NEWMOA
NORTHEAST WASTE MANAGEMENT OFFICIALS' ASSOCIATION

Vapor Intrusion:

Commercial/Industrial Investigation & Mitigation

January 23, 2024

Presented by:

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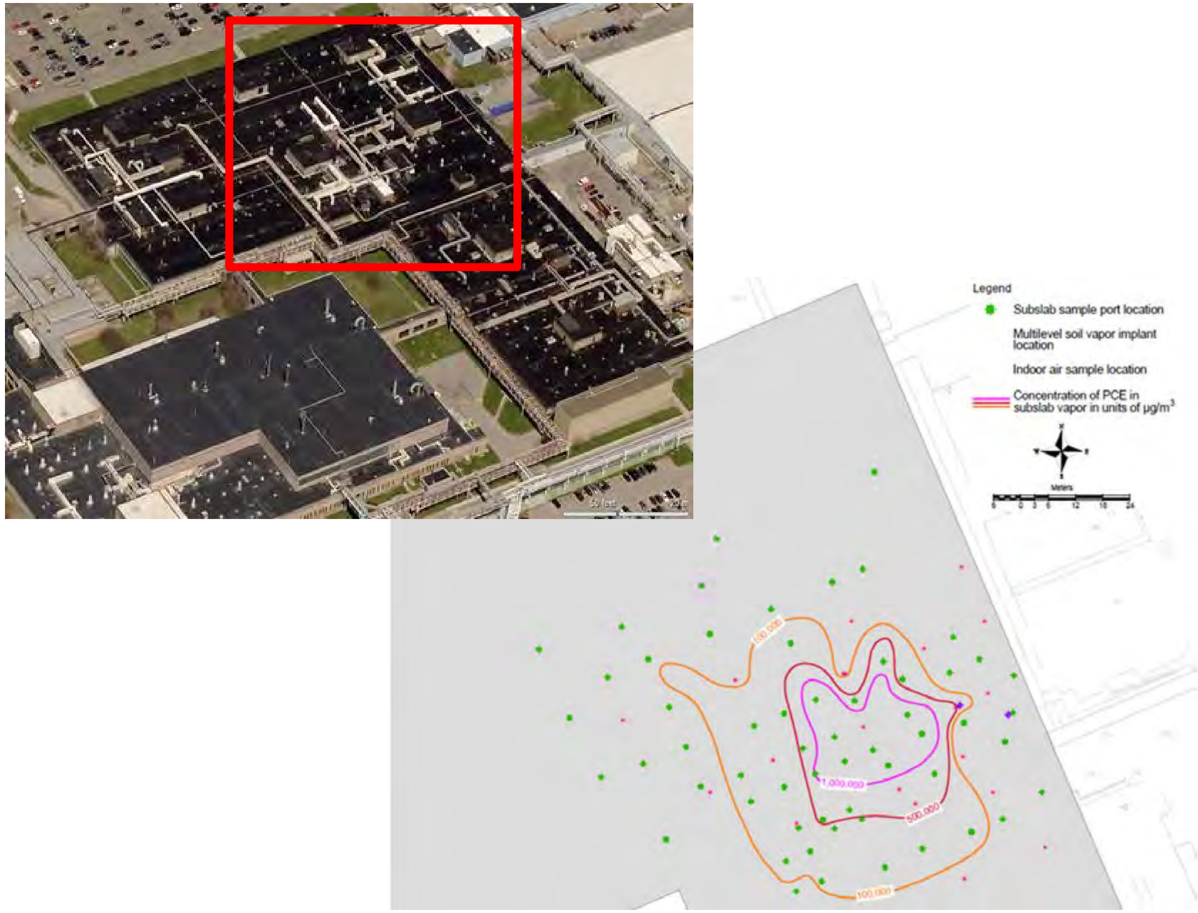

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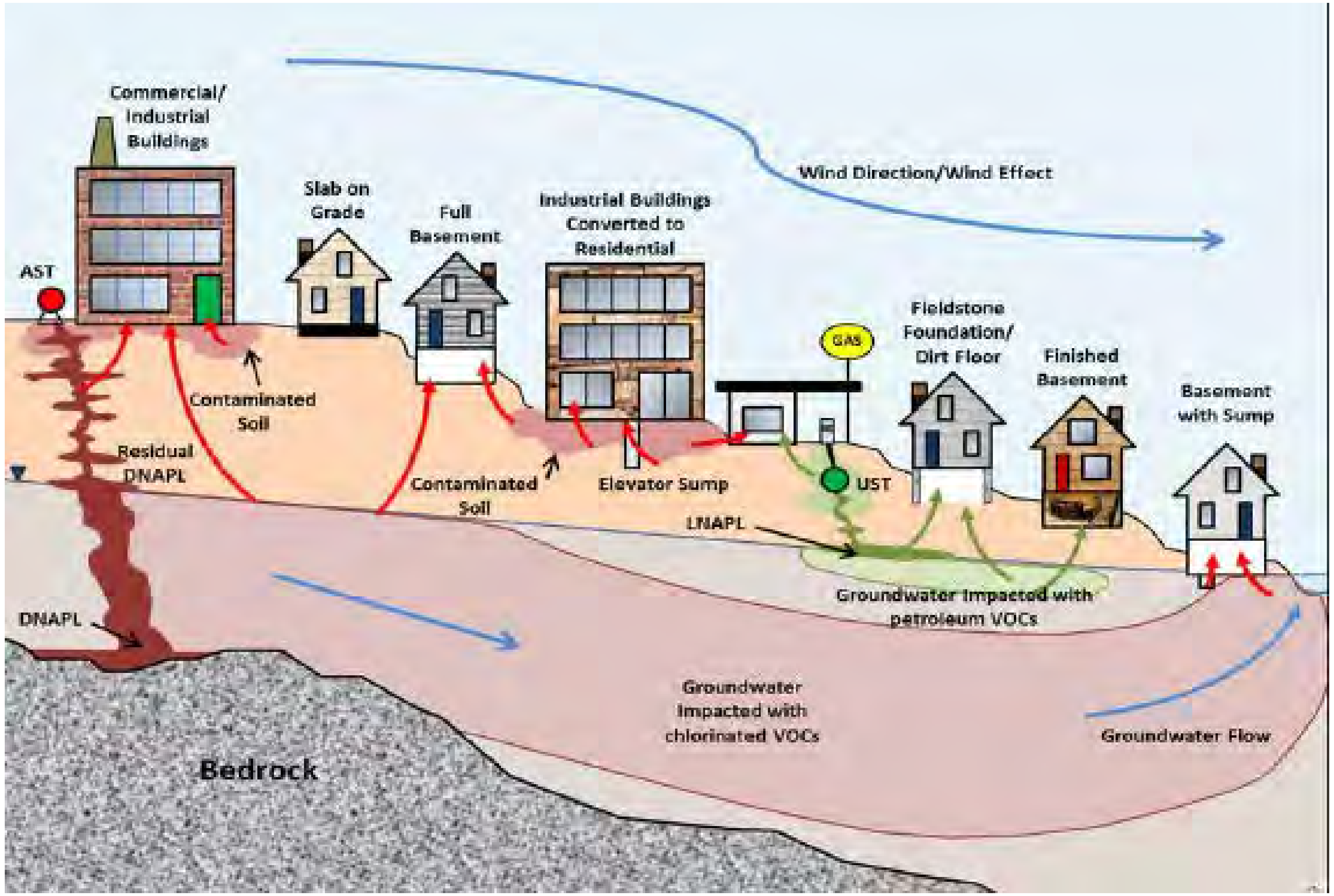
Topics:

- Key Factors for Commercial/Industrial Buildings vs. Residential (e.g., single family, duplexes, small apartment houses)

- VI Investigation and Diagnostic Technologies
  - Examples

- VI Mitigation
  - Existing buildings
  - New buildings
  - Examples

A "complete" VI pathway requires:



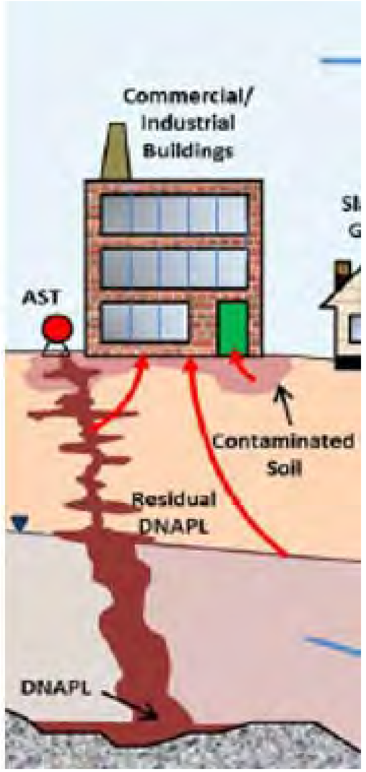
Mass DEP VI Guidance, 2016, Fig 2.1

- A subsurface source of vapor-forming chemicals
- A transport route to a building
- A means of vapor entry into the building (e.g., openings in the foundation)
- One or more receptors (people) in the building when the vapor-forming chemicals are present in indoor air

The VI pathway is incomplete if one or more of the above conditions is absent (and VI mitigation is not generally warranted)

Key Factors Affecting VI for Existing Commercial/Industrial Buildings (vs. typical residential VI assessment)

- Size - Area and volume of building
  - ➢ More ground to cover
- Foundation and infrastructure complexity
  - ➢ More potential VI pathways
  - ➢ Variable construction/additions
- Interior VOC sources
  - ➢ Chemical use in industrial buildings
  - ➢ Off-gassing of VOCs adsorbed to building materials
- Heterogeneity of sub-surface contaminant presence
  - ➢ Potential for separate phase, dissolved phase, and vapor phase VOCs in different areas beneath the building
- Influence of active HVAC systems
  - ➢ May suppress/mask VI, or make VI worse



Mass DEP VI Guidance, 2016, Fig 2.1

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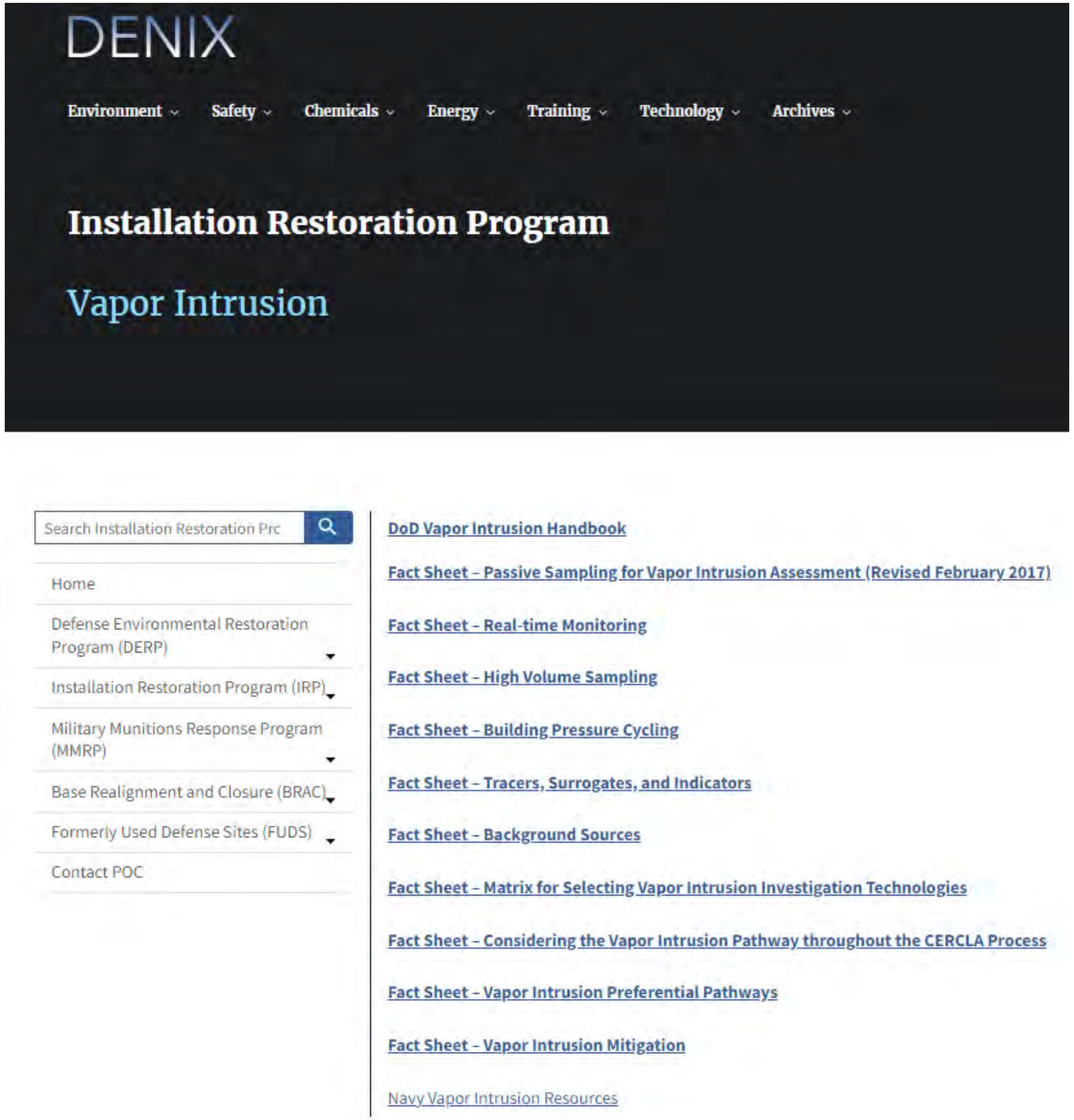
Vapor Intrusion Investigation/Diagnostic Technologies

- Real-time monitoring
- Building pressure control
- HVAC shutdown testing
- High volume sampling



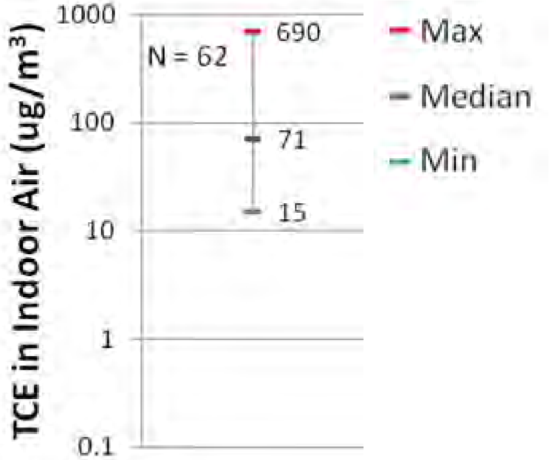
https://www.denix.osd.mil/irp/vaporintrusion/

Real time indoor air screening

Hapsite portable gas chromatograph – mass spectrometer

Indoor air screening with portable GC-MS

- 62 samples during 2 days
- TCE ranged from 15 to 690 ug/m^3 (median of 71)



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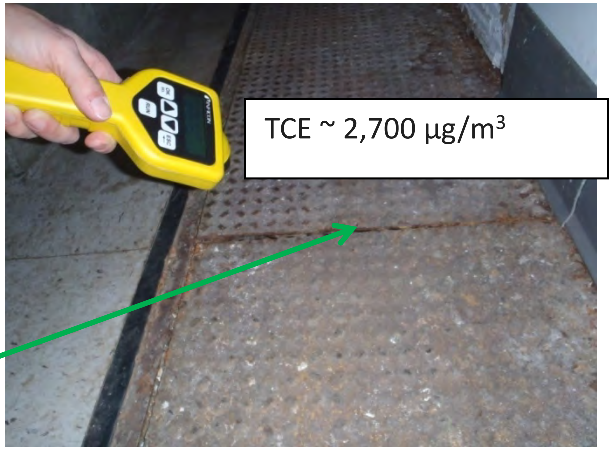
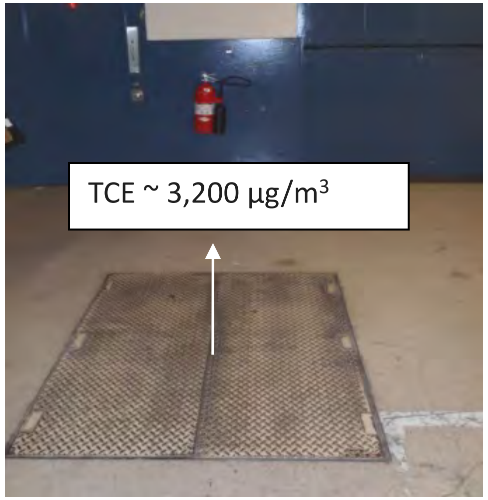
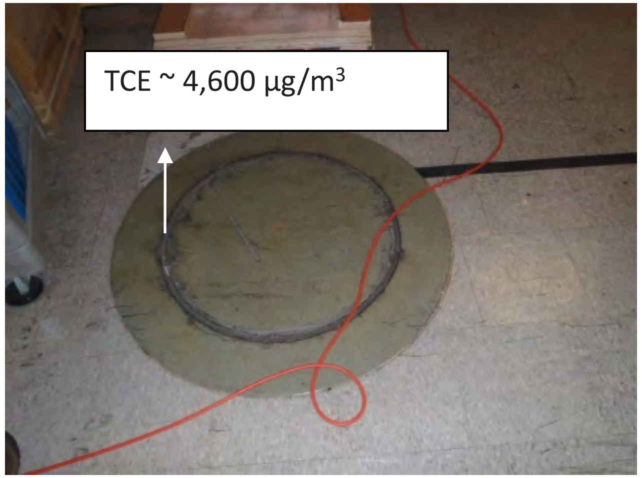
Identifying the vapor entry pathways:

HVAC mechanical rooms under negative pressure

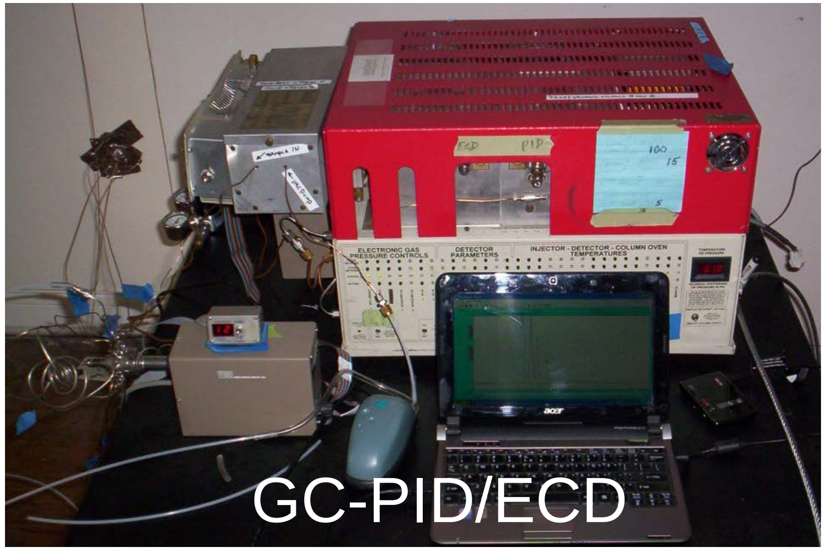


Targeted screening of interior storm drain manholes

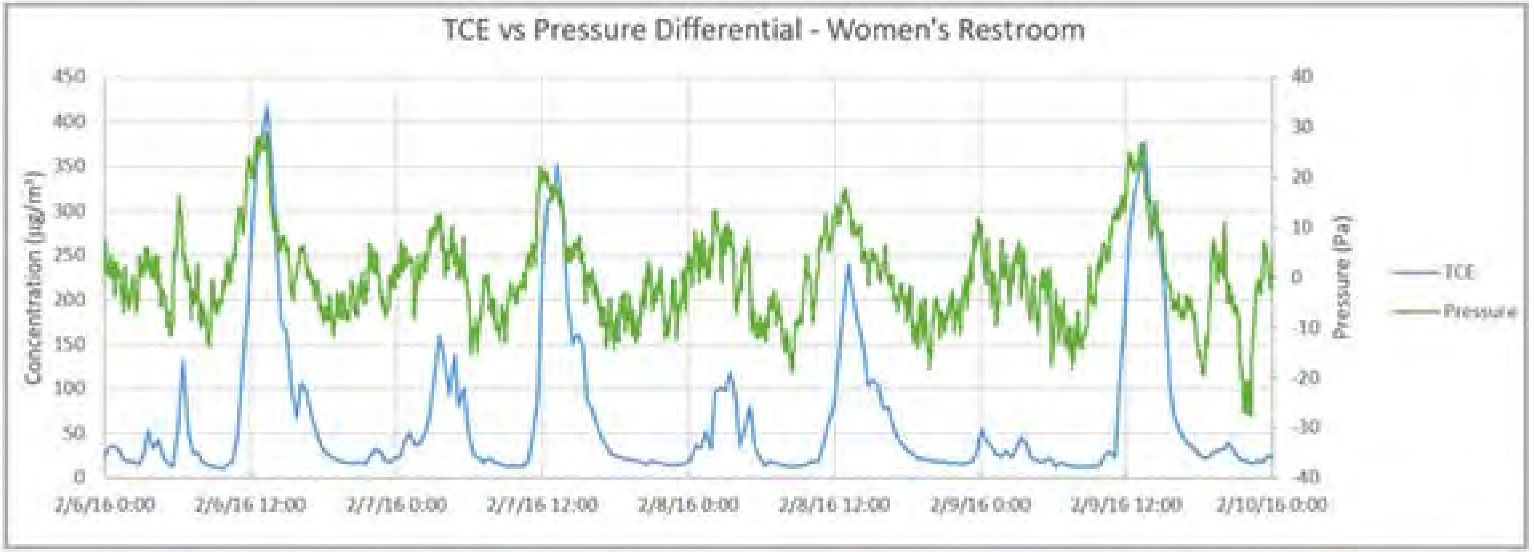




Continuous real-time air monitoring



HARTMAN
ENVIRONMENTAL GEOSCIENCE



GROUNDSWELL
EARTH MONITORING SOFTWARE

Hosangadi *et al.*, 2017, *High Frequency Continuous Monitoring To Track Vapor Intrusion Resulting From Naturally Occurring Pressure Dynamics*, Journal of Remediation, Spring, v.27, no.2, p.9-25.

Real-time monitoring identifies indoor TCE source

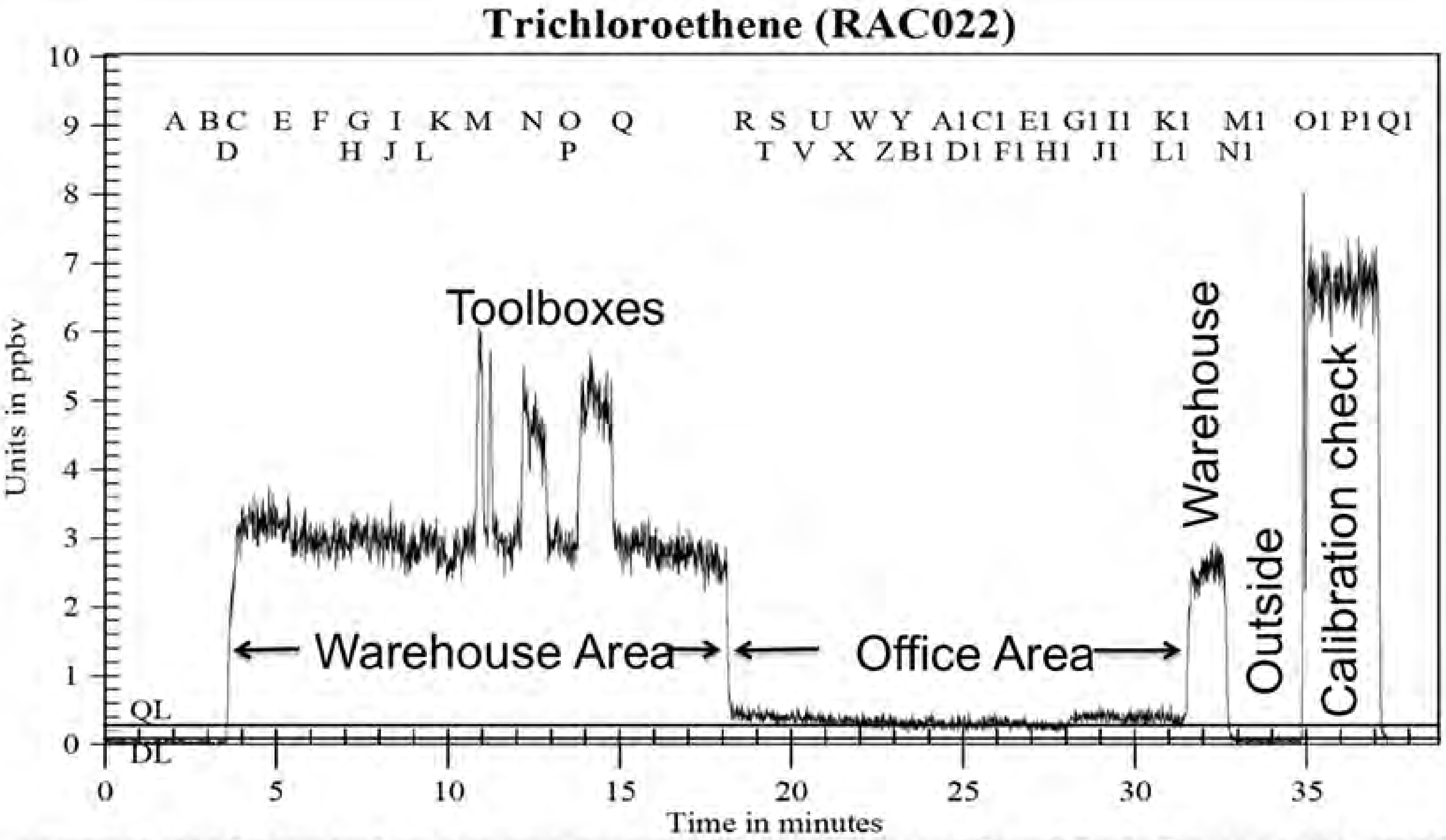
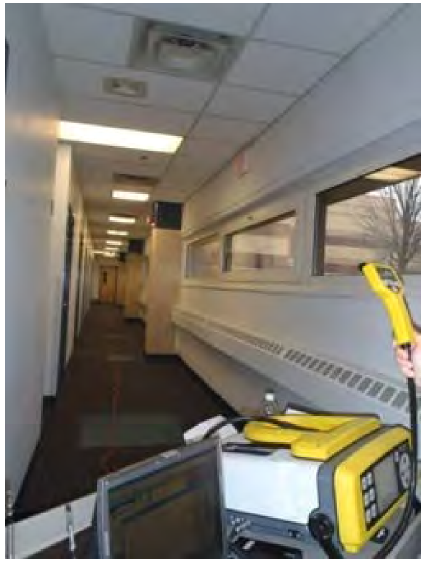


Figure 1: Real-time indoor air monitoring with the TAGA Unit (Modified after U.S. EPA, 2007)

From: DoD VI Handbook
Fact Sheet – Real-time Monitoring
https://www.denix.osd.mil/irp/vaporintrusion/

For more information on TAGA:
Archive of Aug 29, 2018 webinar:
https://clu-in.org/live/archive/



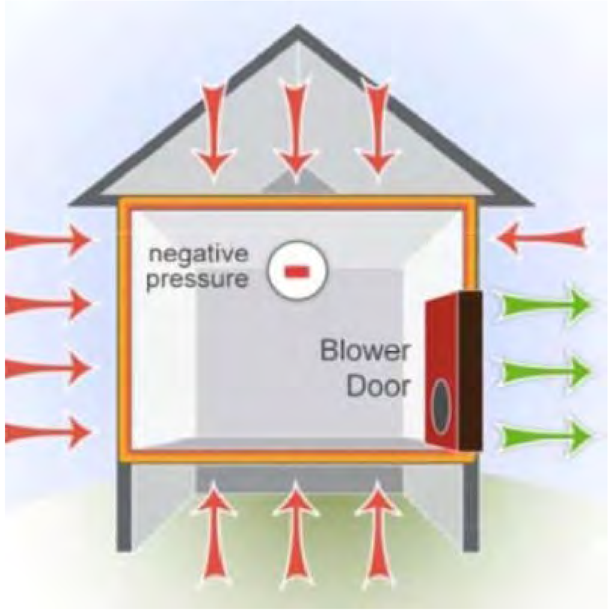
Advantages of real-time and continuous data

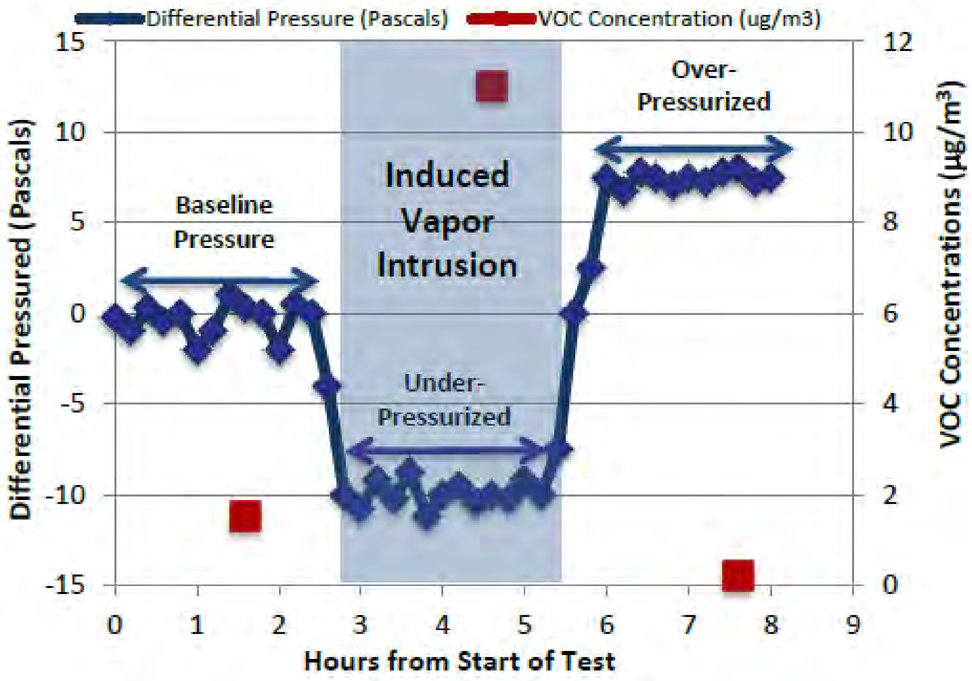
- Field data can be interpreted rapidly to support adaptive investigation
- No waiting 2 weeks or more for lab results, only to find you need another sampling round
- Lots of data offers opportunity to identify variability and patterns
- Can distinguish VI from indoor chemicals
- Find VI entry locations/pathways
- Informs best mitigation strategy

Potential limitations

- Some instruments have limited sensitivity, reliability, or interference challenges
- Data represents a short-term result, may not represent long-term conditions
- Likely higher initial cost, but can save money overall

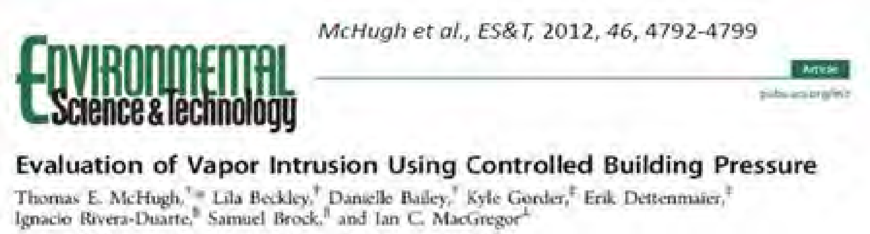
VI Diagnostic Tool: Building Pressure Control





Building pressure manipulation

- Force "near worst case" conditions for VI
- Distinguish between VI and background sources
- Challenges with larger, leaky buildings


McHugh et al., ES&T, 2012, 46, 4792-4799

Environmental Science & Technology

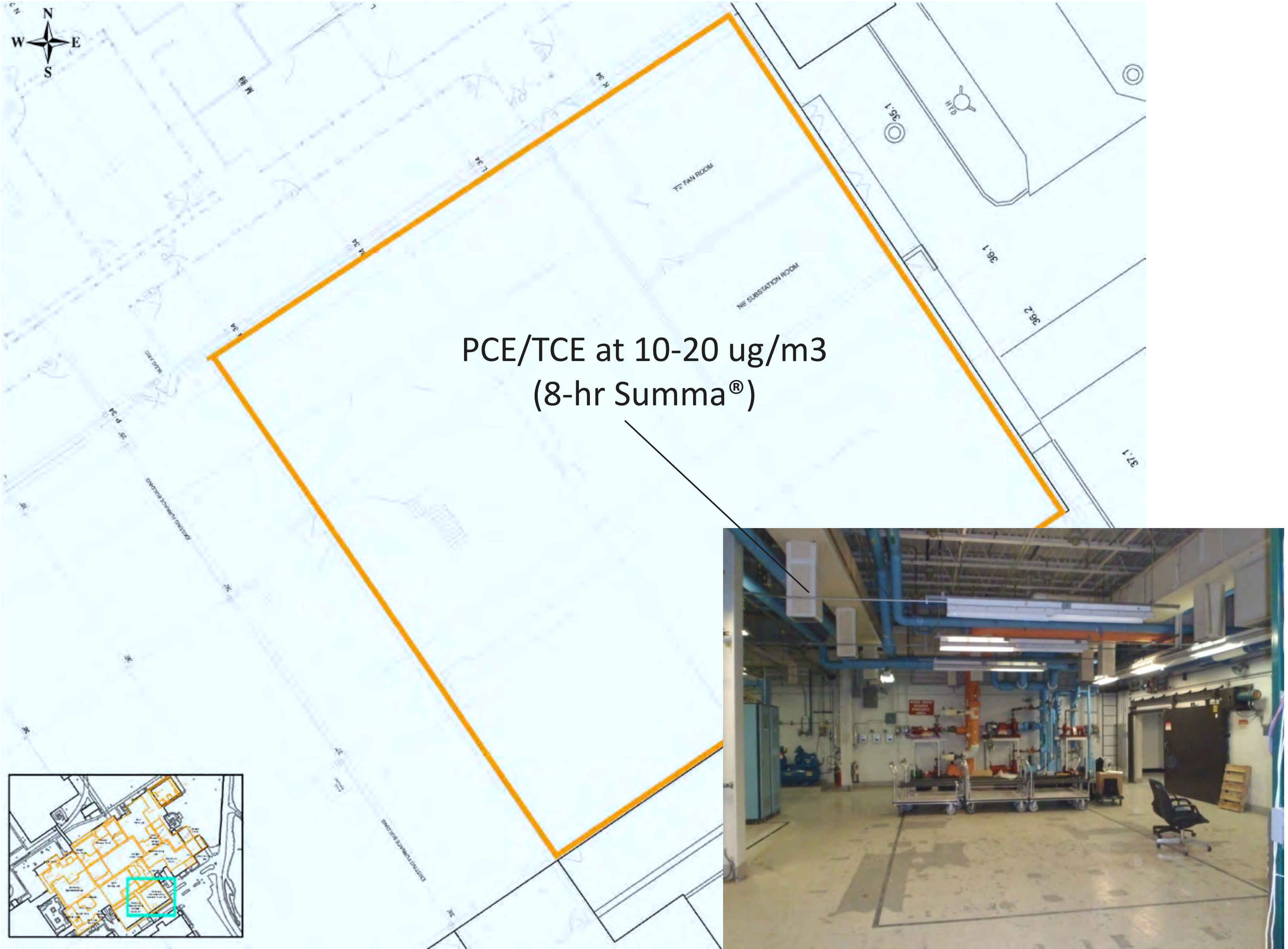
Article

Evaluation of Vapor Intrusion Using Controlled Building Pressure

Thomas E. McHugh, Lila Beckley, Danielle Bailey, Kyle Gorder, Erik Dettenmaier, Ignacio Rivera-Duarte, Samuel Brock, and Ian C. MacGregor

Negative pressure: favors VI
Positive pressure: suppresses VI

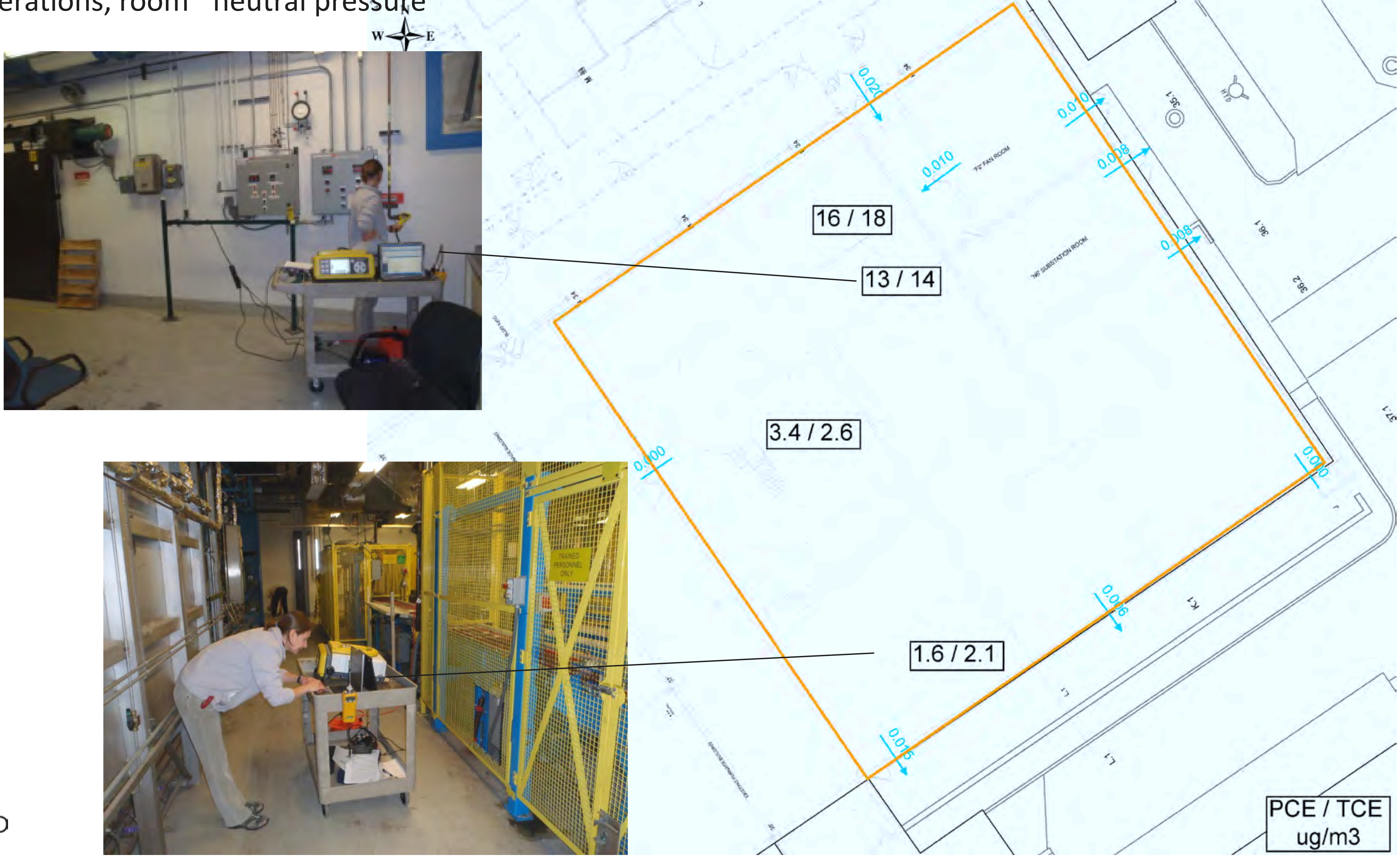
Building pressure manipulation for an industrial building
(real-time VI assessment of a 10,000 ft^2 manufacturing space)



PCE/TCE at 10-20 ug/m3
(8-hr Summa®)

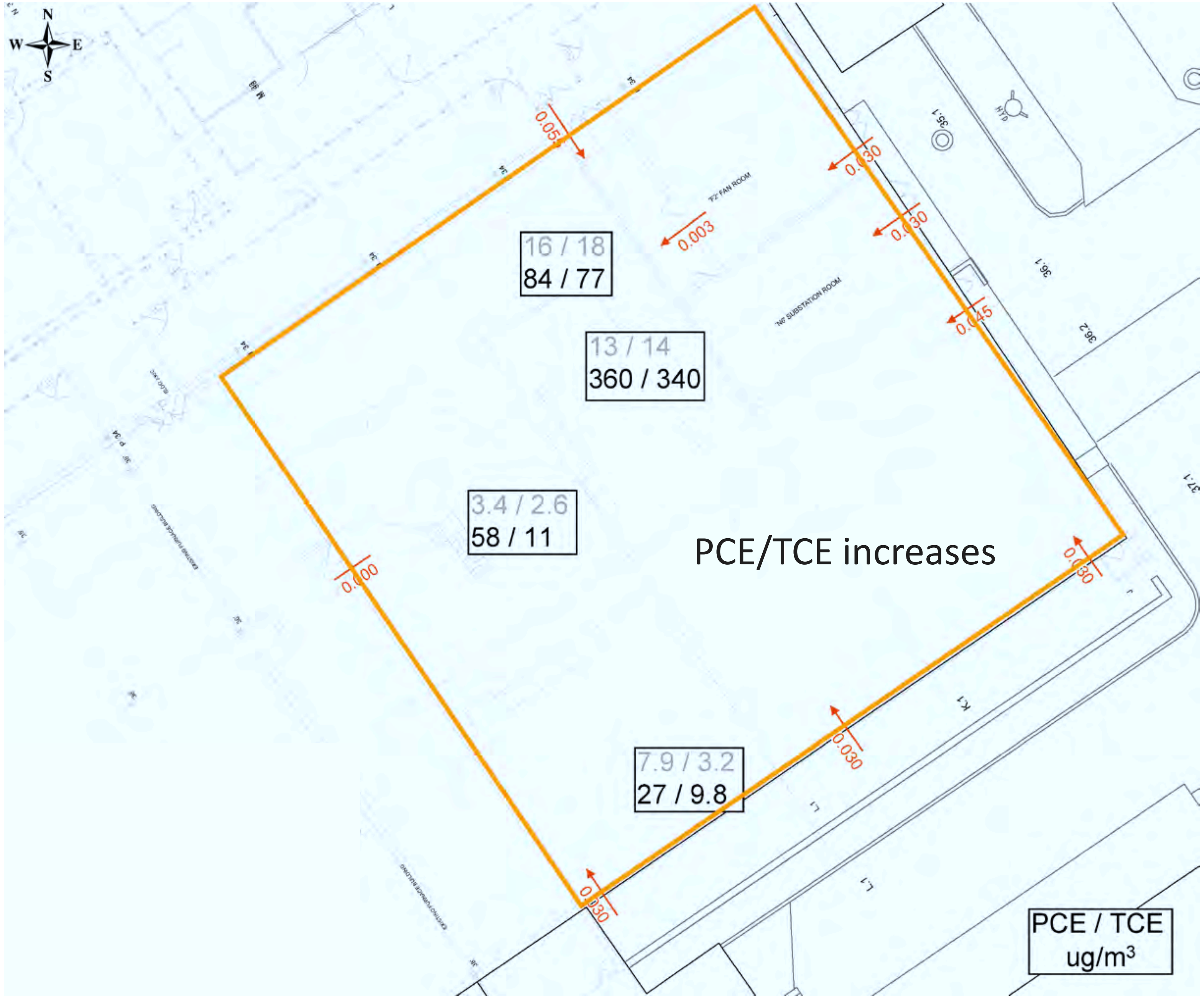
Initial conditions

Normal HVAC operations, room ~neutral pressure



Test conditions:

Shutdown HVAC supply air, and activate exhaust fans, neg. pressure in room



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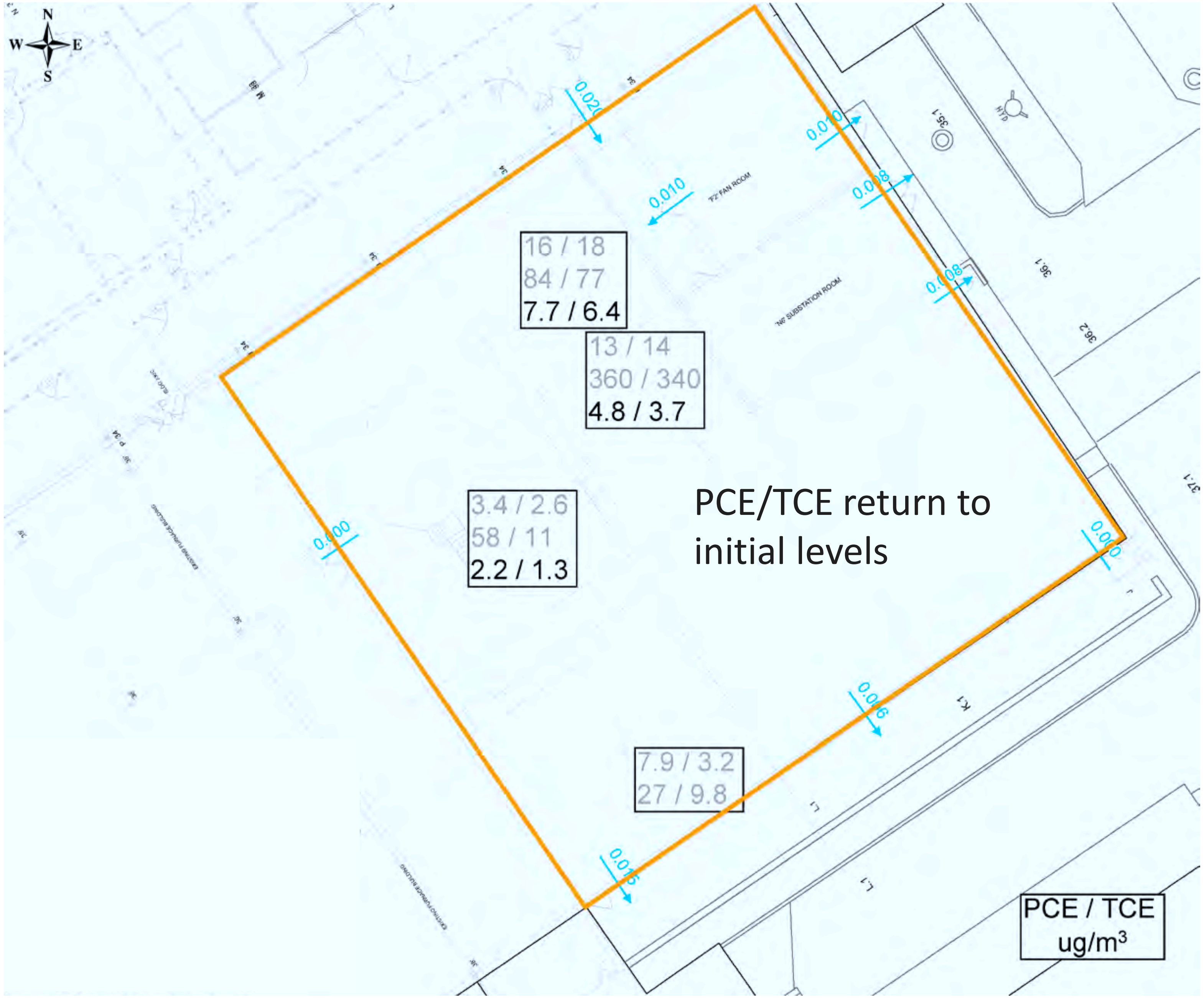
Post-Test conditions:

Shutdown exhaust fans, and restore supply air, neutral pressure in room



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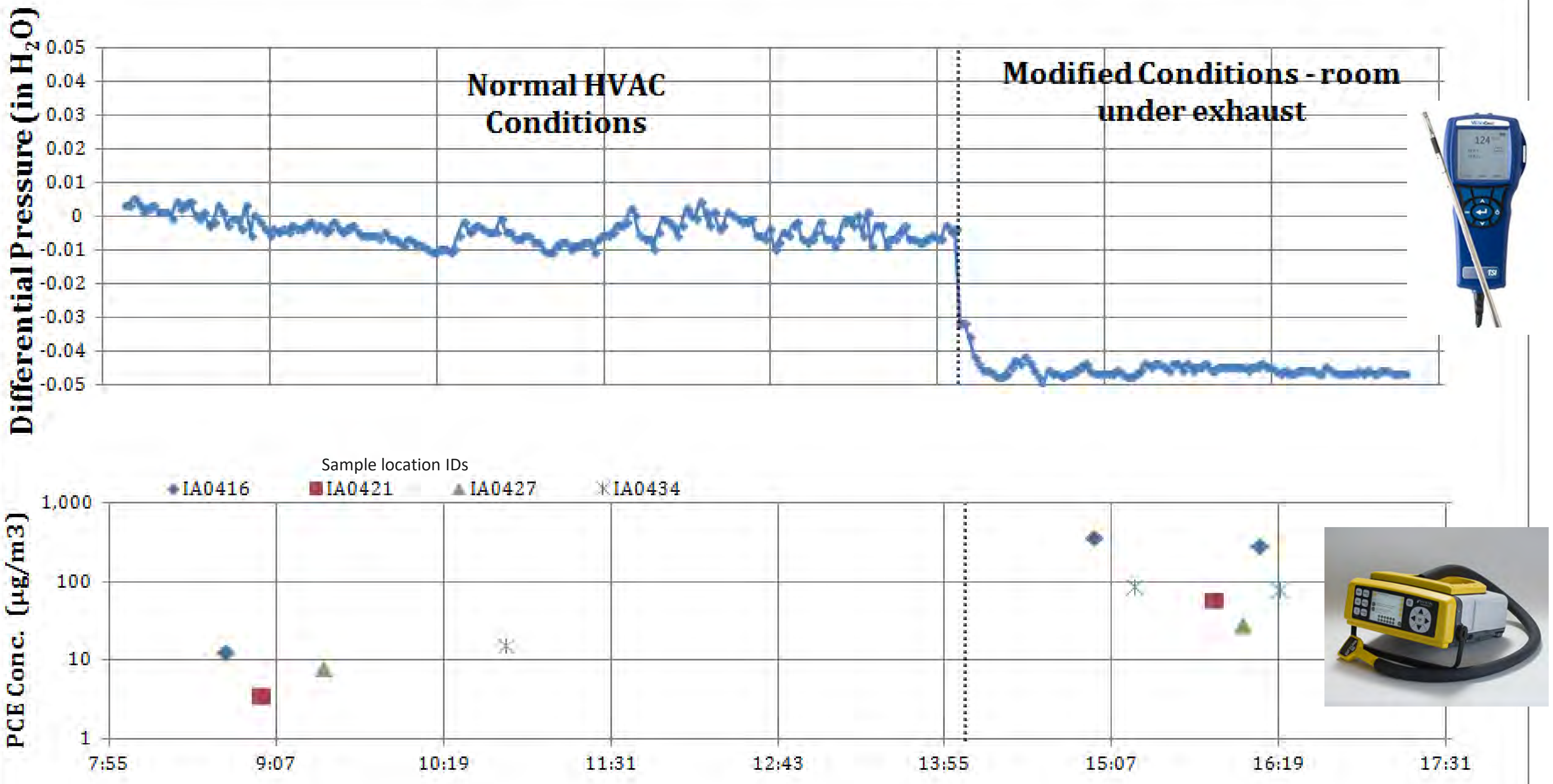
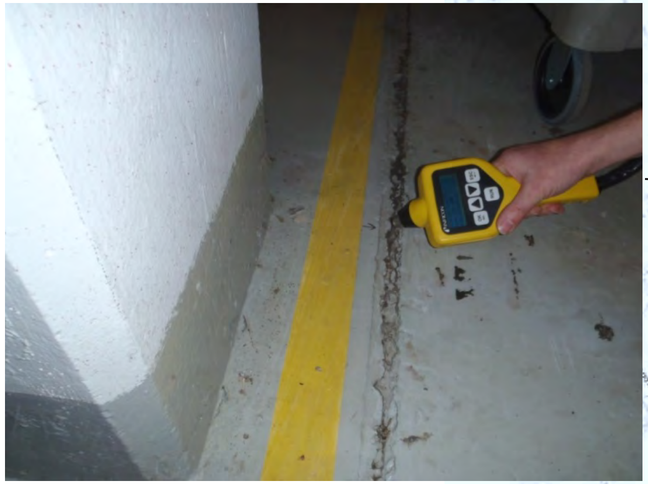
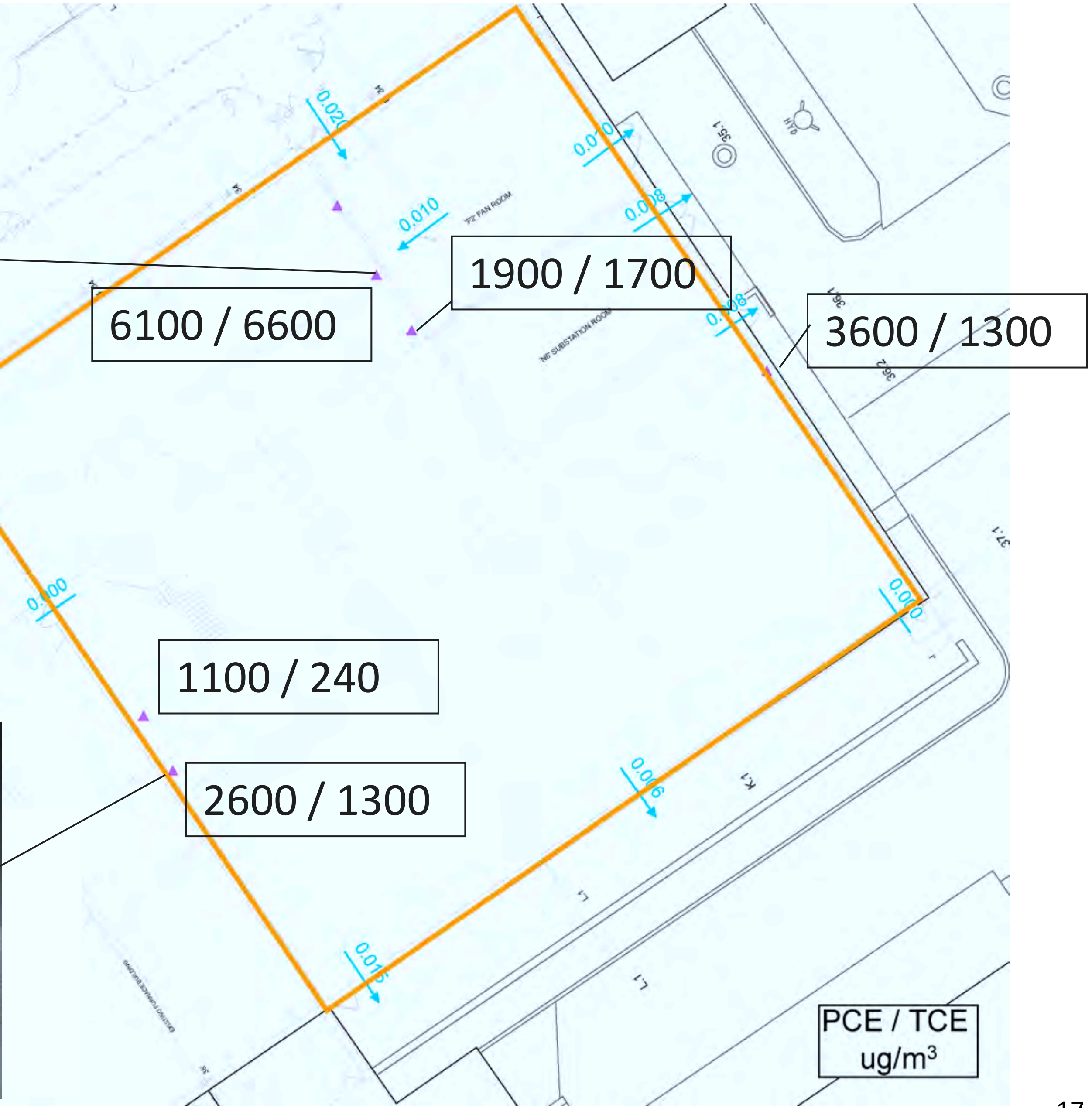


Response of indoor VOC levels to change in room pressure:
negative pressure = higher VOC levels

Identifying the VOC entry points: Expansion joints in floor slab





In 1 day of real-time assessment using Building Pressure Control:

- Analyzed 27 samples using the portable GC-MS
- Established baseline indoor air VOC conditions
- Without sub-slab sampling, confirmed that the PCE/TCE in indoor air was due to vapor intrusion, not background levels
- Identified the VOC entry pathways (i.e. the expansion joints), which pointed to a mitigation solution (re-caulking/sealing the joints)

Optimization of Building Pressure Cycling Methods for Vapor Intrusion Studies in Large Buildings

PREPARED FOR: Naval Facilities Engineering Systems Command Atlantic

PREPARED BY: CH2M HILL, Inc. (CH2M)

DATE: May 2021

Executive Summary

This technical memorandum (TM) provides the Department of the Navy's (Navy's) Environmental Restoration Program Remedial Project Managers with information related to building pressure cycling (BPC) methods for conducting vapor intrusion (VI) investigations in buildings typical of Department of Defense (DoD) installations. During a BPC test, a building—or sampling zone within a building—is depressurized with a fan to create conditions that facilitate VI-related migration of subsurface vapors into the sampling zone indoor air. The data can be used to assess temporal variability of volatile organic compound (VOC) concentrations in indoor air, identify potential background sources of VOCs within the sampling zone, or locate potential VI entry points. Under certain conditions, a single mobilization can suffice to either rule out the VI pathway or conclude that the pathway is complete and determine where VOCs are entering the building. BPC can also be part of the VI investigation toolbox, support the collection of multiple lines of evidence to characterize the VI pathway, and eliminate or limit the collection of subslab vapor samples and/or the number of long-term monitoring events.

BPC data interpretation can be complicated by a variety of factors, including building envelope leakage effects, building or sampling zone complexity, spatial differential pressure distribution during testing, and the presence of indoor sources in areas adjacent to the sampling zone.

After providing a BPC test procedure overview, this TM summarizes the results and presents lessons learned from a series of 10 BPC tests conducted at 9 DoD buildings. These lessons learned are then used to provide recommendations to improve testing procedures and data interpretation.

1 Introduction

1.1 Technical Memorandum Objective

The objective of this technical memorandum (TM) is to provide Remedial Project Managers of the Department of the Navy (Navy) with a rationale for using building pressure cycling (BPC) testing during vapor intrusion (VI) investigations and the preferred procedures for conducting BPC tests. To fulfill this objective, the TM presents an overview of results and lessons learned from a series of BPC tests conducted at several buildings located at Department of Defense (DoD) installations, including large nonresidential buildings (e.g., warehouses) and military housing complexes. Based on the knowledge gained from these tests, this TM provides recommendations to improve testing procedures and data analysis.

1.2 Rationale for Conducting Building Pressure Cycling Testing

BPC consists of using a fan installed through an exterior door or window to induce negative or positive pressure in a building or VI sampling zone within a building. Building or zone depressurization is generally expected to induce subsurface-to-indoor air VI, whereas pressurization tends to suppress VI. The use of BPC to support VI investigations has received increased attention over the past 10 years

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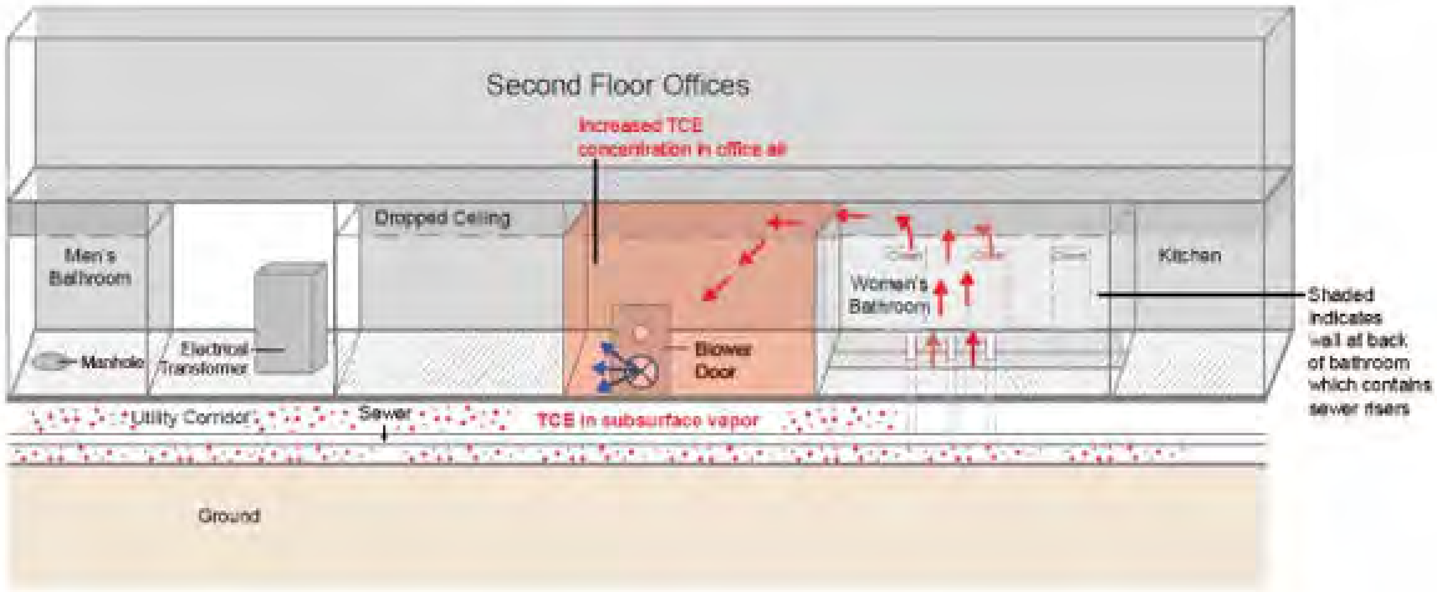


Figure 5. Conceptual model of subsurface vapor transport at the building.

https://www.denix.osd.mil/irp/navyvaporresources/

Diagnosing VI in Commercial/Industrial Buildings using HVAC Shutdown Testing

OSWER Publication 9200.2-154

OSWER TECHNICAL GUIDE FOR ASSESSING AND MITIGATING THE VAPOR INTRUSION PATHWAY FROM SUBSURFACE VAPOR SOURCES TO INDOOR AIR

U.S. Environmental Protection Agency

Office of Solid Waste and Emergency Response

June 2015

Sec 6.3.3 p.80
"…it may be useful…to diagnose vapor intrusion…under conditions when the HVAC system is not operating."

HVAC Shutdown Test Procedure

1. Baseline – screen/sample while HVAC systems are operating normally.

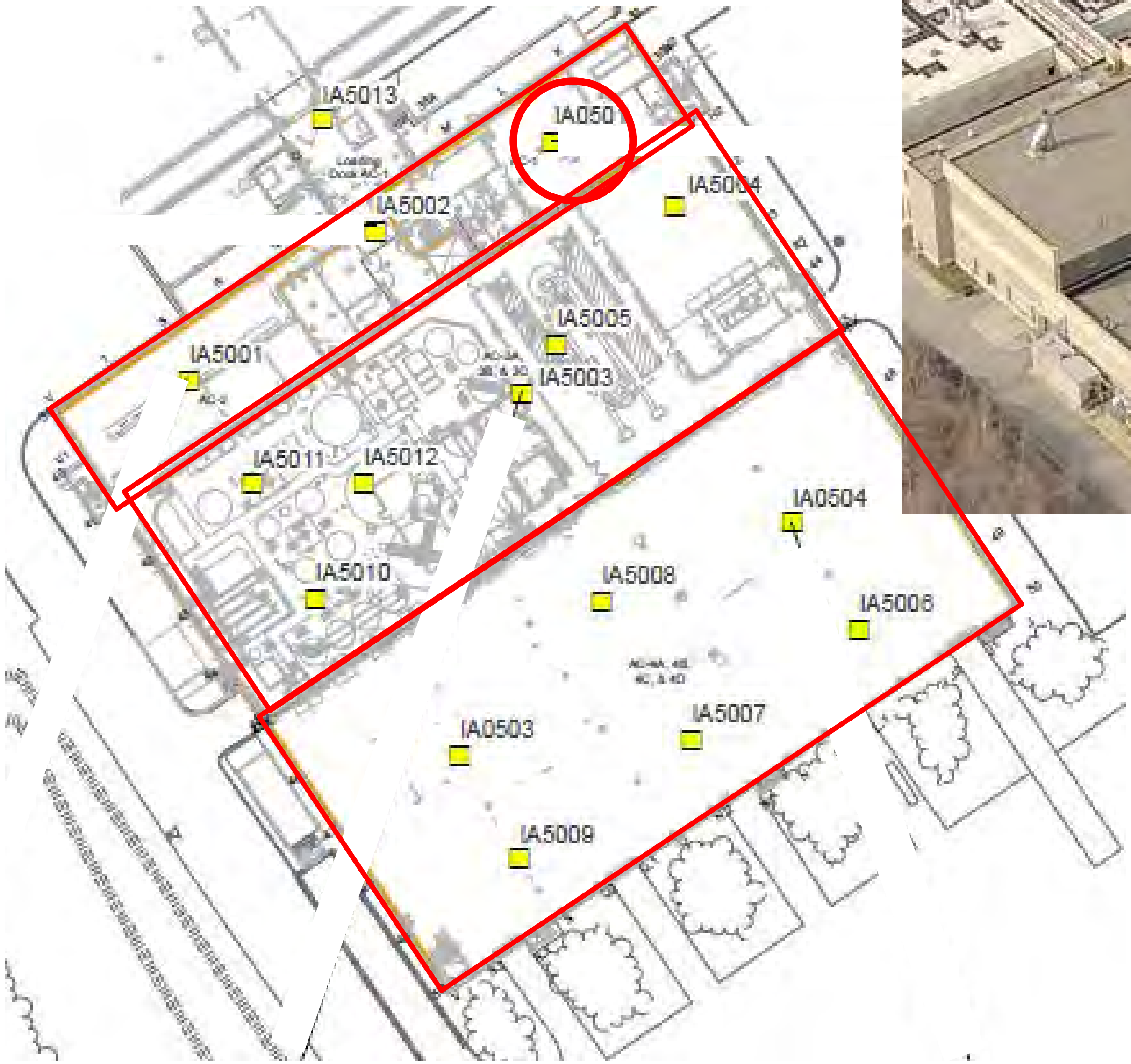
2. Shut down HVAC systems and screen/sample.
   2A. Impose negative pressure on structure (e.g. activate exhaust fans) and screen/sample.

3. Restore HVAC systems to normal operations and screen/sample.

Outcome 1: If indoor air levels are <u>acceptable,</u> then:
- HVAC controls or VI mitigation may <u>not</u> be needed
- Long-term periodic sampling may <u>not</u> be needed if the controls are monitored and maintained

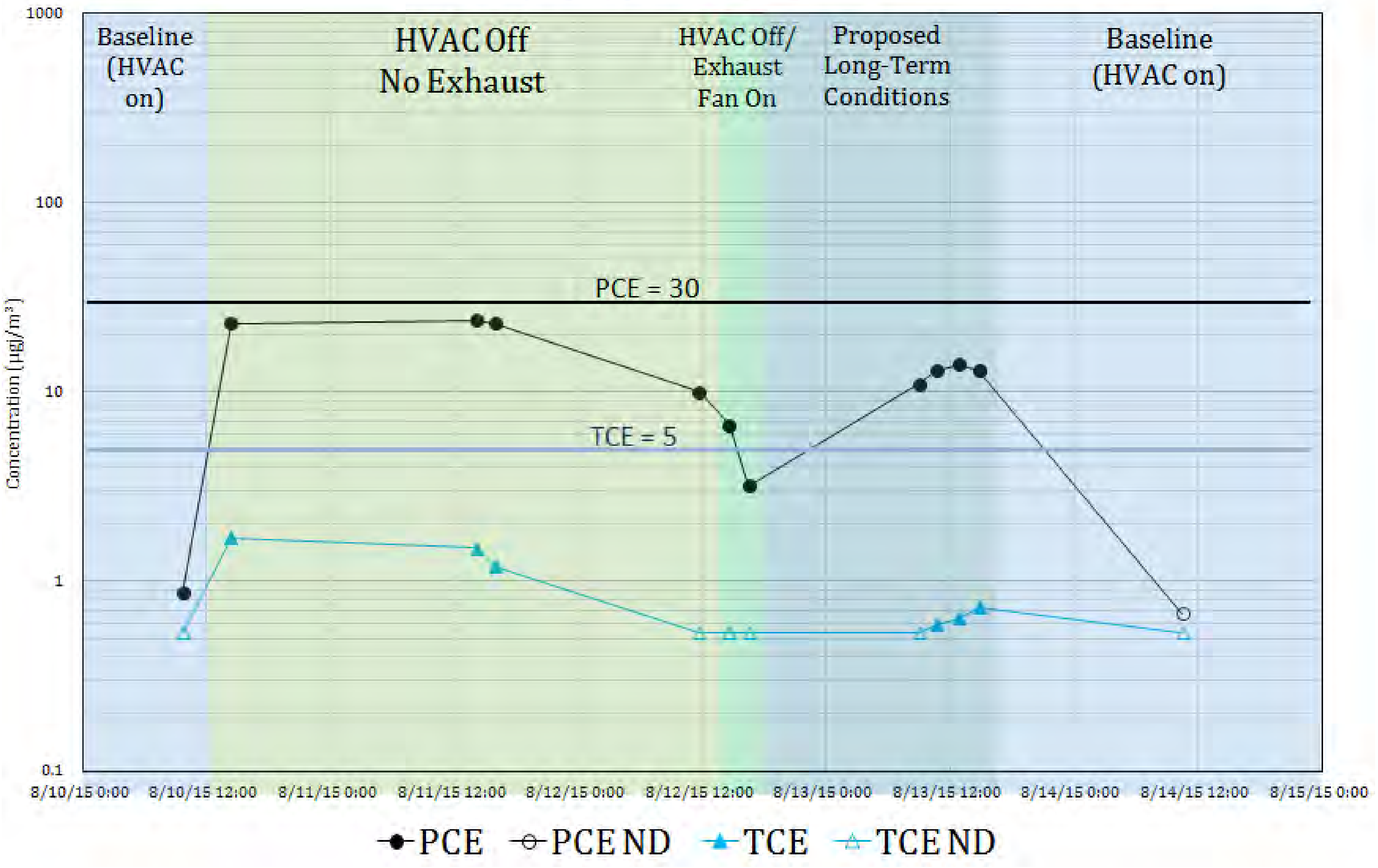
Outcome 2: If indoor air levels are <u>unacceptable</u>, then:
- HVAC operations controls should be established and maintained, or
- other mitigation should be implemented.

60,000 sq. ft. manufacturing bldg



IA0501

August 2015 HVAC Shutdown Testing



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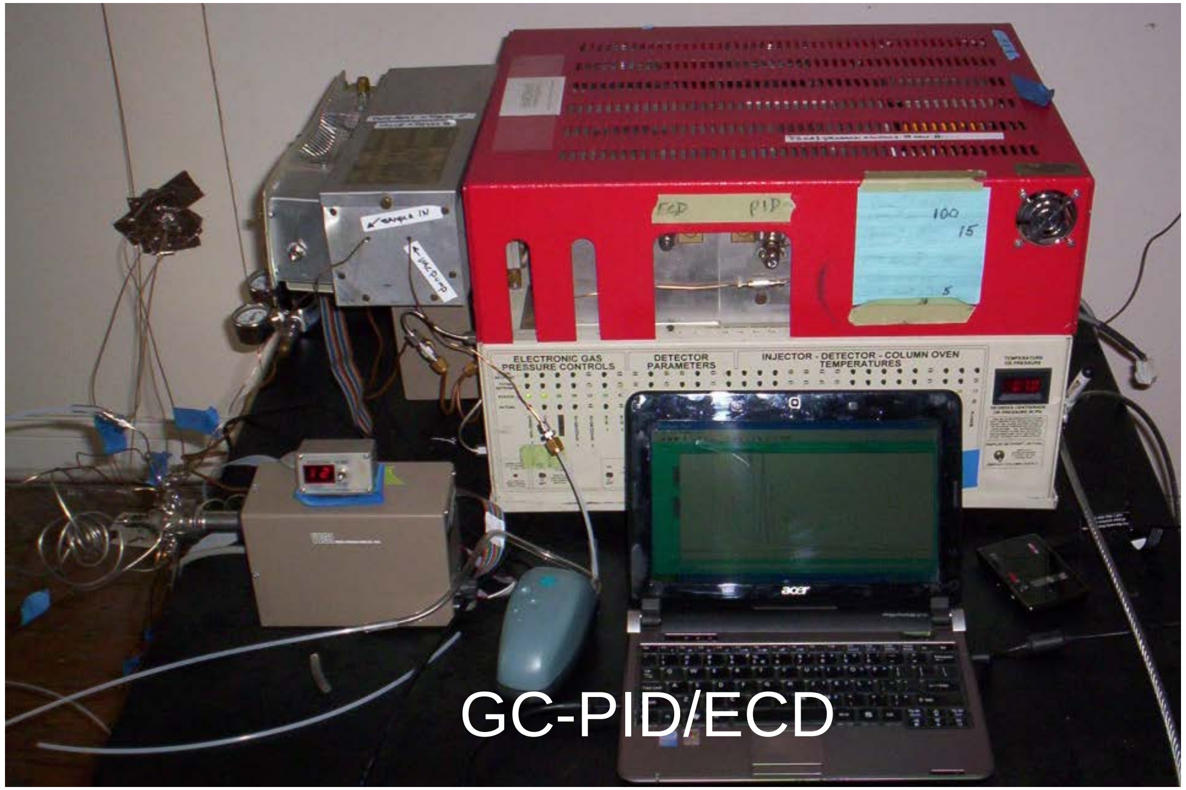
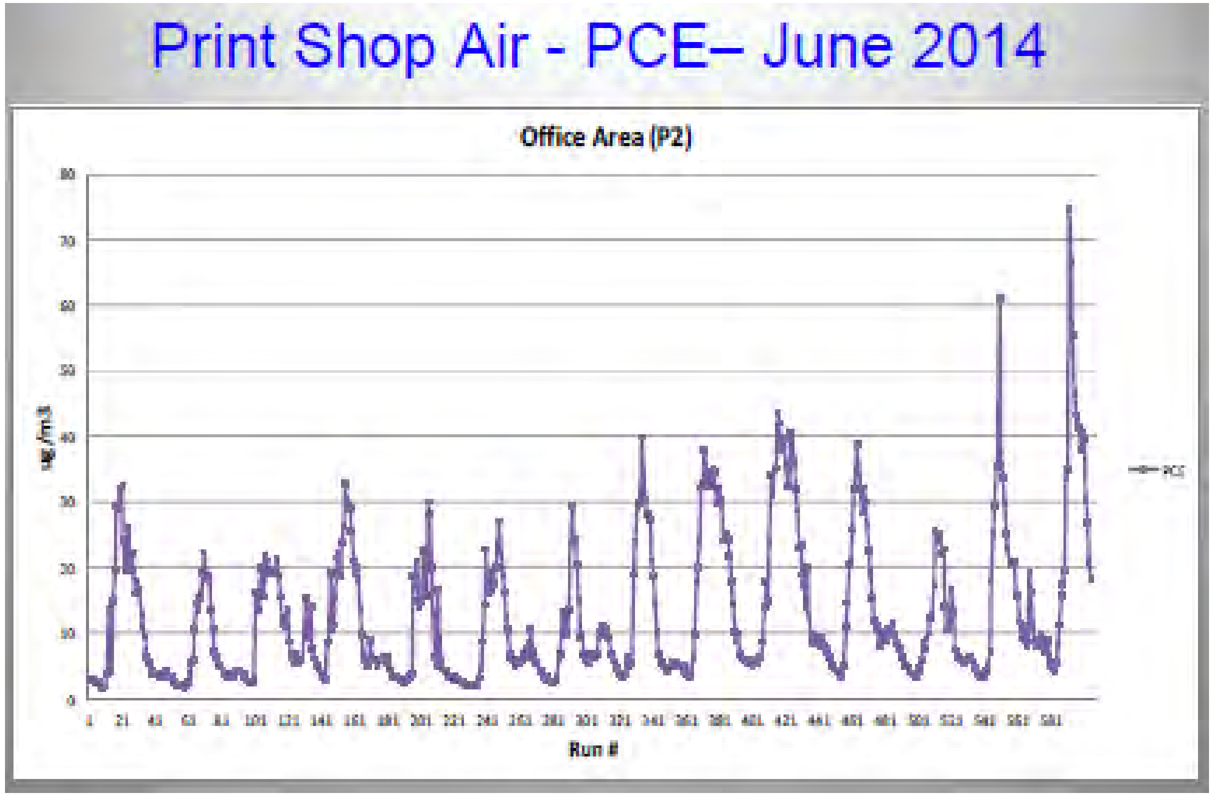
Continuous real-time air monitoring





PCE increases every night when the HVAC system is off

Take-Aways for HVAC Shutdown Testing

- HVAC shutdown testing is a simple diagnostic tool that's effective in revealing the role of HVAC systems in maintaining acceptable indoor air VOC levels.

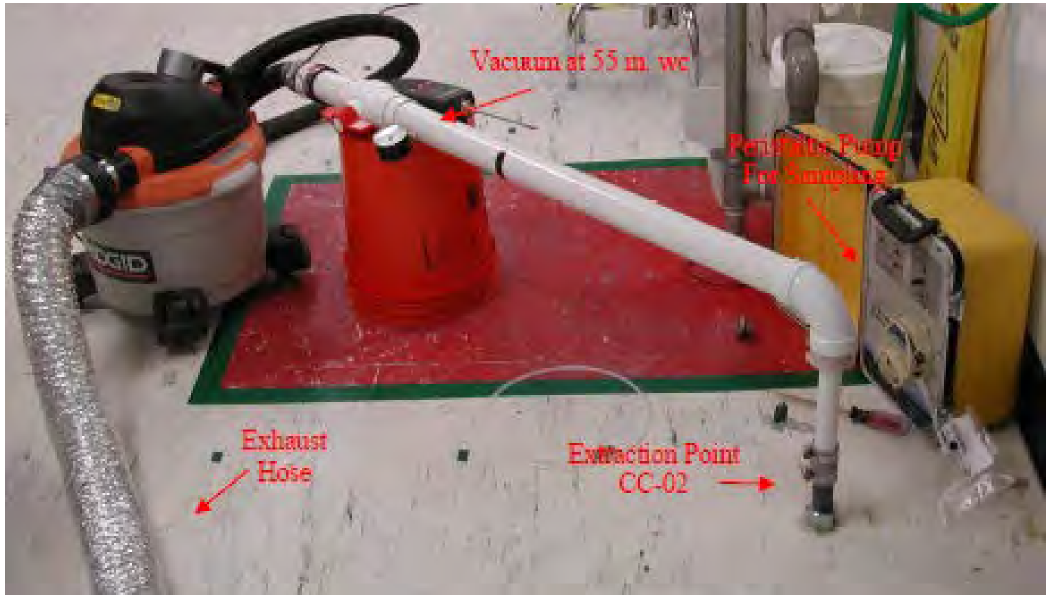
- Indoor air VOC levels respond rapidly to changes in building pressure and air exchange, typically within minutes to hours, which can either reveal VI, or demonstrate its absence.

- Demonstrating unacceptable VOC levels when HVAC is shut down highlights that HVAC controls and a building management plan may be required, or other mitigation is required.

- Demonstrating acceptable indoor air VOC levels when HVAC systems are shut down, or when building is under-pressurized, could support a case that active mitigation is not needed.

High Volume Sampling (HVS)

to assess subslab VOC distribution and support SSDS design



Procedure:

1. Install subslab suction points in representative areas.
2. Extract subslab vapor.
3. Measure VOCs in extracted vapor frequently using a PID or other field instrument.
4. Measure cross-slab differential pressure at various distances and directions from suction point.

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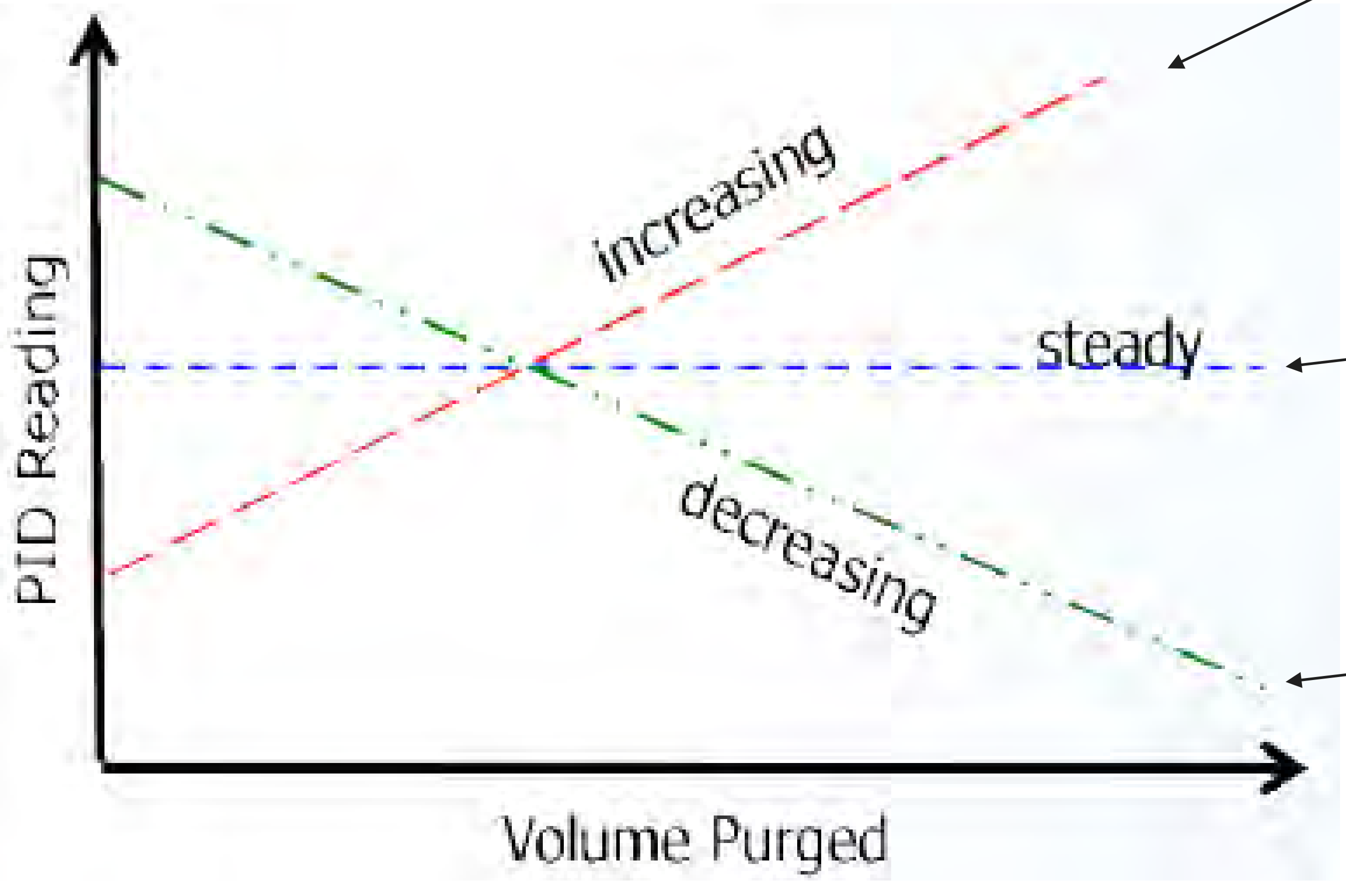
High Volume Sampling (HVS)

to assess subslab VOC distribution support SSDS design



Extraction port is not centered over the highest subslab VOC area

VOC concentrations are fairly uniform within the area of influence – possible dissolved-phase source

Extraction port is over or close to highest subslab VOC area

McAlary, T.A., P. Nicholson, L.K. Yik, D. Bertrand, and G. Thrupp. 2010. High Purge Volume Sampling - A New Paradigm for Sub-Slab Soil Gas Monitoring, *Groundwater Monitoring and Remediation*, V. 30, No. 2, pp 73–85, Spring 2010.

High Volume Sampling (HVS)

to assess subslab VOC distribution and support SSDS design

https://www.denix.osd.mil/irp/vaporintrusion/

Pros

- Reduce number of subslab samples required for assessment of a larger building
- Larger sampling volume means less likelihood of missing a problem area
- Well-suited for larger buildings with multiple potential subslab problem areas
- Pressure field (vacuum) data can support SSDS design if needed

Cons

- Requires a permeable layer below the slab
- More expensive up front (but can save money in the long term by catching issues that might be missed by conventional grab samples)
- Lacks higher spatial resolution provided by lots of subslab samples
- More equipment required than conventional sub-slab sampling

VI Mitigation for Existing and New Buildings

Vapor Intrusion Mitigation in Existing Buildings Fact Sheet

Introduction

Vapor intrusion (VI) is the migration of volatile chemicals from subsurface soil and/or groundwater into the indoor air of overlying buildings. Most VI events occur when volatile organic compounds (VOCs) are released into the subsurface from sources such as underground storage tanks, dry cleaners, gasoline stations, or industrial processes such as degreasing metals. VOCs typically associated with VI are chlorinated solvents including carbon tetrachloride, tetrachloroethene (PCE), trichloroethene (TCE), methylene chloride, and gasoline derivatives such as benzene. Hazards presented by these chemicals are typically chronic human health effects such as cancer, organ toxicity, or reproductive effects. Gases, such as methane migrating from landfills, may also present potential explosive hazards. If it is determined that VI is occurring at your site and the contaminant concentrations attributable to VI are above acceptable risk levels, mitigation measures should then be implemented to reduce the indoor air concentrations to below the acceptable threshold.

This fact sheet provides a brief overview of methods that can be used to mitigate VI in existing buildings along with important considerations for selecting and designing an appropriate mitigation system for your site. The methods discussed include sub-slab depressurization, sub-membrane depressurization, building pressurization, and indoor air treatment; however, the focus is on sub-slab depressurization since that is currently the method most frequently used for VI mitigation in existing buildings. Note that this does not mean that sub-slab depressurization is preferred over other mitigation methods or that it will be the best option for every site. More detailed information on VI mitigation systems for existing buildings can be found in the resources listed at the end of this fact sheet.

Key Factors When Considering VI Mitigation

Developing an effective VI mitigation plan depends on understanding and quantifying the relationship between three key factors that contribute to VI: (1) the properties, concentrations, and locations of the contaminants of concern; (2) the pressure differentials that draw contaminants from the soil gas into the building; and (3) the pathways that allow vapors to pass from soil gas into the building (e.g., cracks, joints, utility penetrations).

Properties, Concentrations, and Locations of VOCs

The first step in developing a VI mitigation plan is to understand as much as possible about the contaminant plume.

- What are the contaminants and what are their physical characteristics?
- What are the concentrations in groundwater and/or in the soil gas adjacent to or beneath the slab?
- What are the concentrations in the indoor air and ambient air outside of the building?
- Are methane or other explosive gases present? If so, explosion proof equipment will need to be integrated with the diagnostic investigation and mitigation specifications.
- How close is the contaminant plume to the building?
- Are the areas where subsurface vapors are infiltrating the building known? If so, are there mitigation measures that can be taken to reduce infiltration?

It is important that investigations performed prior to mitigation have adequately delineated and characterized the vapor plume and conditions inside the building have been adequately assessed. Also, because materials and products commonly found in buildings can cause false positives in indoor air sampling, a careful survey is needed to catalogue potential background sources of VOCs. DON has developed new guidance on assessing background concentrations for VI, which will be released in the near future.

Pressure Differentials

It is important to understand the pressure differentials within the building before designing a mitigation system. For some buildings, exhaust blowers mechanically induce significant negative pressure loads on the interior of the building; such blowers often accelerate the rate at which contaminant vapors are drawn into the building. For example, buildings used for industrial processes, laundromats, and restaurants typically exhaust large volumes of air, creating negative pressures throughout the building envelope. Because of their multiple exhaust blowers, strip malls with businesses such as dry cleaners, restaurants, and beauty salons may have multiple negative pressure zones that influence the migration of sub-slab contaminant plumes.

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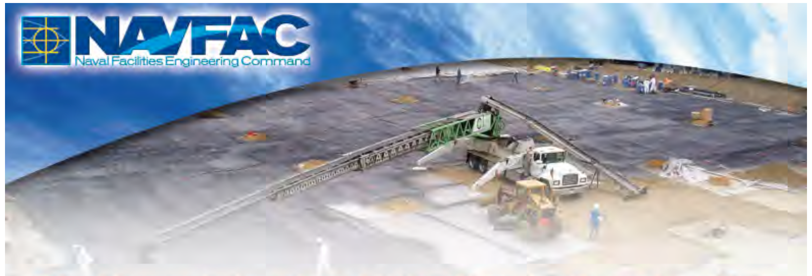

Vapor Intrusion Mitigation in Construction of New Buildings Fact Sheet

Introduction

Vapor intrusion (VI) is the migration of volatile chemicals from subsurface soil and/or groundwater into the indoor air of overlying buildings. Most VI events occur when volatile organic compounds (VOCs) are released into the subsurface from sources such as underground storage tanks, dry cleaners, gasoline stations, or industrial processes such as degreasing metals. VOCs typically associated with VI are chlorinated solvents, including carbon tetrachloride, tetrachloroethene (PCE), trichloroethene (TCE), and methylene chloride, and gasoline derivatives such as benzene. Hazards presented by these chemicals are typically chronic human health effects such as cancer, organ toxicity, or reproductive toxicity. Gases, such as methane migrating from landfills, may also present potential explosive hazards.

If the contaminants present in the subsurface are predicted to result in indoor air concentrations above acceptable risk levels, VI mitigation measures should be incorporated into the design of any new buildings. This fact sheet provides an overview of VI mitigation methods used in new buildings along with important factors to consider when selecting and designing these mitigation systems. In new construction, VI mitigation can include passive methods such as vapor barriers and natural venting systems; active systems such as sub-slab depressurization (SSD) systems; or a combination of passive and active methods. VI mitigation systems integrated during construction of new buildings are more cost effective, function better and are less obtrusive than mitigation systems retrofitted into existing buildings.

This fact sheet was prepared by the Navy Alternative Restoration Technology Team (ARTT) workgroup for use by Navy personnel such as remedial project managers (RPMs) and planners. RPMs may want to consider it for inclusion in Land Use Controls (LUCs) or provide it to base personnel or the public for informational purposes. Typically, Environmental Restoration, Navy (ER,N) funds shall not be used to install VI mitigation systems for new construction; however, RPMs and other Navy personnel should consult the Navy Environmental Restoration Program (NERP)/Defense Environmental Restoration Program (DERP) manuals for the latest guidance.

Key Factors When Considering VI Mitigation

Once the vapor sources have been assessed and it has been determined that there is potential for VI to pose an unacceptable risk in buildings constructed on the site, the next step is to select which preconstruction mitigation strategies should be implemented to prevent VI. Three primary factors drive the occurrence of VI in buildings:

- contaminant properties, concentrations and locations,
- potential entry routes (e.g., floor drains, French drains, sumps, seams or cracks in the floor slab, utility penetrations, and open top blocks in the foundation walls) and
- pressure differentials between the building and the subsurface that could draw contaminants from the soil into the building.

Understanding these components and the effects that they have on the transfer of subsurface VOCs to indoor air will help to determine which VI mitigation strategies should be integrated into the construction of a new building.

Prevention of VI in New Construction

New construction provides many opportunities to prevent VI that are not available for existing buildings. For example, at some sites, the area most likely to produce unacceptable VI can be avoided and set aside for another purpose such as green space. Also, new buildings can sometimes be designed to include a highly ventilated, low occupancy area at ground level, such as an open parking garage. It should be noted, however, that if contaminated areas of the site are to be covered with pavement, the resultant effects on migration of vapors should be considered in order to avoid effects on adjacent structures.

Methods for VI mitigation in new construction can be passive (such as vapor barriers and natural venting systems) or active (using blowers to depressurize the sub-slab area). Frequently in new construction, elements of both passive and active methods are combined (e.g., a vapor barrier may be installed along with active SSD) or a passive ventilation system may be designed to allow for conversion to an active system (e.g., by adding blowers) at a later time if the passive system fails to prevent VI.

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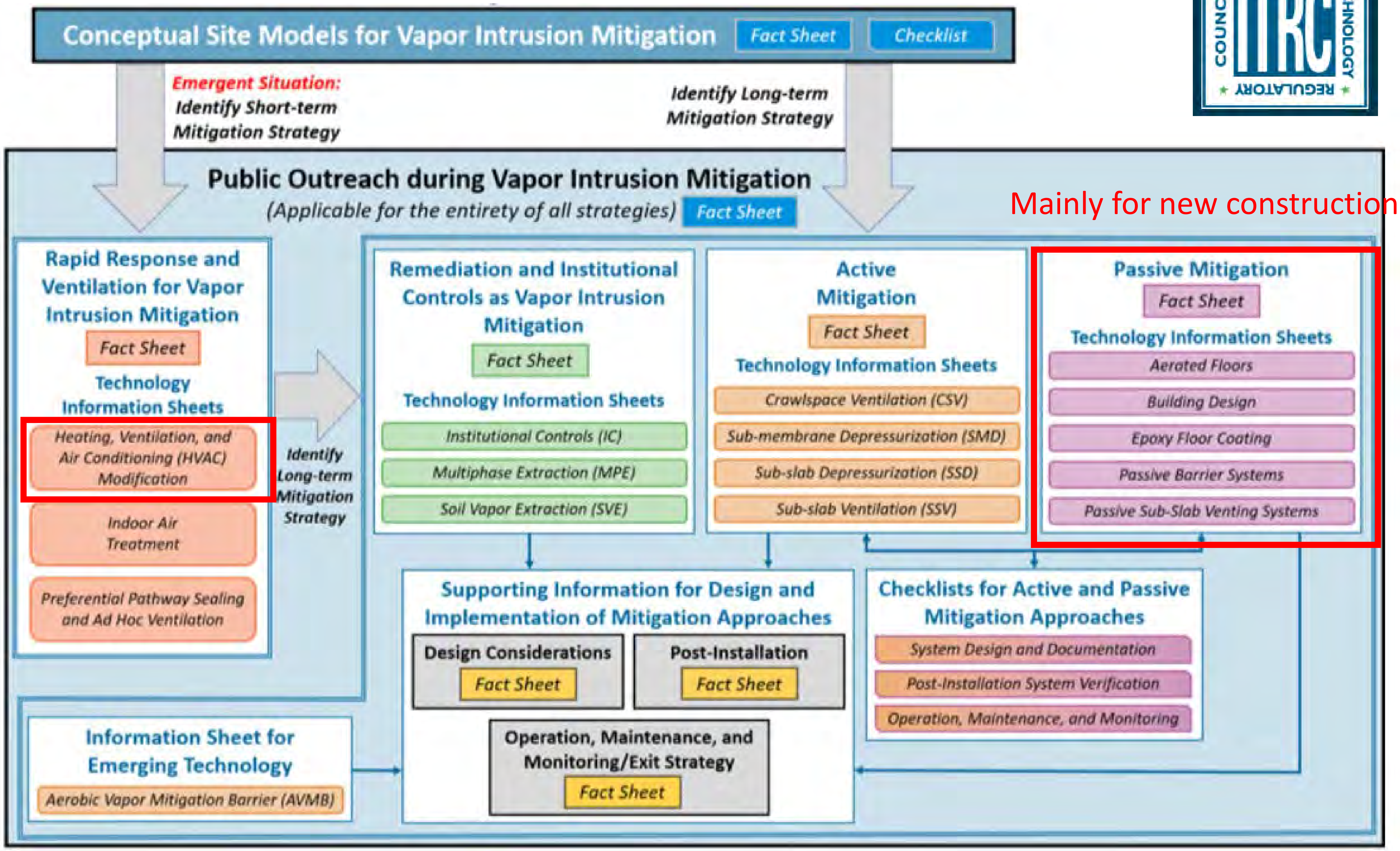
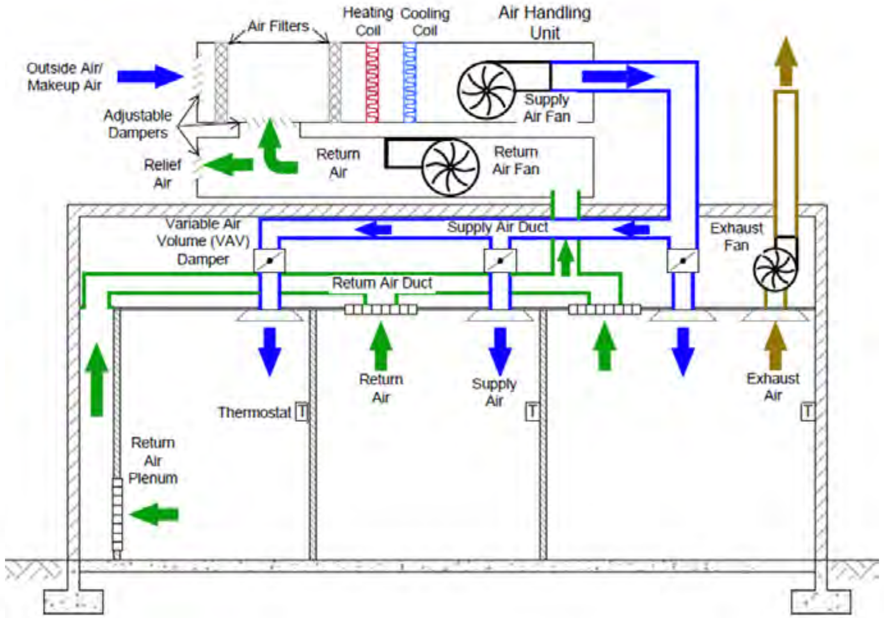
https://www.denix.osd.mil/irp/navyvaporresources/

VI Mitigation Overview – ITRC Guidance

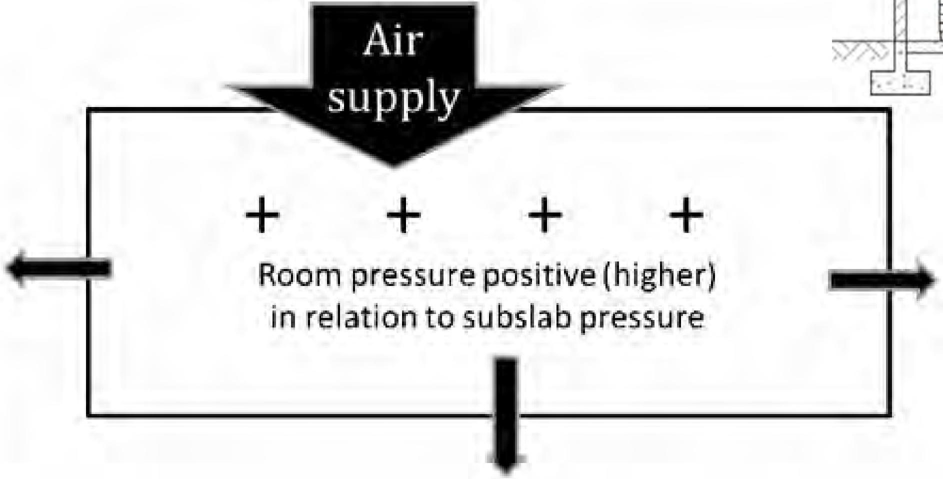


Mainly for commercial, industrial, institutional buildings

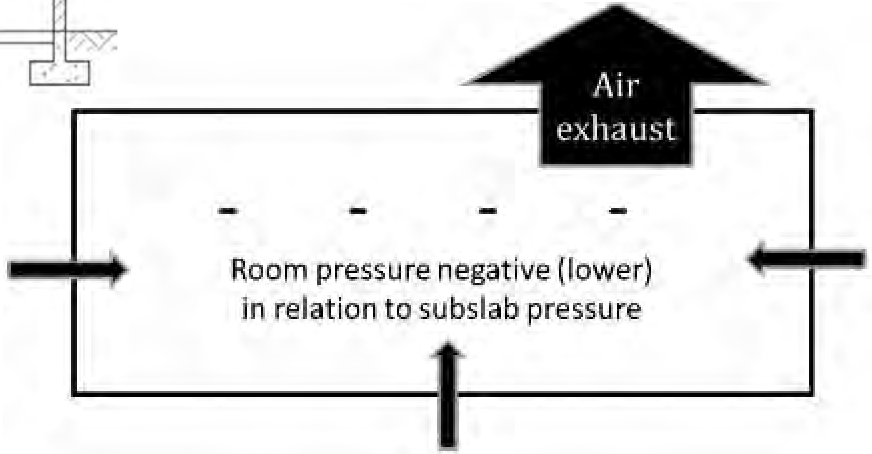
Rapid Response – HVAC Modifications



HVAC 101

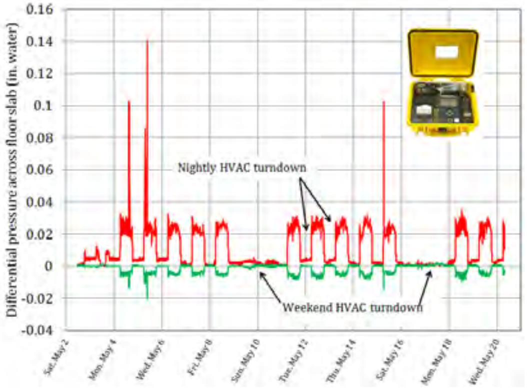


- Air supplied greater than air exhausted
- Positive pressure suppresses VI



- Air exhausted greater than air supplied
- Negative pressure favors VI
- Component of "Building Pressure Cycling" for VI assessment

Positive pressure may not be sufficient to prevent VI because of:



Spatial and temporal variability of building ventilation

- Weekend/night shutoff may allow VI during off hours
- Variability of airflow (unbalanced distribution, VAV dampers, economizers, blower VFDs)

VI from localized areas of negative pressure

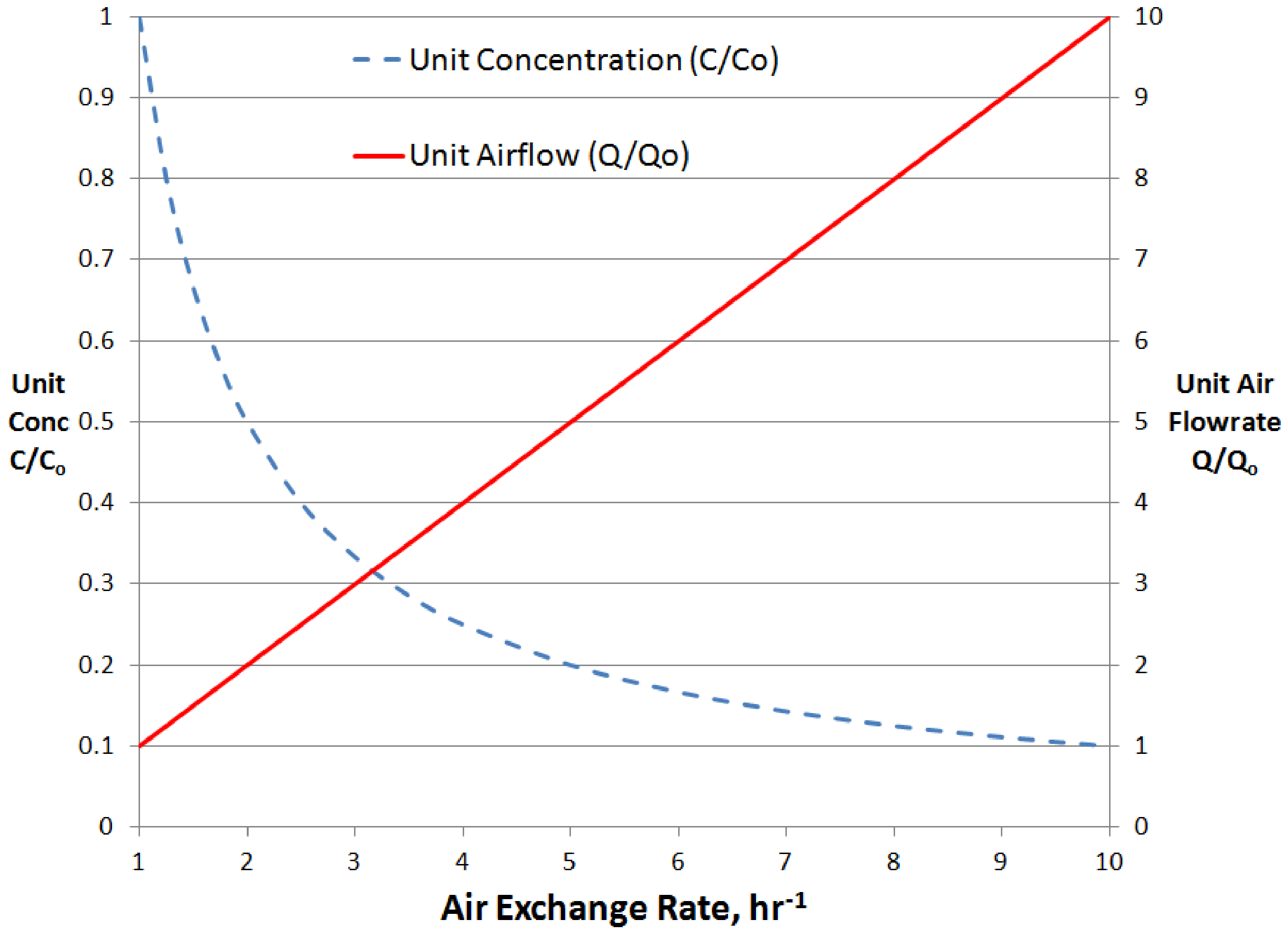
- Kitchens, restrooms, laboratories
- HVAC equipment in contact with floor slab (stand-alone AC units)
- Return air chases and plenums

Diffusive VI

- Through floor slab counter to pressure gradient
- Via alternative pathways (e.g. sumps, pits, trenches, pipe and conduit penetrations)

HVAC can work for rapid VI mitigation

Increasing continuous active outdoor air exchange



Expected %Reduction =
$(1 – AER_{before} / AER_{after})$*100%

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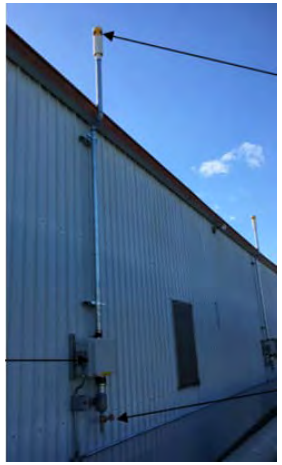
Why are HVAC systems less preferable to SSD systems for long-term VI mitigation?

HVAC Systems
- Do not address/remediate the VI source
- Not intentionally designed for VI mitigation
- Dilution of VI rather than prevention, in some cases
- Wide variety of systems (e.g. old, complex)
- Lots of potentially relevant operating parameters
- Multiple points of operating variability/vulnerability
- Subject to human interference
- Energy intensive



SSD Systems:
- Intentionally designed for VI mitigation
- Capture of VI before entry to building
- Simple concept
- Two key parameters to monitor (run status and sub-slab vacuum)
- Few points of operating variability/vulnerability
- Generally require less energy

Why consider HVAC for VI mitigation control?

1. Some buildings need a rapid response to VI that may be most feasible in the short-term by improving the HVAC operations (i.e. increasing the pressure or air exchange).

2. Some buildings subject to VI may only need simple permanent adjustments to HVAC operations to maintain acceptable indoor air quality at less cost and disruption than installation of an SSD system, even when long-term operating costs are considered.

3. Some buildings are just too technically difficult or costly to mitigate using SSDS alone (e.g. active manufacturing constraints, complex subgrade utility networks, complex foundations, very large areas).

4. Some buildings have acceptable indoor air quality under existing HVAC operations, despite sub-slab VOC presence. The HVAC system is already providing VI mitigation.

Guidance on HVAC for VI Control – Pretty Limited

California – VI Mitigation Advisory, Oct 2011, p.17

"…will consider HVAC alteration as a response action for commercial/industrial buildings on a case-by-case basis..."

New Jersey – VI Technical Guidance, May 2021, p.80, 96

Active HVAC modifications are considered an "alternative mitigation method" requiring more frequent long-term monitoring than SSDS

New York – VI Guidance, Oct 2006, p.59

HVAC modification (i.e. to maintain a positive pressure within the building) is an alternative mitigation method that may be considered where SSD is not practical.

Pennsylvania – VI Guidance, Jan 2017, p. 116

One mention of "building pressurization systems" under "other active mitigation technologies"

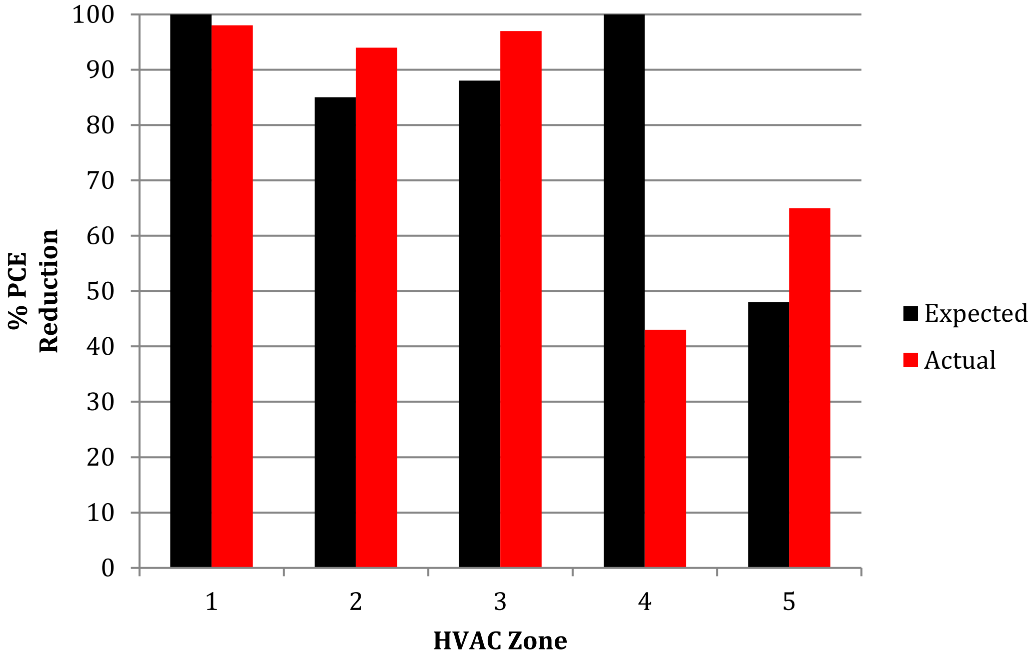
USEPA – VI Guidance, June 2015, p.144-146

HVAC considered an "engineered exposure control" that can achieve both building pressurization to keep VI out, and building ventilation to dilute vapors that have entered the building.

Adjusting HVAC operations to increase air exchange rate (AER): Indoor VOCs decreased to levels consistent with expectations based on increased AER

HVAC Zone	AER Before HVAC Mods [hr^{-1}]	AER After HVAC Mods [hr^{-1}]
1	0.01	13
2	1.0	6.8
3	0.31	2.5
4	0.01	3.1
5	1.2	2.3

Expected Reduction % = $1 - (AER_{before} / AER_{after})$



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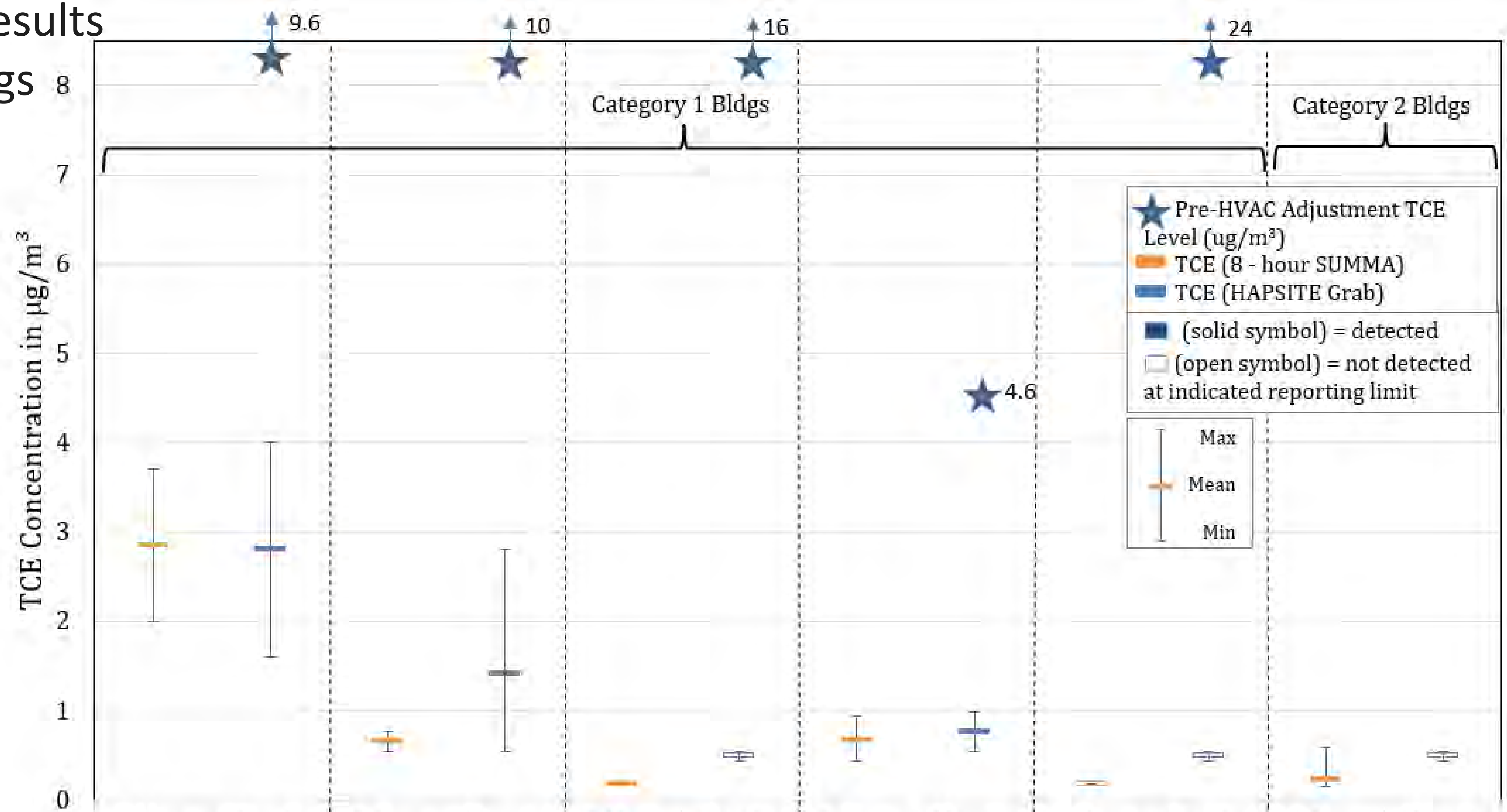
HVAC as VI Engineering Control – 6 Buildings

Dissolved-phase TCE present in groundwater and soil vapor beneath campus buildings.

TCE in Indoor Air Results Over 1 Year – 6 Bldgs



	Bldg 1		Bldg 2		Bldg 3		Bldg 4		Bldg 5		Bldg 6	
	8-Hour	Hapsite	8-Hour	Hapsite	8-Hour	Hapsite	8-Hour	Hapsite	8-Hour	Hapsite	8-Hour	Hapsite
# Detect	6	9	2	2	1	0	10	14	0	0	6	0
# Non-Detect	0	0	0	1	1	3	0	1	2	3	6	18
# Samples	6	9	2	3	2	3	10	15	2	3	12	18

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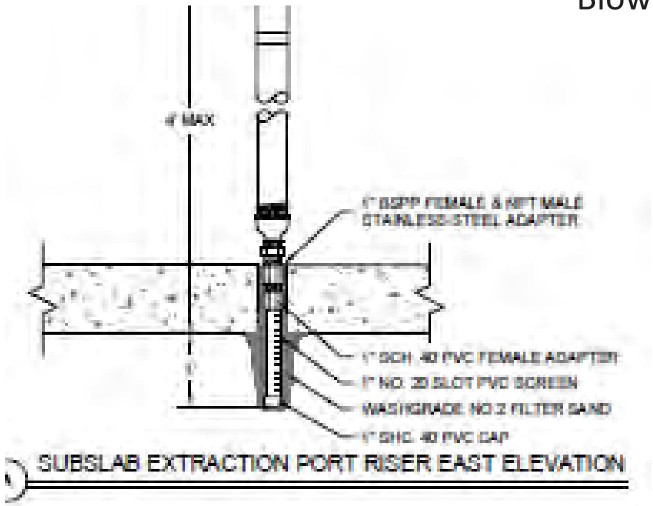
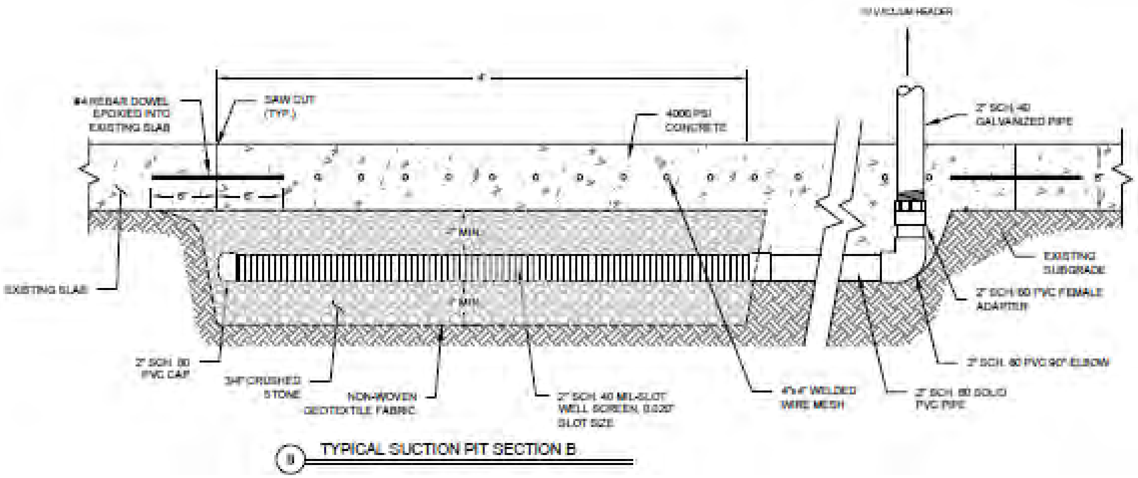
VI Mitigation of Existing Commercial/Industrial/Institutional/Office Buildings by Sub-Slab Depressurization (SSD) or Soil Vapor Extraction (SVE)

Blower on wall

Extraction port and riser

Design standard





Suction Pit Below the Slab

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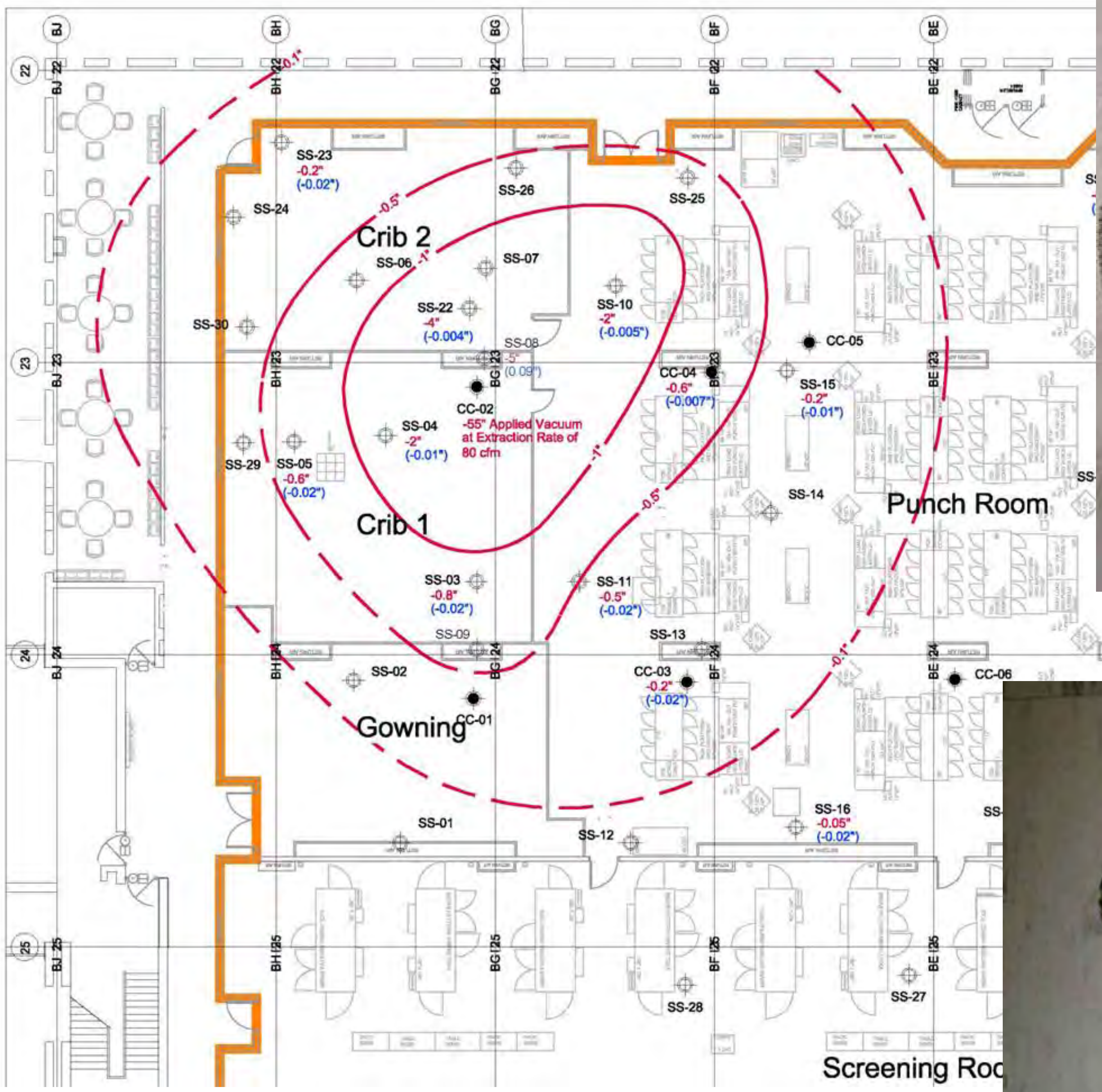
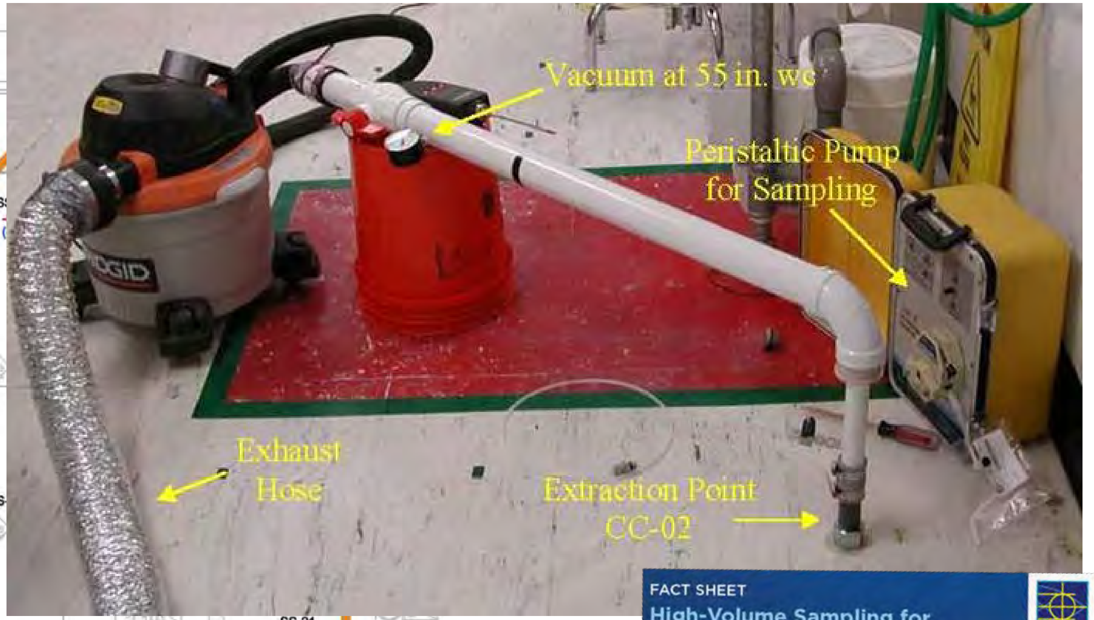
SSD System Design – Diagnostic testing (Pressure field extension)






FACT SHEET
High-Volume Sampling for Vapor Intrusion Assessments
NAVFAC
Introduction
Technology Background
How Does It Work?
How Can It Help?
Case Study 1: Naval Air Station Corpus Christi
Case Study 2: Naval Station Norfolk
Conclusions

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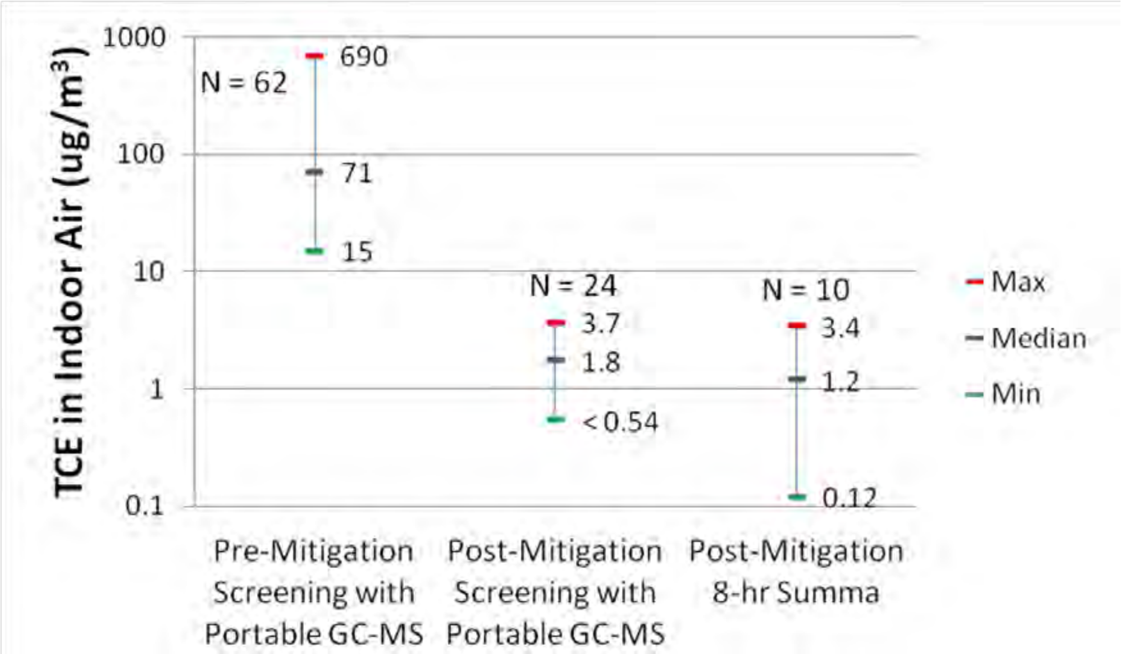
VI Mitigation of mixed-use industrial/office building



Sub-slab Depressurization

- 26 extraction points
- 170 cfm total flow

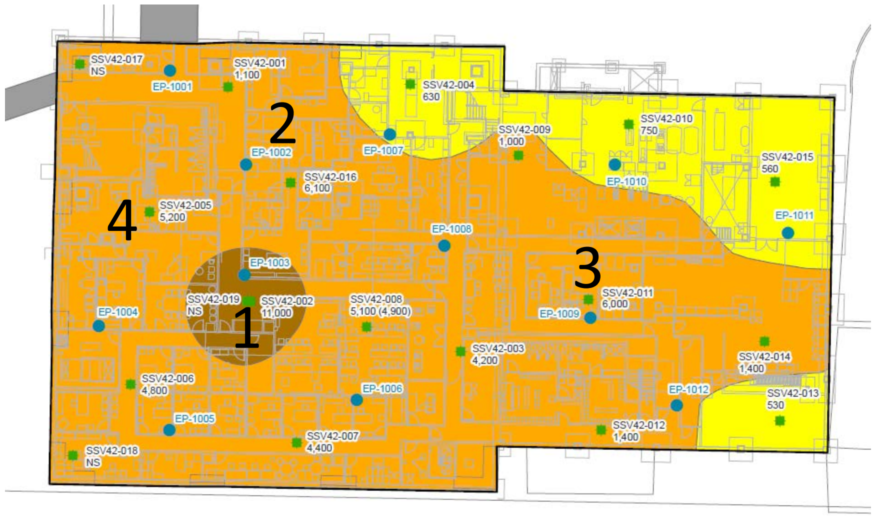
Depressurization of manhole headspace

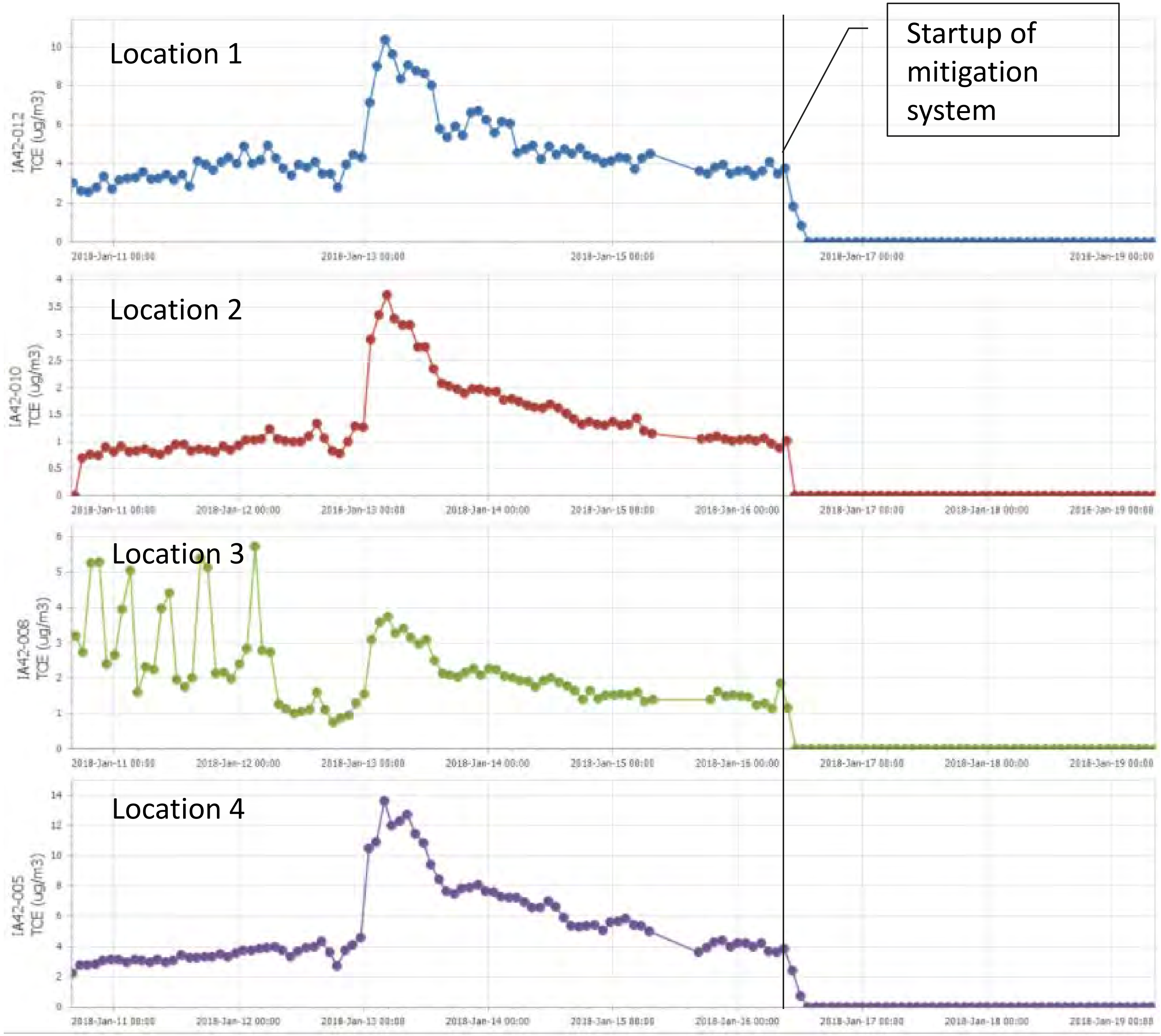
- 4 manholes
- Depressurized to 0.01 inches water column
- 50 cfm/manhole

Residual TCE in indoor air due to air transfer from adjoining building. Confirmed by:

- Smoke testing and air velocity monitoring
- Screening with portable GC-MS

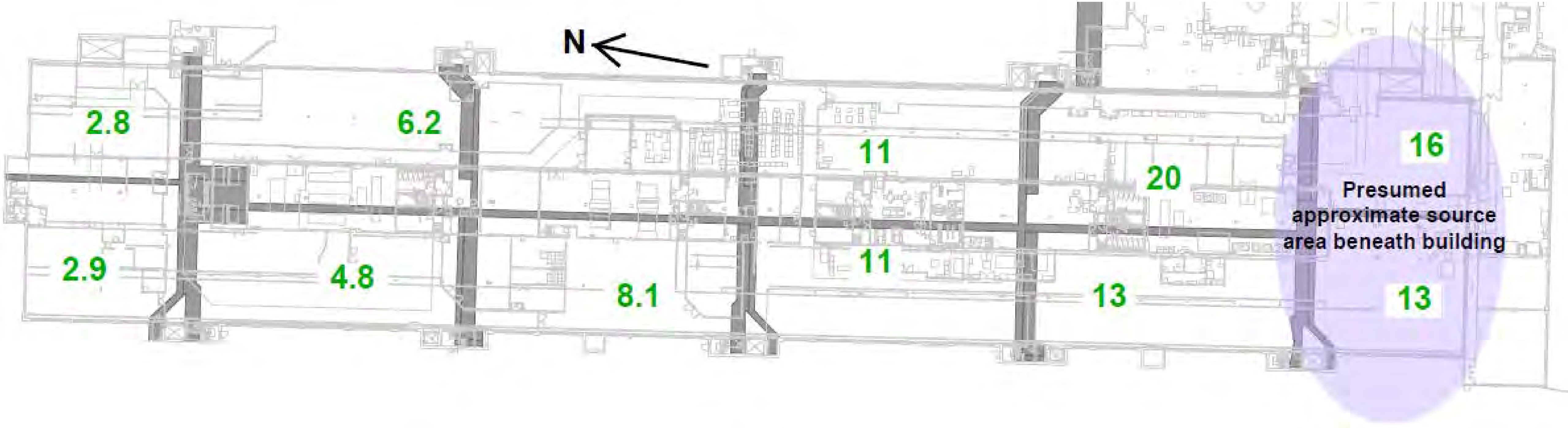
Continuous indoor air monitoring to verify SSDS effectiveness





Mixed manufacturing and office bldg. w/150,000 sq. ft. footprint

- Groundwater 11 to 18 ft below floor slab
- Subslab HVAC air intake tunnel system



20 TCE in indoor air ($\mu g/m^3$)

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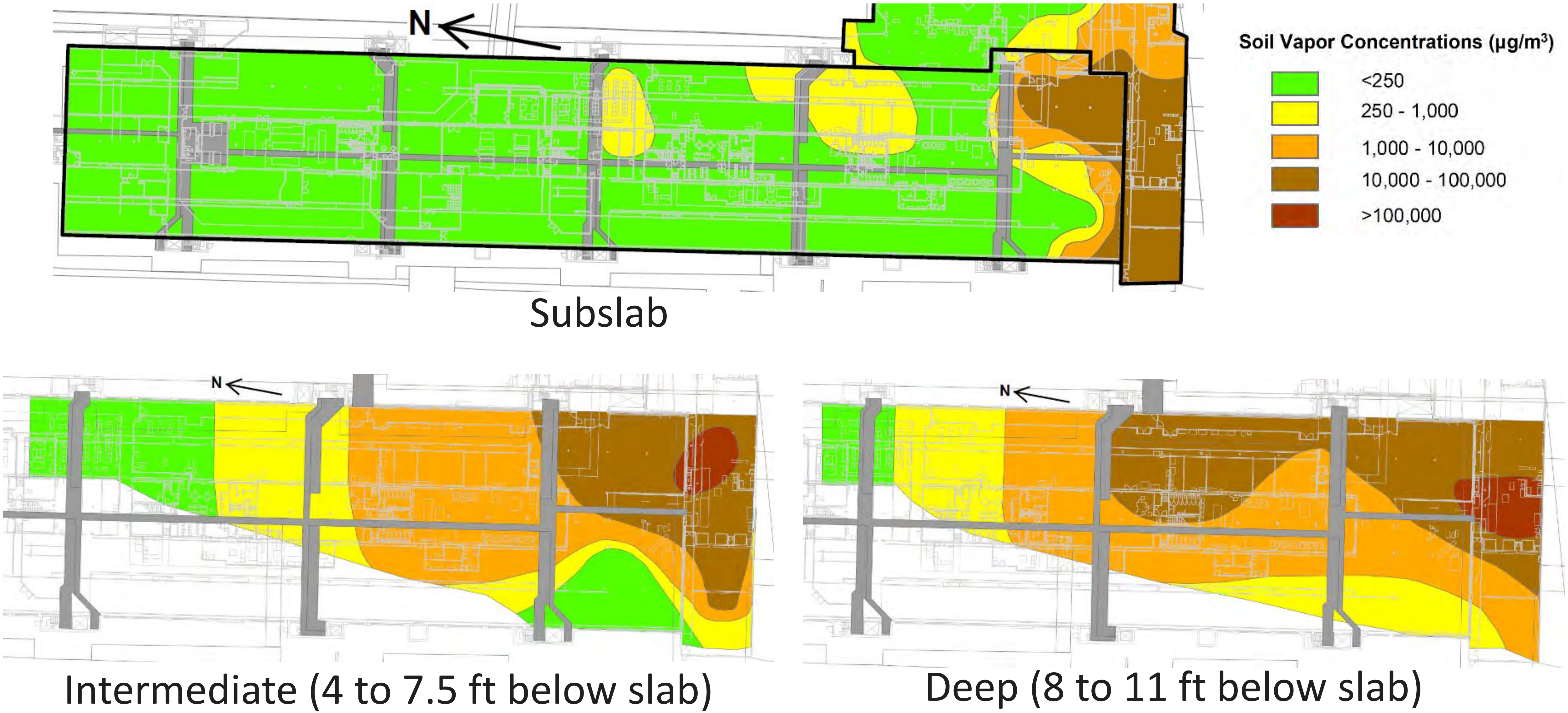
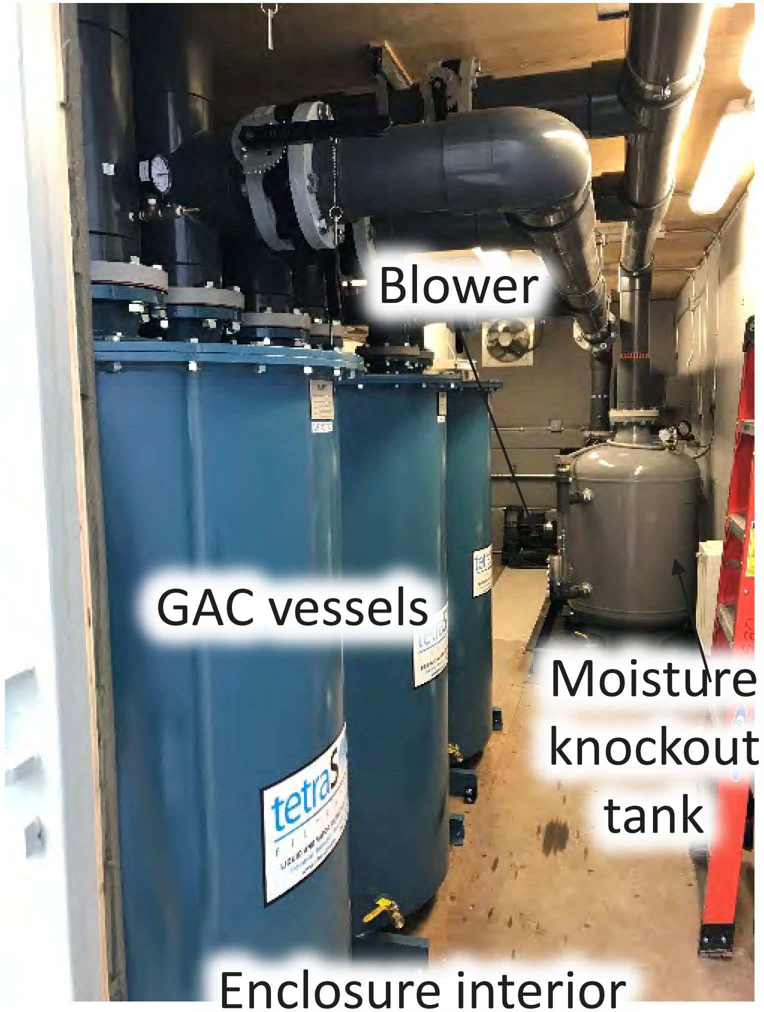
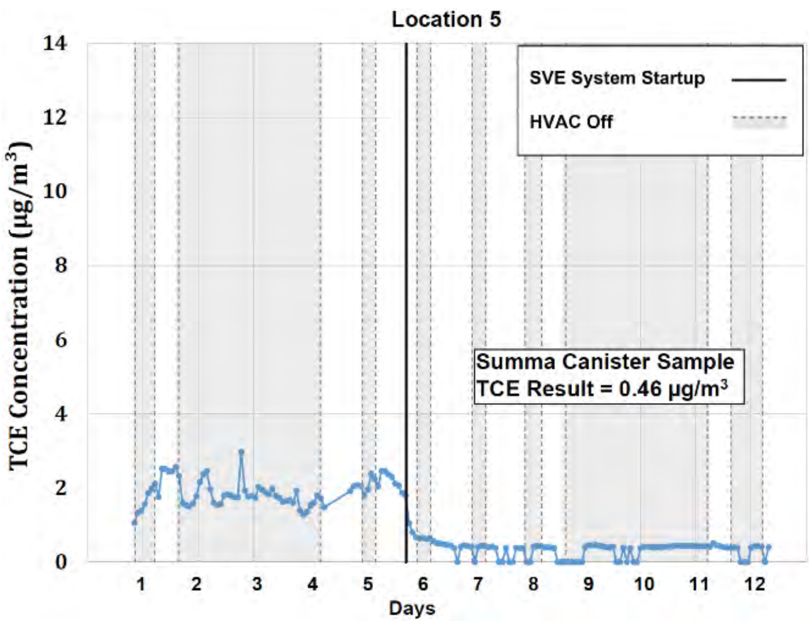
TCE Distribution in Subslab Vapor

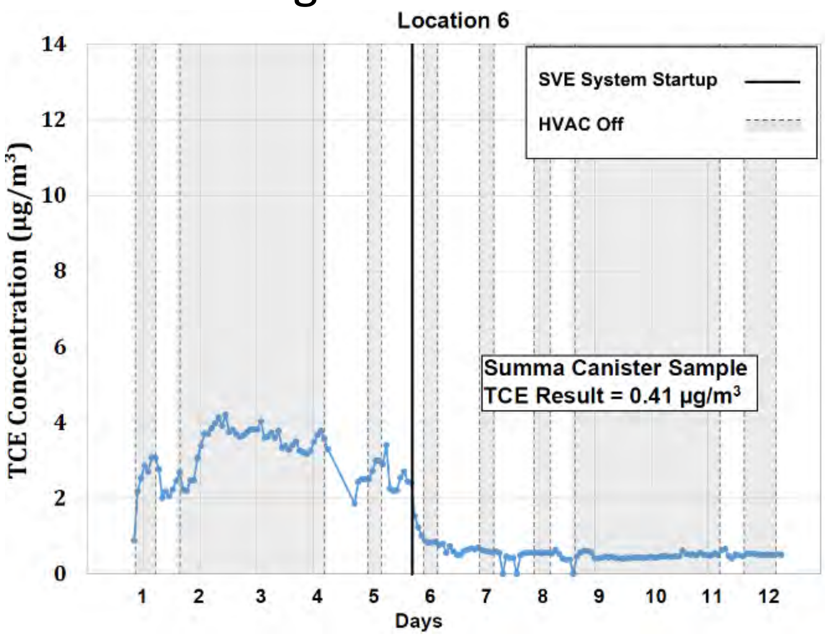


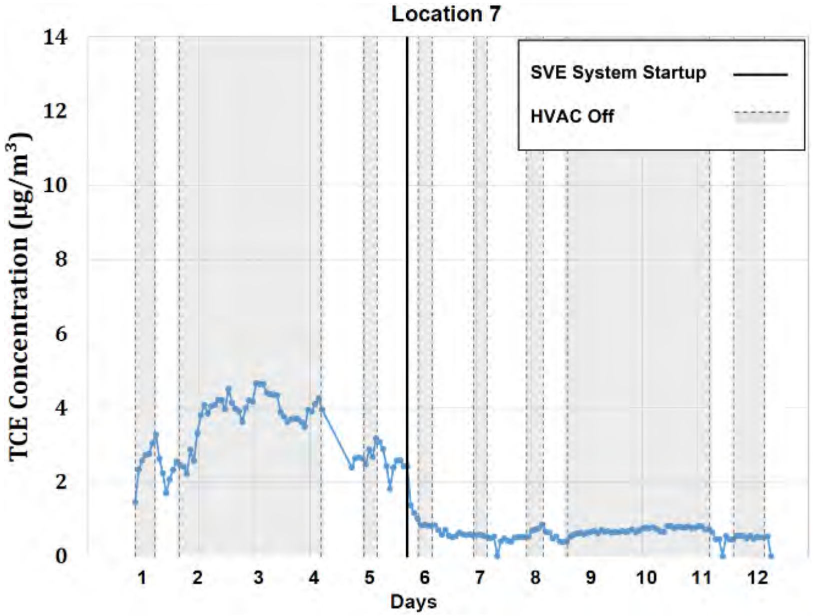
Interior SVE System to target both deeper source zone and subslab vapor

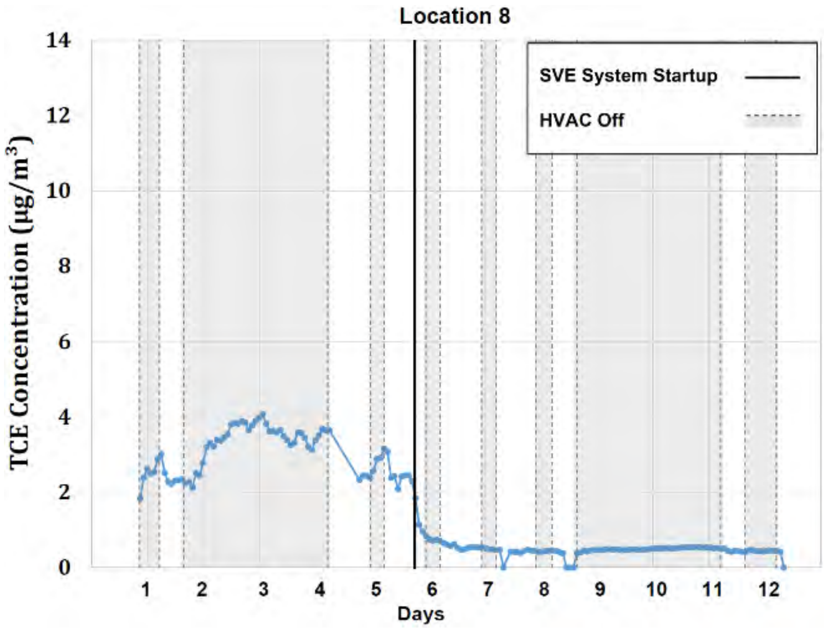


Continuous indoor air monitoring to verify SVE effectiveness for VI mitigation









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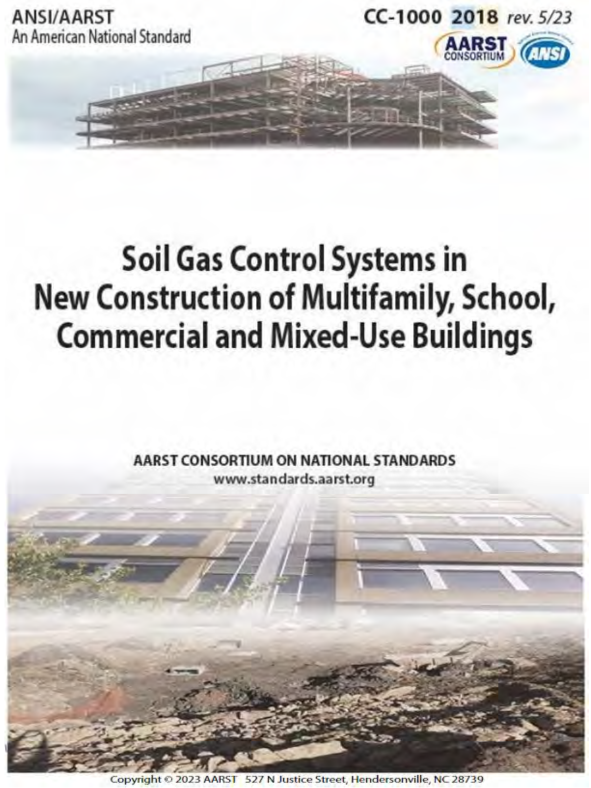
Effectiveness maintained during HVAC shut down periods

VI Mitigation for New Commercial/Industrial/Institutional Construction – Design Guidance



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Soil Gas Control Systems in
New Construction of Multifamily, School,
Commercial and Mixed-Use Buildings

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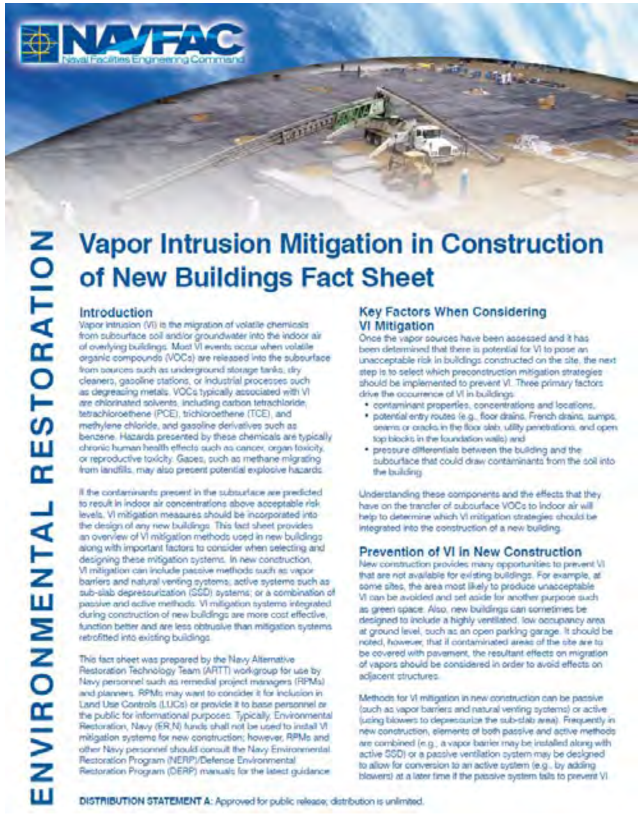


NAVFAC
Naval Facilities Engineering Command

ENVIRONMENTAL RESTORATION

Vapor Intrusion Mitigation in Construction of New Buildings Fact Sheet

Introduction
Vapor intrusion (VI) is the migration of volatile chemicals from subsurface soil and/or groundwater into the indoor air of overlying buildings. Most VI events occur when volatile organic compounds (VOCs) are released into the subsurface from sources such as underground storage tanks, dry cleaners, gasoline stations, or industrial processes such as degreasing metals. VOCs typically associated with VI are chlorinated solvents, including carbon tetrachloride, tetrachloroethene (PCE), trichloroethene (TCE), and methylene chloride, and gasoline derivatives such as benzene. Hazards presented by these chemicals are typically chronic human health effects such as cancer, organ toxicity, or reproductive toxicity. Gases, such as methane migrating from landfills, may also present potential explosive hazards.

If the contaminants present in the subsurface are predicted to result in indoor air concentrations above acceptable risk levels, VI mitigation measures should be incorporated into the design of any new buildings. This fact sheet provides an overview of VI mitigation methods used in new buildings along with important factors to consider when selecting and designing these mitigation systems. In new construction, VI mitigation can include passive methods such as vapor barriers and natural venting systems; active systems such as sub-slab depressurization (SSD) systems; or a combination of passive and active methods. VI mitigation systems integrated during construction of new buildings are more cost effective, function better and are less obtrusive than mitigation systems retrofitted into existing buildings.

This fact sheet was prepared by the Navy Alternative Restoration Technology Team (ARTT) workgroup for use by Navy personnel such as remedial project managers (RPMs) and planners. RPMs may want to consider it for inclusion in Land Use Controls (LUCs) or provide it to base personnel or the public for informational purposes. Typically, Environmental Restoration, Navy (ER,N) funds shall not be used to install VI mitigation systems for new construction; however, RPMs and other Navy personnel should consult the Navy Environmental Restoration Program (NERP)/Defense Environmental Restoration Program (DERP) manuals for the latest guidance.

Key Factors When Considering VI Mitigation
Once the vapor sources have been assessed and it has been determined that there is potential for VI to pose an unacceptable risk in buildings constructed on the site, the next step is to select which preconstruction mitigation strategies should be implemented to prevent VI. Three primary factors drive the occurrence of VI in buildings:
- contaminant properties, concentrations and locations,
- potential entry routes (e.g., floor drains, French drains, sumps, seams or cracks in the floor slab, utility penetrations, and open top blocks in the foundation walls) and
- pressure differentials between the building and the subsurface that could draw contaminants from the soil into the building.

Understanding these components and the effects that they have on the transfer of subsurface VOCs to indoor air will help to determine which VI mitigation strategies should be integrated into the construction of a new building.

Prevention of VI in New Construction
New construction provides many opportunities to prevent VI that are not available for existing buildings. For example, at some sites, the area most likely to produce unacceptable VI can be avoided and set aside for another purpose such as green space. Also, new buildings can sometimes be designed to include a highly ventilated, low occupancy area at ground level, such as an open parking garage. It should be noted, however, that if contaminated areas of the site are to be covered with pavement, the resultant effects on migration of vapors should be considered in order to avoid effects on adjacent structures.

Methods for VI mitigation in new construction can be passive (such as vapor barriers and natural venting systems) or active (using blowers to depressurize the sub-slab area). Frequently in new construction, elements of both passive and active methods are combined (e.g., a vapor barrier may be installed along with active SSD) or a passive ventilation system may be designed to allow for conversion to an active system (e.g., by adding blowers) at a later time if the passive system fails to prevent VI.

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

Benefits to everyone involved:

- Design professionals can rely on them to guide proper installations.
- Regulators can use them as a guide for design review/approval.
- Owners benefit from the assurance of design quality.

VI Barrier Design

Key components of VI mitigation for new construction:

1. Permeable sub-slab support material (e.g. gravel)
2. Venting all sub-slab areas below occupied spaces
3. Properly sized sub-slab and riser pipes
4. A sealed vapor barrier
5. Properly sized blower to maintain sufficient vacuum below the slab

Passive systems include first 4 components
Active systems include the 5th component

Geotextile/HPDE bond (top) layer (from EPRO)

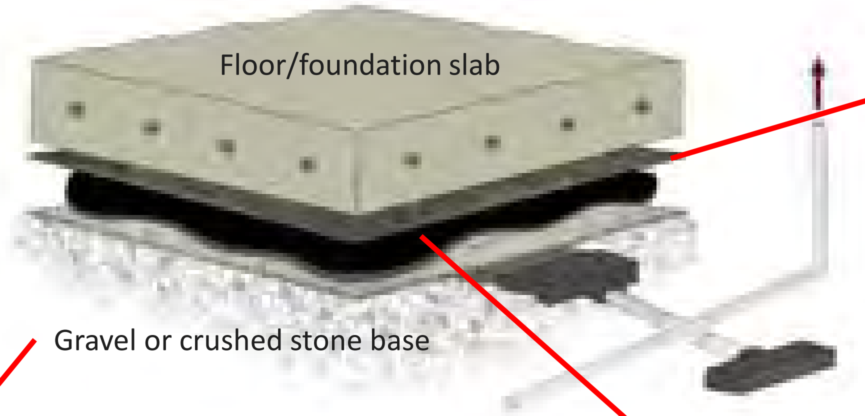


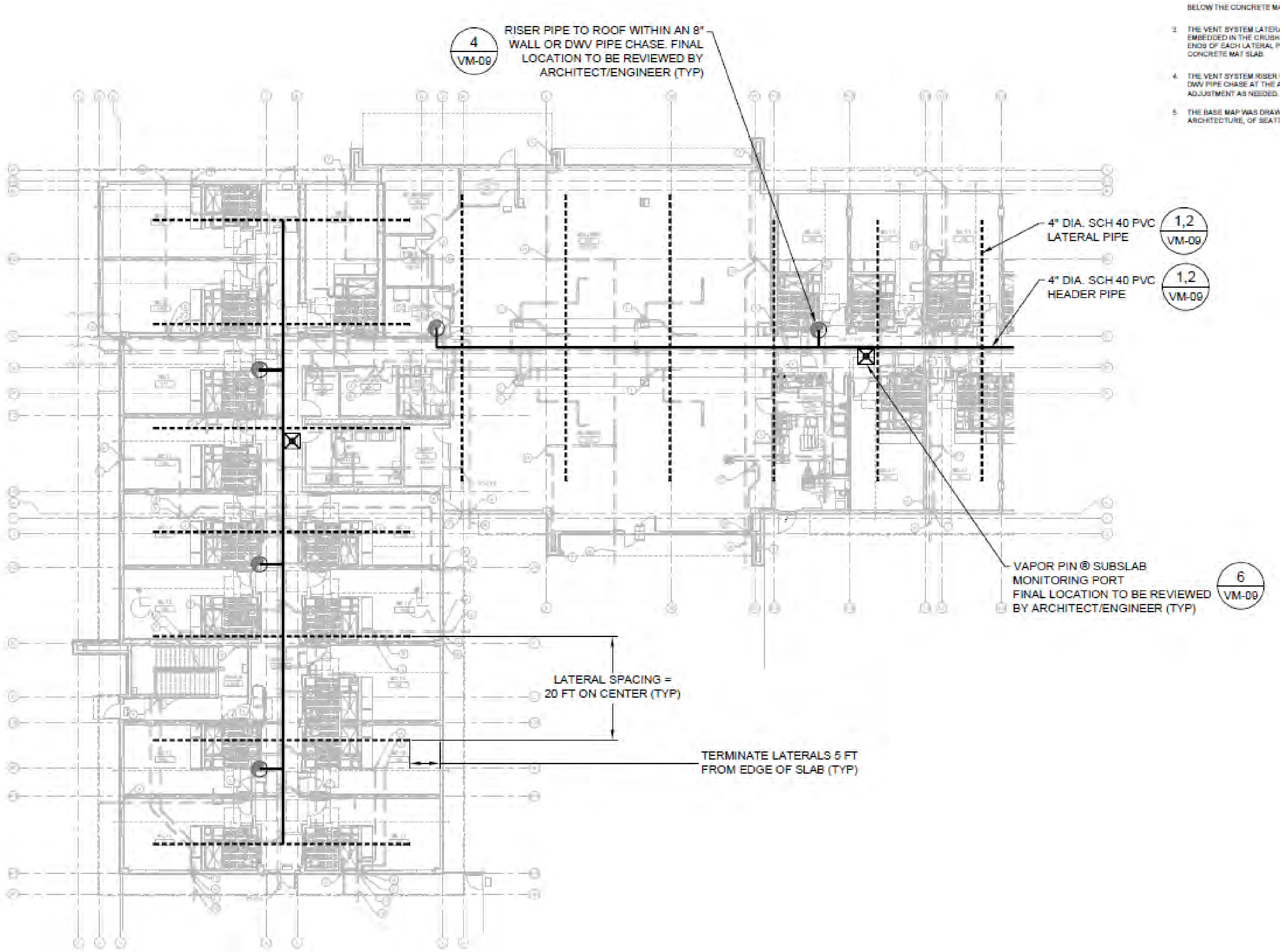
Diagram from CETCO, Liquid Boot®

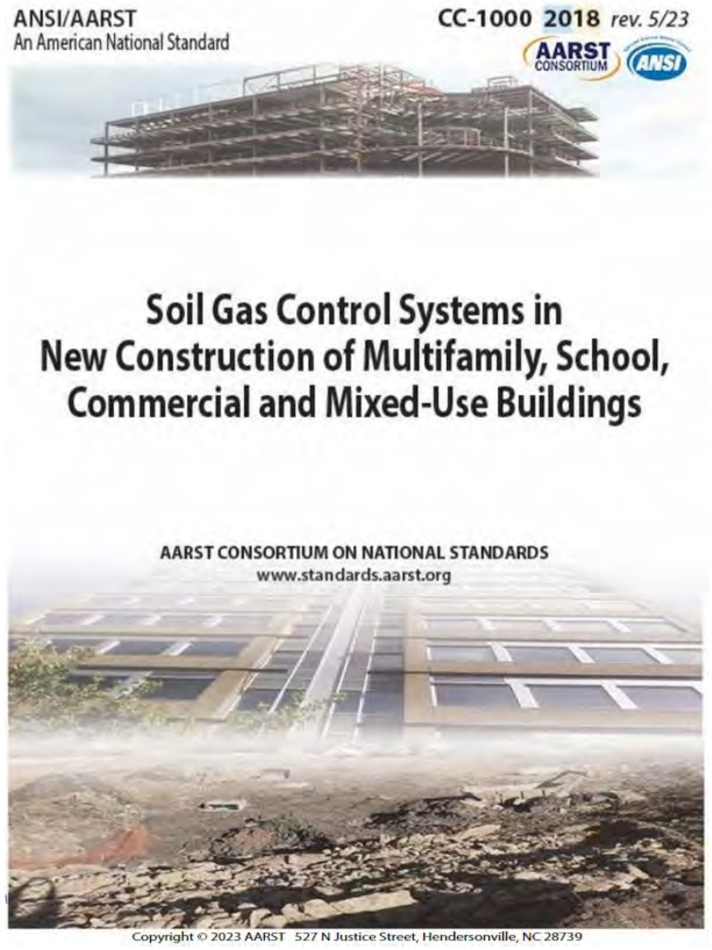
Spray-applied emulsified asphalt latex (from CETCO)

From NAVFAC Fact Sheet, Fig 2

From NAVFAC Fact Sheet, Fig 10

VI Barrier Design





Key design criteria:

- Pipe size vs. area served
- Exhaust risers per area served
- Exhaust locations
- Pipe labels

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Not all VI barriers are created equal

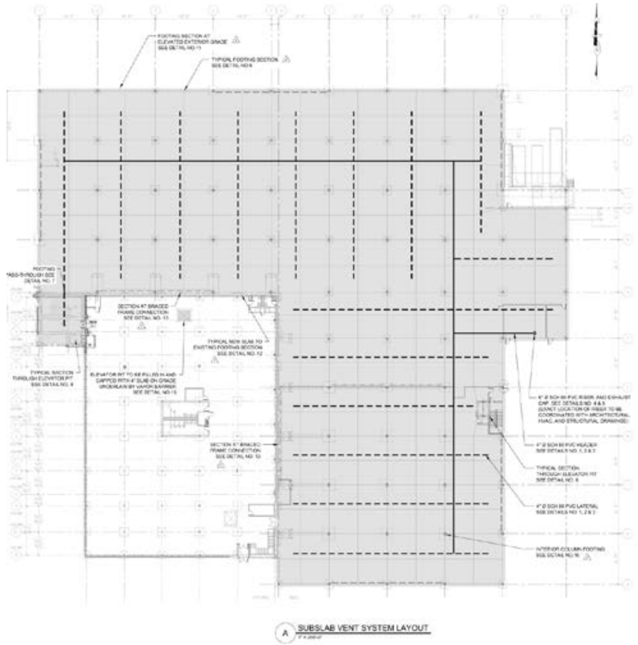
Vapor Barrier Material	Advantages	Disadvantages
6-mil polyethylene or polyolefin	• Inexpensive	• Vapor retarder not a true VOC vapor barrier. • Difficult to seal at walls and penetrations • Low puncture and tear resistance • Unsealed seams are only partially effective for VI prevention
Cross laminate polyethylene or polyolefin	• Lower permeance to vapor transmission than 6-mil poly. • Puncture and tear resistant. • Better sealing at walls and utility penetrations by using tapes and cloth binders.	• Can still be difficult to seal at walls and utility penetrations. • May not be chemically resistant
Spray applied multi-layer composite barrier	• Provides a nearly gas-tight seal to foundation walls and utility penetrations • Leak testing assures quality control	• Most expensive and time consuming to install

Adapted from NAVFAC Fact Sheet – VI Mitigation in Construction of New Buildings

Key Point: The most critical aspect of the effectiveness of any vapor barrier is achieving a tight seal to foundation walls and around utility penetrations.

Passive VI Mitigation Systems

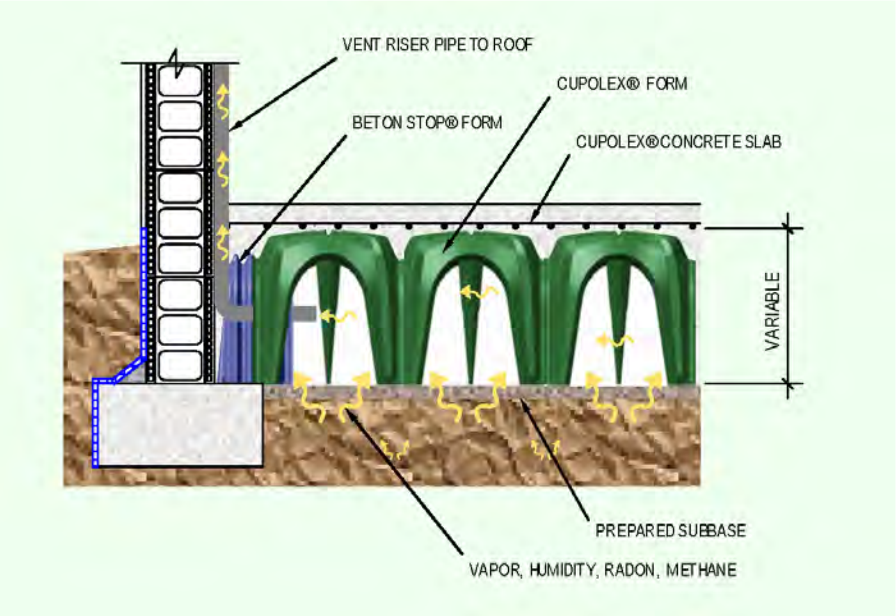
- Should only be used in new building construction.
- May be appropriate for low-strength VOC subsurface presence (e.g., residual VOCs in groundwater or soil), rather than over a VOC source area.
- Rely on natural ventilation (stack effect) to move air from the subsurface to prevent buildup of VOC vapors.
- Performance in terms of sub-slab ventilation flow and depressurization will be variable, depends on factors that will vary passively (e.g., temperature differentials, barometric pressure differentials, wind speed)
- As a result, more verification monitoring may be appropriate.
- A vapor barrier without a venting system is prone to causing buildup of VOCs beneath the barrier and eventual intrusion via defects, preferential pathways, and/or diffusion.
- Good practice is to design a passive system to be converted to an active system if warranted based on performance testing – this requires upfront installation of vent pipes and risers.



Wind-driven turbines

VI prevention for new buildings constructed on old sites

Aerated floor (e.g. Cupolex®) – open space replaces gravel and perforated pipe



Source: http://cupolex.ca

Benefits:
- Less friction loss means smaller fans for active systems and more effective passive venting
- No membranes to seal

Limitations
- Installation cost

Closing Points/Summary

VI Assessment

- Commercial/industrial buildings are typically more complex and challenging to assess than residential structures.
- Consider using investigation technologies other than conventional subslab and indoor air sampling.
  - Real-time and continuous monitoring.
  - Building pressure and HVAC tests.
  - High volume sub-slab soil gas sampling and SSD pilot testing.

VI Mitigation

- Consider whether existing HVAC systems can offer either rapid response or long-term engineering control.
- Active SSD systems are generally the most effective. SVE systems can also be effective.
- Pilot testing is crucial for mitigation design of an existing building.
- For new construction, not all barrier materials are created equal.
- Sealing to foundation walls and around utility penetrations is critical to effectiveness.
- Vapor barriers for new buildings should always be constructed with subslab vent pipes to passively vent vapors or be converted to active systems if needed.
- Refer to and make use of the AARST/ANSI VI mitigation design standards.

Thank you! Questions?