A New Model for Sub-Slab Mitigation for Vapour Intrusion

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SMART Remediation
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SMART Remediation Conference
23 January 2020 – Toronto, ON

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Agenda

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- Case Study
- ESTCP ER201322 Results
- New methods for Mitigation Design

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Vapour Intrusion – Conceptual Model

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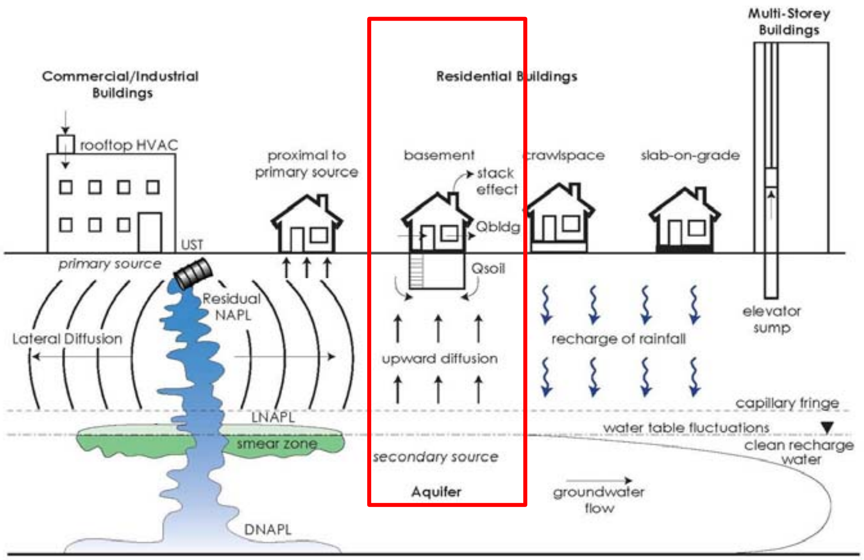

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Case Study – Sub-Slab Depressurization

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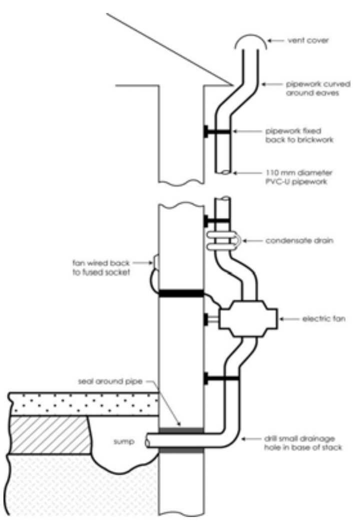

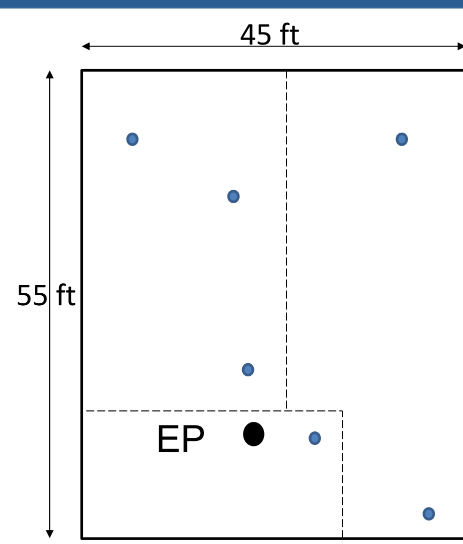

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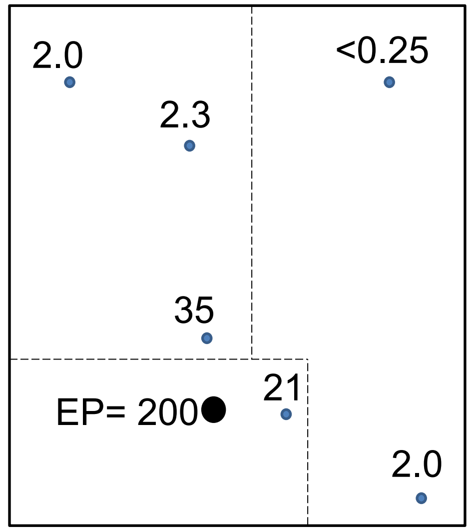
Am I Safe In My Home?

- Sub-slab Rn = 13,200 Bq/m^3
- Indoor air radon = 450 Bq/m^3
- Attenuation factor = 0.03
- Canada Health Guideline = 200 Bq/m^3
- WHO guideline = 100 Bq/m^3



Vacuum in Pascals

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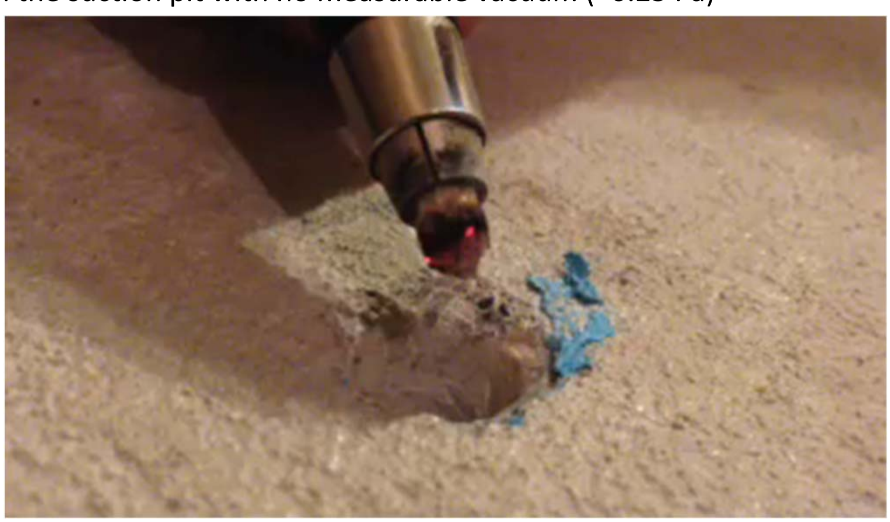
Flow? Or Vacuum? What matters most?

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



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… it depends on the permeability!

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$$Q = \frac{-kA}{\mu}\frac{\Delta P}{\Delta L}$$

(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)
μ = viscosity (Pa s)

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

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

Permeability of silt through gravel spans a range of 1,000,000,000-fold
So, how do we measure permeability?

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Am I safe in my home?

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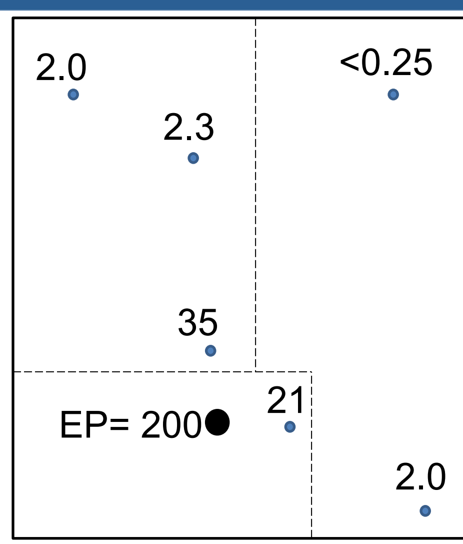
- Canada Health Guideline = 200 Bq/m^3
- WHO guideline = 100 Bq/m^3

- Indoor air after mitigation = <u>35 Bq/m^3</u>

- Be confident in your design before collecting indoor air samples



Vacuum in Pascals

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Cross-Slab Differential Pressure

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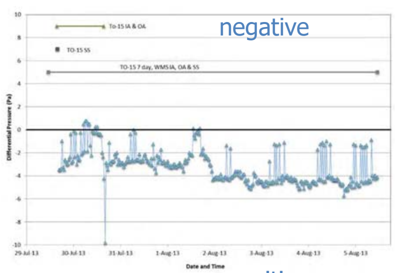
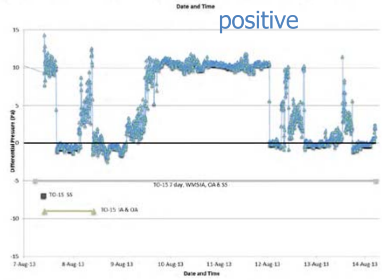
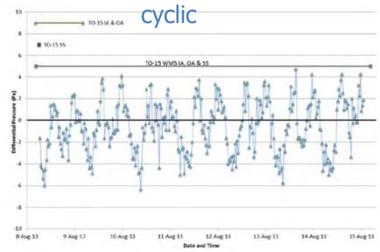
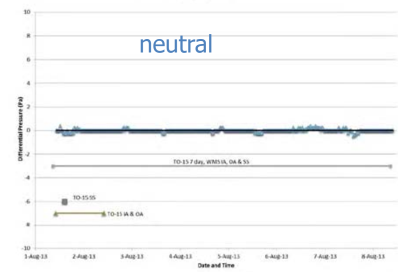




What "target vacuum" level is appropriate?





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ESTCP ER-2013-22 Mitigation Optimization

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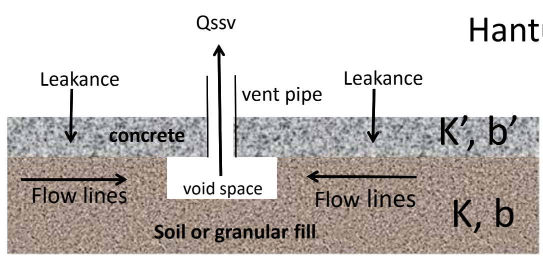
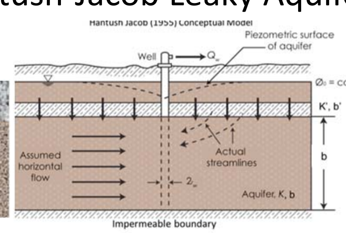
Conceptual Model of Sub-slab Venting



Hantush-Jacob Leaky Aquifer Model



$$T = Kb$$

(T) = Transmissivity below the floor (ft^2/day)
(K) = gas conductivity (ft/day)
(b) = thickness (ft)

$$B = \sqrt{\frac{Tb'}{K'}}$$

(B) = Leakance (ft) (this parameter simplifies equations)

Hantush, M.S. and C.E. Jacob, 1955. Non-steady radial flow in an infinite leaky aquifer, Am. Geophys. Union Trans., vol. 36, pp. 95-100.

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Do the Math!

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Vacuum versus distance:

$$Vacuum = \frac{Q_w}{2\,\pi\,T} K_0(r/B)$$

Velocity versus distance:

$$Velocity = \frac{Q_w}{2\,\pi\,b\,n} \frac{1}{B} K_1(r/B)$$

Travel time for sub-slab gas from a given distance:

$$t_{travel} = \int \frac{\partial r}{v(r)}$$

Proportion of total flow originating below the floor:

$$Q(r)/Q_w = \frac{r}{B} K_1(r/B)$$

Building-specific Attenuation Factor:

$$AF = \frac{Q_{soil}}{Q_{building}} = \frac{K'i\,A}{l\,w\,h\,AER} = \frac{\frac{Kbb'}{B^2}\frac{\Delta P}{b'}A}{A\,h\,AER} = \frac{T\,\Delta P}{B^2\,h\,AER}$$

All of these calculations can be done in a spreadsheet

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New Model for Vapour Mitigation

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- Vacuum is just one metric > cross-slab ΔP
- Sub-slab velocity > 3ft/day
- Travel time <2.4 hrs
- Mass removal rate $M_{SSD} > M_{SSFLUX}$

- Do you need to mitigate – developing building specific attenuation factors.

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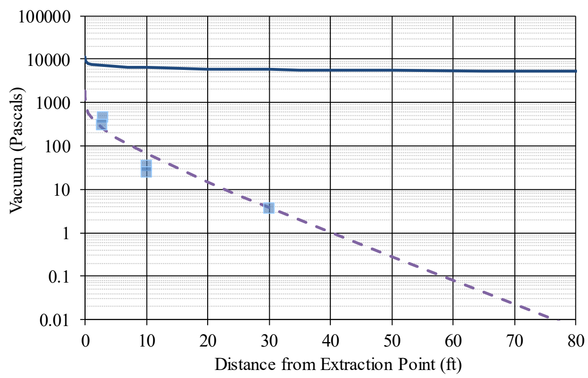
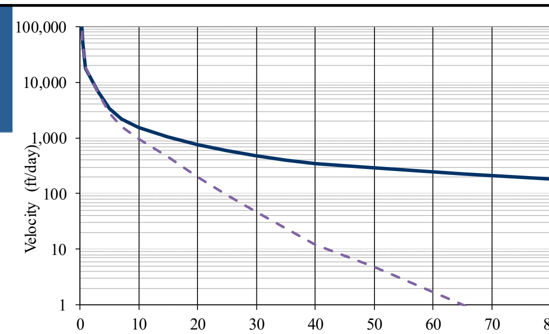
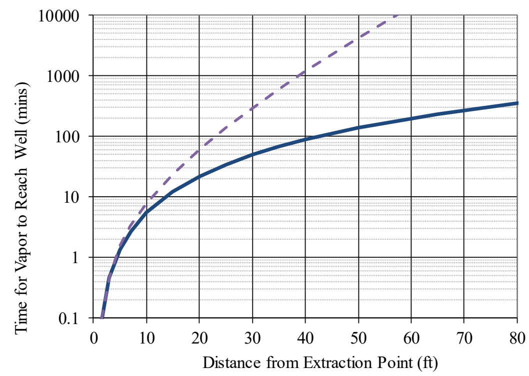
Pneumatic/Pilot Testing

A simple spreadsheet provides the charts for radial profiles of vacuum, velocity, travel time







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Inter-Well Helium Tracer Test (velocity vs time)

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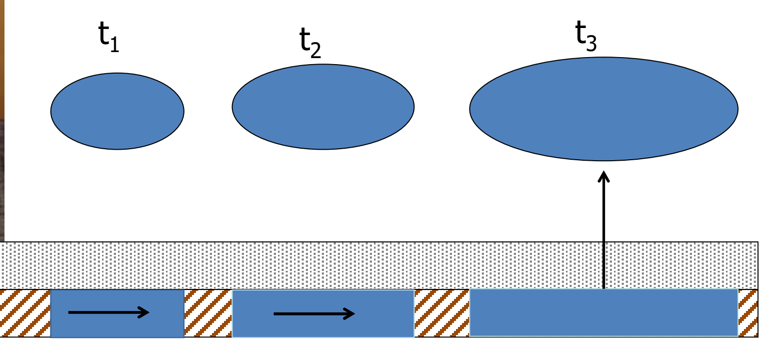
Inject helium into a sub-slab probe near an operating vent-pipe
Monitor Helium in the vent-pipe to get a breakthrough curve



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Helium Inter-Well Test

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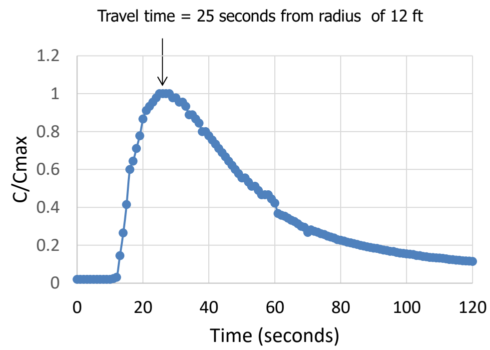
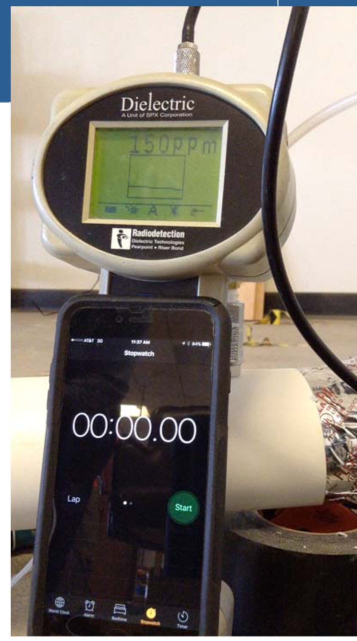


This data took less than 2 minutes to collect

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



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Helium Flood - (travel time)

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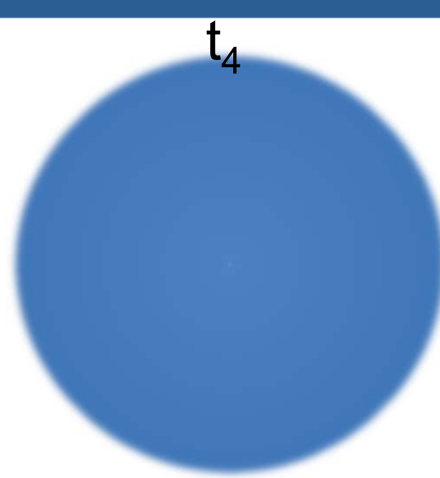
Reverse the flow on a vent-fan
match ΔP and Q to normal operations
Add helium (~1%v/v or so)
monitor transport below the slab



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Helium Flood Results

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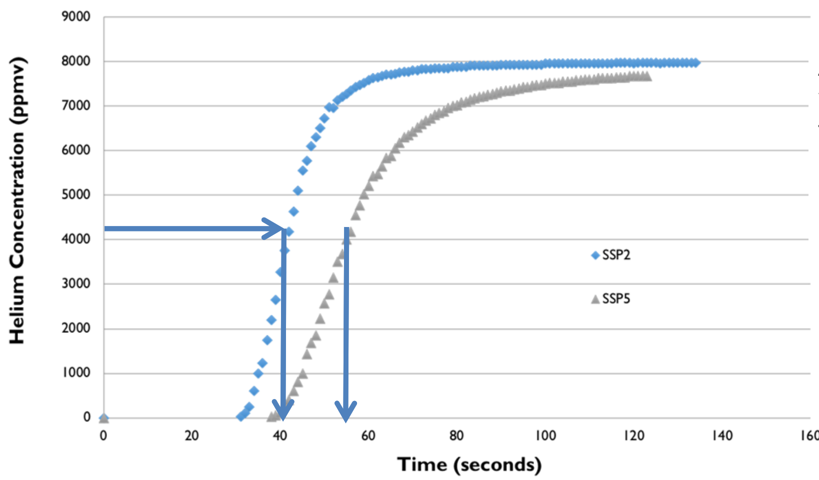

Average travel time is where He reaches 50% of the injected concentration (4,000 ppmv)

~42 seconds for SSP2
~55 seconds for SSP5

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

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Mass Flux Monitoring

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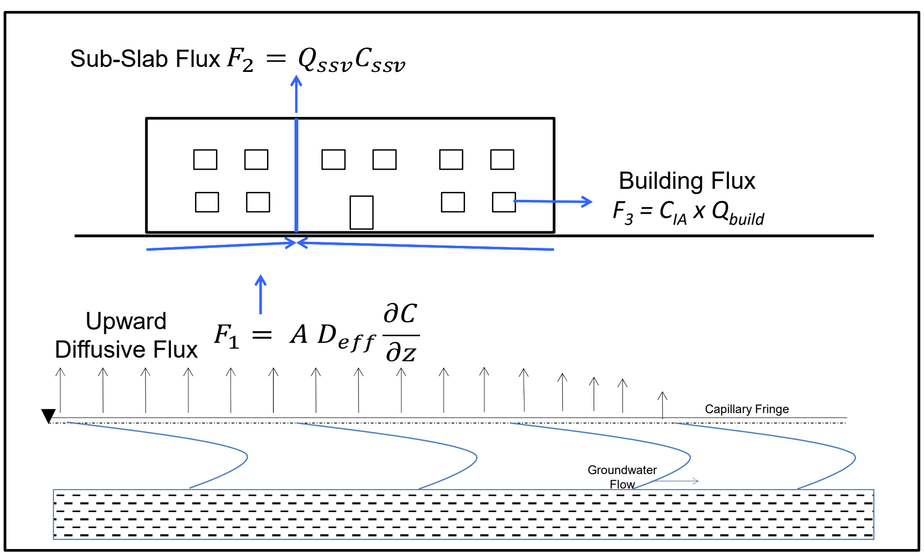

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Mitigation System Optimization

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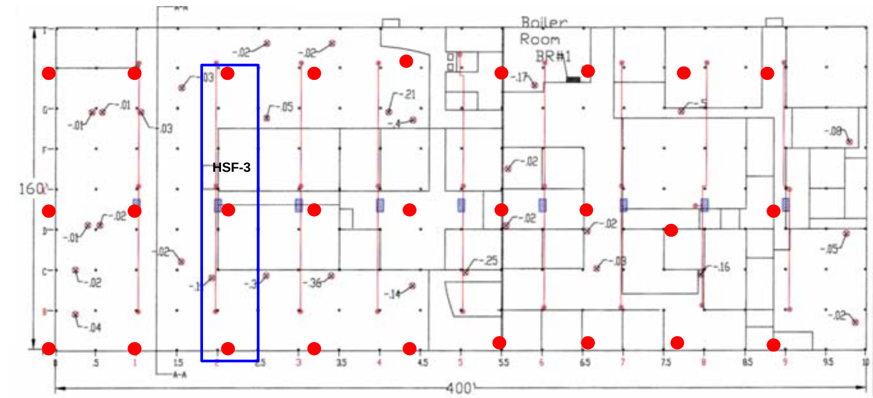
- Original SSD system design:
- 9 Fans Connected to 3 suction points each – 27 total
- Total system flow
- ~14 m3/min (500 cfm)
- Operating 10 years
- Evaluate Optimization

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



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Mitigation System Optimization

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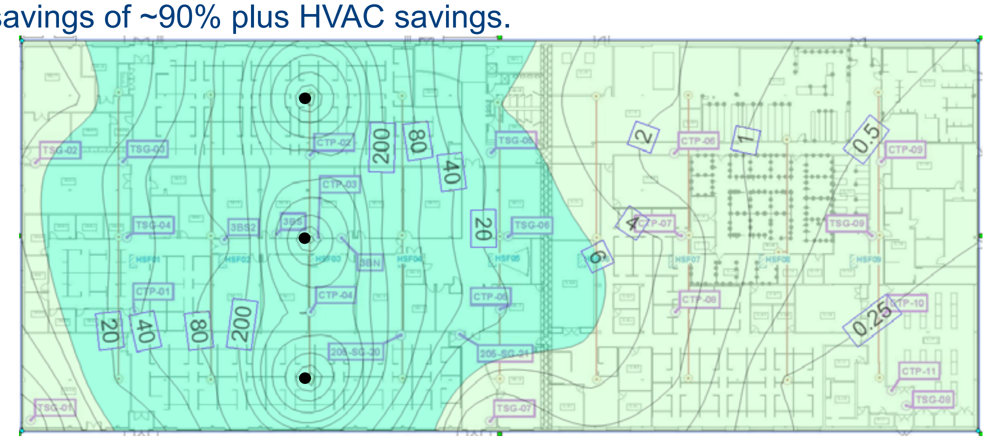
- Vacuum extends throughout the area of TCE vapours
- Single fan captured 96% of TCE mass flux
- Cost savings of ~90% plus HVAC savings.



Subfloor Vacuum in Pascals

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Attenuation Factor Options

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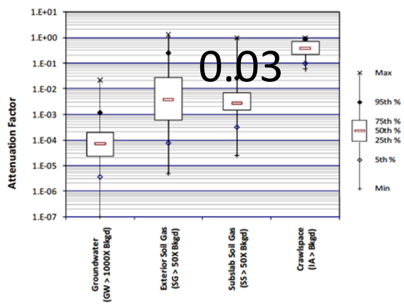
1991 – J&E model

$$\alpha = \frac{\left[\frac{D_T^{eff} A_B}{Q_B L_T}\right] \exp\left(\frac{Q_{soil} L_{crack}}{D_{crack}^{eff} \eta A_B}\right)}{\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack}^{eff} \eta A_B}\right) + \left[\frac{D_T^{eff} A_B}{Q_B L_T}\right] + \left[\frac{D_T^{eff} A_B}{Q_{soil} L_T}\right]\left[\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack}^{eff} \eta A_B}\right) - 1\right]}$$

2012 – USEPA Empirical Data



2018 - AF from flow and vacuum measurements

$$AF = \frac{T\,\Delta P}{B^2\,h\,AER}$$

T = transmissivity of the material below the floor (ft^2/day)
ΔP = differential pressure across the floor slab (ft of air column)
B = leakance of the floor (ft)
h = height of building (ft)
AER = air exchange rate (exchanges/day)

McAlary, T., Gallinatti, J., Thrupp, G., Wertz, W., Mali, D. and H. Dawson, 2018. Fluid Flow Model for Predicting the Intrusion Rate of Subsurface Contaminant Vapors into Buildings, Environmental Science & Technology, 2018, 52(15), pp 8438-8445.

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Take-Home Messages

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- Vacuum isn't the only factor to show mitigation is occurring.
- Understanding the conceptual site model is key
- There are easy to use tools available
- A Multiple Lines of Evidence (MLE) approach works

- Considerable cost savings can be achieved (4 to 10x reduction)

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