# Tools to Reduce Vapour Intrusion Mitigation System (VIMS) Installation and Operating Costs for Brownfields

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# VI Mitigation Stakeholders

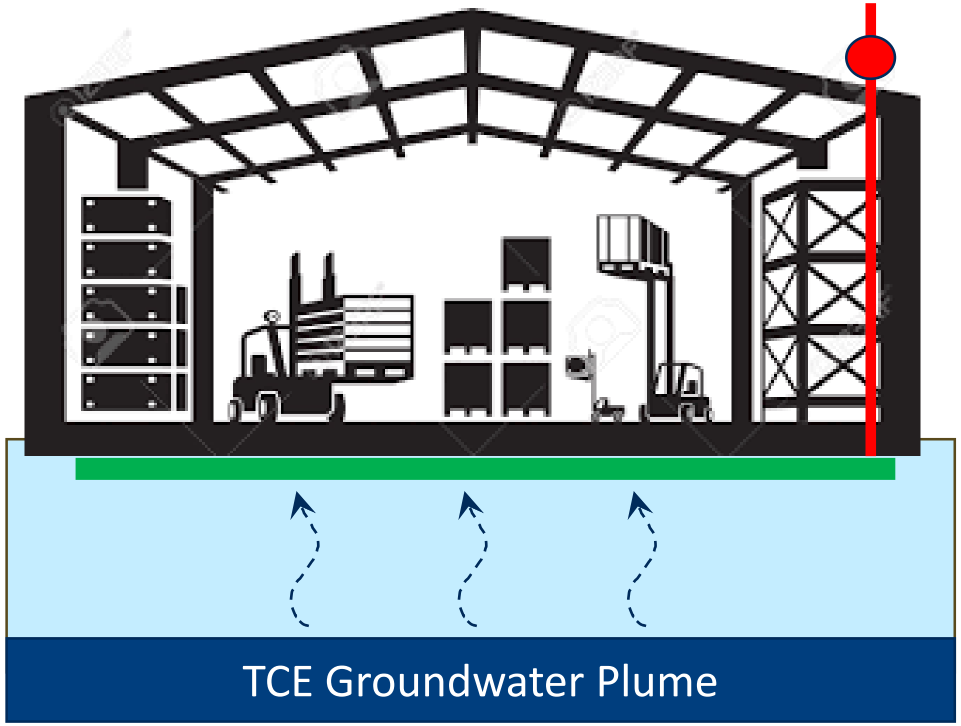
# Balancing stakeholder objectives

- Need to design a system that works
- Need to work within regulatory guidelines/requirements

- Requires understanding how mitigation system controls VI
- Requires making good use of available technologies

- More than one size fits all – systems should be “tailor-made”

# Common Mitigation Design Questions




1. Passive or active system?
2. Type of vapour barrier needed?
3. How much ...

3. Do we even need vacuum?

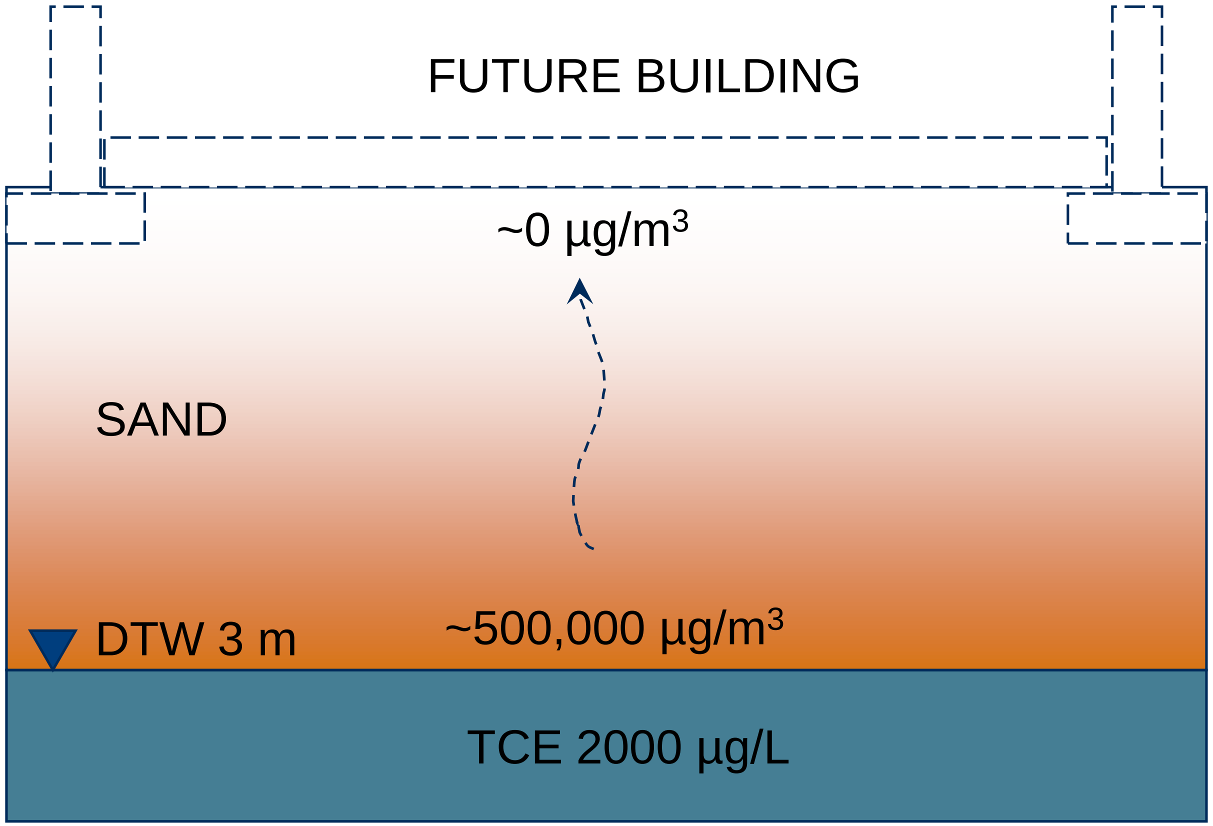
# Q1 – Should my mitigation system be Passive or Active?

## Considerations

- How will the system control vapour intrusion?
- When should vapour barriers be used?
- How do we show the system is working?

# How will the system control the VI pathway at the site?

- Example site before construction

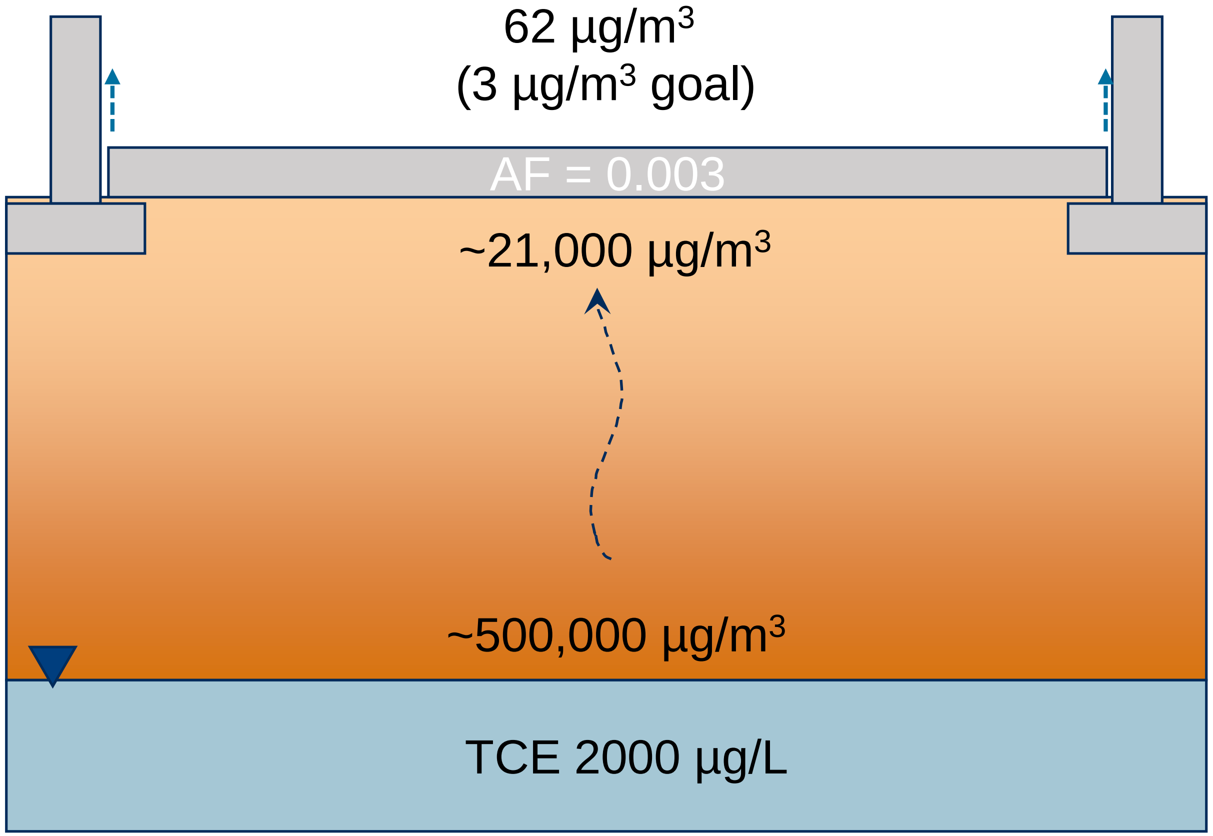



Key Points

- Understand the VI conceptual site model (CSM)
- Simple modeling can indicate relative potential for VI
- This can guide selection of mitigation strategy

# How will the system control the VI pathway at the site?

- Typical slab (moisture barrier only)

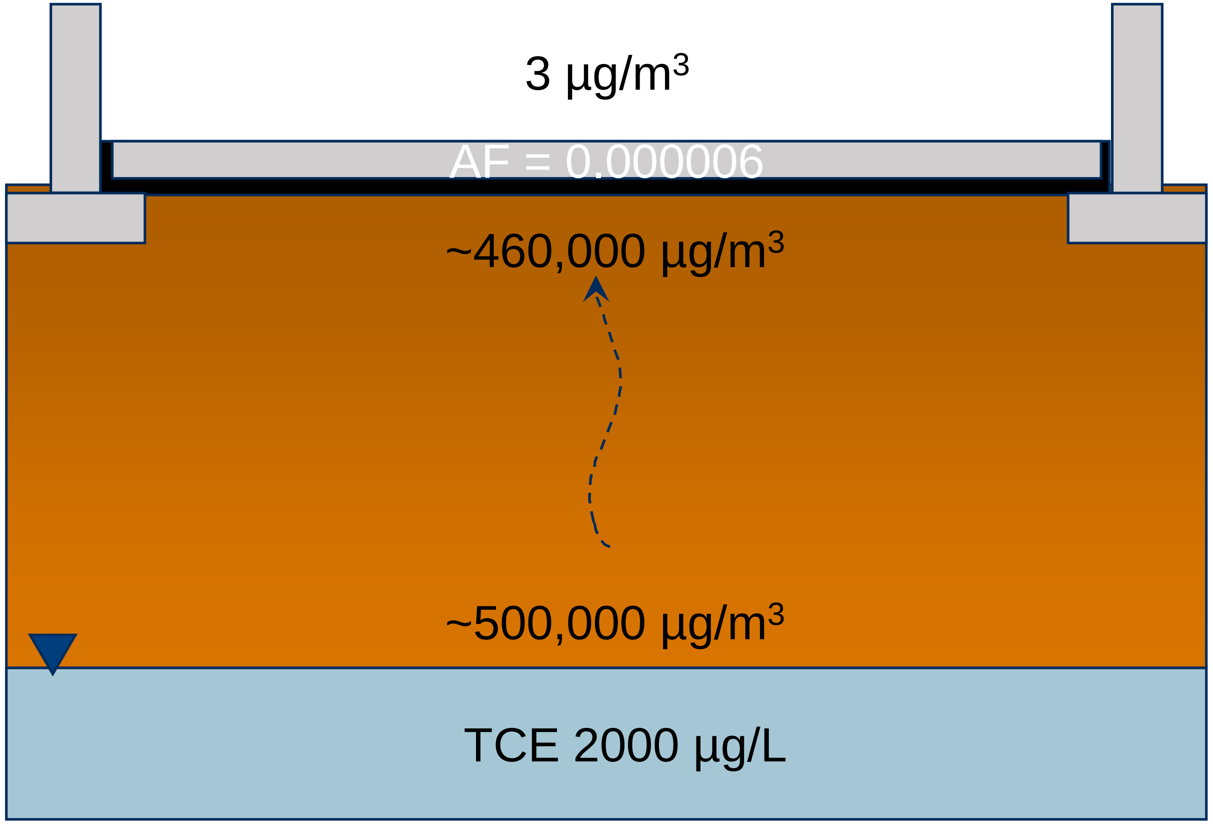



**Key Points**

- Any slab is a passive barrier (to some degree)
- Barriers increase sub-slab soil gas concentration
- Median residential slab AF is 0.003 (EPA 2013)

# How will the system control the VI pathway at the site?

- Passive barrier below slab

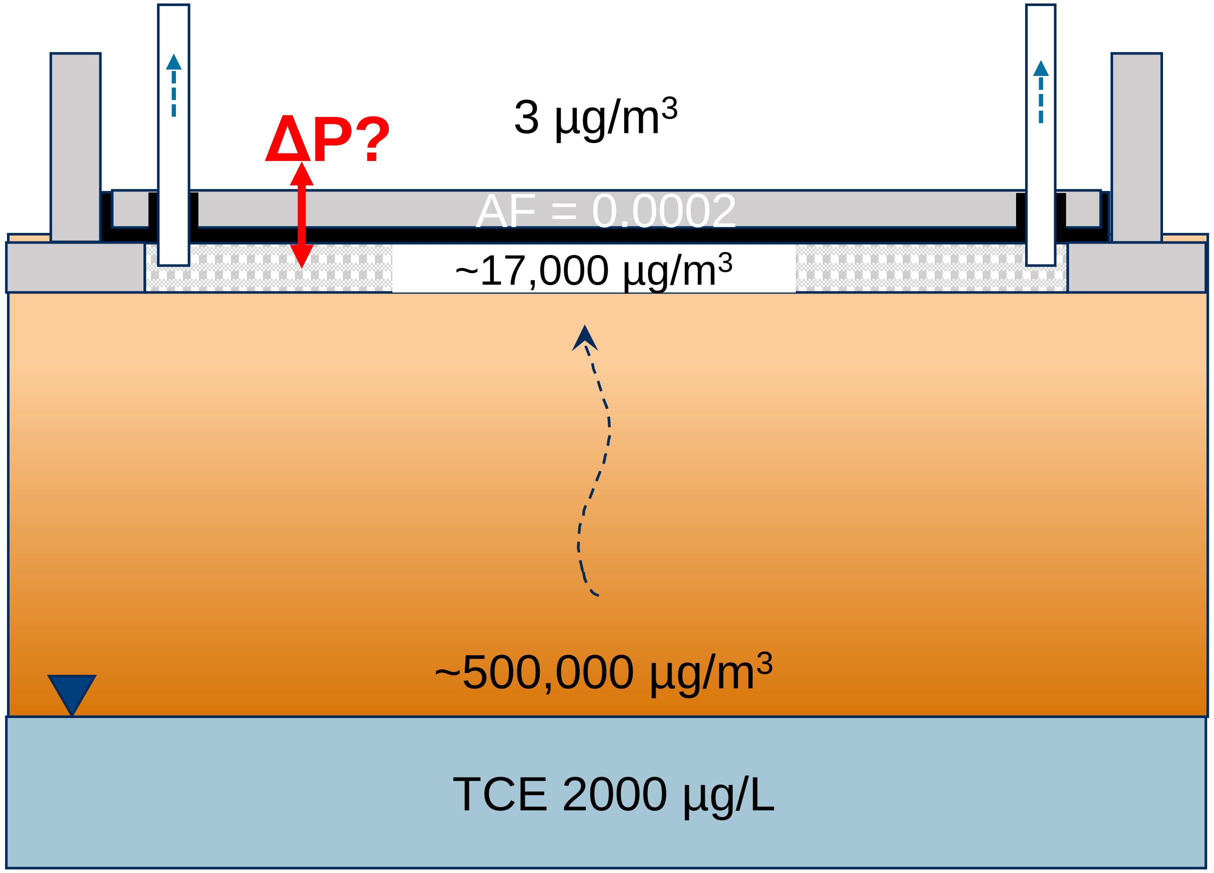



## Key Points

- Passive barrier reduces flux into building
- Increases sub-slab soil gas concentration
- System relies on substantial barrier attenuation

# How will the system control the VI pathway at the site?

- Passive barrier plus passive venting




$Q_{VENT}$ 1 CFM/1000 SF

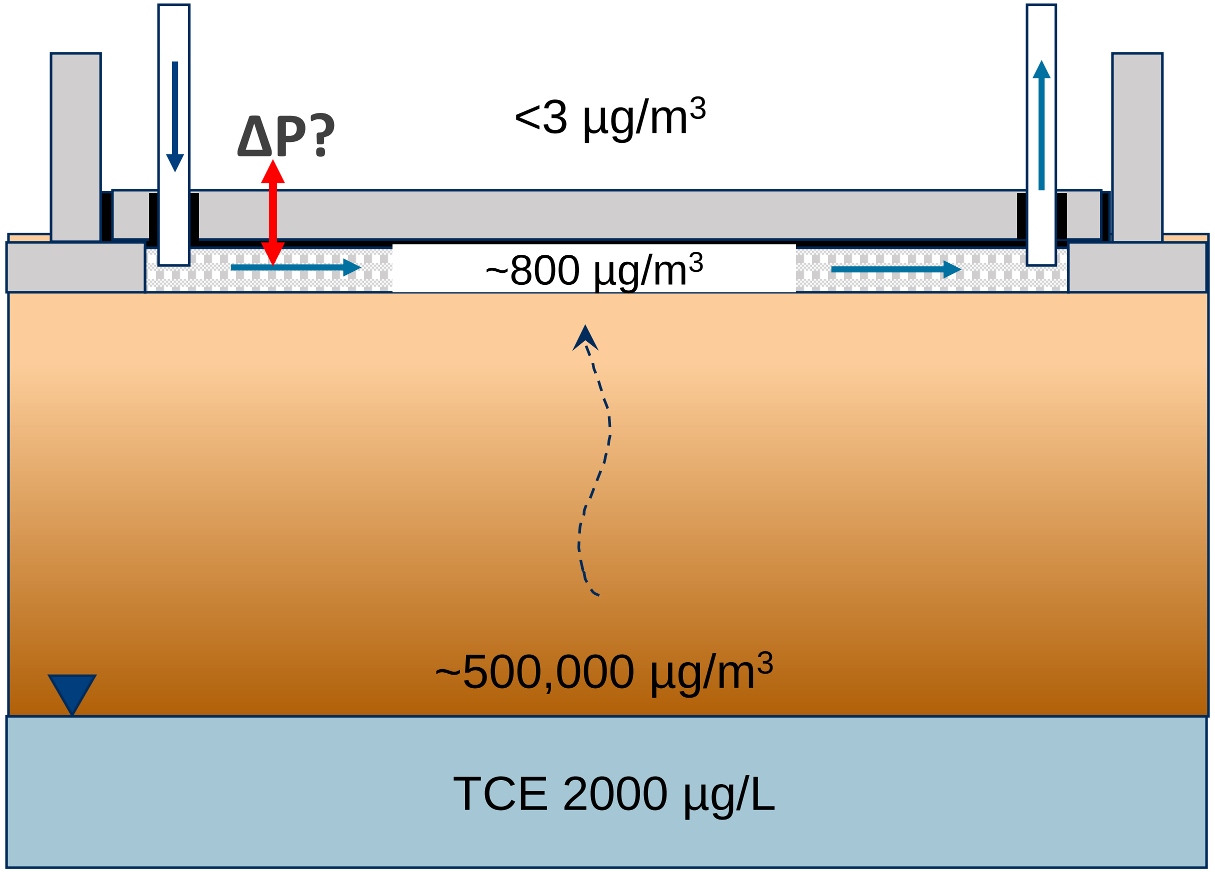
Courtesy Raven Industries

## Considerations

- Limited cross slab differential pressure, but is it needed?
- Reduces long-term operational costs
- Could increase monitoring costs

# How will the system control the VI pathway at the site?

- Active Sub-Slab Venting (SSV)




$Q_{VENT}$ 200 CFM/10,000 SF

Considerations

- Providing active flow, but limited cross-slab vacuum
- Permeability is a key factor

* Based on commercial slab AF of 0.003

# Flow? Or Vacuum? What matters most?

30 ft from the suction pit with no measurable vacuum (<0.25 Pa)

# … it depends on the permeability!

$$Q = \frac{-kA}{\mu}\frac{\Delta P}{\Delta L}$$ (Darcy's Law, 1856)

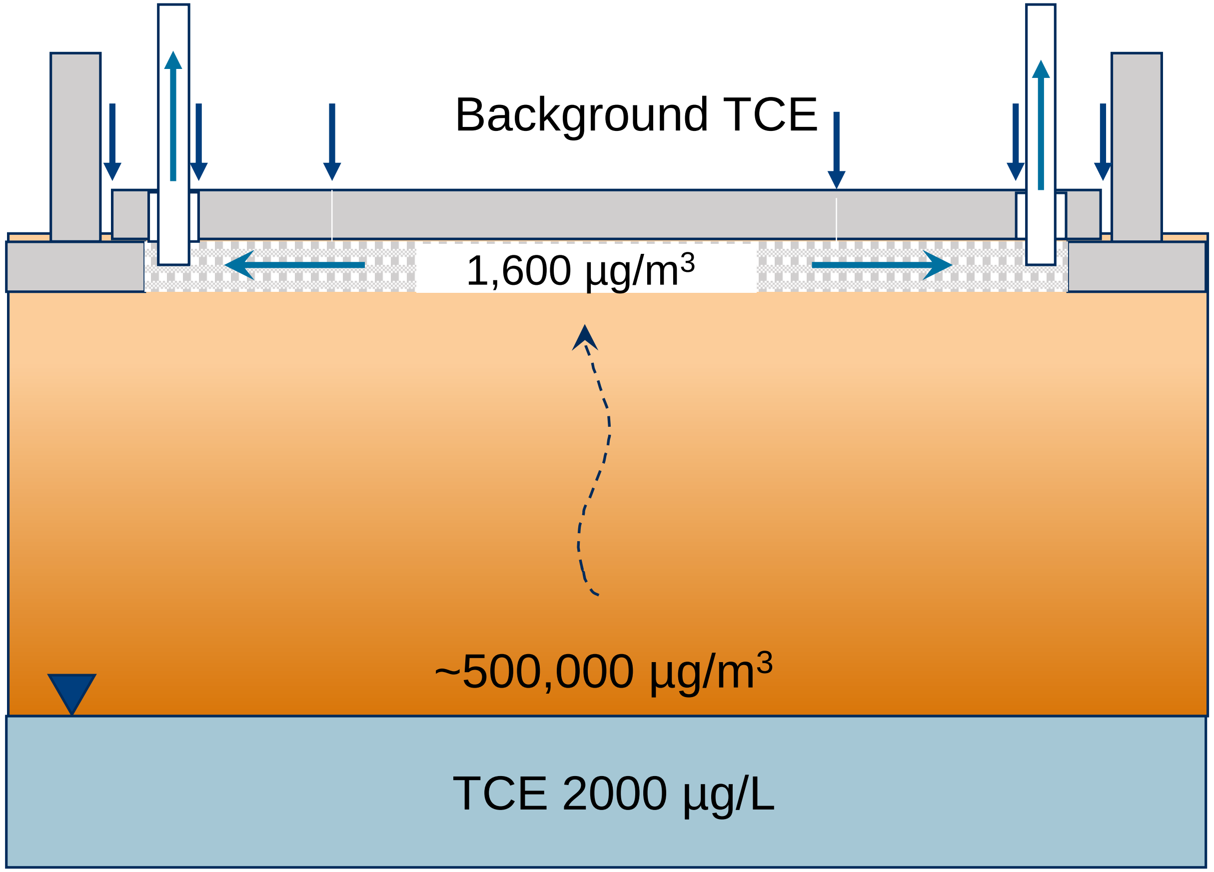
$Q$ = discharge ($m^3/s$)
$k$ = intrinsic permeability ($m^2$)
$A$ = cross sectional area ($m^2$)
$P$ = pressure (Pa)
$L$ = length (m)
$\mu$ = viscosity (Pa s)

But flows of 1 m/day are considered sufficient for SVE (U.S. ACoE, 2002)

Unfortunately, it is hard to directly measure air velocity <70m/day

# How will the system control the VI pathway at the site?

- Sub-Slab Depressurization (SSD)



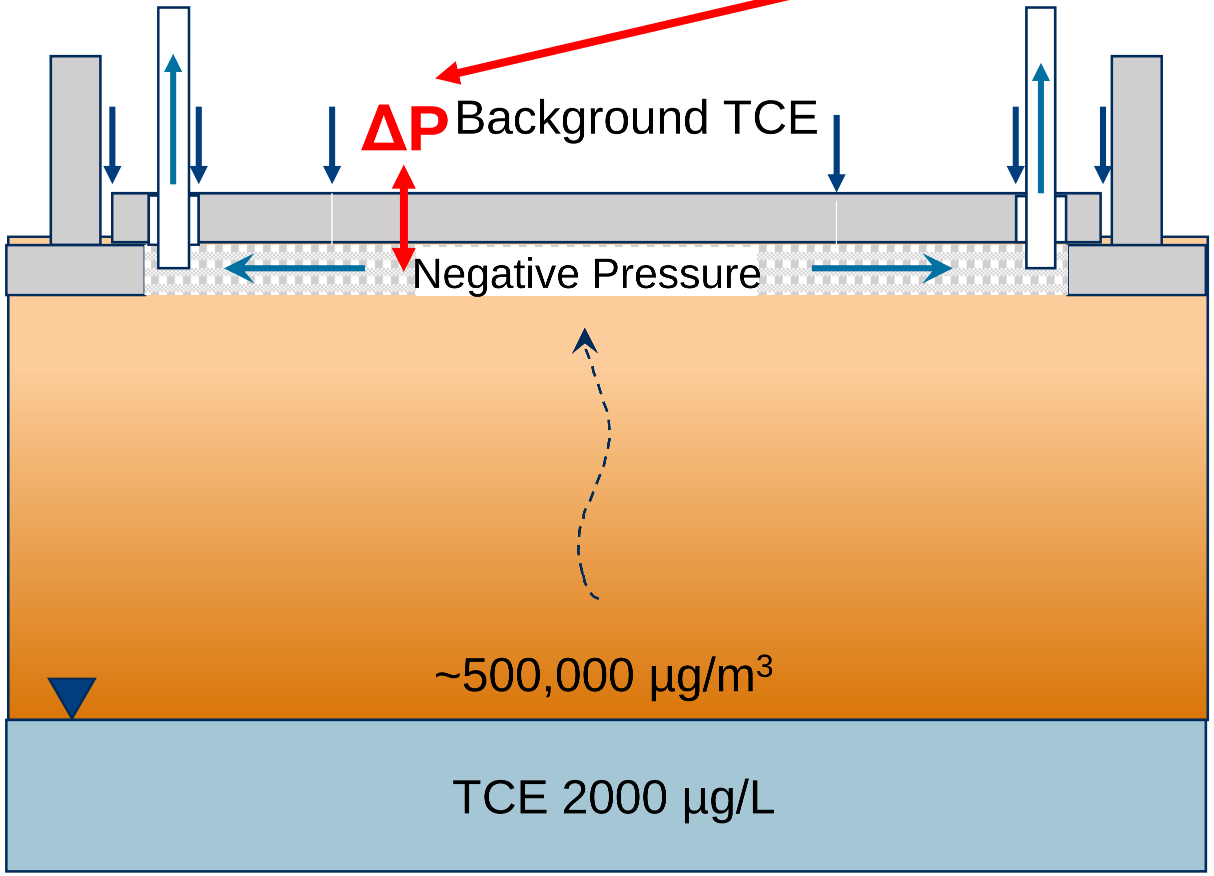

$Q_{VENT}$ 100 CFM/10,000 SF

### Key Points

- Air flows down through cracks rather than up
- Less venting occurring than SSV so higher concentration
- vapour barrier not needed but increases vacuum extension

# How much vacuum is needed?

- Sub-Slab Depressurization (SSD)




$Q_{VENT}$ 100 CFM/10,000 SF

**Vacuum Target Guidance:**

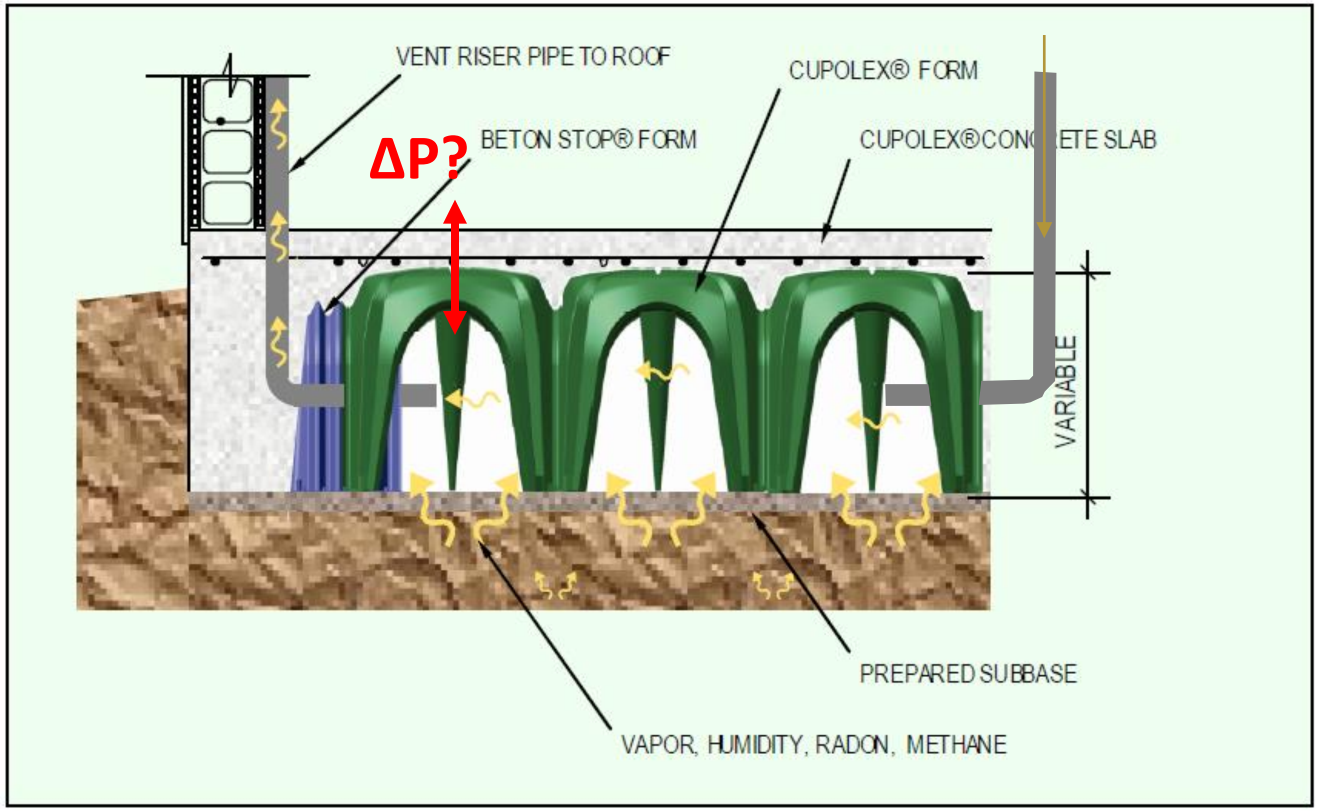
- 6 Pa – Ontario Reg 153/04
- "Measurable" – BC (DTSC, ITRC)
- 4 to 9 Pa – California DTSC & ITRC
- 5 Pa – Michigan DEQ
- 4 Pa – North Carolina DEQ
- 1 Pa – New Jersey DEP

**Considerations**

- 40% to 90% of fan extracted air is indoor air (Moorman, 2009)
- Vapour barrier can decrease leakage across floor slab
- Need to evaluate cost benefit

# Aerated Floor Systems

## Soil Venting System

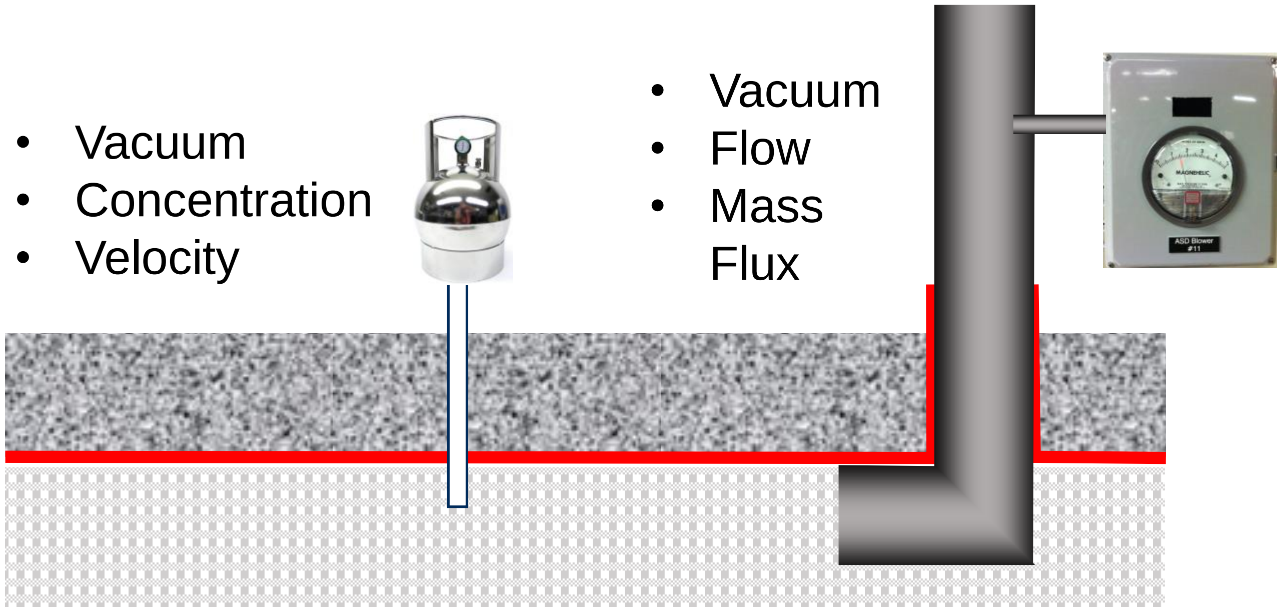



### Considerations

- Limited resistance to flow so what about measurable vacuum
- Can limit air inlets but lose benefit of biodegradation
- Do you need vacuum?

# How will we show that it's working?

## SSD System




**New advances** – ROI can now be assessed using multiple lines of evidence: vacuum, velocity, travel time, flux balance, and proportion of flow across the floor (ESTCPER201322 and McAlary et al 2020).

### Key Points

- Vacuum provides direct evidence of advective control
- Other options exist for showing performance
- In some cases sub-slab concentration below SSSL

# ESTCP Funded Research

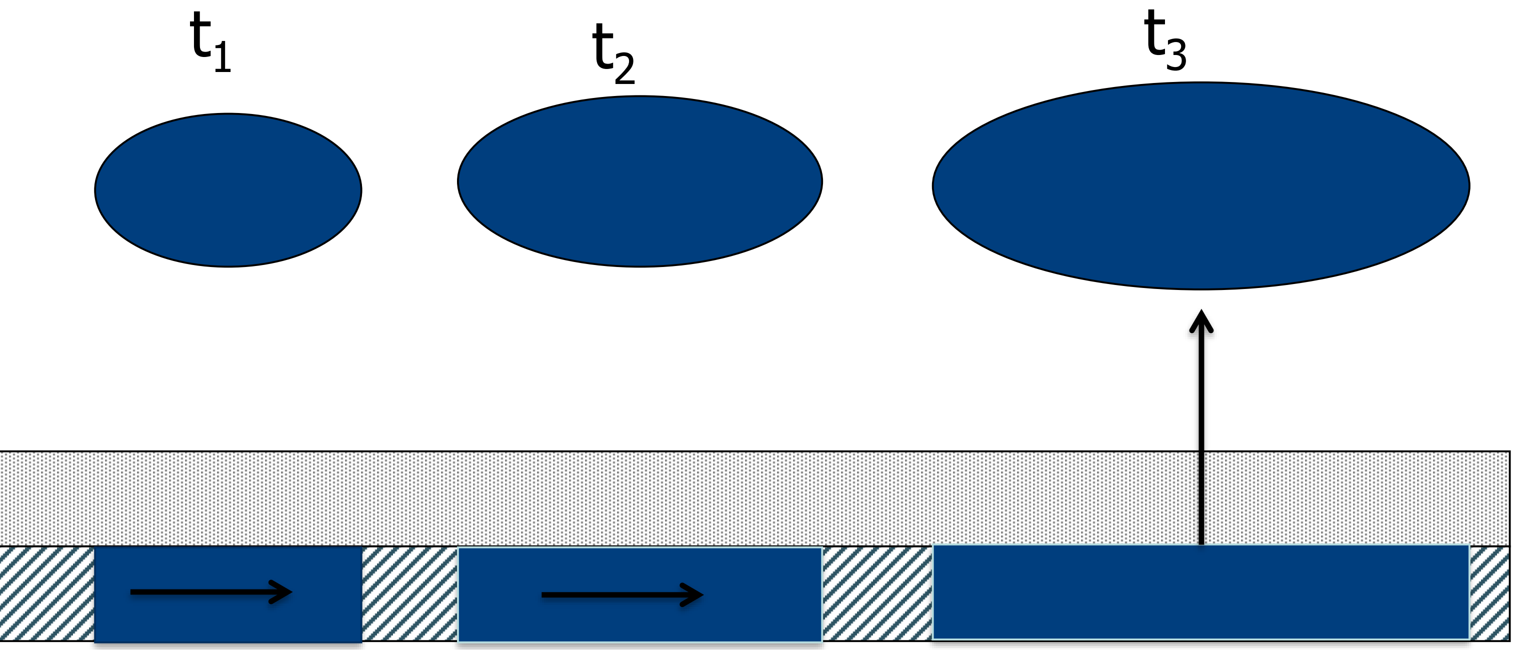
The MGRA Guidance (Appendix 8b) acknowledges
That vacuum may not always be the sole metric
Engineer can consider additional lines of evidence

| | |
|---|---|
| Vacuum | >cross-slab ΔP |
| Sub-slab velocity | >3 ft/day (1m/day) |
| Travel time | <1 day |
| Mass removal rate | $M_{SSD} > M_{SSFLUX}$ |

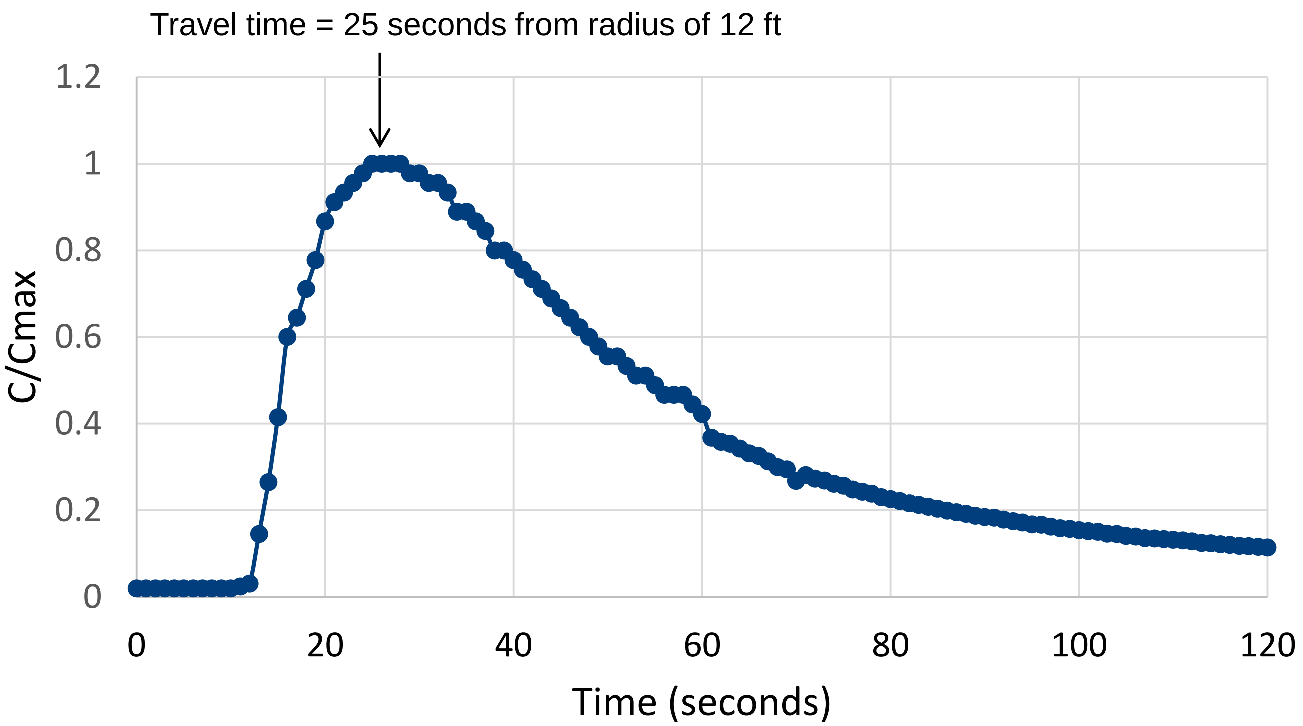
So how do we measure these other parameters?

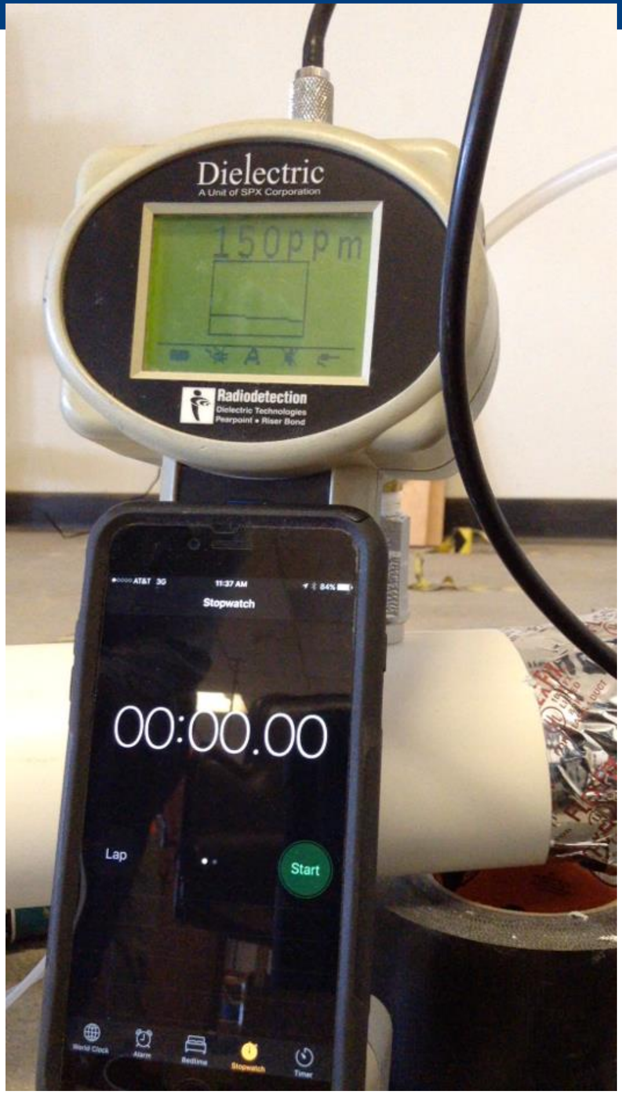
# Inter-Well Helium Tracer Test (velocity vs time)

Inject helium into a sub-slab probe near an operating vent-pipe
Monitor Helium in the vent-pipe to get a breakthrough curve



# Helium Inter-Well Test



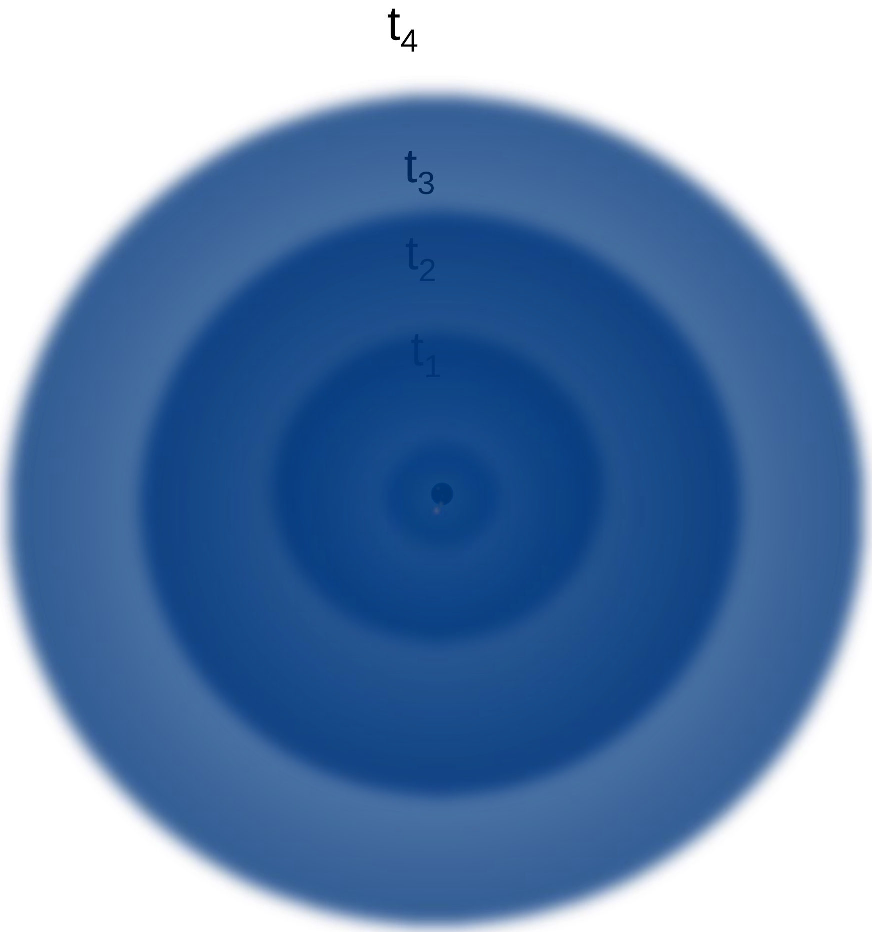




This data took less than 2 minutes to collect

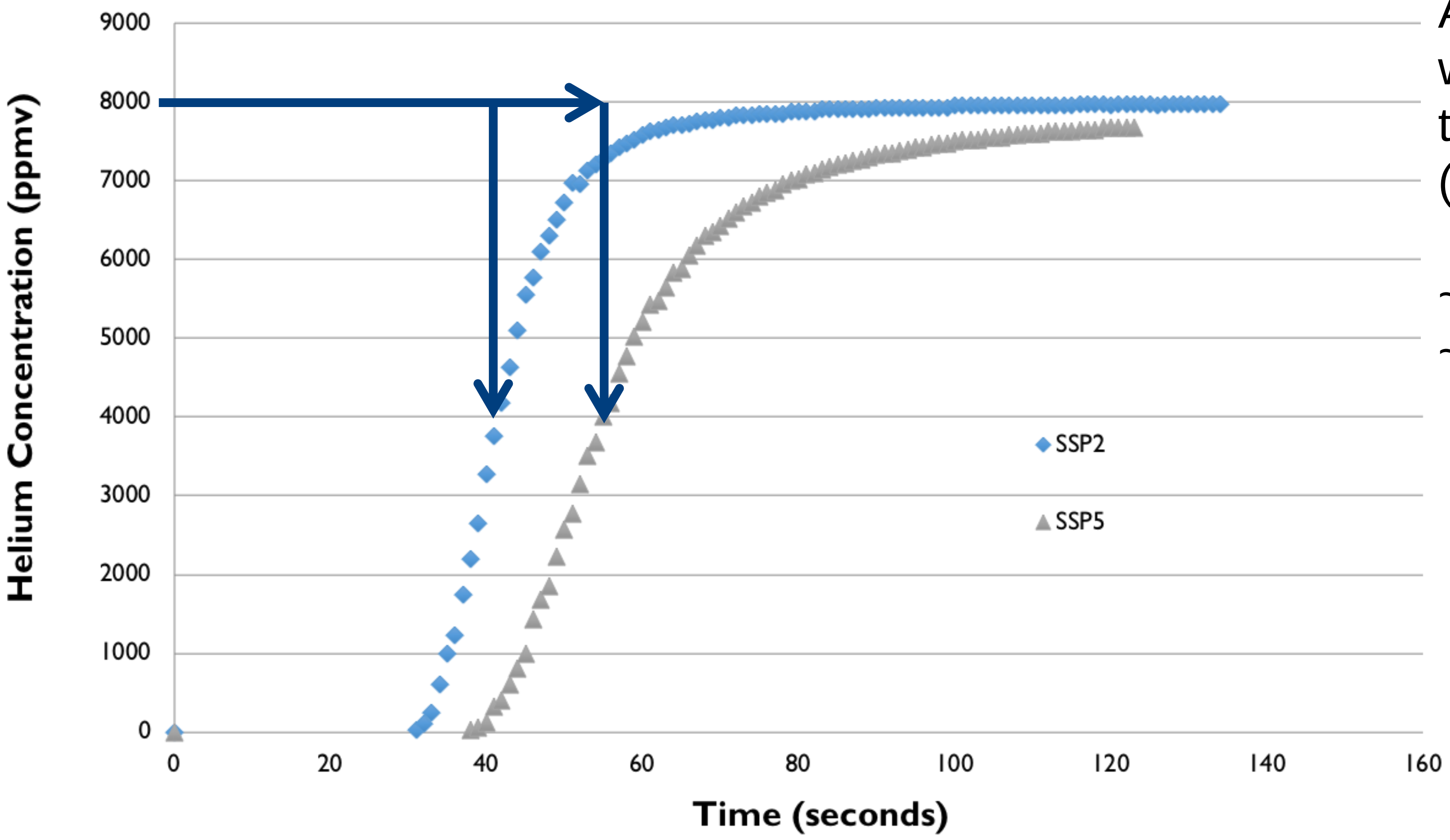
These tests are quick, simple and informative using low-cost equipment that is easily rented

# Helium Flood - (travel time)

- Reverse the flow on a fan
- match ΔP and Q to normal operations
- Add helium (~1%v/v or so)
- monitor transport below the slab



# Helium Flood Results

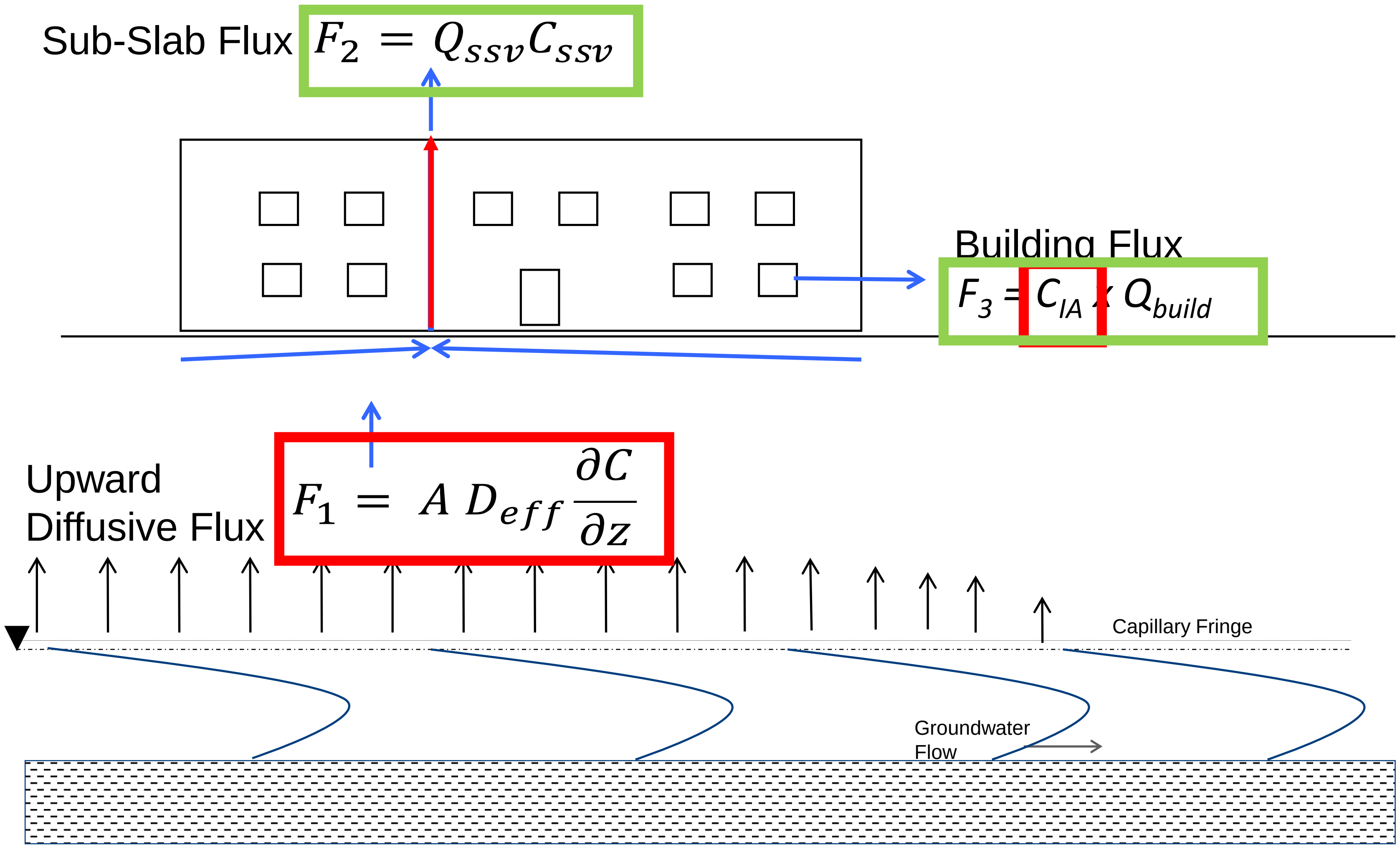



Average travel time is where He reaches 50% of the injected concentration (i.e. 4,000 ppmv)

~42 seconds for SSP2
~55 seconds for SSP5

Also very quick, simple and very informative using low-cost equipment that is easily rented

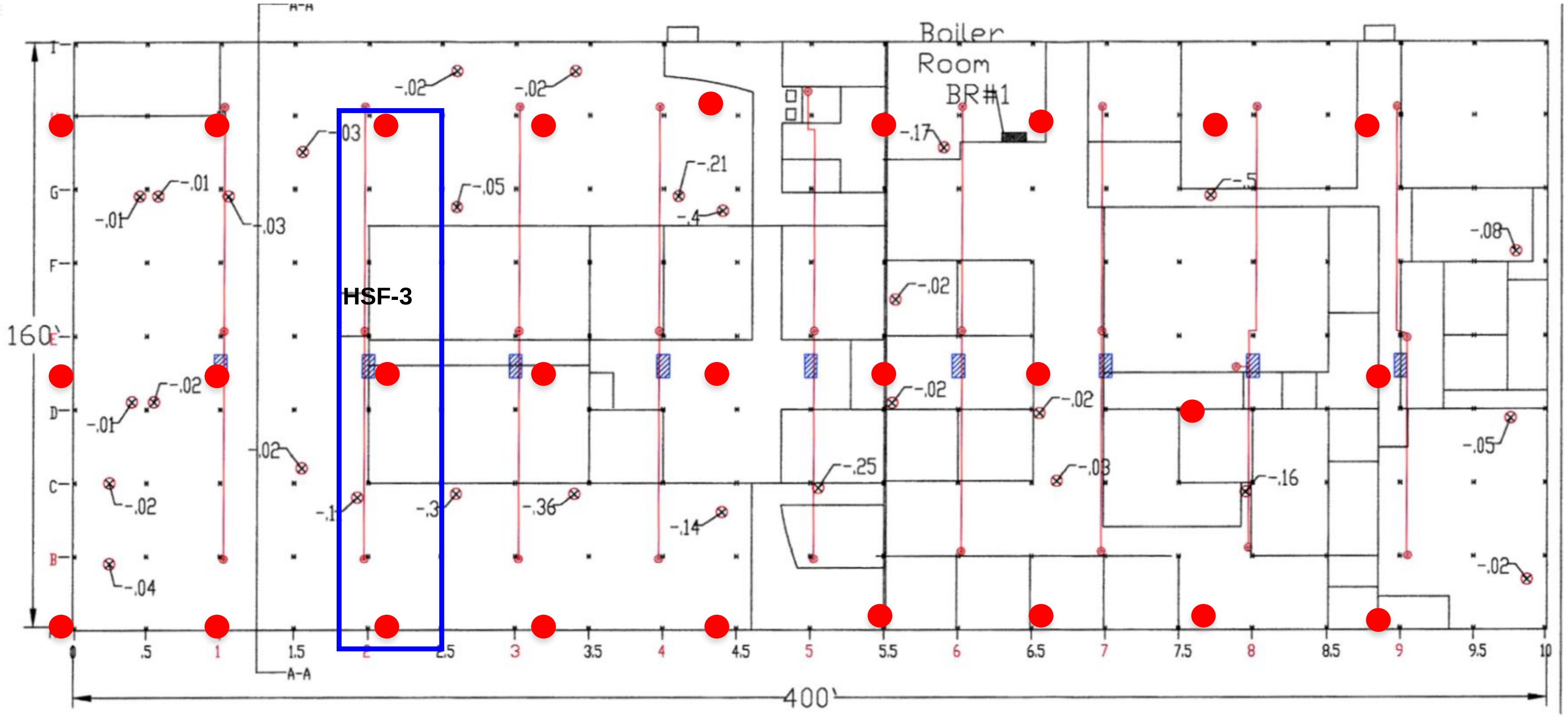
# Mass Flux Monitoring



# Mitigation System Optimization

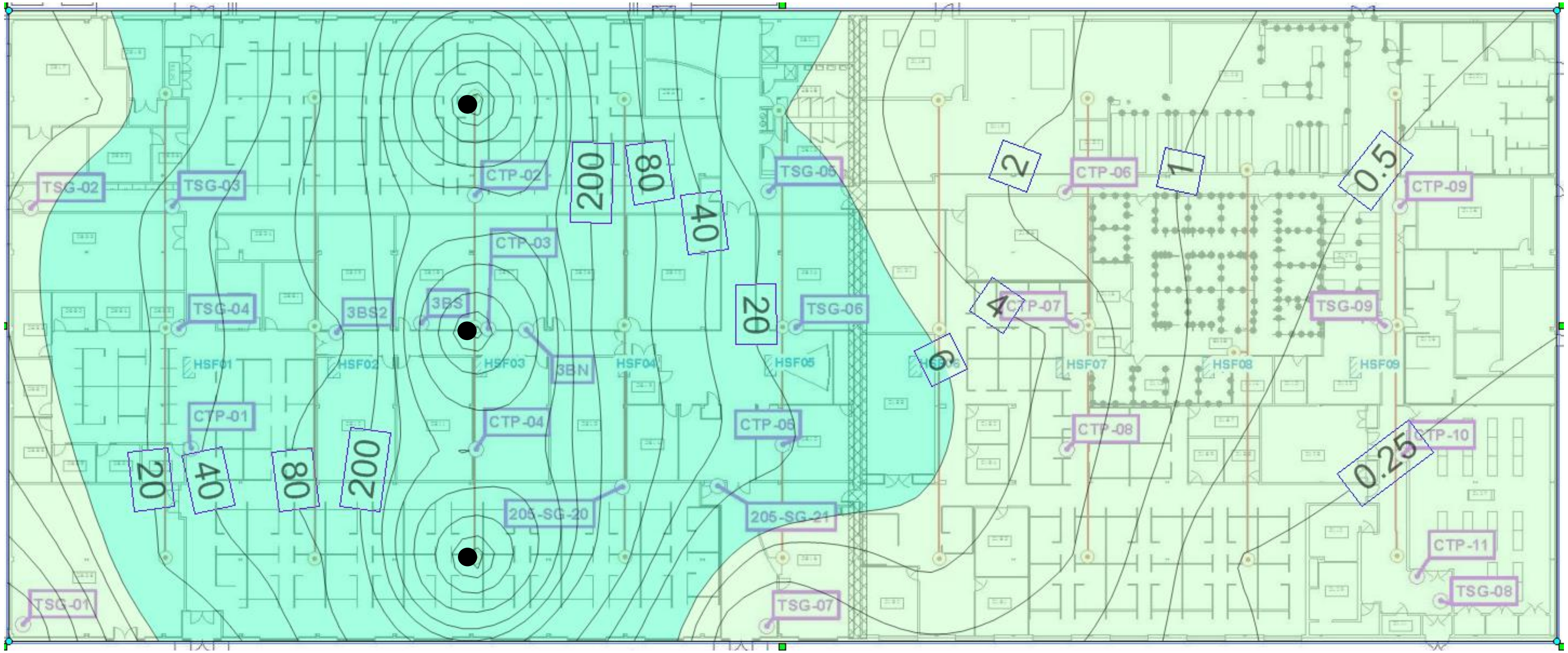
- Original SSD system design:
- 9 Fans Connected to 3 suction points each – 27 total
- Total system flow
- ~14 m3/min (500 cfm)
- Operating 10 years
- Evaluate Optimization

6,000 m$^2$ (64,000SF) Office space



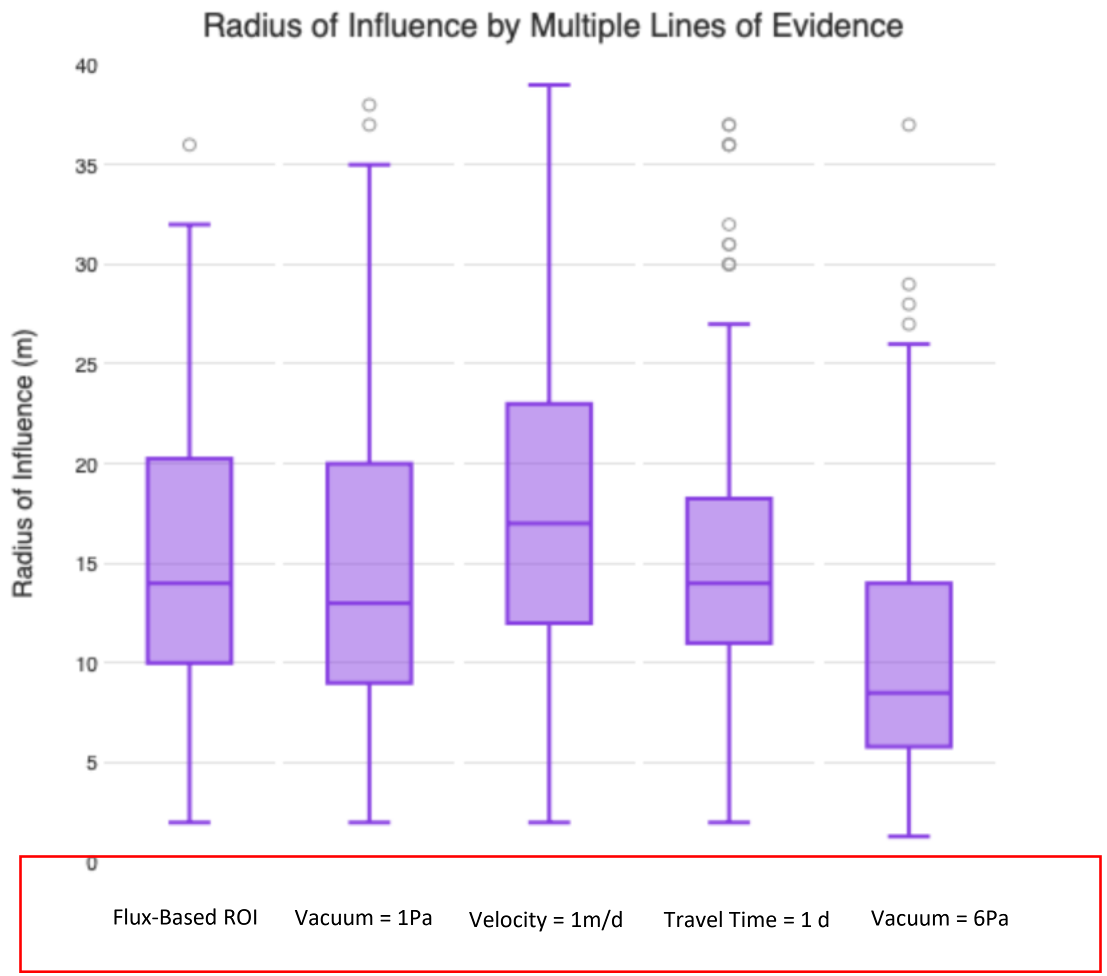
# Mitigation System Optimization

- Vacuum extends throughout the area of TCE vapours
- Single fan captured 96% of TCE mass flux
- Cost savings of ~90% plus HVAC savings.




Subfloor Vacuum in Pascals

# Radius Of Influence




McAlary, 2020. Mathematical Analysis and flux-based radius of influence for radon/VOC vapour intrusion mitigation systems
Science of the Total Environment, 740 (2020)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## Mathematical analysis and flux-based radius of influence for radon/VOC vapor intrusion mitigation systems


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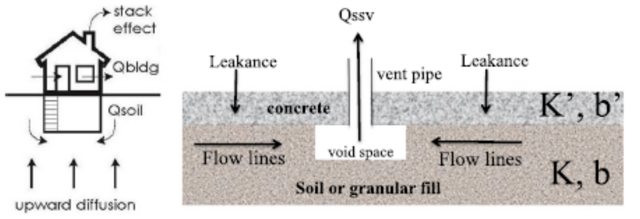
HIGHLIGHTS

- A new model is derived for the ROI of subslab venting systems based on mass flux.
- A 2-layer flow model was used to analyze 121 pneumatic data sets.
- Multiple lines of evidence (vacuum, velocity, and travel time) are generated.
- New performance metrics are proposed for each line of evidence.
- The incremental cost is small compared to the life-cycle savings.

GRAPHICAL ABSTRACT




$$\text{Vacuum} = \frac{Q_w}{2\pi T} K_0(r/B) \quad Velocity = \frac{Q_w}{2\pi b n B} \frac{1}{} K_1(r/B)$$

$$\text{Flux-Based ROI: } K_1\left(\frac{r}{B}\right) = \frac{2\pi Bb}{Q_{ssv}}\left(\frac{T\Delta P}{B^2} + \frac{D_{eff}}{b}\right)$$

# Q1 – Should my mitigation system be Passive or Active?

Considerations:

- Site and building conditions
- Saturated/Unsaturated zone
- Occupancy of Lower Level
- Storage Garage design
- Regulatory requirements
- Stakeholder priorities
- ECA or EASR required in both cases

| PRIORITY/CONDITION | PREFERENCE | |
|---|---|---|
| | Passive | Active |
| Lower construction cost | | Y |
| No operating system | Y | |
| Continuous monitoring | | Y |
| Low concentrations/risk | Y | |
| High concentrations/risk | | Y |

- Understand how system controls VI
- Be able to demonstrate performance
- Consider long term stewardship

# Q2 – What type of vapour barrier should I use?

Considerations:

- Thickness required
- Active vs passive system
- Construction durability
- Need for protective layers
- Cost
- Chemical Compatibility
- Integration with Foundation and Waterproofing Systems

# Thickness Required?

EPA United States Environmental Protection Agency

Engineering Issue

Indoor Air Vapor Intrusion Mitigation Approaches

Table of Contents



1 PURPOSE

The U.S. Environmental Protection Agency (EPA) Engineering Issue in one of a new series of technology transfer documents that summarize the latest available information on selected treatment and site remediation technologies and related issues. The Engineering Issues are designed to help remedial project managers (RPMs), on-scene coordinators (OSCs), contractors, and other site managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their specific sites. Each Engineering Issue document is developed in conjunction with a small group of scientists inside the EPA and with outside consultants and relies on peer-reviewed literature, EPA reports, Web sources, current research, and other pertinent information. The purpose of this document is to present the "state of the science" regarding management and treatment of vapor intrusion into building structures.

Wherever feasible, this information relies on independently reviewed mitigation performance information. In an effort to keep this Engineering Issue paper concise, important information is summarized, while references and Web links are provided for readers interested in additional information; **these Web links, verified as accurate at the time of publication, are subject to change.** Although we have endeavored to make these links fully functional with a mouse click, if they do not function on your system, you may need to copy them into your browser or reenter them. As science and technology associated with this route of exposure continues to develop, other mitigation measures may become available.

EPA (2008) commonly referenced

- recommends min 40 mil for passive barriers (HDPE)

Several 20 mil barriers developed since then

- Raven vapourBlock Plus
- Stego Drago
- GeoSeal EV20

EPA (2008) has no barrier criteria for active systems

**New advances** – Newer composite membranes provide increased strength, flexibility, and diffusion control, including 20, 30, and 40 mil liner systems

*No product endorsements are made or implied by this presentation

## Key Points

- EPA 2008 thickness criteria are outdated
- Select barrier based on properties not thickness alone
- Active systems do not need (but benefit from) barriers

# Q2 – What type of barrier should I use?

Depends on several factors, including:

- Active versus passive
- High versus low concentrations
- Potential for diffusion transport

| Condition | Potential Barrier |
|---|---|
| Active/low concentration | 15 mil membrane |
| Active/mod concentration | 15-20 mil membrane |
| Active/high concentration | Based on diffusivity |
| Passive/low concentration | 20 mil membrane |
| Passive/mod concentration | 20-30 mil membrane |
| Passive/high concentration | 40 mil membrane |

Courtesy Raven Industries

- Active systems do not require but are more cost-efficient with barriers
- Integrity at seams and penetrations is most important
- Diffusion control needed only if high sub-slab vapour levels (e.g., millions of $\mu/m^3$)

# Why not calculate it?

$$J = D\left(\frac{C_{SS} - C_{IASL}}{\boxed{L}}\right)$$

Fick's Law

J = mass flux [M/L$^2$/T]
D = diffusion coefficient [L$^2$/T]
$C_{IASL}$ - indoor air health based screening level concentration [M/L$^3$]
$C_{SS}$ = the COC concentration in soil gas [M/L$^3$]
L = thickness of the vapour barrier [L]

## Key Points

- Concentration gradient is key
- Diffusivity is based on contaminant of concern
- Thickness can be calculated

# In Summary – new tools for mitigation designs

- Understand Stakeholder/Regulator objectives
  - Understand how the system is controlling VI
  - Balance pros & cons with stakeholder priorities
  - Be able to show its working
- Do you need Vacuum?
  - 6 Pa Reg 153/04, lower levels are generally protective, e.g., 1 Pa
  - Depends on how the system is designed
  - Use new tools to evaluate alternative performance metrics
- Type of Vapour Barrier?
  - Passive and active system barriers play different roles
  - Advective flow control at joints and penetrations most important
  - Barrier properties more important than thickness (40 mil criteria is out of date)

# Questions?

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www.Geosyntec.com/VI