TCE Vapor Intrusion: State of the Science, Regulations, and Technical Options Workshop

Practical Aspects of VI Assessment for TCE

Presented by:
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Monday April 13, 2015
Brown University in Providence, RI
and
Tuesday April 14, 2015
UMass Lowell Inn and Conference Center in Lowell, MA
and
Wednesday May 20, 2015
Fireside Inn & Suites in West Lebanon, NH

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Robert Truesdale — RTI INTERNATIONAL

and colleagues at SANBORN | HEAD

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TCE in background air (residential)

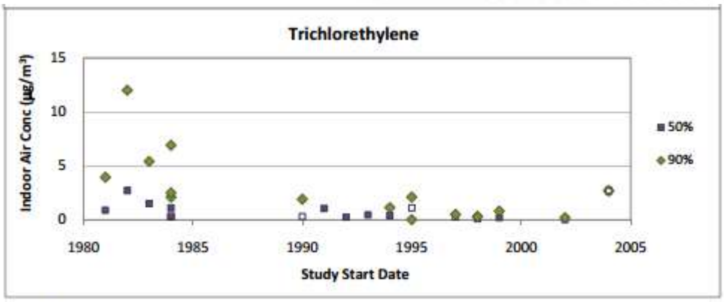

Figure 1. (cont.) Background indoor air concentration (µg/m³) percentiles (50th and 90th) versus time (1981–2005) for selected VOCs in background indoor air. The percentiles are plotted versus the starting sample date of the individual studies. Percentiles below a study's reporting limit are shown with open symbols. See Appendix C for figure data.

Number of studies = 14
Number of samples = 2503
% Detections = 42.6%

Reference: Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990-2005): A Compilation of Statistics for Assessing Vapor Intrusion, June 2011, EPA 530-R-10-001

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TCE in background air (commercial/public buildings) where VI is not expected (1994 – 1998)

Analyte (Indoors)	Number of Buildings	Building Frequency Detected Indoors (%)	Analyte Concentration Indoors Percentile (ug/m³)			Analyte Concentration Indoors Arithmetic Mean (ug/m³)
			5th	50th	95th	
Trichloroethene	70	66	≤ LOQ	0.29	2.6	0.76

Reference: Building Assessment Survey and Evaluation (BASE) Study, http://www.epa.gov/iaq/base/

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Comparison of VI Sampling and Screening Tools

Green	Well suited in most cases
Yellow	Suited in some cases
Orange	Not suited in most cases

Sampling/Screening Tool	Indoor Air/ Outdoor Air	Sub-slab / Soil Gas	VI Preferential Pathway Screening	Background Source Screening
Summa Canisters	Green	Yellow	Orange	Orange
Passive Samplers	Green	Orange	Yellow	Yellow
HAPSITE Portable GC/MS	Green	Green	Green	Green
Glass Vials/Syringe	Orange	Green	Orange	Orange
Tedlar Bags	Orange	Yellow	Yellow	Orange
PID/FID	Orange	Yellow	Yellow	Yellow

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Sampling/ Screening Tool	Pros	Cons
Summa canisters	• Applicable for most VOCs. • Very low detection limits (<0.1 μg/m³) with EPA Method TO-15 in selective ion monitoring (SIM) mode. • Allows for time-weighted-average composite samples from 1 to 24 hours using appropriate flow controllers. • Standard tool/method for regulatory compliance sampling and final decision making.	• Cost per sample is relatively high ($400 to $500 ea.). • Canisters and flow controllers are bulky and cumbersome to use and ship. Equipment problems are not uncommon. • Since samples must be analyzed in an off-site lab, Summa samples are not suited for fast-track, real-time VOC source or background assessments.
Passive samplers (e.g. Radiello, Waterloo Membrane Sampler, ATD tubes)	• Very low detection limits similar to those achieved using Summa canisters. • Small and easy to use. • Allows for time-weighted-average composite samples over long periods (typically 1 to 14 days or more). • Cost per sample about 50% of Summa canister sample.	• Not suited for some VOCs (e.g. vinyl chloride). • Different types of passive samplers can give different results, and results can be affected by environmental conditions (e.g. temp, humidity). • Regulators may not be familiar with/accepting of method without some Summa duplicates.
HAPSITE portable GC/MS	• Provides real-time analytical results at very low detection limits (~1 μg/m³) for most VOCs. • Facilitates fast-track, real-time identification of vapor intrusion sources vs. background sources. • Analysis of 20 to 40 samples per day. • Rapid results offers potential for significant savings in investigation time and cost compared to conventional sampling methods, and allow for real-time decisions in response to results.	• Not suited for determining time-weighted-average concentrations typically used for comparison to indoor air regulatory standards. • Regulators may not be familiar with/accepting of method without some Summa duplicates. • Must use caution when analyzing higher VOC concentrations to avoid overloading instrument. • Equipment use and interpretation of results requires training.
Glass vials/ syringes	• Small, lightweight, and easy to use - facilitates rapid, grab sample collection. • Best suited for soil gas and sub-slab gas grab sampling. • Cost per sample less than 50% of Summa canister.	• Not widely available/offered by labs. • Not suited for determining time-weighted-average concentrations typically used for comparison to indoor air regulatory standards. • Not suited for very low level detection limits. • Some loss of VOCs possible through vial cap as time passes before lab analysis. • Regulators may not be familiar with/accepting of method without some Summa duplicates.
Tedlar bags	• Best suited for higher concentration grab samples (VOCs > 1 ppmv) associated with VOC source screening and on-site mobile lab availability. • Many samples can be collected quickly.	• Requires air sample pump to fill bag. • Samples must be analyzed quickly after collection or risk of loss of VOCs through bag. • Bags can contain background VOCs. • Not suited for determining time-weighted-average concentrations.

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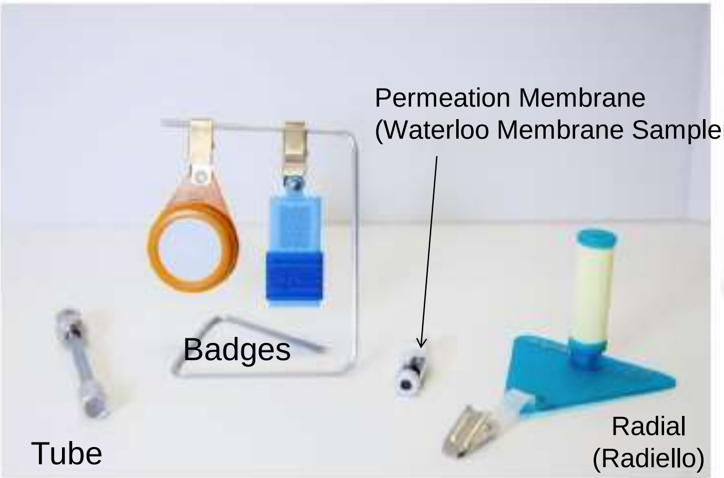
Passive sampling devices



Reference: *Passive Samplers for Investigations of Air Quality*, USEPA Engineering Issue Paper, 2015 (in process)

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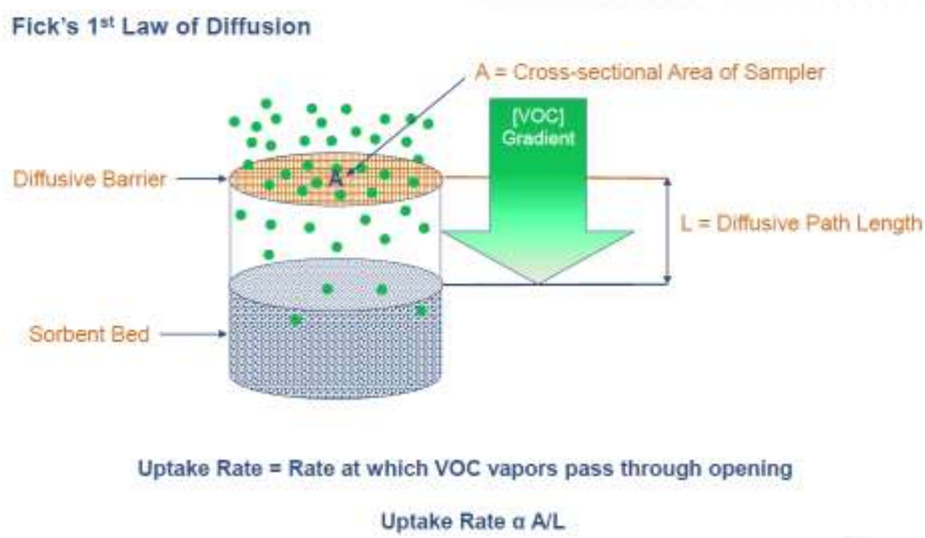
Passive Sampling Concept



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Passive Sampling Concept

Measured in lab

$$\text{Concentration } (\mu g/m^3) = \frac{\text{Analytical Result } (\mu g) \times \frac{1000 \text{ mL}}{1 \text{L}} \times \frac{1000 \text{ L}}{m^3}}{\text{Uptake Rate (mL/min)} \times \text{Sampling duration (min)}}$$

Sampler Geometry specific
Chemical specific
Sorbent performance
Environmental conditions

Recorded in the field

Passive Sampling Sorbents

	Charcoal-based	Thermally-Desorbable
Examples	Activated charcoal, Anasorb 747	Tenax TA, Carbopack, Carbograph, Carboxen
Performance	Strong VOC Retention	Weaker VOC Adsorption
Capacity	High surface area	Relatively less capacity
Prep Method	Solvent Extraction (SE)	Thermal Desorption (TD)
Analytical Sensitivity	Low: ~0.1 µg	High: ~0.01 to 0.001 µg

Sorbent must effectively retain compounds of interest during sample collection while efficiently releasing the compound at the time of analysis.

Passive Sampler Selection

Trichloroethene Indoor Air Reporting Limits* (μg/m³)
Assume C_{RBSL} = 0.48 μg/m³

Type	Sorbent	1 day	3 days	7 days	14 days	30 days
Radial	TD	0.064	0.021	0.0092	0.0046	0.0021
Badge	TD	0.15	0.050	0.017	0.0083	0.0039
Permeation	TD	0.57	0.19	0.082	0.040	0.019
Radial	SE	1.0	0.34	0.14	0.072	0.034
Badge	SE	6.1	2.0	0.86	0.43	0.20
Permeation	SE	11	3.5	1.5	0.76	0.35

TD = thermal desorption
SE = solvent extraction

*Actual RLs will vary depending on specific laboratory capabilities. Values presented are representative of methods. Duration of TD methods depends on specific sorbent selected.

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Sun Devil Manor Study Site (2010-15)

- 10 – 60 μg/L TCE and 1,1 DCE in groundwater
- 1500 pCi/L radon in soil gas
- Groundwater at about 10 ft BGS
- Fine-grained soil

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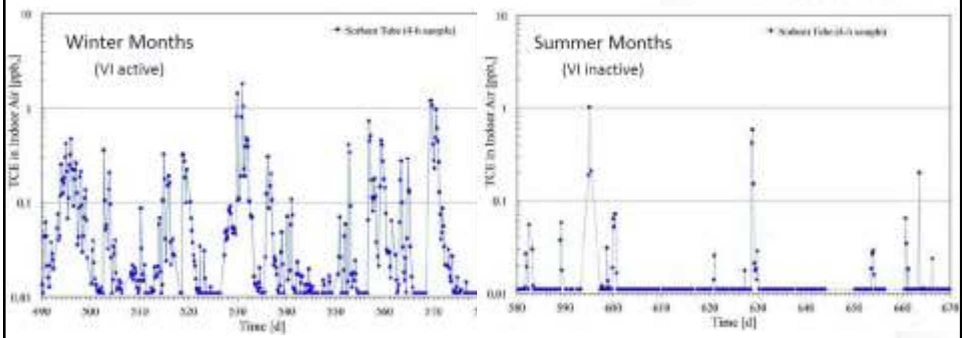
TCE in indoor air under natural conditions



Holton et al., ES&T, 2013, 47, 13347-13354

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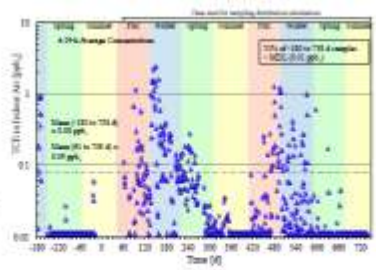
Simulation of Indoor Air Sampling Plan Effectiveness

1. Create synthetic 24-h sample data from high temporal resolution data
2. Perform 10,000+ simulations for three VI assessment plans
   - 4 samples (Fall, Winter, Spring, Summer)
   - 2 samples (Winter, Summer)
   - 2 samples (Winter, Winter)
3. Analyze statistics, assess decision



- High potential for false negative conclusions concerning VI occurrence
- High potential to incorrectly characterize long-term exposure
- High potential to incorrectly characterize maximum short-term exposure

Holton et al., ES&T, 2013, 47, 13347-13354

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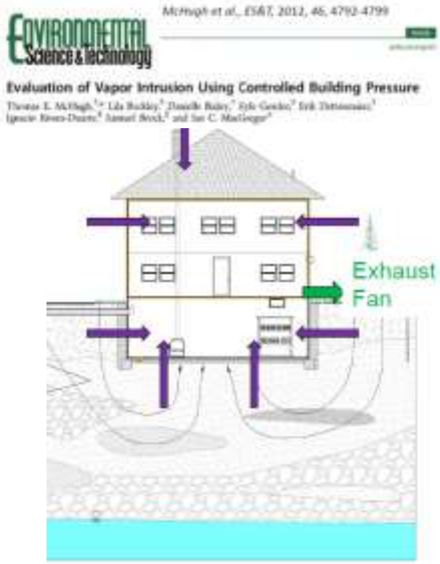
Controlled Pressure Method (CPM) Testing Approach



- Impose negative (or positive) pressure on structure and assess effects with on-site analysis.
- Simulate "worst case" VI condition to address temporal variability
- Resolve "background" from VI

from Beckly et al. AWMA VI Conference

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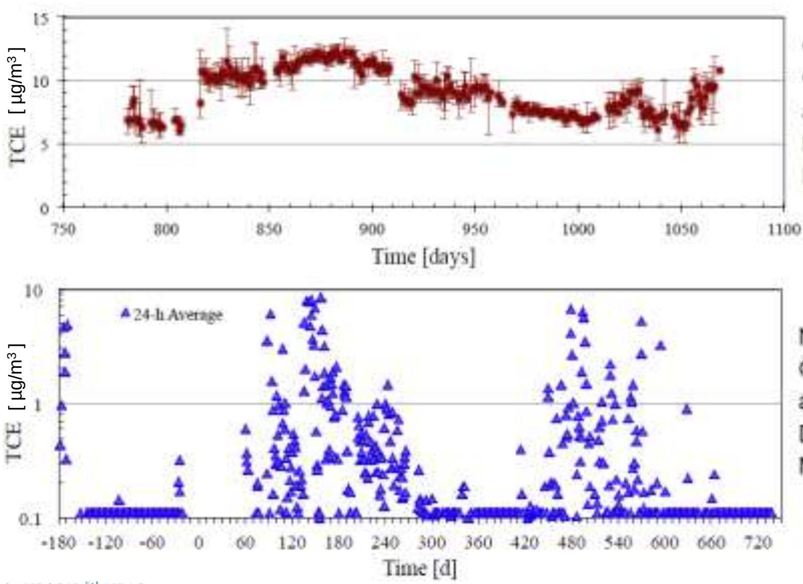
CPM vs. Natural Conditions at SDM



CPM Condition at Sun Devil Manor

Natural Condition at Sun Devil Manor

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Controlled Pressure Method (CPM) test at Sun Devil Manor

	TCE [µg/m³]	
Condition	Natural Conditions (128 to 730 d)	CPM (780 to 1045 d)
Mean	0.35	9.3
Median	0.068	9.1
Maximum	13	12
Minimum	<0.04	6.0

← CPM results >> long-term average natural conc.

← CPM results ~ max. natural conc.

← No false negatives in CPM results

"the CPM results were a reliable indicator of VI occurrence and worst-case exposure regardless of day or time of year of the CPM test" Holton et al., ES&T, 2015, 49 (4), pp 2091–2098

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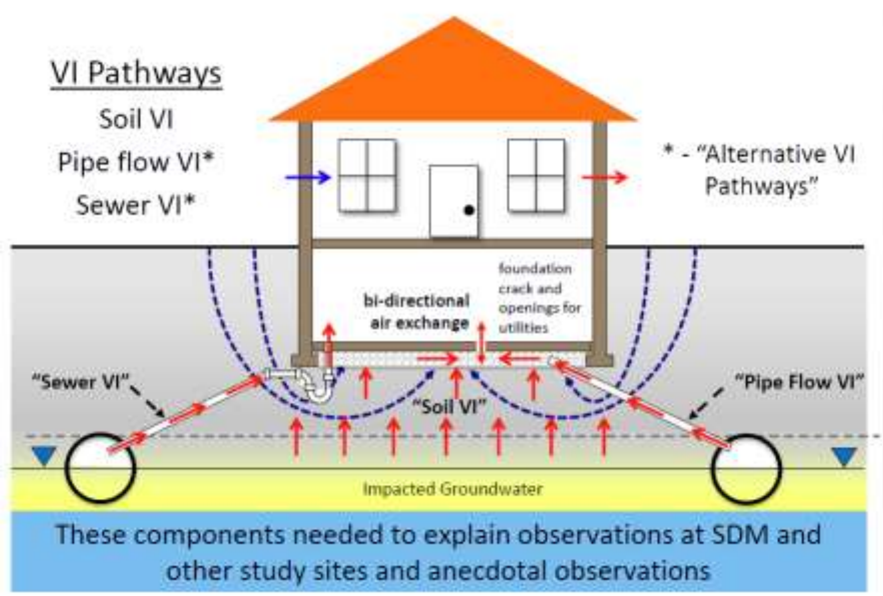
VI Pathway Re-Conceptualization



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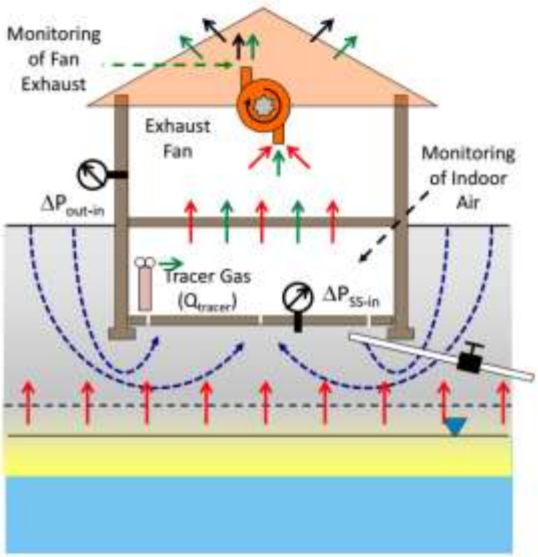
Phase III: Closed Land Drain Lateral



Close land drain lateral and:

- Maintain house at constant under-pressurization relative to sub-slab soil gas using blower(s) for about 80 days
- Turn off blower, study house under natural conditions (Fall/Winter, 150 days)

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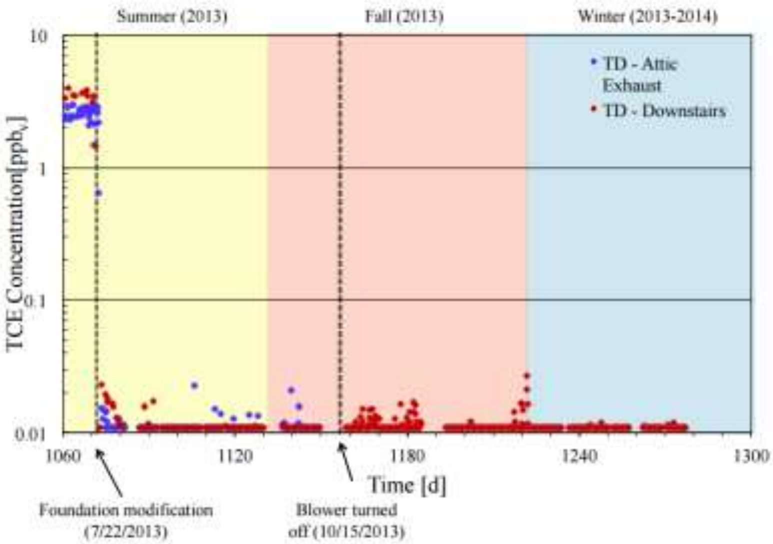
Phase III



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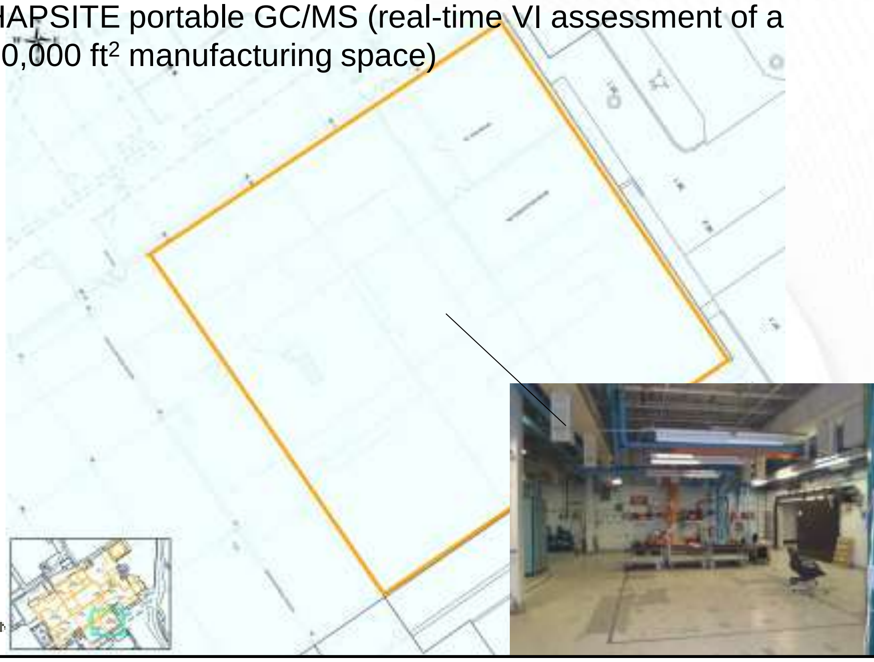
Controlled Pressure Method for an industrial building using HAPSITE portable GC/MS (real-time VI assessment of a 10,000 ft^2 manufacturing space)



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Real-time data analysis – A useful tool in the right hands

Portable gas chromatograph-mass spectrometer (GC-MS)

Hazardous Air Pollutants on-Site: HAPSITE® manufactured by INFICON, Syracuse, NY

- Air samples drawn into the instrument through the probe
- Portable at ~35 lbs
- Typically 5-10 minutes from sample collection to result
- Capable of analyzing ~40 samples/day
- Detects a wide range of VOCs at the low µg/m^3 level

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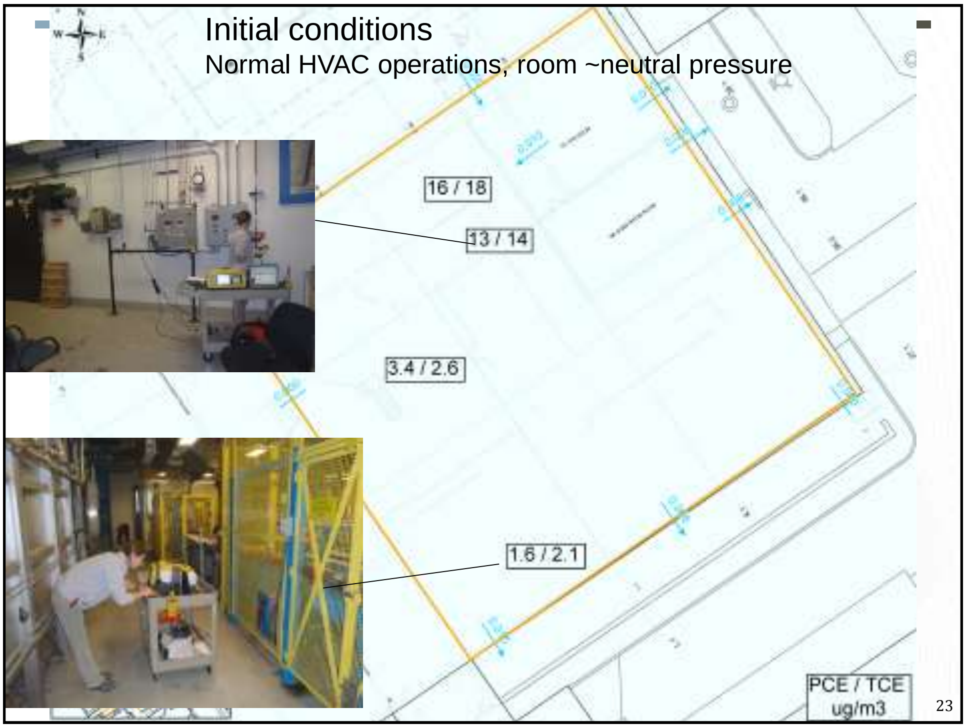
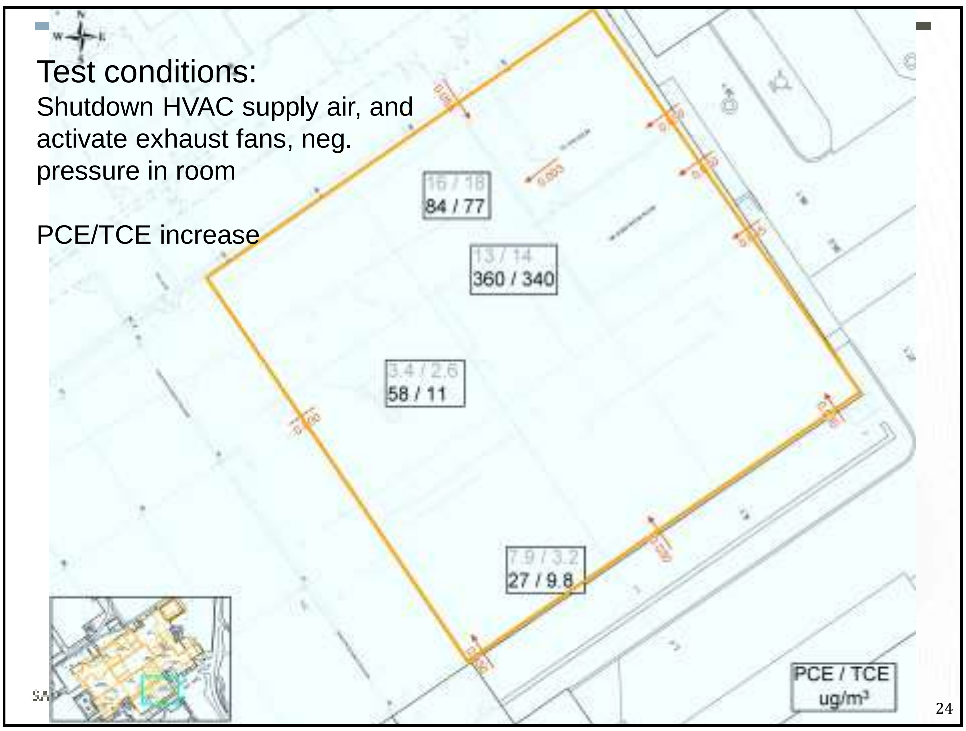
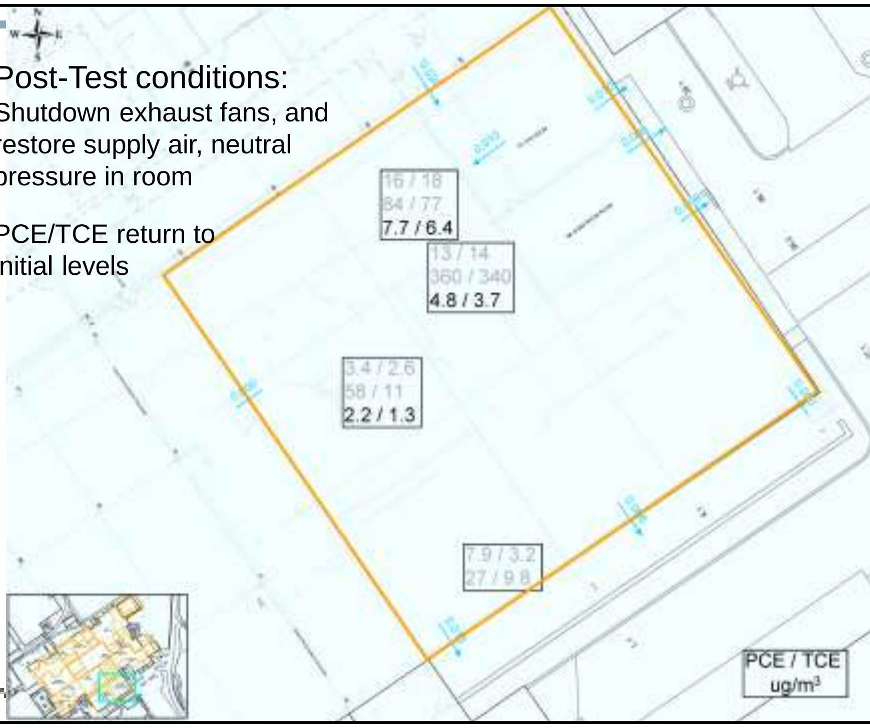

Initial conditions
Normal HVAC operations, room ~neutral pressure
16 / 18
13 / 14
3.4 / 2.6
1.6 / 2.1
PCE / TCE
ug/m3
23

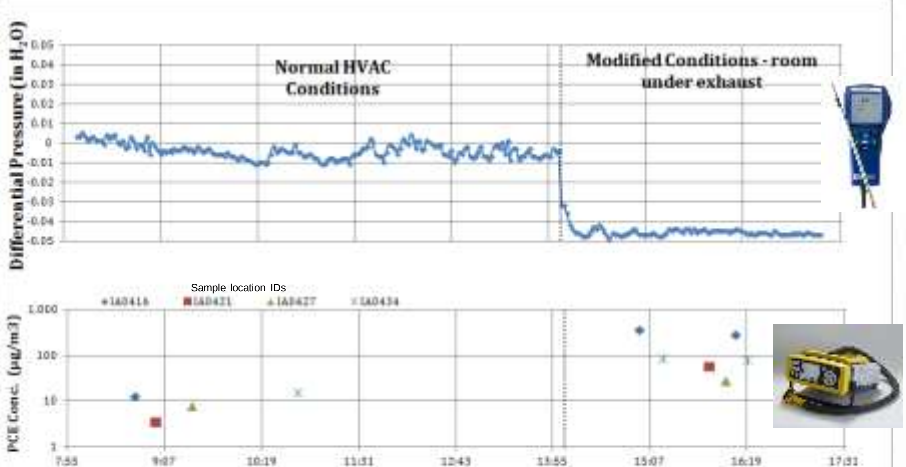

Test conditions:
Shutdown HVAC supply air, and activate exhaust fans, neg. pressure in room
PCE/TCE increase
16 / 18
84 / 77
13 / 14
360 / 340
3.4 / 2.6
58 / 11
7.9 / 3.2
27 / 9.8
PCE / TCE
ug/m³
24

Post-Test conditions:

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

PCE/TCE return to initial levels





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

Results indicate VI rather than interior VOC source.

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Identifying the vapor entry points: Expansion joints in floor slab

In 1 day of real-time assessment:

- Obtained and analyzed 27 samples using the HAPSITE® GC-MS
- Established baseline indoor air VOC conditions
- Using CPM and without sub-slab sampling, confirmed that baseline conditions were due to vapor intrusion, not interior sources
- Identified the vapor entry pathways (i.e. the expansion joints), which suggested a remedial solution (re-caulking/sealing the joints)

Distinguishing background from VI: Is it VI or art supplies?

Hapsite set up on mobile cart in laundry room

- Analyzed ~80 samples over 2 days in 25 apartments
- Analyzed household products, art supplies, and potential VI pathways

PCE and TCE in indoor air in former mill building converted to apartments (artistic residences)

Sniffing for VI from cracks under rugs

Results:
PCE due to art supplies.
TCE due to VI through floor cracks.

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Courtesy of StoneHill Environmental

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Hypothetical Cost Comparison*: VI assessment of 20,000 sq ft building

Conventional				
Description	Qty	Unit Cost	Units	Cost
Baseline Sampling				
Indoor Air (TO-15)	5	$450	sample	$2,250
Sub-slab (TO-15)	5	$450	sample	$2,250
Labor	4	$1,200	person-days	$4,800
Focused Follow-up Sampling				
Indoor Air (TO-15)	10	$450	sample	$4,500
Labor	2	$1,200	person-days	$2,400
			Total	$16,200

Portable GC-MS				
Description	Qty	Unit Cost	Units	Cost
Baseline and Focused Sampling				
GC-MS Calibration	1	$900	lump	$900
GC-MS	1	$500	day	$500
Labor	2	$1,200	person-days	$2,400
Confirmatory (TO-15)	5	$450	sample	$2,250
			Total	$6,100

* Cost estimates are for relative comparison and do not include other items likely common to both approaches, such as report preparation, project management, and QA/QC

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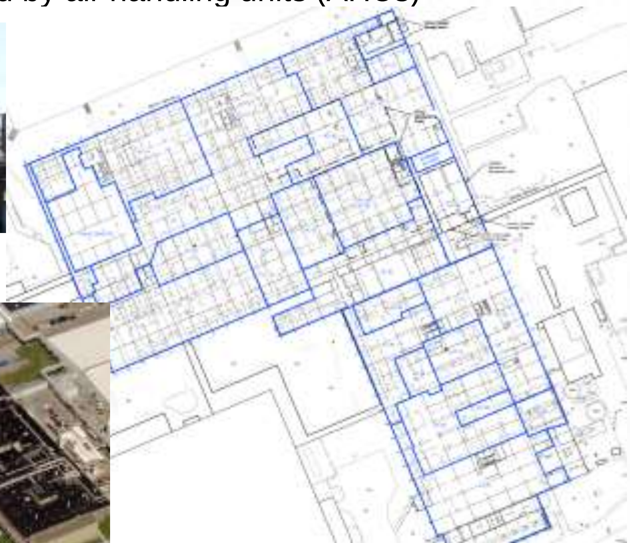
HVAC Basics: Most large buildings are designed with multiple HVAC zones served by air handling units (AHUs)

Rooftop AHU



330,000 sq.ft. industrial bldg

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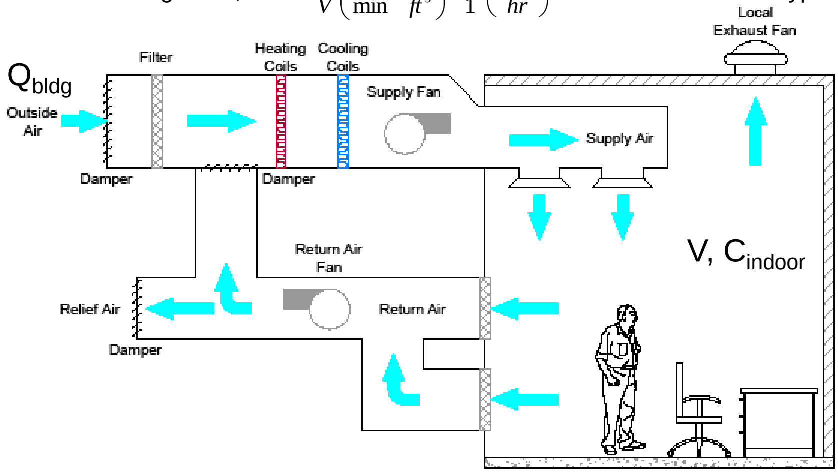
AHU Basics

- Supply fan: moves air, creates +/- pressure
- Return fan: re-circulates/recycles and exhausts air
- Dampers: adjusts air flow through ducts
- Coils: heat or cool air

V= Volume
C_{indoor} = indoor concentration
Q_{bldg} = bldg air flow

Air exchange rate, $AER = \frac{Q}{V}\left(\frac{ft^3}{\min}\cdot\frac{1}{ft^3}\right)\cdot\frac{60}{1}\left(\frac{\min}{hr}\right) = hr^{-1}$

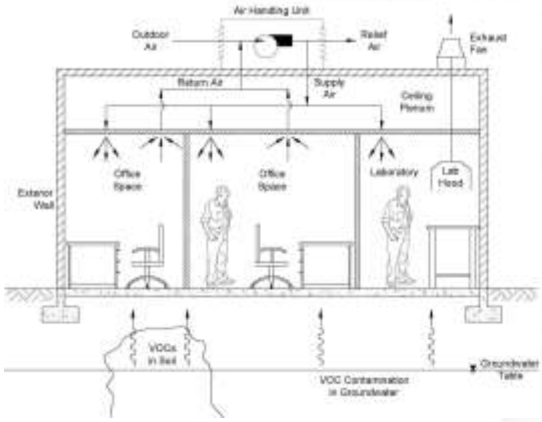
1 to 4/hr is typical



Mass load from VI ≈ Q_{bldg} x C_{indoor} = AER x V x C_{indoor} [g/day]

Things to look for when evaluating VI vulnerabilities in large buildings

- AHU/Airflow Balance: AHU Balance = Outdoor Air - Relief Air – Exhaust = + or -
- HVAC equipment/components in contact with the floor slab
- Building-wide plenum for return air (often above ceilings or beneath raised flooring).
- Areas of "dead" or low AER/ACH (vacant areas, storage areas)
- Areas of potential low air pressure (mechanical rooms, fan rooms, laboratories, kitchens)
- Variability of HVAC operations (nightly and weekend turndown, outside air damper position – economizers, operator over-rides)



- Alternate pathways – cracks, joints, sumps, pits, trenches, etc.

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Challenges of Assessing and Mitigating Large Buildings

- Size and volume of building
- Heterogeneity of sub-surface contaminant presence
- Complex foundation and infrastructure
- Confounding influence of HVAC design and operations

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- 100,000 sq. ft. footprint
- TCE used in 1960s and 1970s
- Subsurface TCE presence indentified in 1990s
- Groundwater at depth of 3 to 5 feet below slab

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VI Investigation Components

1. HVAC system review

2. Real-time indoor air screening using a portable GC-MS (HAPSITE)

3. Targeted screening for VI pathways

4. Sub-slab gas and differential pressure monitoring

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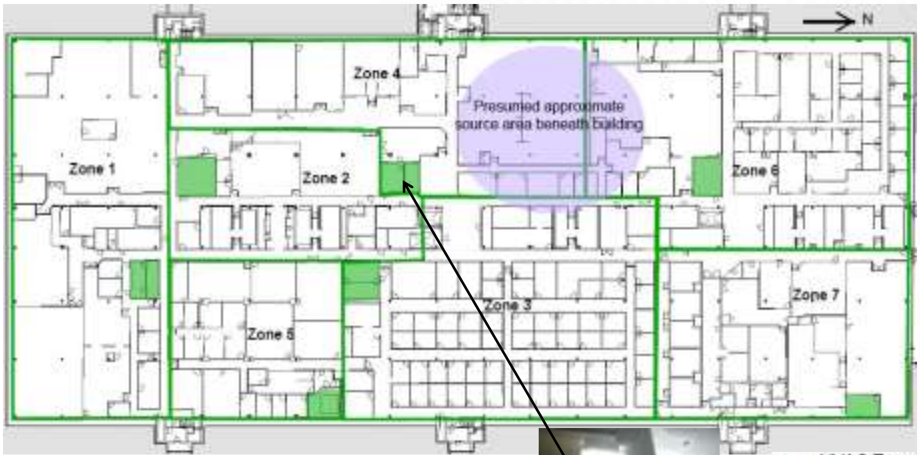

HVAC System Review

- 7 zones
- AHU rooms at lower pressure
- Air exchange of 0.9/hr (avg)
- Total outside air flow ~15,600 cfm

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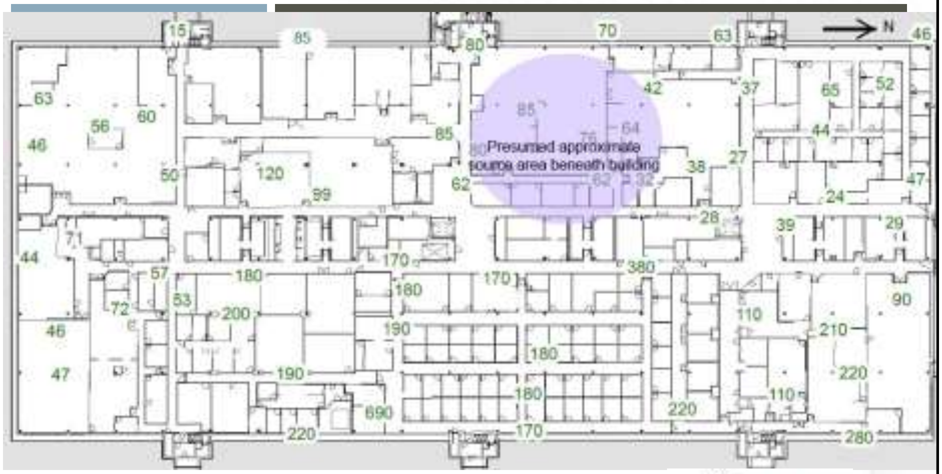
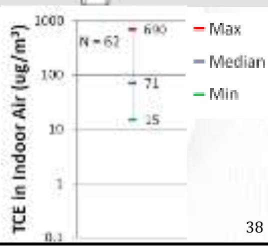


Indoor air screening with portable GC-MS

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



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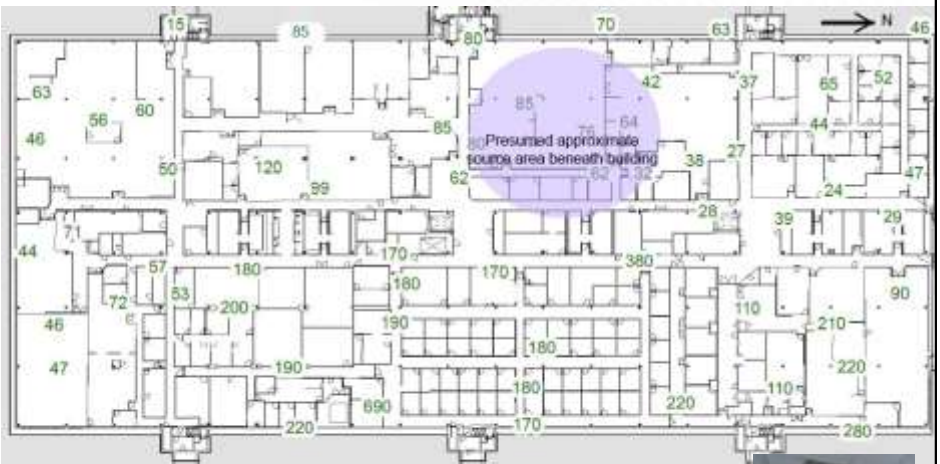
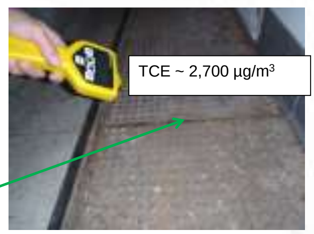


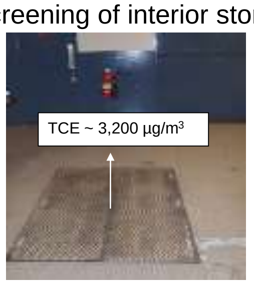
$$\text{TCE mass load} = Q_{bldg} \times C_{median}$$
$$= 15{,}600 \text{ cfm} \times 71 \text{ ug/m}^3$$
$$= 0.1 \text{ lbs/day } (0.05 \text{ kg/day})$$

Identifying the vapor entry pathways:

Air handler unit rooms under negative pressure

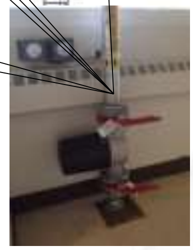


Targeted screening of interior storm drain manholes



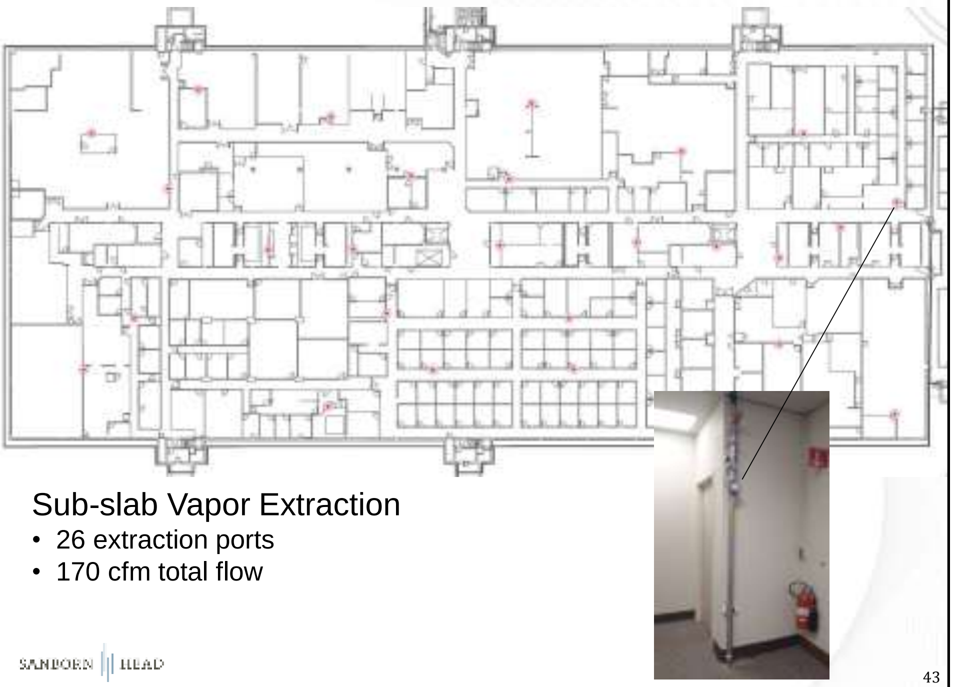
Depressurization of floor trenches

- 1,200 linear ft of trench
- 6 ventilation ports
- Depressurized to 0.01 inches water column
- 500 cfm or 0.4 cfm/ft



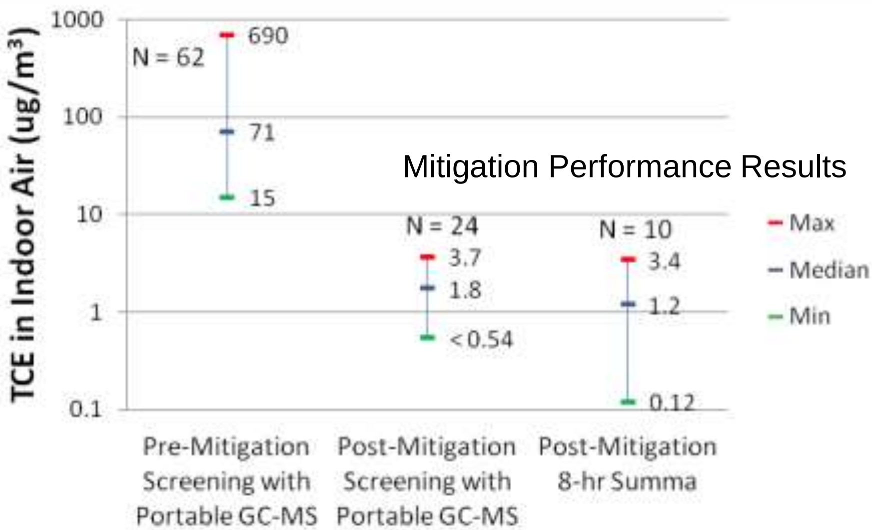
Depressurization of manhole headspace

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

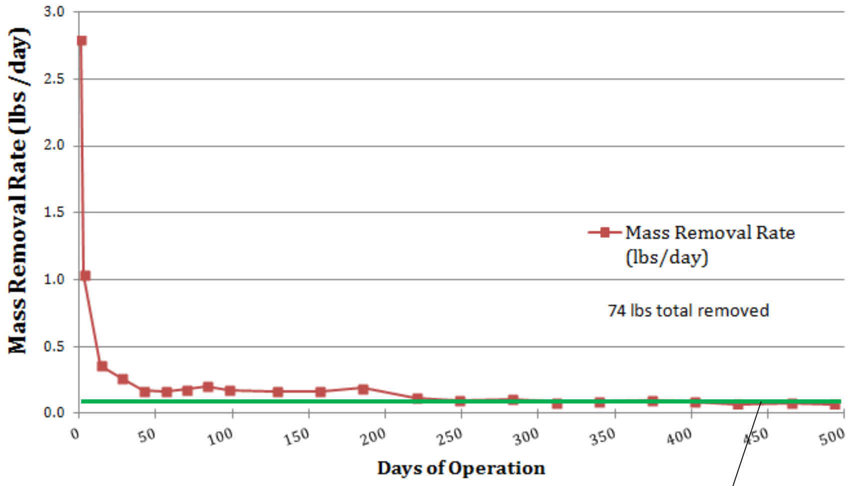


Sub-slab Vapor Extraction

- 26 extraction ports
- 170 cfm total flow



TCE Mass Removal



Mass load based on pre-mitigation median indoor TCE level = 0.1 lbs/day

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Introduction to Mass Flux Concepts for VI Assessment

ESTCP Research Project Mass Flux for VI Assessment

$(MF1 \approx MF2 \approx MF3)$

Mass flux estimation under natural conditions

$MF1 = D_{eff} A_{bldg}(\Delta C/\Delta z)$

Mass flux estimation under forced depressurization within the building

$MF2 = (C_{IA,\ BPC})(Q_{BPC})$

Mass flux estimation under forced depressurization beneath the building

$MF3 = (C_{SSD})(Q_{SSD})$

$MF_{bldg,\ natural} = C_{IA}\ Q_{bldg} = C_{IA}V_{bldg}AER$

$MF_{soil,\ natural} = - D_{eff}\ A_{bldg}\Delta C/\Delta Z$

$MF_{bldg,\ forced} = C_{IA,BPC}Q_{BPC}$

$MF_{soil,\ natural} = - D_{eff}\ A_{bldg}\Delta C/\Delta Z$

$Mf_{soil,\ forced} = C_{SSD}\ Q_{SSD}$

$MF_{soil,\ natural} = - D_{eff}\ A_{bldg}\Delta C/\Delta Z$

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Courtesy of Helen Dawson

Geosyntec consultants

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Introduction to Mass Flux Concepts for VI Assessment

- Calculate RME indoor air concentration from mass flux:

$$IA_{RME} = MF_{1,\ 2,\ or\ 3} / (V_{bldg} AER)$$

- Calculate mass flux threshold from target indoor air concentration:

$$MF_{threshold} = IA_{target}\ V_{bldg}\ AER$$

IA	=	indoor air concentration
$MF_{1, 2, or 3}$	=	mass flux characterized by Methods 1, 2, or 3
AER	=	air exchange rate
RME	=	reasonable maximum exposure

ESTCP Research Project Mass Flux for VI Assessment

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Introduction to Mass Flux Concepts for VI Assessment

ESTCP Research Project Mass Flux for VI Assessment

May 2014: Colorado Water Quality Control Commission (WQCC) **established site-specific groundwater standards** for **TCE protective of the VI pathway** in residential areas overlying a shallow TCE plume adjacent to the former Lowry Air Force Base (LAFB).

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Introduction to Mass Flux Concepts for VI Assessment

- Threshold mass flux:
  $MF3 = C_{IA\ Target} \times Q_{bldg}/A_{bldg} =$ **21 ug/m²/day**
  $C_{IA\ Target} = 0.48\ ug/m^3$
  $Q_{bldg}/A_{bldg} = AER \times H_{bldg} = 12/day \times 3.66\ m$
- Mass flux from groundwater at 11 ug/L:
  $MF1 = D_{eff} \times \Delta C / \Delta z =$ **2.4 ug/m²/day**
  $D_{eff} = 0.0046\ m^2/day$
  $\Delta C = [GW]_{equilibrium\ vapor} - 0 = 2400\ ug/m^3$
  Δz = DTW – Basement Depth = 20 ft – 6 ft = 4.57 m

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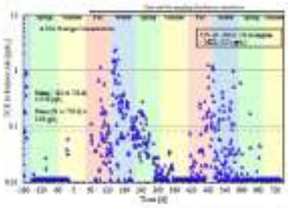
Summary

Vapor intrusion can be variable in time (Sun Devil Manor, Indianapolis Duplex). *But most of the variability at SDM was attributable to an alternate VI pathway!*



For residences, one-time 24-hr sampling has a high probability of missing short-term, episodic VI.

To address variability, consider:
- Long-term passive sampling
- Controlled pressure method (CPM) testing
- Real-time sleuthing for background sources and alternate VI pathways (e.g., drain pipes) using portable GC/MS

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Summary (cont.)

VI assessment of commercial/industrial buildings should consider:

- HVAC system air flow/pressure balance of building
- Negative pressure areas - equipment in contact with floor, return air configuration

- Dead/stagnant zones (vacant or storage areas)
- Plenums that can mix/distribute VOCs throughout building
- Physical VI vulnerabilities (cracks, sumps, trenches, elevator pits, etc.)

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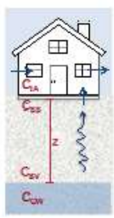
Summary (cont.)

Mass flux estimation offers another (possibly better) approach to predict VI, and for developing exit strategies for mitigation

Mass flux estimation under natural conditions

$MF1 = D_{eff} A_{bldg} (\Delta C/\Delta z)$



$MF_{bldg,\ natural} = C_{IA} Q_{bldg} = C_{IA} V_{bldg} AER$

$MF_{soil,\ natural} = - D_{eff} A_{bldg} \Delta C/\Delta Z$

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Mass Flux For Vapor Intrusion Characterization

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Questions?

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