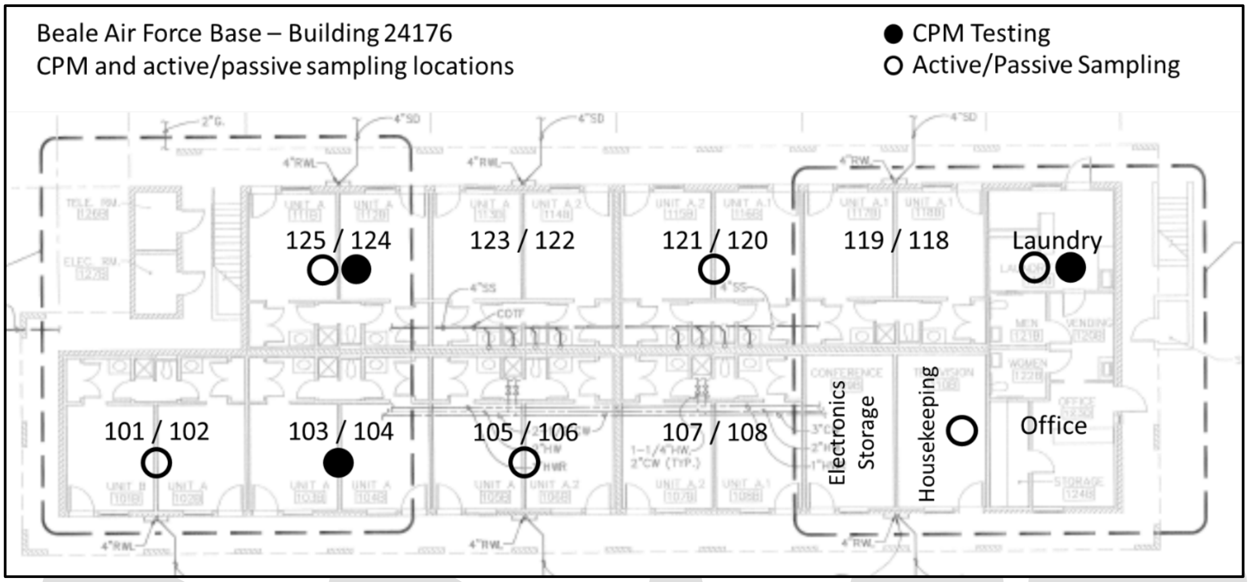

Figure 7. Beale AFB building 24176 CPM and active/passive sampling locations.

A single blower was used for pressure control in each room/suite and was operated at a constant speed to maintain as uniform flowrate as possible. Flowrate was determined by adjusting the blower speed to achieve the desired indoor-to-outdoor pressure differential. While a magnitude 10 Pa was the baseline for pressure testing as shown in the SOP, an increased pressure magnitude was used to increase flowrate. This decreased the time required for the negative pressure test and allowed for positive pressure testing during the same day. In addition, it minimized pressure fluctuations that might have occurred if wind picked up during the test. That approximate flowrate was then used for both negative and positive pressure testing.

CPM Demonstration - Negative Pressure Testing:

The blower-door/blower was installed in one of the doorways for the suites and the main doorway for the laundry room. Fig. 9 shows the blower installation locations for CPM testing.

Blower operation was initiated and blower speed was adjusted to achieve the indoor to outdoor differential pressure shown in Table 2. Other operational conditions for blower-door operation are also shown in Table 2.

Table 2. Operational conditions for CPM negative pressure testing, Building 24176.

Location	Pressure Differential (Pa)	Flowrate (cfm)	Duration of Neg Pressure Test (min)	Air exchange rate (min/vol.)	Approximate number of air exchanges
Laundry	-17	360	330	11	30
B124/125	-15*	360	500	11	45
B103/104	-18	350	400	11	36

* Inexplicable change in –dP and flowrate in suite B124/125 during testing.

Figures 10, 11, and 12 provide time series graphics for flowrate and differential pressure vs. time for the Laundry, B124/125, and B103/104, respectively.

Air sampling during negative pressure testing included indoor blower intake and ambient outdoor locations. Blower intake air analyte concentration, functionally a composite of indoor air, was monitored to determine when concentration equilibrium was achieved. Samples were collected at a defined location 1-2 ft from the blower intake as a cumulative representation of building air quality. Ambient outdoor air sampling was performed in two locations for Nov. 3 and a single location for Nov. 4 sampling to determine the baseline concentration of analytes drawn into the building.

Blower intake grab samples were collected throughout negative pressure testing to determine when concentration equilibrium was achieved. Figures 14, 15, and 16 provide graphics for blower intake TCE concentration vs. elapsed time for the Laundry, B124/125, and B103/104, respectively.

Two rounds of ambient outdoor air grab samples were collected from two locations, northeast and northwest of the building, for the Laundry and Suite B124/125 tests, and two rounds of ambient outdoor grab sampling were collected from a single location south of the building for Suite B103/104 sampling. These samples provided a baseline concentration for air quality and is representative of air that was drawn into the building during pressure testing.

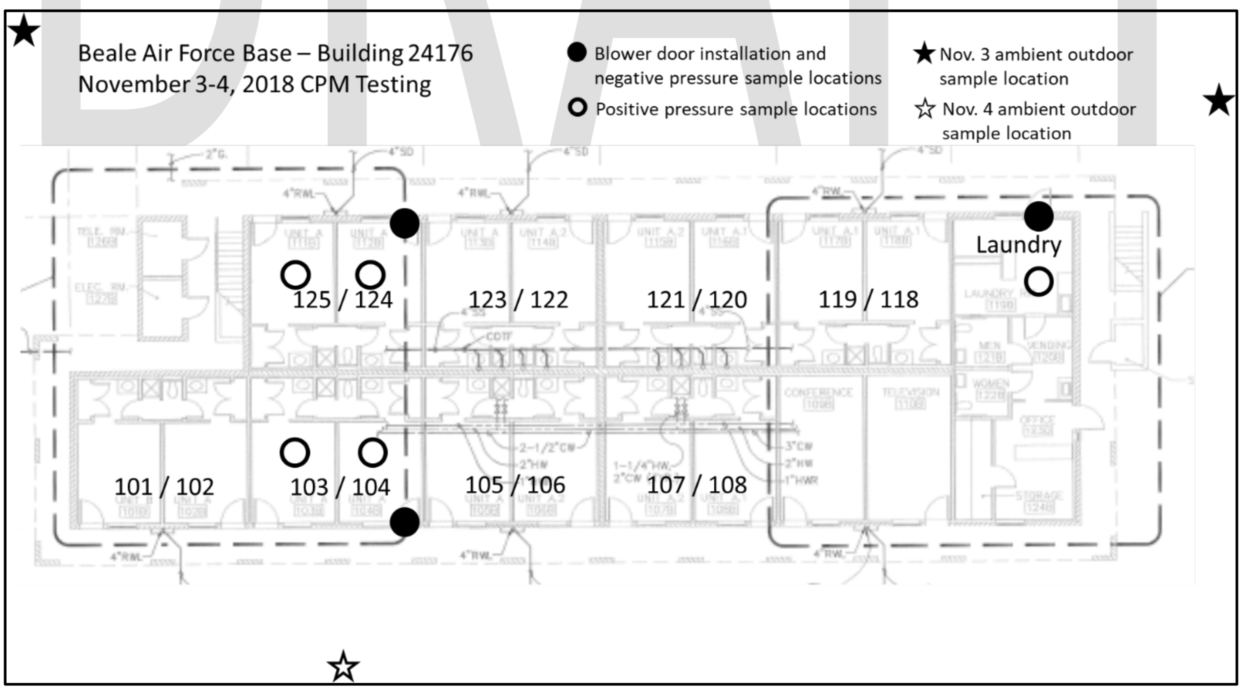

Figure 9. Blower door installation location and sampling location map for indoor and ambient outdoor air grab samples during negative and positive pressure testing.

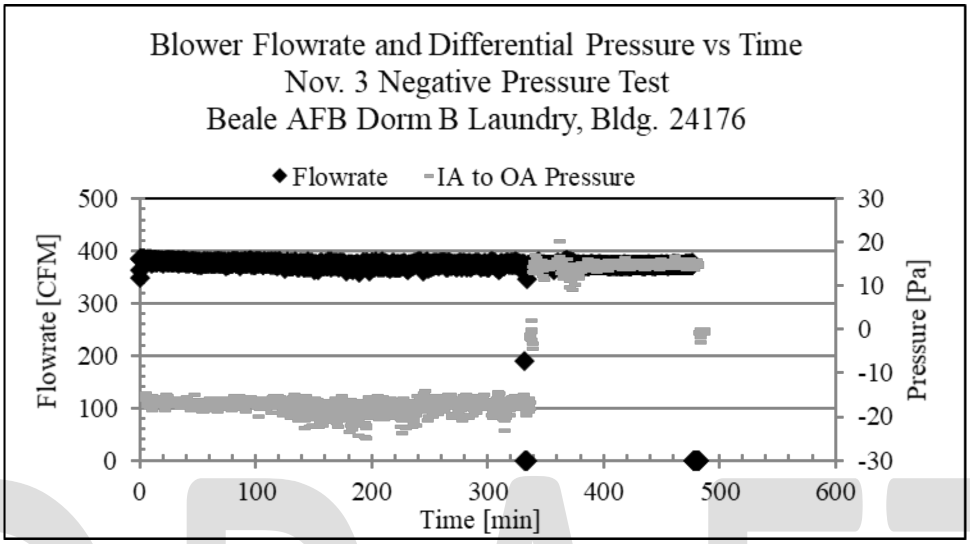

Figure 10. Blower flowrate and differential pressure vs time, Nov. 3 pressure testing. Beale AFB Dorm B Laundry, Bldg. 24176.

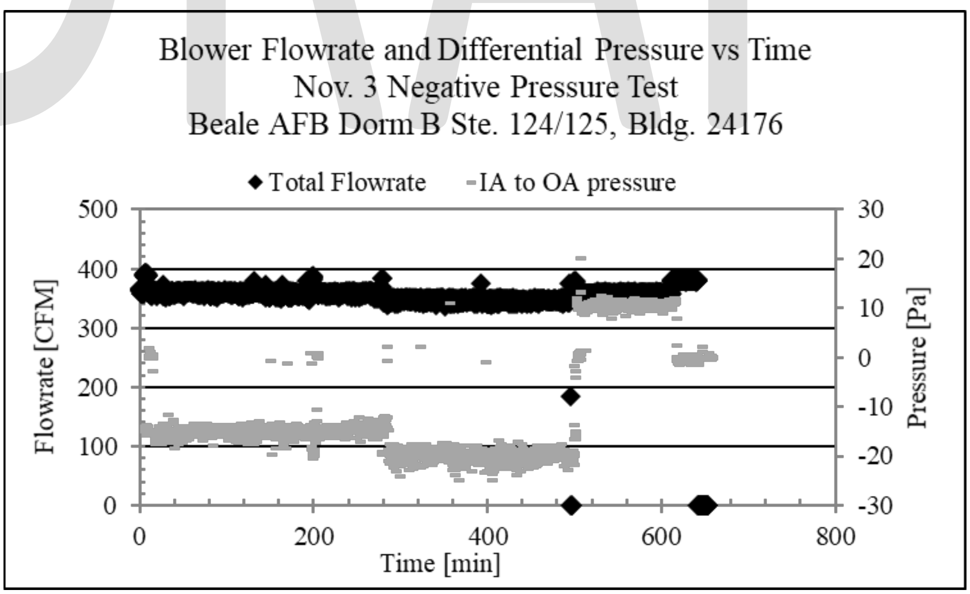

Figure 11. Blower flowrate and differential pressure vs time, Nov. 3 pressure testing. Beale AFB Dorm B Ste. B124/125, Bldg. 24176.

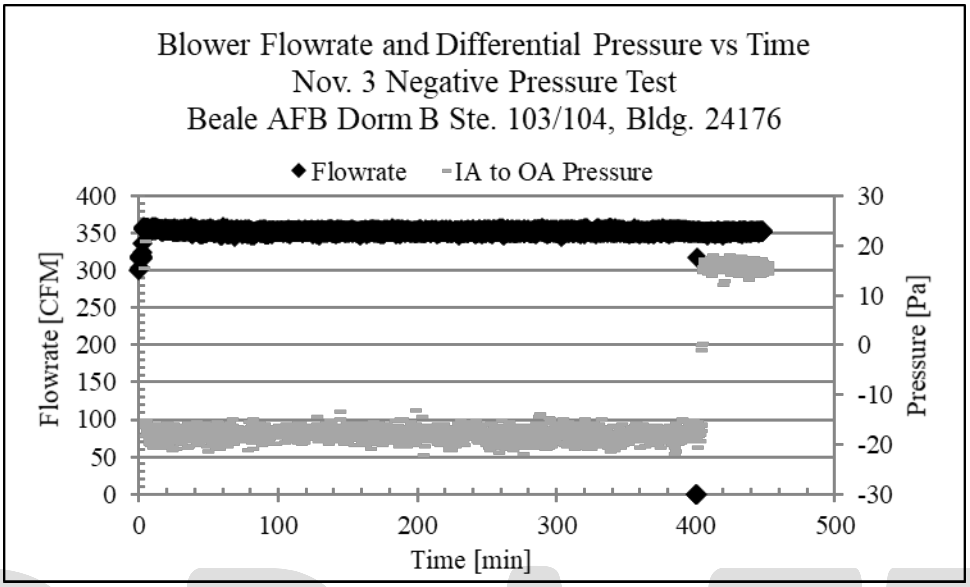

Figure 12. Blower flowrate and differential pressure vs time, Nov. 4 pressure testing. Beale AFB Dorm B Ste. B103/104, Bldg. 24176.

Figure 13. Blower door installation in a suite and the use of floor fans to facilitate air mixing.

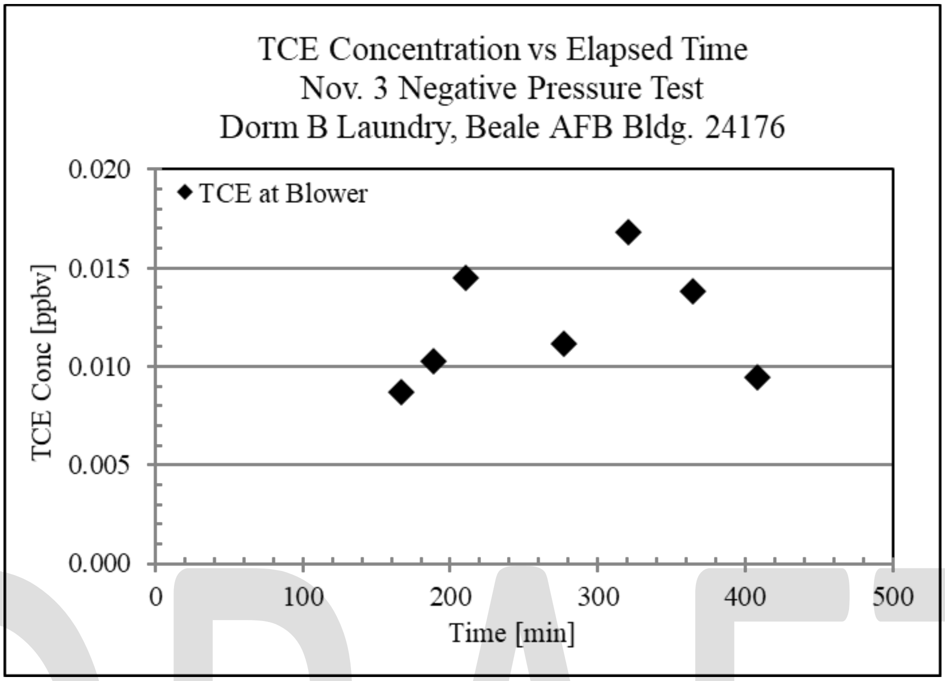

Figure 14. TCE air concentrations at the blower intake, Nov. 3 negative pressure test. Beale AFB Dorm B Laundry, Bldg. 24176.

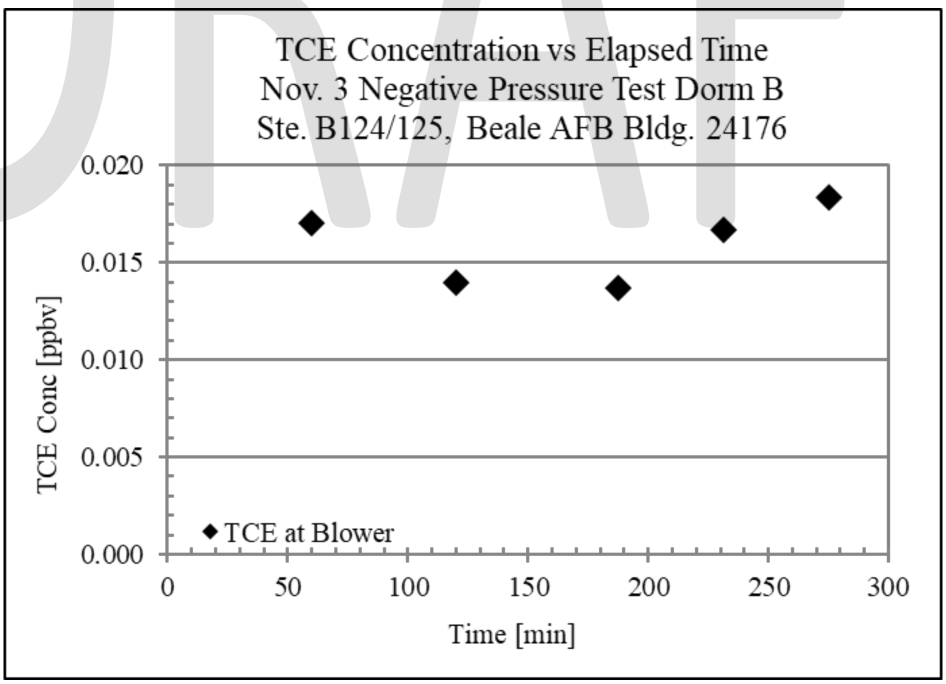

Figure 15. TCE air concentrations at the blower intake, Nov. 3 negative pressure test. Beale AFB Dorm B Ste. B124/125, Bldg. 24176.

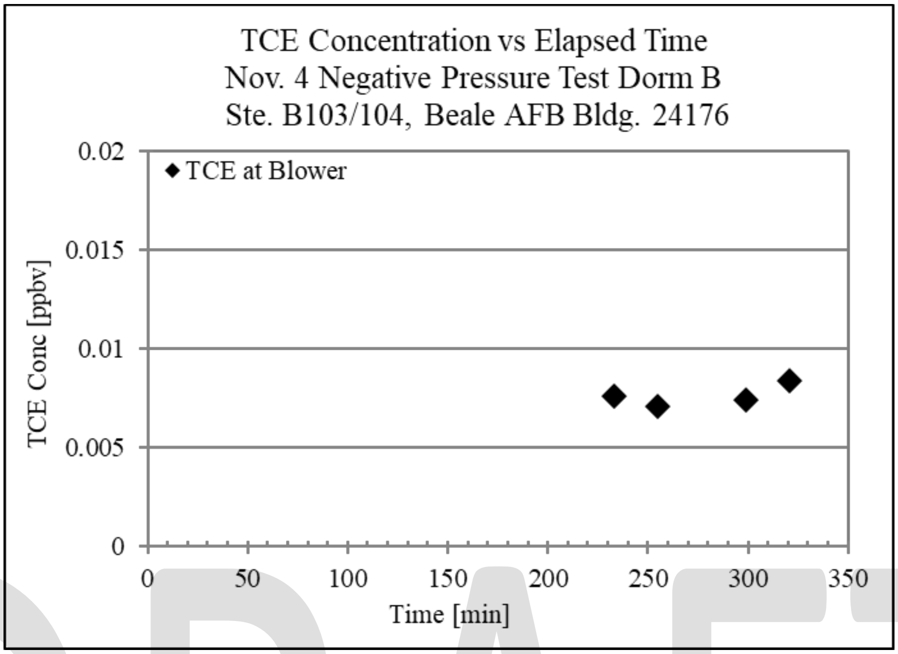

Figure 16. TCE air concentrations at the blower intake, Nov. 4 negative pressure test. Beale AFB Dorm B Ste. 103/104, Bldg. 24176.

<u>Analytical Results – Negative Pressure Testing</u>

Table 3 shows contaminant concentrations for ambient and indoor air.

Indoor air concentrations for TCE were somewhat elevated in the Laundry and Ste. B124/125, but well below the EPA screening levels of 0.08 ppbv for residential and 0.65 ppbv for industrial buildings (USEPA, 2015/2020). In addition, other analytes, when adjusted for ambient outdoor concentrations, were all less than both the residential and industrial screening levels. As such, there was no complete VI pathway for the Laundry or suites B124/125 or B103/104 as per the definition provided in the Introduction. Based on these results, no positive pressure CPM tests were necessary and the CPM test would be complete. However, for demonstration purposes, positive pressure tests were performed.

<u>Positive pressure testing:</u>

For positive pressure testing, blowers were reversed and blower operation was initiated. Blower speed (rather than the magnitude of differential pressure) was maintained at the same speed as was used for negative pressure testing. Operational conditions for blower-door operation are shown in Table 4.

Figures 10, 11, and 12 above provide time series graphics of flowrate and differential pressure for the Laundry, B124/125, and B103/104, respectively.

Table 3. Indoor and ambient outdoor air sampling results for Nov. 3/4 negative pressure testing.

Location	Analyte Concentration in Air (ppbv)											
	TCE[1]		1,1-DCE[1]		1,2-DCA[1]		1,1,1-TCA[1]		1,1,2-TCA[1]		PCE[1]	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Ambient Nov. 3	0.001	0.003	0.018	0.042	0.034	0.049	0.005	0.008	ND	ND	0.005	0.008
Laundry Neg Pressure	0.016	0.018	0.045	0.050	0.052	0.057	0.016	0.019	0.008	0.009	0.021	0.023
B124/125 Neg Pressure	0.012	0.017	0.029	0.055	0.047	0.054	0.004	0.005	0.003	0.005	0.006	0.007
Ambient Nov. 4	ND	ND	0.043	0.047	0.026	0.028	0.003	0.004	ND	ND	0.004	0.005
B103/104 Neg Pressure	0.008	0.008	0.040	0.047	0.022	0.024	0.002	0.004	0.015	0.059	0.004	0.004

ND - Non-detectable
1 - Calibration limit of 0.01 ppbv. Highlighted concentrations were detectable and estimated.

Table 4. Operational conditions for CPM positive pressure testing, Building 24176.

Location	-dP (Pa)	Flowrate (cfm)	Duration of Pos Pressure Test (min)	Air exchange rate (min/vol.)	Approximate number of air exchanges
Laundry	15	370	140	11	12
B124/125	11	355	110	11	10
B103/104	15	350	48	11	4

Ambient outdoor air sampling was performed at the same locations as were used for negative pressure testing to determine the baseline concentration of contaminants. Those samples provided a baseline reference for air quality and is representative of air that which was drawn into the building during pressure testing.

As per the SOP, a minimum of four (4) air exchanges were achieved prior to sampling those indoor air locations shown in Figure 9.

<u>Analytical Results – Positive Pressure Testing</u>

Table 5 provides the analytical data for positive pressure testing. Results indicate that there were no indoor air sources of concern in any location tested.

4.2 **Background Indoor Air Sampling**

Background indoor air sampling of suites B101/102, B105/106, B120/121, B124/125, B110 (Housekeeping), and the Laundry was performed Sept. 8 – Sept. 12, 2018. Those locations relative to the CPM test locations are shown above in Figure 7. Sampling included long-term TD tube sampling and Passive sampling.

Table 5. Indoor and ambient outdoor air sampling results for Nov. 3/4 positive pressure testing.

Location	Analyte Concentration in Air (ppbv)											
	TCE[1]		1,1-DCE[1]		1,2-DCA[1]		1,1,1-TCA[1]		1,1,2-TCA[1]		PCE[1]	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Ambient Nov. 3	0.001	0.003	0.018	0.042	0.034	0.049	0.005	0.008	ND	ND	0.005	0.008
Laundry Pos Pressure	0.009	0.010	0.035	0.044	0.047	0.050	0.010	0.011	ND	ND	0.013	0.014
B124 Pos Pressure	0.005	0.011	0.048	0.051	0.054	0.063	0.002	0.006	0.003	0.005	0.005	0.005
B125 Pos Pressure	0.002	0.005	0.046	0.047	0.055	0.056	ND	ND	ND	ND	0.005	0.005
Ambient Nov. 4	ND	ND	0.043	0.047	0.026	0.028	0.003	0.004	ND	ND	0.004	0.005
B103 Pos Pressure	0.003	0.004	0.042	0.034	0.025	0.029	0.001	0.004	ND	ND	0.004	0.006
B104 Pos Pressure	ND	ND	0.033	0.034	0.025	0.033	ND	ND	0.012	0.031	0.003	0.007

ND - Non-detectable
1 - Calibration limit of 0.01 ppbv. Highlighted concentrations were detectable and estimated.

Laboratory analytical results for TD tube and passive sampling of background indoor air conditions are shown in Table 6 and are attached in Appendices 24176A and 24176B for active TD tube and passive sampler results, respectively. Note that the elevated detection limits for passive air sampling was due to the limited deployment time of 4 days, a period that was too short for an effective detection limit. While there was interest in performing a longer sampling event, the building was under renovation and a four-day window was all that was possible for undisturbed testing.

27.CPM DEMONSTRATION SUMMARY

Negative Pressure CPM Testing Summary

Table 3 provided ambient outdoor and indoor air concentration data collected during the negative pressure tests of the laundry, and suites B124/125 and B103/104. As indicated previously, indoor air concentrations for TCE were slightly elevated in the Laundry and Ste. B124/125, but well below the EPA screening levels of 0.08 ppbv for residential and 0.65 ppbv for industrial buildings. In addition, other analytes, when adjusted for ambient outdoor concentrations, were all less than both the residential and industrial screening levels. As such, there was no complete VI pathway for the Laundry, Ste. B124/125, or Ste. B103/104 as per the definition provided in the Introduction.

Table 6. Laboratory analytical results for TD tube and passive sampling during natural building pressure conditions, Sept. 8-12, 2018, Building 24176.

Analyte	Analyte Concentration in Air[1]											
	B101/102		B105/106		B110		B laundry		B120/121		B124/125	
	Active TD Tube[2]	Passive[3] (ug/m3 : ppbv)	Active TD Tube[2]	Passive[3] (ug/m3 : ppbv)	Active TD Tube[2]	Passive[3] (ug/m3 : ppbv)	Active TD Tube[2]	Passive[3] (ug/m3 : ppbv)	Active TD Tube[2]	Passive[3] (ug/m3 : ppbv)	Active TD Tube[2]	Passive[3] (ug/m3 : ppbv)
1,1-DCE	No analysis	<5.88 : <1.48	<0.01	<5.88 : <1.48	<0.01	<5.89 : <1.48	<0.01	<5.95 : <1.50	<0.01	<5.94 : <1.49	<0.01	<5.93 : <1.49
t-1,2-DCE		<4.41 : <1.12	<0.01	<4.41 : <1.12	<0.01	<4.42 : <1.12	<0.01	<4.46 : <1.12	<0.01	<4.46 : <1.12	<0.01	<4.44 : <1.12
1,1-DCA		<2.31 : <0.57	<0.01	<2.31 : <0.57	<0.01	<2.31 : <0.57	<0.01	<2.34 : <0.58	<0.01	<2.33 : <0.57	<0.01	<2.33 : <0.57
c-1,2-DCE		<3.59 : <0.90	<0.01	<3.60 : <0.91	<0.01	<3.60 : <0.91	<0.01	<3.64 : <0.92	<0.01	<3.63 : <0.91	<0.01	<3.62 : <0.91
1,2-DCA		<3.46 : <0.85	<0.01	<3.47 : <0.85	<0.01	<3.47 : <0.85	<0.01	<3.51 : <0.86	<0.01	<3.50 : <0.86	<0.01	<3.49 : <0.86
1,1,1-TCA		<1.90 : <0.35	<0.01	<1.90 : <0.35	<0.01	<1.91 : <0.35	<0.01	<1.93 : <0.35	<0.01	<1.92 : <0.35	<0.01	<1.92 : <0.35
TCE		<5.70 : <1.06	<0.01	<5.71 : <1.06	<0.01	<5.72 : <1.06	<0.01	<5.78 : <1.07	<0.01	<5.77 : <1.07	<0.01	<5.75 : <1.07
PCE		<4.73 : <0.70	<0.01	<4.74 : <0.70	<0.01	<4.74 : <0.70	<0.01	<4.79 : <0.70	<0.01	<4.78 : <0.70	<0.01	<4.77 : <0.70

1-For concentrations noted as "<", concentrations were non-detectable or less than the limits of quantitation shown.

2-Active TD tube concentrations based on a minimum of 166L of sample. Actual volumes can be found in lab report in App. A.

3-Concentrations reported in ug/m3 and converted to ppbv using the EPA Indoor Air Unit Conversion, Online Tools for Site Assessment Calculation (USEPA, 2020). Passive samples based on an approximate 4.5 day deployment.

Positive Pressure CPM Testing Summary

As indicated previously, indoor air concentrations during negative pressure testing were less than any regulatory concern. As such, there was no complete VI pathway and there was little utility in performing a positive pressure CPM test. However, for completeness of demonstration, a positive pressure test was performed.

In short, the results indicated that there was no evidence of indoor air sources of concern in any of the locations tested.

However, the apparent low level TCE detects in the Laundry and Ste. B124/125 were of interest: Detectable concentrations during positive pressure testing suggest an indoor air source, and those concentrations were similar to those during negative pressure testing. A similar occurrence occurred in the Theatre, Bldg. 2474, prompting additional investigation as to that occurrence. Investigations to clarify the issue included potable water analysis and drain gas investigations. The results indicated the likely source of the apparent TCE detects was in fact co-elution with bromodichloromethane, a water disinfection by-product: The retention time for bromodichloromethane was the same as that for TCE for the GC configuration used for on-site analyses, and its detection was misidentified as TCE. Given these results, the TCE signature in the dorms during both negative and positive pressure tests was not surprising given the presence of potable water and sewer services in both those locations. In any case, the apparent TCE detections were well below the EPA action levels for both residential and industrial air, and as such, were of no consequence.

Summary of Background Sampling Under Natural Building Pressure Conditions

Background testing was performed in the Laundry, Ste. B124/125, and four other locations within the dorm building. No contaminants of interest were detected in background sampling under natural building pressure conditions: Active thermal desorption tube sampling indicated all analytes less than 0.01 ppbv, while passive sampling results, of limited use due to the high detection limits, also showed non-detectable concentrations. In summary, background sampling results suggested that there was no complete VI pathway. Those results correlated with CPM test results.

28.CPM DEMONSTRATION CONCLUSIONS

As stated in the Introduction, a complete VI pathway was defined as vapor intrusion with indoor vapor contaminant concentrations in excess of a regulatory limit or action level. CPM testing indicated that there was no complete VI pathway for any of the dorm facilities tested. This result was corroborated with more traditional active and passive sampling techniques within the building under passive pressure conditions.

Of note, however, were the apparent TCE detections during GC analysis. Additional investigation suggested those apparent detects to be a compound co-eluting with TCE during GC analysis. The compound, identified using GCMS analysis of a potable tap water sample, was bromodichloromethane, a common disinfection by-product associated with the chlorination during water treatment. As such, its presence in tap water and in the sewer system was not surprising. That said, we recommend that Beale confirm those results via analysis of tap water and sewer gas samples.

29. REFERENCES

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USEPA, 2015. Regional Screening Level (RSL) Summary Table June 2015 (revised) https://archive.epa.gov/region9/superfund/web/pdf/master_sl_table_run_june2015_rev.pdf

USEPA, 2020. Regional Screening Level (RSL) Summary Table (TR=1E-06, HQ=1) May 2020 (corrected). https://semspub.epa.gov/work/HQ/200043.pdf

Appendix 24176A
Background Indoor Air Sampling - Active TD Tube Results
Analytical Report

BEACON ENVIRONMENTAL SERVICES, INC.

The Leaders in Air Surveys and Vapor Intrusion Monitoring

Arizona State University
660 South College Avenue, Room 507
Tempe, AZ 85281
Attn: Paul Dahlen

Air Samples -- Analytical Report

Date: October 17, 2018
Beacon Project No. 4367.1A

Project Reference:	Beale AFB
Sampling Date:	September 8 through 12, 2018
Samples Received:	September 20, 2018
Analyses Completed:	September 24, 2018

Results for the following samples are included in this data package:

Sample ID	Matrix	Analysis
B101B	Air	TO-17
B105B	Air	TO-17
B110B	Air	TO-17
BLaundry	Air	TO-17
B121B	Air	TO-17
B125B	Air	TO-17

Sample Collection

Beacon Environmental provided Arizona State University with thermally conditioned multi-bed stainless steel tubes to target a custom list of analytes. A total of approximately 175 liters of air was drawn through each tube and the resulting mass of target analytes captured on each sampler was reported as a concentration.

U. S. EPA Method TO-17

All samples were analyzed for a custom target compound list following U.S. EPA Method TO-17. The analytical results are reported in micrograms per meter cubed (µg/m^3) and ppbv based on the measured mass and volume of gas sampled.

Reporting Limits (RLs) for EPA Method TO-17

The lowest point in the calibration curve and the limit of quantitation (LOQ) is 10 nanograms (ng), which is the RL; however, when reporting concentration data the values are provided in µg/m^3 and ppbv. The RLs represent a baseline above which results exceed laboratory-determined limits of precision and accuracy.

Calibration Verification

The initial laboratory control sample (LCS) also serves as the calibration verification and values for the analytes were all within ±30% of the true values as defined by the initial five-point calibration and met the requirements specified in Beacon Environmental's Quality Manual. Both the LCS and the laboratory control duplicate (LCSD) are spiked at 50 ng and percentage of recovery is calculated and reported. Acceptance criteria for surrogate and analyte recoveries are 70 to 130 percent; all surrogates and analytes were within the acceptance criteria.

Internal Standards and Surrogates

Internal standards and surrogates are spiked on each field and QC sample at 100 ng and 50 ng, respectively, and the percentage of recovery is calculated. Acceptance criteria for internal standards are 60 to 140 percent and surrogate recoveries are 70 to 130 percent; all internal standards and surrogates were within the acceptance criteria.

Blank Contamination

No targeted compounds above the limit of detection (LOD) for each compound were observed in the Laboratory Method Blank (LB_180924).

Discussion

Six (6) samples were collected following U.S. EPA Method TO-17. Sampling start and stop times, and total sampling volume can be found in the Chain of Custody (**Attachment 1**). Intended sample B101B was not able to be analyzed due to instrument error, and therefore, no results are reported for that sample.

Dilutions were required for one (1) sample (B121B), which had high levels of p&m-Xylene. Dilution analysis was performed for this sample to bring the detected concentrations of p&m-Xylene into the calibration range of the GC/MSD instrument. Sample B101B was diluted once with a dilution factor of 8.42. The LOQ of the diluted sample result is higher and noted in **Table 1**.

Demonstrated Linear Range of the GC-MS Instrumentation (EPA Method TO-17)

An initial five-point calibration is performed on the instrumentation from 10 to 200 ng per analyte.

Attachments:

-1- Chain of Custody

ALL DATA MEET REQUIREMENTS AS SPECIFIED IN THE BEACON ENVIRONMENTAL SERVICES, INC. QUALITY MANUAL AND THE RESULTS RELATE ONLY TO THE SAMPLES REPORTED. BEACON ENVIRONMENTAL SERVICES IS ACCREDITED TO ISO/IEC 17025:2005, AND THE WORK PERFORMED WAS IN ACCORDANCE WITH ISO/IEC 17025 REQUIREMENTS. THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY. RELEASE OF THE DATA HAS BEEN AUTHORIZED BY THE LABORATORY DIRECTOR OR HIS SIGNEE, AS VERIFIED BY THE FOLLOWING SIGNATURES:

Steven C. Thornley
Laboratory Director

Patti J. Riggs
Quality Manager

Date: October 17, 2018

Beacon Environmental Services, Inc.
2203A Commerce Road Suite 1
Forest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4367.1
Analysis Method TO17
Matrix: QC

Lab Sample ID: LCS_180924

Client:
Arizona State University
Tempe, AZ

ph: 480-385-9671

Analysis	Lab FileID
initial	A18092402
1st Dilution	
2nd Dilution	
3rd Dilution	

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
Vinyl Chloride	75-01-4	**114%**	%REC	70-130	9/24/18 8:58	A18092402
1,1-Dichloroethene	75-35-4	**110%**	%REC	70-130	9/24/18 8:58	A18092402
1,1,2-Trichlorotrifluoroethane (Fr.113)	76-13-1	**96%**	%REC	70-130	9/24/18 8:58	A18092402
trans-1,2-Dichloroethene	156-60-5	**122%**	%REC	70-130	9/24/18 8:58	A18092402
Methyl-t-butyl ether	1634-04-4	**95%**	%REC	70-130	9/24/18 8:58	A18092402
1,1-Dichloroethane	75-34-3	**108%**	%REC	70-130	9/24/18 8:58	A18092402
cis-1,2-Dichloroethene	75-34-3	**109%**	%REC	70-130	9/24/18 8:58	A18092402
Chloroform	67-66-3	**107%**	%REC	70-130	9/24/18 8:58	A18092402
1,2-Dichloroethane	107-06-2	**105%**	%REC	70-130	9/24/18 8:58	A18092402
1,1,1-Trichloroethane	71-55-6	**105%**	%REC	70-130	9/24/18 8:58	A18092402
Carbon Tetrachloride	56-23-5	**110%**	%REC	70-130	9/24/18 8:58	A18092402
Benzene	71-43-2	**105%**	%REC	70-130	9/24/18 8:58	A18092402
Trichloroethene	79-01-6	**102%**	%REC	70-130	9/24/18 8:58	A18092402
1,4-Dioxane	123-91-1	**99%**	%REC	70-130	9/24/18 8:58	A18092402
1,1,2-Trichloroethane	79-00-5	**102%**	%REC	70-130	9/24/18 8:58	A18092402
Toluene	108-88-3	**103%**	%REC	70-130	9/24/18 8:58	A18092402
Tetrachloroethene	127-18-4	**95%**	%REC	70-130	9/24/18 8:58	A18092402
1,1,1,2-Tetrachloroethane	630-20-6	**108%**	%REC	70-130	9/24/18 8:58	A18092402
Chlorobenzene	108-90-7	**101%**	%REC	70-130	9/24/18 8:58	A18092402
Ethylbenzene	100-41-4	**101%**	%REC	70-130	9/24/18 8:58	A18092402
p &m-Xylene	108-38-3	**98%**	%REC	70-130	9/24/18 8:58	A18092402
1,1,2,2-Tetrachloroethane	79-34-5	**107%**	%REC	70-130	9/24/18 8:58	A18092402
o-Xylene	95-47-6	**98%**	%REC	70-130	9/24/18 8:58	A18092402
1,2,3-Trichloropropane	96-18-4	**99%**	%REC	70-130	9/24/18 8:58	A18092402
Isopropylbenzene	98-82-8	**97%**	%REC	70-130	9/24/18 8:58	A18092402
1,3,5-Trimethylbenzene	99-06-6	**104%**	%REC	70-130	9/24/18 8:58	A18092402
1,2,4-Trimethylbenzene	95-63-6	**98%**	%REC	70-130	9/24/18 8:58	A18092402
1,3-Dichlorobenzene	541-73-1	**98%**	%REC	70-130	9/24/18 8:58	A18092402
1,4-Dichlorobenzene	106-46-7	**98%**	%REC	70-130	9/24/18 8:58	A18092402
1,2-Dichlorobenzene	95-50-1	**96%**	%REC	70-130	9/24/18 8:58	A18092402
1,2,4-Trichlorobenzene	120-82-1	**89%**	%REC	70-130	9/24/18 8:58	A18092402
Naphthalene	91-20-3	**74%**	%REC	70-130	9/24/18 8:58	A18092402
1,2,3-Trichlorobenzene	87-61-6	**107%**	%REC	70-130	9/24/18 8:58	A18092402
2-Methylnaphthalene	91-57-6	**109%**	%REC	70-130	9/24/18 8:58	A18092402

U = Not detected or below Reporting Limit (RL).; E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Beacon Environmental Services, Inc.
2203A Commerce Road Suite 1
Forest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4367.1
Analysis Method TO17
Matrix: QC

Lab Sample ID: LB_180924

Client:	Analysis	Lab File ID
Arizona State University	**initial**	A18092403
Tempe, AZ	1st Dilution	
	2nd Dilution	
	3rd Dilution	

ph: 480-385-9671

COMPOUNDS	CAS#						
Vinyl Chloride	75-01-4	U	0.1	U	0.02	9/24/18 9:21	A18092403
1,1-Dichloroethene	75-35-4	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,1,2-Trichlorotrifluoroethane (Fr.113)	76-13-1	U	0.1	U	0.01	9/24/18 9:21	A18092403
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.01	9/24/18 9:21	A18092403
Methyl-t-butyl ether	1634-04-4	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,1-Dichloroethane	75-34-3	U	0.1	U	0.01	9/24/18 9:21	A18092403
cis-1,2-Dichloroethene	75-34-3	U	0.1	U	0.01	9/24/18 9:21	A18092403
Chloroform	67-66-3	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,2-Dichloroethane	107-06-2	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	9/24/18 9:21	A18092403
Carbon Tetrachloride	56-23-5	U	0.1	U	0.01	9/24/18 9:21	A18092403
Benzene	71-43-2	U	0.1	U	0.02	9/24/18 9:21	A18092403
Trichloroethene	79-01-6	U	0.1	U	0.01	9/24/18 9:21	A18092403 1,4-
Dioxane	123-91-1	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,1,2-Trichloroethane	79-00-5	U	0.1	U	0.01	9/24/18 9:21	A18092403
Toluene	108-88-3	U	0.1	U	0.01	9/24/18 9:21	A18092403
Tetrachloroethene	127-18-4	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,1,1,2-Tetrachloroethane	630-20-6	U	0.1	U	0.01	9/24/18 9:21	A18092403
Chlorobenzene	108-90-7	U	0.1	U	0.01	9/24/18 9:21	A18092403
Ethylbenzene	100-41-4	U	0.1	U	0.01	9/24/18 9:21	A18092403 p &
m-Xylene	108-38-3	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,1,2,2-Tetrachloroethane	79-34-5	U	0.1	U	0.01	9/24/18 9:21	A18092403 o-
Xylene	95-47-6	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,2,3-Trichloropropane	96-18-4	U	0.1	U	0.01	9/24/18 9:21	A18092403
Isopropylbenzene	98-82-8	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,3,5-Trimethylbenzene	99-06-6	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,2,4-Trimethylbenzene	95-63-6	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,3-Dichlorobenzene	541-73-1	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,4-Dichlorobenzene	106-46-7	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,2-Dichlorobenzene	95-50-1	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,2,4-Trichlorobenzene	120-82-1	U	0.1	U	0.01	9/24/18 9:21	A18092403
Naphthalene	91-20-3	U	0.1	U	0.01	9/24/18 9:21	A18092403
1,2,3-Trichlorobenzene	87-61-6	U	0.1	U	0.01	9/24/18 9:21	A18092403
2-Methylnaphthalene	91-57-6	U	0.1	U	0.01	9/24/18 9:21	A18092403

U = Not detected or below Reporting Limit (RL).; E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Beacon Environmental Services, Inc.
2203A Commerce Road Suite 1
Forest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4367.1
Analysis Method TO17
Matrix: QC

Lab Sample ID: LCSD_180924

Client:	Analysis	Lab File ID
	initial	A18092404
Arizona State University	1st Dilution	
Tempe, AZ	2nd Dilution	
	3rd Dilution	

ph: 480-385-9671

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
Vinyl Chloride	75-01-4	**114%**	%REC	70-130	9/24/18 9:44	A18092404
1,1-Dichloroethene	75-35-4	**105%**	%REC	70-130	9/24/18 9:44	A18092404
1,1,2-Trichlorotrifluoroethane (Fr.113)	76-13-1	**107%**	%REC	70-130	9/24/18 9:44	A18092404
trans-1,2-Dichloroethene	156-60-5	**110%**	%REC	70-130	9/24/18 9:44	A18092404
Methyl-t-butyl ether	1634-04-4	**100%**	%REC	70-130	9/24/18 9:44	A18092404
1,1-Dichloroethane	75-34-3	**106%**	%REC	70-130	9/24/18 9:44	A18092404
cis-1,2-Dichloroethene	75-34-3	**101%**	%REC	70-130	9/24/18 9:44	A18092404
Chloroform	67-66-3	**104%**	%REC	70-130	9/24/18 9:44	A18092404
1,2-Dichloroethane	107-06-2	**103%**	%REC	70-130	9/24/18 9:44	A18092404
1,1,1-Trichloroethane	71-55-6	**114%**	%REC	70-130	9/24/18 9:44	A18092404
Carbon Tetrachloride	56-23-5	**117%**	%REC	70-130	9/24/18 9:44	A18092404
Benzene	71-43-2	**104%**	%REC	70-130	9/24/18 9:44	A18092404
Trichloroethene	79-01-6	**104%**	%REC	70-130	9/24/18 9:44	A18092404
1,4-Dioxane	123-91-1	**107%**	%REC	70-130	9/24/18 9:44	A18092404
1,1,2-Trichloroethane	79-00-5	**110%**	%REC	70-130	9/24/18 9:44	A18092404
Toluene	108-88-3	**106%**	%REC	70-130	9/24/18 9:44	A18092404
Tetrachloroethene	127-18-4	**109%**	%REC	70-130	9/24/18 9:44	A18092404
1,1,1,2-Tetrachloroethane	630-20-6	**115%**	%REC	70-130	9/24/18 9:44	A18092404
Chlorobenzene	108-90-7	**100%**	%REC	70-130	9/24/18 9:44	A18092404
Ethylbenzene	100-41-4	**102%**	%REC	70-130	9/24/18 9:44	A18092404
p & m-Xylene	108-38-3	**98%**	%REC	70-130	9/24/18 9:44	A18092404
1,1,2,2-Tetrachloroethane	79-34-5	**111%**	%REC	70-130	9/24/18 9:44	A18092404
o-Xylene	95-47-6	**97%**	%REC	70-130	9/24/18 9:44	A18092404
1,2,3-Trichloropropane	96-18-4	**111%**	%REC	70-130	9/24/18 9:44	A18092404
Isopropylbenzene	98-82-8	**99%**	%REC	70-130	9/24/18 9:44	A18092404
1,3,5-Trimethylbenzene	99-06-6	**106%**	%REC	70-130	9/24/18 9:44	A18092404
1,2,4-Trimethylbenzene	95-63-6	**102%**	%REC	70-130	9/24/18 9:44	A18092404
1,3-Dichlorobenzene	541-73-1	**99%**	%REC	70-130	9/24/18 9:44	A18092404
1,4-Dichlorobenzene	106-46-7	**96%**	%REC	70-130	9/24/18 9:44	A18092404
1,2-Dichlorobenzene	95-50-1	**96%**	%REC	70-130	9/24/18 9:44	A18092404
1,2,4-Trichlorobenzene	120-82-1	**87%**	%REC	70-130	9/24/18 9:44	A18092404
Naphthalene	91-20-3	**79%**	%REC	70-130	9/24/18 9:44	A18092404
1,2,3-Trichlorobenzene	87-61-6	**90%**	%REC	70-130	9/24/18 9:44	A18092404
2-Methylnaphthalene	91-57-6	**102%**	%REC	70-130	9/24/18 9:44	A18092404

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Beacon Environmental Services, Inc.
2203A Commerce Road Suite 1
Forest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4367.1
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: **B105B**
Lab Sample ID: B105B-1078697

Client:
Arizona State University
Tempe, AZ

ph: 480-385-9671

Analysis	Lab FileID	Dilution Factor
initial	A18092406	1
1st Dilution		
2nd Dilution		
3rd Dilution		

Sample Collection Time: 9/18/18 2:50 PM
Sample Volume in Liters: 194.09
Date Received: 9/20/2018

COMPOUNDS	CAS#						
Vinyl Chloride	75-01-4	U	0.1	U	0.02	9/24/18 11:49	A18092406
1,1-Dichloroethene	75-35-4	U	0.1	U	0.01	9/24/18 11:49	A18092406
1,1,2-Trichlorotrifluoroethane (Fr.113)	76-13-1	**0.28**	0.1	**0.04**	0.01	9/24/18 11:49	A18092406
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.01	9/24/18 11:49	A18092406
Methyl-t-butyl ether	1634-04-4	U	0.1	U	0.01	9/24/18 11:49	A18092406
1,1-Dichloroethane	75-34-3	U	0.1	U	0.01	9/24/18 11:49	A18092406
cis-1,2-Dichloroethene	75-34-3	U	0.1	U	0.01	9/24/18 11:49	A18092406
Chloroform	67-66-3	**0.11**	0.1	**0.02**	0.01	9/24/18 11:49	A18092406
1,2-Dichloroethane	107-06-2	U	0.1	U	0.01	9/24/18 11:49	A18092406
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	9/24/18 11:49	A18092406
Carbon Tetrachloride	56-23-5	**0.19**	0.1	**0.03**	0.01	9/24/18 11:49	A18092406
Benzene	71-43-2	U	0.1	U	0.02	9/24/18 11:49	A18092406
Trichloroethene	79-01-6	U	0.1	U	0.01	9/24/18 11:49	A18092406 1,4-
Dioxane	123-91-1	U	0.1	U	0.01	9/24/18 11:49	A18092406
1,1,2-Trichloroethane	79-00-5	U	0.1	U	0.01	9/24/18 11:49	A18092406
Toluene	108-88-3	**0.09**	0.1	**0.02**	0.01	9/24/18 11:49	A18092406
Tetrachloroethene	127-18-4	U	0.1	U	0.01	9/24/18 11:49	A18092406
1,1,1,2-Tetrachloroethane	630-20-6	U	0.1	U	0.01	9/24/18 11:49	A18092406
Chlorobenzene	108-90-7	U	0.1	U	0.01	9/24/18 11:49	A18092406
Ethylbenzene	100-41-4	**0.08**	0.1	**0.02**	0.01	9/24/18 11:49	A18092406
p & m-Xylene	108-38-3	**0.3**	0.1	**0.07**	0.01	9/24/18 11:49	A18092406
1,1,2,2-Tetrachloroethane	79-34-5	U	0.1	U	0.01	9/24/18 11:49	A18092406 o-
Xylene	95-47-6	**0.12**	0.1	**0.03**	0.01	9/24/18 11:49	A18092406
1,2,3-Trichloropropane	96-18-4	U	0.1	U	0.01	9/24/18 11:49	A18092406
Isopropylbenzene	98-82-8	U	0.1	U	0.01	9/24/18 11:49	A18092406
1,3,5-Trimethylbenzene	99-06-6	U	0.1	U	0.01	9/24/18 11:49	A18092406
1,2,4-Trimethylbenzene	95-63-6	U	0.1	U	0.01	9/24/18 11:49	A18092406
1,3-Dichlorobenzene	541-73-1	U	0.1	U	0.01	9/24/18 11:49	A18092406
1,4-Dichlorobenzene	106-46-7	U	0.1	U	0.01	9/24/18 11:49	A18092406
1,2-Dichlorobenzene	95-50-1	U	0.1	U	0.01	9/24/18 11:49	A18092406
1,2,4-Trichlorobenzene	120-82-1	U	0.1	U	0.01	9/24/18 11:49	A18092406
Naphthalene	91-20-3	U	0.1	U	0.01	9/24/18 11:49	A18092406
1,2,3-Trichlorobenzene	87-61-6	U	0.1	U	0.01	9/24/18 11:49	A18092406
2-Methylnaphthalene	91-57-6	U	0.1	U	0.01	9/24/18 11:49	A18092406

U = Not detected or below Reporting Limit (RL).; E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Beacon Environmental Services, Inc.
2203A Commerce Road Suite 1
Forest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number:	4367.1
Analysis Method	TO17
Matrix:	Air
Client ID/Field Sampling Location:	**B110B**
Lab Sample ID:	B110B-1078709

Client:	Analysis	Lab File ID	Dilution Factor
Arizona State University	**initial**	A18092407	1
Tempe, AZ	1st Dilution		
	2nd Dilution		
ph: 480-385-9671	3rd Dilution		

Sample Collection Time:	9/18/18 2:44 PM
Sample Volume in Liters:	180.71
Date Received:	9/20/2018

COMPOUNDS	CAS#						
Vinyl Chloride	75-01-4	U	0.1	U	0.02	9/24/18 12:36	A18092407
1,1-Dichloroethene	75-35-4	U	0.1	U	0.01	9/24/18 12:36	A18092407
1,1,2-Trichlorotrifluoroethane (Fr.113)	76-13-1	**0.26**	0.1	**0.03**	0.01	9/24/18 12:36	A18092407
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.01	9/24/18 12:36	A18092407
Methyl-t-butyl ether	1634-04-4	U	0.1	U	0.02	9/24/18 12:36	A18092407
1,1-Dichloroethane	75-34-3	U	0.1	U	0.01	9/24/18 12:36	A18092407
cis-1,2-Dichloroethene	75-34-3	U	0.1	U	0.01	9/24/18 12:36	A18092407
Chloroform	67-66-3	**1.01**	0.1	**0.21**	0.01	9/24/18 12:36	A18092407
1,2-Dichloroethane	107-06-2	U	0.1	U	0.01	9/24/18 12:36	A18092407
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	9/24/18 12:36	A18092407
Carbon Tetrachloride	56-23-5	**0.27**	0.1	**0.04**	0.01	9/24/18 12:36	A18092407
Benzene	71-43-2	**0.06**	0.1	**0.02**	0.02	9/24/18 12:36	A18092407
Trichloroethene	79-01-6	U	0.1	U	0.01	9/24/18 12:36	A18092407 1,4-
Dioxane	123-91-1	U	0.1	U	0.02	9/24/18 12:36	A18092407
1,1,2-Trichloroethane	79-00-5	U	0.1	U	0.01	9/24/18 12:36	A18092407
Toluene	108-88-3	**0.98**	0.1	**0.26**	0.01	9/24/18 12:36	A18092407
Tetrachloroethene	127-18-4	U	0.1	U	0.01	9/24/18 12:36	A18092407
1,1,1,2-Tetrachloroethane	630-20-6	U	0.1	U	0.01	9/24/18 12:36	A18092407
Chlorobenzene	108-90-7	U	0.1	U	0.01	9/24/18 12:36	A18092407
Ethylbenzene	100-41-4	**0.12**	0.1	**0.03**	0.01	9/24/18 12:36	A18092407
p & m-Xylene	108-38-3	**0.35**	0.1	**0.08**	0.01	9/24/18 12:36	A18092407
1,1,2,2-Tetrachloroethane	79-34-5	U	0.1	U	0.01	9/24/18 12:36	A18092407 o-
Xylene	95-47-6	**0.14**	0.1	**0.03**	0.01	9/24/18 12:36	A18092407
1,2,3-Trichloropropane	96-18-4	U	0.1	U	0.01	9/24/18 12:36	A18092407
Isopropylbenzene	98-82-8	U	0.1	U	0.01	9/24/18 12:36	A18092407
1,3,5-Trimethylbenzene	99-06-6	**0.09**	0.1	**0.02**	0.01	9/24/18 12:36	A18092407
1,2,4-Trimethylbenzene	95-63-6	U	0.1	U	0.01	9/24/18 12:36	A18092407
1,3-Dichlorobenzene	541-73-1	U	0.1	U	0.01	9/24/18 12:36	A18092407
1,4-Dichlorobenzene	106-46-7	U	0.1	U	0.01	9/24/18 12:36	A18092407
1,2-Dichlorobenzene	95-50-1	U	0.1	U	0.01	9/24/18 12:36	A18092407
1,2,4-Trichlorobenzene	120-82-1	U	0.1	U	0.01	9/24/18 12:36	A18092407
Naphthalene	91-20-3	U	0.1	U	0.01	9/24/18 12:36	A18092407
1,2,3-Trichlorobenzene	87-61-6	U	0.1	U	0.01	9/24/18 12:36	A18092407
2-Methylnaphthalene	91-57-6	U	0.1	U	0.01	9/24/18 12:36	A18092407

U = Not detected or below Reporting Limit (RL).; E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Beacon Environmental Services, Inc.
2203A Commerce Road Suite 1
Forest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4367.1
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: **Blaundry**
Lab Sample ID: BLaundry-1078610

Client:
Arizona State University
Tempe, AZ

ph: 480-385-9671

Analysis	Lab FileID	Dilution Factor
initial	A18092408	1
1st Dilution		
2nd Dilution		
3rd Dilution		

Sample Collection Time: 9/18/18 4:11 PM
Sample Volume in Liters: 166.50
Date Received: 9/20/2018

COMPOUNDS	CAS#							
Vinyl Chloride	75-01-4	U	0.1	U	0.02	9/24/18 12:58	A18092408	
1,1-Dichloroethene	75-35-4	U	0.1	U	0.02	9/24/18 12:58	A18092408	
1,1,2-Trichlorotrifluoroethane (Fr.113)	76-13-1	**0.26**	0.1	**0.03**	0.01	9/24/18 12:58	A18092408	
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.02	9/24/18 12:58	A18092408	
Methyl-t-butyl ether	1634-04-4	U	0.1	U	0.02	9/24/18 12:58	A18092408	
1,1-Dichloroethane	75-34-3	U	0.1	U	0.01	9/24/18 12:58	A18092408	
cis-1,2-Dichloroethene	75-34-3	U	0.1	U	0.02	9/24/18 12:58	A18092408	
Chloroform	67-66-3	**0.19**	0.1	**0.04**	0.01	9/24/18 12:58	A18092408	
1,2-Dichloroethane	107-06-2	U	0.1	U	0.01	9/24/18 12:58	A18092408	
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	9/24/18 12:58	A18092408	
Carbon Tetrachloride	56-23-5	**0.24**	0.1	**0.04**	0.01	9/24/18 12:58	A18092408	
Benzene	71-43-2	U	0.1	U	0.02	9/24/18 12:58	A18092408	
Trichloroethene	79-01-6	U	0.1	U	0.01	9/24/18 12:58	A18092408	1,4-
Dioxane	123-91-1	U	0.1	U	0.02	9/24/18 12:58	A18092408	
1,1,2-Trichloroethane	79-00-5	U	0.1	U	0.01	9/24/18 12:58	A18092408	
Toluene	108-88-3	**0.23**	0.1	**0.06**	0.02	9/24/18 12:58	A18092408	
Tetrachloroethene	127-18-4	U	0.1	U	0.01	9/24/18 12:58	A18092408	
1,1,1,2-Tetrachloroethane	630-20-6	U	0.1	U	0.01	9/24/18 12:58	A18092408	
Chlorobenzene	108-90-7	U	0.1	U	0.01	9/24/18 12:58	A18092408	
Ethylbenzene	100-41-4	U	0.1	U	0.01	9/24/18 12:58	A18092408	p &
m-Xylene	108-38-3	**0.18**	0.1	**0.04**	0.01	9/24/18 12:58	A18092408	
1,1,2,2-Tetrachloroethane	79-34-5	U	0.1	U	0.01	9/24/18 12:58	A18092408	o-
Xylene	95-47-6	**0.07**	0.1	**0.02**	0.01	9/24/18 12:58	A18092408	
1,2,3-Trichloropropane	96-18-4	U	0.1	U	0.01	9/24/18 12:58	A18092408	
Isopropylbenzene	98-82-8	U	0.1	U	0.01	9/24/18 12:58	A18092408	
1,3,5-Trimethylbenzene	99-06-6	U	0.1	U	0.01	9/24/18 12:58	A18092408	
1,2,4-Trimethylbenzene	95-63-6	U	0.1	U	0.01	9/24/18 12:58	A18092408	
1,3-Dichlorobenzene	541-73-1	U	0.1	U	0.01	9/24/18 12:58	A18092408	
1,4-Dichlorobenzene	106-46-7	U	0.1	U	0.01	9/24/18 12:58	A18092408	
1,2-Dichlorobenzene	95-50-1	U	0.1	U	0.01	9/24/18 12:58	A18092408	
1,2,4-Trichlorobenzene	120-82-1	U	0.1	U	0.01	9/24/18 12:58	A18092408	
Naphthalene	91-20-3	U	0.1	U	0.01	9/24/18 12:58	A18092408	
1,2,3-Trichlorobenzene	87-61-6	U	0.1	U	0.01	9/24/18 12:58	A18092408	
2-Methylnaphthalene	91-57-6	U	0.1	U	0.01	9/24/18 12:58	A18092408	

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Beacon Environmental Services, Inc.
2203A Commerce Road Suite 1
Forest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4367.1
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: **B121B**
Lab Sample ID: B121B-1078523

Client:
Arizona State University
Tempe, AZ
ph: 480-385-9671

Analysis	Lab File ID	Dilution Factor
initial	A18092409	1
1st Dilution	A18092412	8.42
2nd Dilution		
3rd Dilution		

Sample Collection Time: 9/18/18 4:12 PM
Sample Volume in Liters: 180.54
Date Received: 9/20/2018

COMPOUNDS	CAS#						
Vinyl Chloride	75-01-4	U	0.1	U	0.02	9/24/18 13:21	A18092409
1,1-Dichloroethene	75-35-4	U	0.1	U	0.01	9/24/18 13:21	A18092409
1,1,2-Trichlorotrifluoroethane (Fr.113)	76-13-1	**0.24**	0.1	**0.03**	0.01	9/24/18 13:21	A18092409
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.01	9/24/18 13:21	A18092409
Methyl-t-butyl ether	1634-04-4	U	0.1	U	0.02	9/24/18 13:21	A18092409
1,1-Dichloroethane	75-34-3	U	0.1	U	0.01	9/24/18 13:21	A18092409
cis-1,2-Dichloroethene	75-34-3	U	0.1	U	0.01	9/24/18 13:21	A18092409
Chloroform	67-66-3	**0.06**	0.1	**0.01**	0.01	9/24/18 13:21	A18092409
1,2-Dichloroethane	107-06-2	U	0.1	U	0.01	9/24/18 13:21	A18092409
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	9/24/18 13:21	A18092409
Carbon Tetrachloride	56-23-5	**0.22**	0.1	**0.03**	0.01	9/24/18 13:21	A18092409
Benzene	71-43-2	U	0.1	U	0.02	9/24/18 13:21	A18092409
Trichloroethene	79-01-6	U	0.1	U	0.01	9/24/18 13:21	A18092409 1,4-
Dioxane	123-91-1	U	0.1	U	0.02	9/24/18 13:21	A18092409
1,1,2-Trichloroethane	79-00-5	U	0.1	U	0.01	9/24/18 13:21	A18092409
Toluene	108-88-3	**0.24**	0.1	**0.06**	0.01	9/24/18 13:21	A18092409
Tetrachloroethene	127-18-4	U	0.1	U	0.01	9/24/18 13:21	A18092409
1,1,1,2-Tetrachloroethane	630-20-6	U	0.1	U	0.01	9/24/18 13:21	A18092409
Chlorobenzene	108-90-7	U	0.1	U	0.01	9/24/18 13:21	A18092409
Ethylbenzene	100-41-4	**0.51**	0.1	**0.12**	0.01	9/24/18 13:21	A18092409
p & m-Xylene	108-38-3	**2.64 D**	0.5	**0.61 D**	0.11	9/24/18 15:17	A18092412
1,1,2,2-Tetrachloroethane	79-34-5	U	0.1	U	0.01	9/24/18 13:21	A18092409 o-
Xylene	95-47-6	**0.91**	0.1	**0.21**	0.01	9/24/18 13:21	A18092409
1,2,3-Trichloropropane	96-18-4	U	0.1	U	0.01	9/24/18 13:21	A18092409
Isopropylbenzene	98-82-8	U	0.1	U	0.01	9/24/18 13:21	A18092409
1,3,5-Trimethylbenzene	99-06-6	U	0.1	U	0.01	9/24/18 13:21	A18092409
1,2,4-Trimethylbenzene	95-63-6	U	0.1	U	0.01	9/24/18 13:21	A18092409
1,3-Dichlorobenzene	541-73-1	U	0.1	U	0.01	9/24/18 13:21	A18092409
1,4-Dichlorobenzene	106-46-7	U	0.1	U	0.01	9/24/18 13:21	A18092409
1,2-Dichlorobenzene	95-50-1	U	0.1	U	0.01	9/24/18 13:21	A18092409
1,2,4-Trichlorobenzene	120-82-1	U	0.1	U	0.01	9/24/18 13:21	A18092409
Naphthalene	91-20-3	U	0.1	U	0.01	9/24/18 13:21	A18092409
1,2,3-Trichlorobenzene	87-61-6	U	0.1	U	0.01	9/24/18 13:21	A18092409
2-Methylnaphthalene	91-57-6	U	0.1	U	0.01	9/24/18 13:21	A18092409

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Beacon Environmental Services, Inc.
2203A Commerce Road Suite 1
Forest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4367.1
Analysis Method TO17
Matrix: Air
Client ID/Field Sampling Location: **B125B**
Lab Sample ID: B125B-1078876

Client:	Analysis	Lab File ID	Dilution Factor
Arizona State University	**initial**	A18092410	1
Tempe, AZ	1st Dilution		
	2nd Dilution		
	3rd Dilution		

ph: 480-385-9671

Sample Collection Time: 9/18/18 4:14 PM
Sample Volume in Liters: 169.02
Date Received: 9/20/2018

COMPOUNDS	CAS#							
Vinyl Chloride	75-01-4	U	0.1	U	0.02	9/24/18 13:44	A18092410	
1,1-Dichloroethene	75-35-4	U	0.1	U	0.01	9/24/18 13:44	A18092410	
1,1,2-Trichlorotrifluoroethane (Fr.113)	76-13-1	**0.27**	0.1	**0.04**	0.01	9/24/18 13:44	A18092410	
trans-1,2-Dichloroethene	156-60-5	U	0.1	U	0.01	9/24/18 13:44	A18092410	
Methyl-t-butyl ether	1634-04-4	U	0.1	U	0.02	9/24/18 13:44	A18092410	
1,1-Dichloroethane	75-34-3	U	0.1	U	0.01	9/24/18 13:44	A18092410	
cis-1,2-Dichloroethene	75-34-3	U	0.1	U	0.01	9/24/18 13:44	A18092410	
Chloroform	67-66-3	U	0.1	U	0.01	9/24/18 13:44	A18092410	
1,2-Dichloroethane	107-06-2	U	0.1	U	0.01	9/24/18 13:44	A18092410	
1,1,1-Trichloroethane	71-55-6	U	0.1	U	0.01	9/24/18 13:44	A18092410	
Carbon Tetrachloride	56-23-5	**0.25**	0.1	**0.04**	0.01	9/24/18 13:44	A18092410	
Benzene	71-43-2	U	0.1	U	0.02	9/24/18 13:44	A18092410	
Trichloroethene	79-01-6	U	0.1	U	0.01	9/24/18 13:44	A18092410	1,4-
Dioxane	123-91-1	U	0.1	U	0.02	9/24/18 13:44	A18092410	
1,1,2-Trichloroethane	79-00-5	U	0.1	U	0.01	9/24/18 13:44	A18092410	
Toluene	108-88-3	**0.28**	0.1	**0.08**	0.02	9/24/18 13:44	A18092410	
Tetrachloroethene	127-18-4	U	0.1	U	0.01	9/24/18 13:44	A18092410	
1,1,1,2-Tetrachloroethane	630-20-6	U	0.1	U	0.01	9/24/18 13:44	A18092410	
Chlorobenzene	108-90-7	U	0.1	U	0.01	9/24/18 13:44	A18092410	
Ethylbenzene	100-41-4	**0.09**	0.1	**0.02**	0.01	9/24/18 13:44	A18092410	
p & m-Xylene	108-38-3	**0.3**	0.1	**0.07**	0.01	9/24/18 13:44	A18092410	
1,1,2,2-Tetrachloroethane	79-34-5	U	0.1	U	0.01	9/24/18 13:44	A18092410	o-
Xylene	95-47-6	**0.12**	0.1	**0.03**	0.01	9/24/18 13:44	A18092410	
1,2,3-Trichloropropane	96-18-4	U	0.1	U	0.01	9/24/18 13:44	A18092410	
Isopropylbenzene	98-82-8	U	0.1	U	0.01	9/24/18 13:44	A18092410	
1,3,5-Trimethylbenzene	99-06-6	U	0.1	U	0.01	9/24/18 13:44	A18092410	
1,2,4-Trimethylbenzene	95-63-6	U	0.1	U	0.01	9/24/18 13:44	A18092410	
1,3-Dichlorobenzene	541-73-1	U	0.1	U	0.01	9/24/18 13:44	A18092410	
1,4-Dichlorobenzene	106-46-7	U	0.1	U	0.01	9/24/18 13:44	A18092410	
1,2-Dichlorobenzene	95-50-1	U	0.1	U	0.01	9/24/18 13:44	A18092410	
1,2,4-Trichlorobenzene	120-82-1	U	0.1	U	0.01	9/24/18 13:44	A18092410	
Naphthalene	91-20-3	U	0.1	U	0.01	9/24/18 13:44	A18092410	
1,2,3-Trichlorobenzene	87-61-6	U	0.1	U	0.01	9/24/18 13:44	A18092410	
2-Methylnaphthalene	91-57-6	U	0.1	U	0.01	9/24/18 13:44	A18092410	

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Beacon Environmental Services, Inc.
2203A Commerce Road Suite 1
Forest Hill, MD 21050 USA
ph:410-838-8780
www.beacon-usa.com

Beacon Job Number: 4367.1
Analysis Method TO17
Matrix: QC

Lab Sample ID: CL_LCS_180924

	Analysis	Lab File ID
Client:	initial	A18092413
Arizona State University	1st Dilution	
Tempe, AZ	2nd Dilution	
	3rd Dilution	
ph: 480-385-9671		

COMPOUNDS	CAS#	Results	Units	Limits	Analysis Time	Lab File ID
Vinyl Chloride	75-01-4	**73%**	%REC	50-150	9/24/18 15:39	A18092413
1,1-Dichloroethene	75-35-4	**107%**	%REC	50-150	9/24/18 15:39	A18092413
1,1,2-Trichlorotrifluoroethane (Fr.113)	76-13-1	**80%**	%REC	50-150	9/24/18 15:39	A18092413
trans-1,2-Dichloroethene	156-60-5	**114%**	%REC	50-150	9/24/18 15:39	A18092413
Methyl-t-butyl ether	1634-04-4	**95%**	%REC	50-150	9/24/18 15:39	A18092413
1,1-Dichloroethane	75-34-3	**103%**	%REC	50-150	9/24/18 15:39	A18092413
cis-1,2-Dichloroethene	75-34-3	**100%**	%REC	50-150	9/24/18 15:39	A18092413
Chloroform	67-66-3	**104%**	%REC	50-150	9/24/18 15:39	A18092413
1,2-Dichloroethane	107-06-2	**108%**	%REC	50-150	9/24/18 15:39	A18092413
1,1,1-Trichloroethane	71-55-6	**115%**	%REC	50-150	9/24/18 15:39	A18092413
Carbon Tetrachloride	56-23-5	**125%**	%REC	50-150	9/24/18 15:39	A18092413
Benzene	71-43-2	**97%**	%REC	50-150	9/24/18 15:39	A18092413
Trichloroethene	79-01-6	**106%**	%REC	50-150	9/24/18 15:39	A18092413
1,4-Dioxane	123-91-1	**98%**	%REC	50-150	9/24/18 15:39	A18092413
1,1,2-Trichloroethane	79-00-5	**101%**	%REC	50-150	9/24/18 15:39	A18092413
Toluene	108-88-3	**105%**	%REC	50-150	9/24/18 15:39	A18092413
Tetrachloroethene	127-18-4	**102%**	%REC	50-150	9/24/18 15:39	A18092413
1,1,1,2-Tetrachloroethane	630-20-6	**138%**	%REC	50-150	9/24/18 15:39	A18092413
Chlorobenzene	108-90-7	**100%**	%REC	50-150	9/24/18 15:39	A18092413
Ethylbenzene	100-41-4	**103%**	%REC	50-150	9/24/18 15:39	A18092413
p & m-Xylene	108-38-3	**101%**	%REC	50-150	9/24/18 15:39	A18092413
1,1,2,2-Tetrachloroethane	79-34-5	**105%**	%REC	50-150	9/24/18 15:39	A18092413
o-Xylene	95-47-6	**100%**	%REC	50-150	9/24/18 15:39	A18092413
1,2,3-Trichloropropane	96-18-4	**100%**	%REC	50-150	9/24/18 15:39	A18092413
Isopropylbenzene	98-82-8	**102%**	%REC	50-150	9/24/18 15:39	A18092413
1,3,5-Trimethylbenzene	99-06-6	**113%**	%REC	50-150	9/24/18 15:39	A18092413
1,2,4-Trimethylbenzene	95-63-6	**105%**	%REC	50-150	9/24/18 15:39	A18092413
1,3-Dichlorobenzene	541-73-1	**103%**	%REC	50-150	9/24/18 15:39	A18092413
1,4-Dichlorobenzene	106-46-7	**97%**	%REC	50-150	9/24/18 15:39	A18092413
1,2-Dichlorobenzene	95-50-1	**98%**	%REC	50-150	9/24/18 15:39	A18092413
1,2,4-Trichlorobenzene	120-82-1	**102%**	%REC	50-150	9/24/18 15:39	A18092413
Naphthalene	91-20-3	**91%**	%REC	50-150	9/24/18 15:39	A18092413
1,2,3-Trichlorobenzene	87-61-6	**103%**	%REC	50-150	9/24/18 15:39	A18092413
2-Methylnaphthalene	91-57-6	**133%**	%REC	50-150	9/24/18 15:39	A18092413

U = Not detected or below Reporting Limit (RL).; E = Measurement exceeded upper calibration range of instrument. D = Sample dilution performed.

Attachment 1

Chain of Custody

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1. Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information		Project Manager: Paul Dahlen	BEACON Project No.: 4367.1
Company: AZ State Univ		Phone: 480-727-2960	Client PO No.
Address:		Project Name: Apts.	Analysis Turnaround Time
City/State/Zip: Tempe AZ		Location: Beale AFB	✓ Normal ✓
Phone:		Sampler Name(s): Paul Dahlen	Rush (Specify): ____ days

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	TO-17	8260B	TICs	Indoor/Ambient Air	Soil Gas
B101B	1078605	Passive Sampler	9/18/18	1452	9/12/18	0834	49.18	48.57	175.95		5382		min	
B105B	1078697		"	1450	"	0824	54.07	53.94	194.09		5374		min	
B110B	1078709		"	1444	"	0812	51.26	49.64	180.71		5368		min	
BLaundry	1078610		"	1611	"	0844	48.30	45.77	166.50		5313		min	
B121B	1078523		"	1612	"	0853	51.30	50.70	180.54		5321		min	
B125B	1078876		"	1614	"	0910	48.89	46.33	169.02		5336		min	
	TD sampling for 1 hour every 1.5 hours throughout sampling period						Total TD volume				Passive Sampler Exposure Time			

Ambient Conditions When Sampling	Temperature (F)	Barometric Pressure (mmHg)	Date
Start	~70		
Stop	~70		

Pump(s) Calibration and Flow Rate Check: Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Pre-Survey			
Post-Survey			

Special Notes/Instructions:

Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:
Paul Dahlen	9/18/18	Courier	
FedEx		[signature]	9/20/18 1307

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	FedEx	Good		Yes No (None)	

Base	Bldg	Location	Test Condition	Manifold port	Sample Name via Sample Type					Pump	Deploy	Retrieve	Deploy Time (min)	TD Runtime (min)	Flow (ml/min)			Total volume (L)
					Beacon Passive	Beacon TD	TD	TD Backup	MTS-32						Start	Stop	Avg.	
Beale	Apts	B101B	Passive	1	---	---	1067954	---	---	11	9/8/18 14:52	9/12/18 8:34	5382	3600	36.90	36.46	36.68	132.05
				2	Yes	1078605	---	---	---						49.18	48.57	48.88	175.95
				3	---	---	1100874	1100817	---						51.54	51.32	51.43	185.15
		B105B		1	---	---	1100863	---	---	10	9/8/18 14:50	9/12/18 8:24	5374	3594	44.39	43.54	43.97	158.01
				2	Yes	1078697	---	---	---						54.07	53.94	54.01	194.09
				3	---	---	1101494	1100921	---						54.87	54.38	54.63	196.32
		B110B		1	---	---	1049361	1101456	---	12	9/8/18 14:44	9/12/18 8:12	5368	3582	53.55	52.51	53.03	189.95
				2	---	---	1101178	---	---						42.32	41.00	41.66	149.23
				3	Yes	1078709	---	---	---						51.26	49.64	50.45	180.71
		Blaundry		1	---	---	1101121	---	---	13	9/8/18 16:11	9/12/18 8:44	5313	3540	39.89	37.17	38.53	136.40
				2	Yes	1078610	---	---	---						48.30	45.77	47.04	166.50
				3	---	---	1101345	1100891	---						52.66	51.28	51.97	183.97
		B121B		1	---	---	1101088	---	---	14	9/8/18 16:12	9/12/18 8:53	5321	3540	52.48	51.77	52.13	184.52
				2	---	---	1101373	---	---						48.60	47.54	48.07	170.17
				3	Yes	1078523	---	---	---						51.30	50.70	51.00	180.54
		B125B		1	---	---	1101314	---	---	15	9/8/18 16:14	9/12/18 9:10	5336	3550	47.27	46.50	46.89	166.44
				2	Yes	1078876	---	---	---						48.89	46.33	47.61	169.02
				3	---	---	1100816	1100953	---						55.37	55.04	55.21	195.98

Appendix 24176B
Background Indoor Air Sampling – Passive Air Sampler
Analytical Report

Arizona State University
660 South College Avenue, Room 507
Tempe, AZ 85281
Attn: Paul Dahlen

Passive Air Sampling – Analytical Report
Date: October 17, 2018

Beacon Project No. 4367.1B

Site Name/Location:	Beale AFB
Sampling Period:	September 8 through 12, 2018
Samples Received:	September 20, 2018
Analyses Completed:	September 24, 2018

Results for the following air samples are included in this data package:

Sample ID	Matrix	Analytical Method
B101B	Air	EPA Method TO-17
B105B	Air	EPA Method TO-17
B110B	Air	EPA Method TO-17
BLaundry	Air	EPA Method TO-17
B121B	Air	EPA Method TO-17
B125B	Air	EPA Method TO-17

Sample Collection

Beacon Environmental provided thermally conditioned passive samplers to target a select list of compounds, with analyses following U.S. EPA Method TO-17. These air samples were exposed to air for four (4) days and the resulting mass of target analytes captured on each sampler was reported as a concentration.

U. S. EPA Method TO-17

All samples were analyzed for a custom target compound list following U.S. EPA Method TO-17.

The analytical results are reported in **Table 1**, with results reported in micrograms per cubic meter (µg/m^3) using the following equations:

$$C = \frac{1000 \times M \times d}{U \times t}$$

where:

C	=	concentration (µg/m^3)
M	=	mass (ng)
d	=	dilution factor
U	=	uptake rate (ml/min),
t	=	sampling time (minutes)

The following table provides uptake rates for the compounds reported in this investigation.

Compound	Uptake Rate (ml/min)
Vinyl Chloride	0.74
1,1-Dichloroethane	0.32
1,1,2-Trichlorotrifluoroethane (Freon 113)	0.82
Trans-1,2-Dichloroethene	0.42
Methyl t butyl ether	0.49
1,1 Dichloroethane	0.80
Cis-1,2-dichloroethene	0.52
Chloroform	0.34
1,2-Dichloroethane	0.54
1,1,1Trichloroethane	0.98
Carbon Tetrachloride	0.41
Benzene	0.52
Trichloroethene	0.33
1,4-Dioxane	0.40
1,1,2-Trichloroethane	0.32
Toluene	0.39
1,2-Dibromoethane (EDB)	0.37
Tetrachloroethene	0.39
1,1,1,2-Tetrachloroethane	0.39
Chlorobenzene	0.80
Ethylbenzene	0.80
p&m-Xylene	0.82
1,1,2,2-Tetrachloroethane	0.39
o-Xylene	0.82
1,2,3-Trichloropropane	0.70
Isopropylbenzene	0.77
1,3,5-Trimethylbenzene	0.77
1,2,4-Trimethylbenzene	0.77
1,3-Dichlorobenzene	0.70
1,4 Dichlorobenzene	0.70
1,2-Dichlorobenzene	0.70
1,2,4-Trichlorobenzene	0.38
Naphthalene	0.75
1,2,3-Trichlorobenzene	0.38
2-Methylnaphthalene	0.71
TPH C_4-C_9	0.57
TPH C_{10}-C_{15}	0.64

Practical Quantification Levels (PQL) for EPA Method TO-17

The lowest point in the calibration curve and the limit of quantitation (LOQ) is 10 nanograms (ng); however, when reporting concentration data in **Table 1**, the values are provided in micrograms per meter cubed ($\mu g/m^3$). The LOQs are additionally based on the sample collection times, the uptake rates, and the dilution factors.

Calibration Verification

The continuing calibration verification (CCV) values for the analytes were all within ±20% of the true values as defined by the initial five-point calibration and met the requirements specified in Beacon Environmental's Quality Manual.

Internal Standards and Surrogates

Internal standards and surrogates are spiked at 100 ng and 50 ng, respectively, and percentage of recovery is calculated. Acceptance criteria for internal standards are 60 to 140 percent and surrogate recoveries are 70 to 130 percent; all internal standards and surrogates were within the acceptance criteria.

Blank Contamination

No targeted compounds above the LOQ for each compound were observed in the Laboratory Method Blank (LB_180924). For comparison to field sample results, the longest sampling time was used to calculate the LOQs for the blanks.

Laboratory Control Sample/Calibration Verification

The first laboratory control sample (LCS) in the analytical sequence, which is the continuing calibration verification (CCV), is spiked at the mid-point of the initial calibration. Reported measurements for each targeted compound for this sample were within ±20% of the true value as defined by the initial five-point calibration. The laboratory control sample duplicate (LSCD) is from a second source and is also spiked at the mid-point of the initial calibration. Reported measurements for each targeted compound were within ±20% of the true value as defined by the initial five-point calibration; the LCS that served as the closing calibration was within ±50% of the true value.

Discussion

Six (6) air samples were received by Beacon Environmental on September 20, 2018. Sampling start and stop dates and times can be found in the Chain of Custody (**Attachment 1**).

Demonstrated Linear Range of the GC-MS Instrumentation (EPA Method TO-17)

An initial five-point calibration is performed on the instrumentation from 10 to 200 ng per analyte.

Attachments:

-1- Chain of Custody

ALL DATA MEET REQUIREMENTS AS SPECIFIED IN THE BEACON ENVIRONMENTAL SERVICES, INC. QUALITY ASSURANCE PROJECT PLAN AND THE RESULTS RELATE ONLY TO THE SAMPLES REPORTED. BEACON ENVIRONMENTAL SERVICES IS ACCREDITED TO ISO/IEC 17025, AND THE WORK PERFORMED WAS IN ACCORDANCE WITH ISO/IEC 17025 REQUIREMENTS, WITH THE EXCEPTION THAT SAMPLES WERE ANALYZED WITHIN A 24-HOUR TUNE WINDOW AND TPH C_4-C_9 AND TPH C_{10}-C_{15} ARE NOT INCLUDED IN BEACON'S SCOPE OF ACCREDITATION. THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY. RELEASE OF THE DATA CONTAINED IN THIS HARDCOPY DATA PACKAGE HAS BEEN AUTHORIZED BY THE LABORATORY DIRECTOR OR HIS SIGNEE, AS VERIFIED BY THE FOLLOWING SIGNATURES:

Steven C. Thornley
Laboratory Director

Patti J. Riggs
Quality Manager

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

Sample ID:	LB_180924	B101B	B105B	B110B	BLaundry	B121B
Project Number:	4367.1B	4367.1B	4367.1B	4367.1B	4367.1B	4367.1B
Lab File ID:	A18092415	A18092417	A18092418	A18092419	A18092420	A18092421
Received Date:		9/20/2018	9/20/2018	9/20/2018	9/20/2018	9/20/2018
Analysis Date:	9/24/2018	9/24/2018	9/24/2018	9/24/2018	9/24/2018	9/24/2018
Analysis Time:	16:48	17:33	17:58	18:23	18:48	19:13
Dilution Factor:	1.00	1.00	1.00	1.00	1.00	1.00
Units:	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
COMPOUNDS						
Vinyl Chloride	<2.52	<2.52	<2.52	<2.52	<2.55	<2.55
1,1-Dichloroethene	<5.88	<5.88	<5.88	<5.89	<5.95	<5.94
1,1,2-Trichlorotrifluoroethane (Fr.113)*	<2.25	<2.25	<2.26	<2.26	<2.28	<2.28
trans-1,2-Dichloroethene	<4.41	<4.41	<4.41	<4.42	<4.46	<4.46
Methyl-t-butyl ether*	<3.81	<3.81	<3.82	<3.82	<3.86	<3.86
1,1-Dichloroethane	<2.31	<2.31	<2.31	<2.31	<2.34	<2.33
cis-1,2-Dichloroethene	<3.59	<3.59	<3.60	<3.60	<3.64	<3.63
Chloroform*	<5.43	<5.43	<5.44	**6.10**	<5.50	<5.49
1,2-Dichloroethane	<3.46	<3.46	<3.47	<3.47	<3.51	<3.50
1,1,1-Trichloroethane	<1.90	<1.90	<1.90	<1.91	<1.93	<1.92
Carbon Tetrachloride*	<4.56	<4.56	<4.56	<4.57	<4.61	<4.61
Benzene	<3.59	<3.59	<3.60	<3.60	<3.64	<3.63
Trichloroethene	<5.70	<5.70	<5.71	<5.72	<5.78	<5.77
1,4-Dioxane*	<4.63	<4.63	<4.63	<4.64	<4.69	<4.68
1,1,2-Trichloroethane *	<5.75	<5.75	<5.75	<5.76	<5.82	<5.81
Toluene	<4.73	<4.73	<4.74	**10.03**	**11.80**	<4.78
1,2-Dibromoethane (EDB)*	<5.03	<5.03	<5.04	<5.05	<5.10	<5.09
Tetrachloroethene	<4.73	<4.73	<4.74	<4.74	<4.79	<4.78
1,1,1,2-Tetrachloroethane *	<4.76	<4.76	<4.77	<4.77	<4.82	<4.81
Chlorobenzene*	<2.32	<2.32	<2.32	<2.33	<2.35	<2.35
Ethylbenzene	<2.34	<2.34	<2.34	<2.34	<2.37	<2.36
p & m-Xylene	<2.25	<2.25	<2.26	<2.26	<2.28	<2.28
1,1,2,2-Tetrachloroethane*	<4.76	<4.76	<4.77	<4.77	<4.82	<4.81
o-Xylene	<2.25	<2.25	<2.26	<2.26	<2.28	<2.28
1,2,3-Trichloropropane*	<2.66	<2.66	<2.66	<2.66	<2.69	<2.69
Isopropylbenzene*	<2.40	<2.40	<2.40	<2.40	<2.43	<2.43
1,3,5-Trimethylbenzene*	<2.40	<2.40	<2.40	<2.40	<2.43	<2.43
1,2,4-Trimethylbenzene*	<2.40	<2.40	<2.40	<2.40	<2.43	<2.43
1,3-Dichlorobenzene*	<2.65	<2.65	<2.66	<2.66	<2.69	<2.68
1,4-Dichlorobenzene*	<2.65	<2.65	<2.66	<2.66	<2.69	<2.68
1,2-Dichlorobenzene*	<2.65	<2.65	<2.66	<2.66	<2.69	<2.68
1,2,4-Trichlorobenzene*	<4.95	<4.95	<4.95	<4.96	<5.01	<5.00
Naphthalene*	<2.48	<2.48	<2.48	<2.48	<2.51	<2.51
1,2,3-Trichlorobenzene*	<4.95	<4.95	<4.95	<4.96	<5.01	<5.00
2-Methylnaphthalene*	<2.61	**2.43 J**	<2.61	<2.62	<2.64	<2.64
TPH c4-c9*	<1,640.01	<1,640.01	<1,642.45	<1,644.28	<1,661.31	<1,658.81
TPH c10-c15*	<1,446.64	<1,446.64	<1,448.79	<1,450.41	<1,465.43	<1,463.23

Results in micrograms per cubic meter (ug/m3). B = Detected in method blank. J = Value below limit of quantitation (LOQ) but above limit of detection (LOD).
*=Uptake rate estimated using Graham's Law of Diffusion.

Table 1

Beacon Environmental Services, Inc.
2203A Commerce Road, Suite 1
Forest Hill, MD 21050 USA

Analysis by EPA Method TO-17

Sample ID:	B125B
Project Number:	4367.1B
Lab File ID:	A18092422
Received Date:	9/20/2018
Analysis Date:	9/24/2018
Analysis Time:	19:39
Dilution Factor:	1.00
Units:	ug/m3

COMPOUNDS	
Vinyl Chloride	<2.54
1,1-Dichloroethene	<5.93
1,1,2-Trichlorotrifluoroethane (Fr.113)*	<2.27
trans-1,2-Dichloroethene	<4.44
Methyl-t-butyl ether*	<3.85
1,1-Dichloroethane	<2.33
cis-1,2-Dichloroethene	<3.62
Chloroform*	<5.47
1,2-Dichloroethane	<3.49
1,1,1-Trichloroethane	<1.92
Carbon Tetrachloride*	<4.59
Benzene	<3.62
Trichloroethene	<5.75
1,4-Dioxane*	<4.67
1,1,2-Trichloroethane *	<5.80
Toluene	<4.77
1,2-Dibromoethane (EDB)*	<5.08
Tetrachloroethene	<4.77
1,1,1,2-Tetrachloroethane *	<4.80
Chlorobenzene*	<2.34
Ethylbenzene	<2.36
p & m-Xylene	<2.27
1,1,2,2-Tetrachloroethane*	<4.80
o-Xylene	<2.27
1,2,3-Trichloropropane*	<2.68
Isopropylbenzene*	<2.42
1,3,5-Trimethylbenzene*	<2.42
1,2,4-Trimethylbenzene*	<2.42
1,3-Dichlorobenzene*	<2.68
1,4-Dichlorobenzene*	<2.68
1,2-Dichlorobenzene*	<2.68
1,2,4-Trichlorobenzene*	<4.99
Naphthalene*	<2.50
1,2,3-Trichlorobenzene*	<4.99
2-Methylnaphthalene*	<2.63
TPH c4-c9*	<1,654.15
TPH c10-c15*	<1,459.11

Results in micrograms per cubic meter (ug/m3). B = Detected in method blank. J = Value below limit of quantitation (LOQ) but above limit of detection (LOD).
*=Uptake rate estimated using Graham's Law of Diffusion.

Attachment 1

Chain of Custody

BEACON ENVIRONMENTAL SERVICES, INC.

CHAIN-OF-CUSTODY

2203A Commerce Road, Suite 1. Forest Hill, MD 21050
P: 410-838-8780 / fax: 410-838-8740

Client Contact Information	Project Information	BEACON Information
Company: AZ State Univ	Project Manager: Paul Dahlen	BEACON Project No.: 4367.1
Address:	Phone: 480-727-2960	Client PO No.
City/State/Zip: Tempe AZ	Project Name: Apts.	Analysis Turnaround Time: ✓ Normal ✓
Phone:	Location: Beale AFB	Rush (Specify): ______ days
	Sampler Name(s): Paul Dahlen	

Location ID	Tube ID Number	Pump ID Number	Start Time Date	Start Time Time	Stop Time Date	Stop Time Time	Pre-survey Measured Pump Flow Rate (mL/min)	Post-survey Measured Pump Flow Rate (mL/min)	Total Volume (L)	TO-17	8260B	TICs	Indoor/Ambient Air	Soil Gas
B101B	1078605	Passive Sampler	9/18/18	1452	9/12/18	0834	49.18	48.57	175.95		5382		min	
B105B	1078697		"	1450	"	0824	54.07	53.94	194.09		5374		min	
B110B	1078709		"	1444	"	0812	51.26	49.64	180.71		5368		min	
B Laundry	1078610		"	1611	"	0844	48.30	45.77	166.50		5313		min	
B121B	1078523		"	1612	"	0853	51.30	50.70	180.54		5321		min	
B125B	1078876		"	1614	"	0910	48.89	46.33	169.02		5336		min	

TD sampling for 1 hour every 1.5 hours throughout sampling period. Total TD volume. Passive Sampler Exposure Time.

Ambient Conditions When Sampling

	Temperature (F)	Barometric Pressure (mmHg)	Date
Start	~70		
Stop	~70		

Pump(s) Calibration and Flow Rate Check:

Cal. Tube ID:	Date	Lab or Field	Flow Meter Make/Serial #
Pre-Survey			
Post-Survey			

Special Notes/Instructions:

Relinquished by: (signature) Paul Dahlen	Date/Time: 9/18/18	Received by: (signature) Courier	Date/Time:
Relinquished by: (signature) FedEx	Date/Time:	Received by: (signature) [signature]	Date/Time: 9/20/18 1307
Relinquished by: (signature)	Date/Time:	Received by: (signature)	Date/Time:

Lab Use Only	Courier Name	Shipment Condition	Sample Delivery Group ID	Custody Seal Intact	Custody Seal No.
	FedEx	Good		Yes No (None)	

Beacon Project 4367.1B -- Page 7 of 8

Base	Bldg	Location	Test Condition	Manifold port	Sample Name via Sample Type					Pump	Deploy	Retrieve	Deploy Time (min)	TD Runtime (min)	Flow (ml/min)			Total volume (L)
					Beacon Passive	Beacon TD	TD	TD Backup	MTS-32						Start	Stop	Avg.	
Beale	Apts	B101B	Passive	1	---	---	1067954	---	---	11	9/8/18 14:52	9/12/18 8:34	5382	3600	36.90	36.46	36.68	132.05
				2	Yes	1078605	---	---	---						49.18	48.57	48.88	175.95
				3	---	---	1100874	1100817	---						51.54	51.32	51.43	185.15
		B105B		1	---	---	1100863	---	---	10	9/8/18 14:50	9/12/18 8:24	5374	3594	44.39	43.54	43.97	158.01
				2	Yes	1078697	---	---	---						54.07	53.94	54.01	194.09
				3	---	---	1101494	1100921	---						54.87	54.38	54.63	196.32
		B110B		1	---	---	1049361	1101456	---	12	9/8/18 14:44	9/12/18 8:12	5368	3582	53.55	52.51	53.03	189.95
				2	---	---	1101178	---	---						42.32	41.00	41.66	149.23
				3	Yes	1078709	---	---	---						51.26	49.64	50.45	180.71
		Blaundry		1	---	---	1101121	---	---	13	9/8/18 16:11	9/12/18 8:44	5313	3540	39.89	37.17	38.53	136.40
				2	Yes	1078610	---	---	---						48.30	45.77	47.04	166.50
				3	---	---	1101345	1100891	---						52.66	51.28	51.97	183.97
		B121B		1	---	---	1101088	---	---	14	9/8/18 16:12	9/12/18 8:53	5321	3540	52.48	51.77	52.13	184.52
				2	---	---	1101373	---	---						48.60	47.54	48.07	170.17
				3	Yes	1078523	---	---	---						51.30	50.70	51.00	180.54
		B125B		1	---	---	1101314	---	---	15	9/8/18 16:14	9/12/18 9:10	5336	3550	47.27	46.50	46.89	166.44
				2	Yes	1078876	---	---	---						48.89	46.33	47.61	169.02
				3	---	---	1100816	1100953	---						55.37	55.04	55.21	195.98

APPENDIX F SUB-SLAB DEPRESSURIZATION SYSTEM FLOWRATE DETERMINATION USINGTHE ESTCP PROJECT ER-201322 DESIGN APPROACH.

APPENDIX F: SUB-SLAB DEPRESSURIZATION SYSTEM FLOWRATE DETERMINATION USING THE ESTCP PROJECT ER-201322 DESIGN APPROACH.

ESTCP Project ER-201322 sub-slab depressurization system design overview.

A novel approach for the design of sub-slab depressurization (SSD) mitigation systems was developed recently through ESTCP Project ER-201322. The approach employs sub-slab pneumatic and tracer tests to determine the transmissivity (T) of the material below the floor, the leakage (B) across the floor slab, and the thickness of the zone through which flow predominantly occurs (b). Those are then input to design calculations that determine the vacuum, gas velocity, and travel time distributions, and relative proportions of flow from above and below the slab for a given extraction flow rate (Q_{SSV}). These calculations guide the selection of the SSD fan flowrate and the location/spacing of suction points to meet the following criteria:

- The induced vacuum within the radius of influence (ROI) of the SSD system should exceed the 95th percentile of the subslab to indoor pressure differential under natural conditions.
- The air flow velocity within the SSD ROI should be greater than a safety factor (SF) × 3 ft/d.
- The travel time from all locations within the ROI should be less than 0.1 day.
- The portion of flow coming from below the floor should be greater than SF × 5L/min/1000 ft^2.

Site specific measurements at Sun Devil Manor

Building-specific pneumatic and tracer testing was conducted at Sun Devil Manor by the ER-201322 project team and is found in the ER-201322 final report, section 7. Key test results are summarized below:

- The best-fit transmissivity (T) was 1200 ft^2/day
- The calculated leakage ranged from 7.4 ft to 30 ft using data from different sub-slab sampling points

For reference, the Sun Devil Manor SSD system has a single suction point installed near an exterior wall (Figure 6.4.1.1), so the longest radial distance to a vapor collection point is 20 ft (6.1 m). The total foundation area is 915 ft^2 (84 m^2).

ESTCP Project ER-201322 design approach applied to Sun Devil Manor

Cross slab differential pressure data for a period of 180 days under natural pressure condition was used to calculate the 95th percentile values at six monitoring locations distributed across the foundation. Table S1 summarizes the results. It should be noted that monitoring points 1-SS and

4-SS are located in the garage, and that part of the foundation is separated from the foundation beneath the lower level living area by a supporting sternum wall which acts as an impediment to soil gas flow through the sub-foundation gravel pack. Therefore, only the results from the other monitoring locations (2-SS, 3-SS, 5-SS, 6-SS) were used in the SSD system flowrate calculation. The greatest 95th percentile pressure difference was found at location 6-SS (0.58 Pa), and that value was used in the flowrate design calculation

Table S1. 95th percentile sub-slab soil gas to indoor air pressure differences for 180-day natural condition monitoring results.

Location	1-SS*	2-SS	3-SS	4-SS*	5-SS	6-SS
Pressure differences (Pa)	2.05	0.33	0.28	2.53	0.55	0.58

From an operation perspective, 27 CFM is the minimum soil vapor extraction rate that can be controlled with the SSD system at Sun Devil Manor. Thus, the equations developed in ER-201322 were used to predict vacuum distributions and vapor velocities for that flowrate. Those results are presented in Figures S1 and S2.

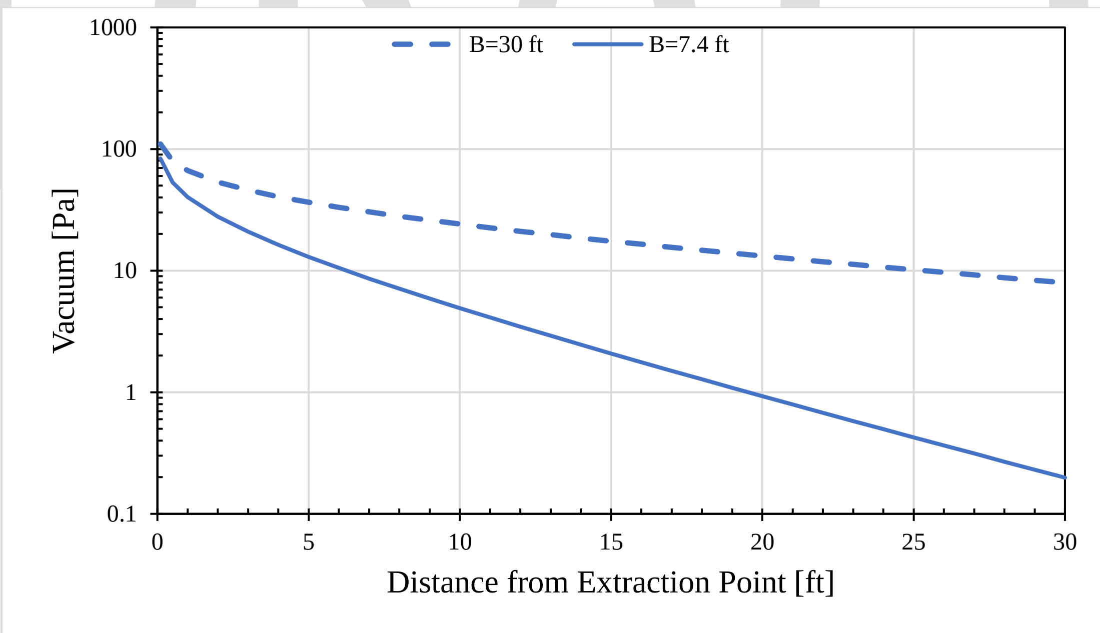

Figure S1. Predicted pressure difference vs. distance from the SSD soil vapor extraction point at a 27 CFM extraction flow rate.

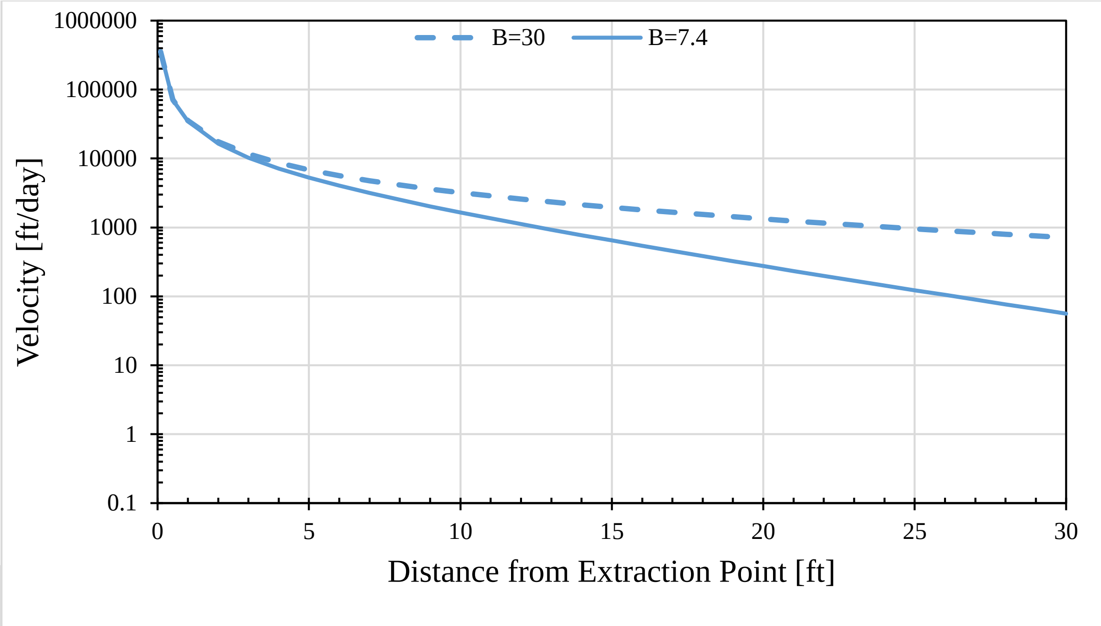

Figure S2. Predicted vapor velocity vs. distance from the SSD soil vapor extraction point at a 27 CFM extraction flow rate.

These results suggest that the SSD system at Sun Devil Manor, operating at its minimum flow rate of 27 CFM, should protect the building against vapor intrusion. With respect to the design criteria discussed above:

- At the 20 ft distance, pressure differences of 0.92 Pa and 13.2 Pa are predicted for B = 7.4 ft and B = 30 ft simulations, respectively. These values are all greater than the maximum 95th percentile pressure difference of all the monitoring points under natural conditions.
- Predicted air velocities are 275 ft/d and 1327 ft/d, and these are more than 10x greater than the 3 ft/d criterion.
- Travel times within 20 ft distance are calculated at 0.06 d and 0.01 d for B = 7.4 ft and B = 30 ft simulations, respectively. Both are less than the recommended 0.1 day criterion.
- The portion of flow coming from beneath the foundation for B = 7.4 ft and B = 30 ft calculations are 124 L/m/1000 ft^2 and 598 L/m/1000 ft^2, respectively. These are greater than the 5L/min/1000 ft^2 criterion.

Thus, when testing the protectiveness of the Sun Devil Manor SSD system, flowrates of 27, 54, and 110 CFM (110 CFM is the maximum system flow rate) are expected to be protective according to the ESTCP Project ER-201322 design approach.