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Building-Specific Attenuation Factors from Flow and Vacuum Measurements

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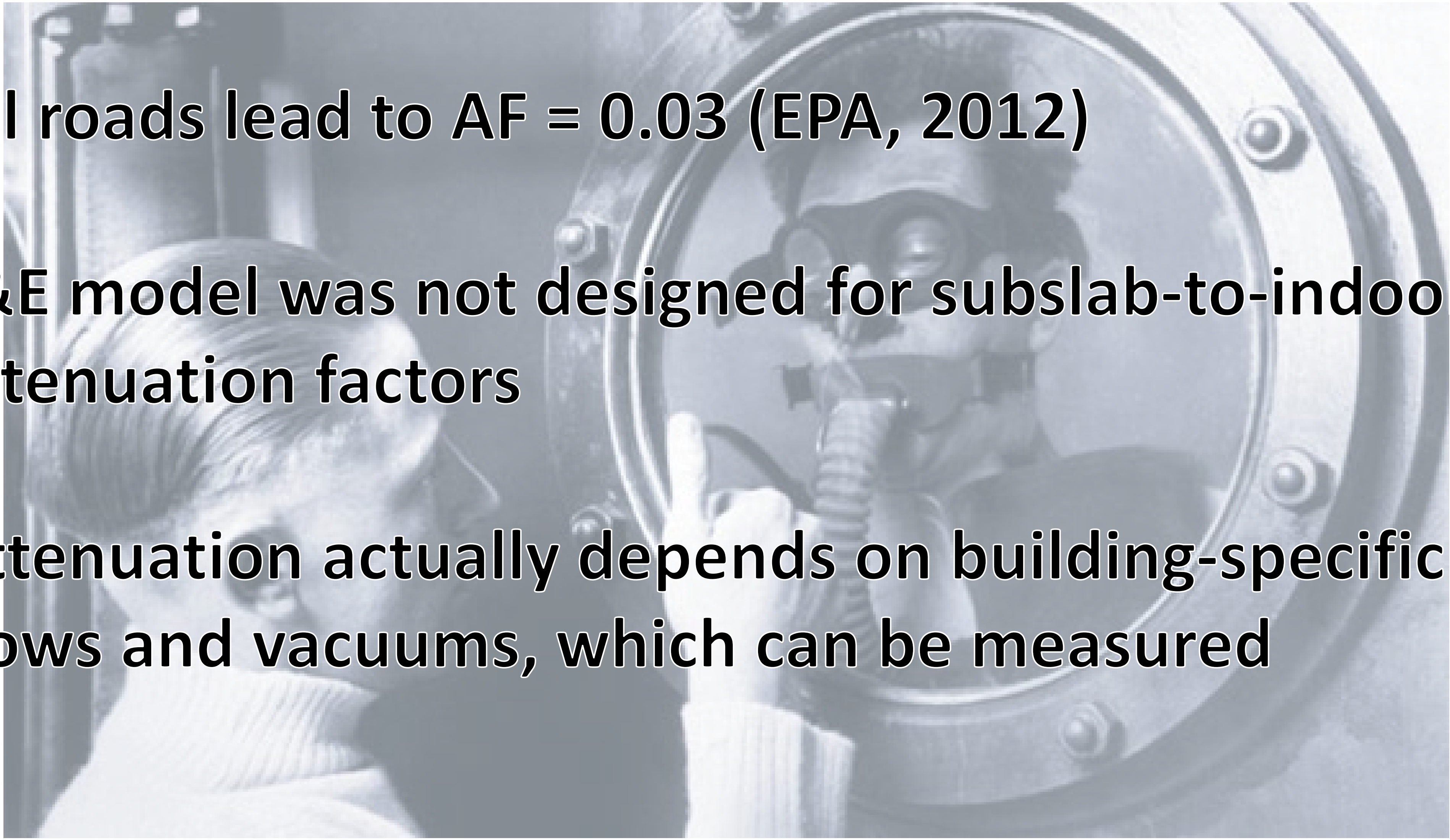
Why Do We Need Another Model?

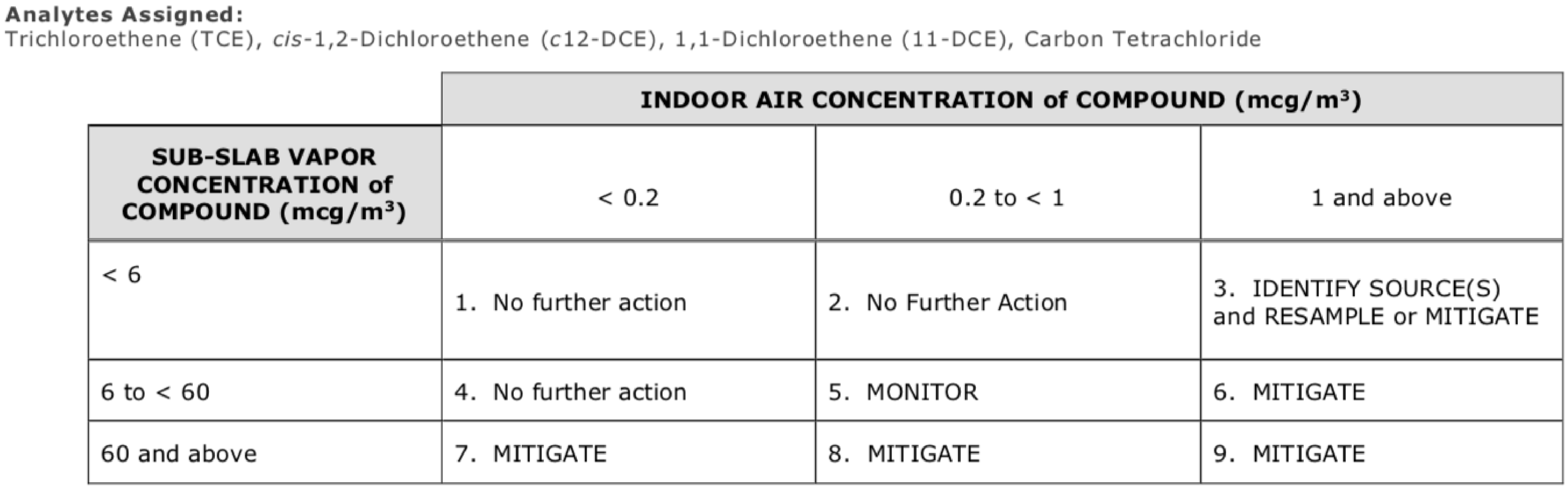


All roads lead to AF = 0.03 (EPA, 2012)

J&E model was not designed for subslab-to-indoor air attenuation factors

Attenuation actually depends on building-specific flows and vacuums, which can be measured

State Driven Subslab Values for Mitigation



Analytes Assigned:
Trichloroethene (TCE), *cis*-1,2-Dichloroethene (*c*12-DCE), 1,1-Dichloroethene (11-DCE), Carbon Tetrachloride

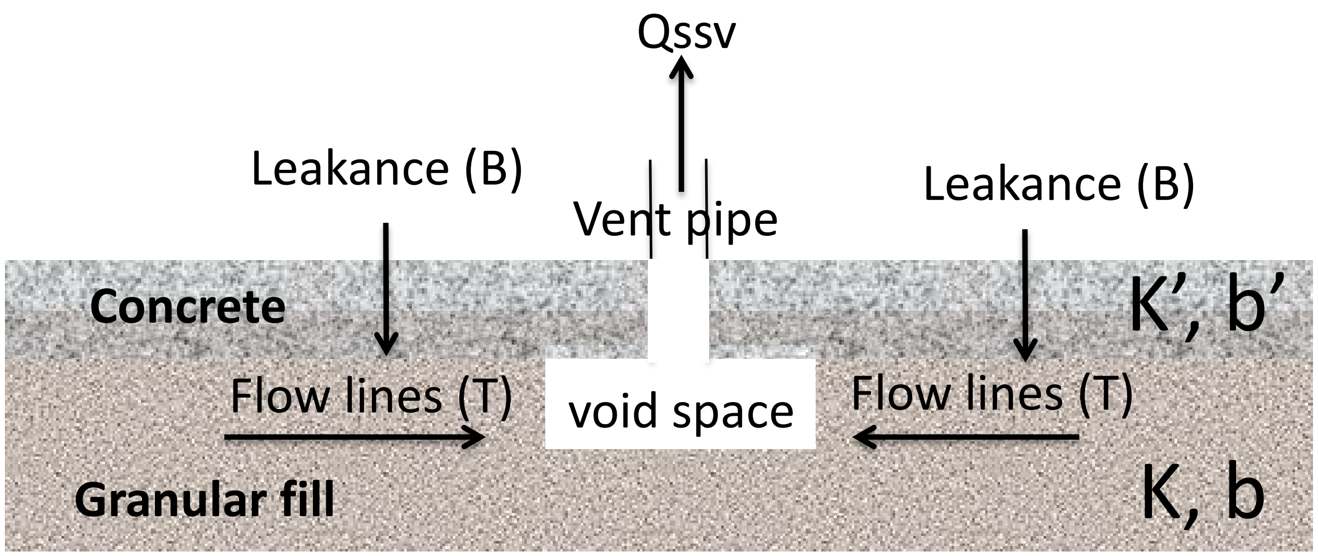
	INDOOR AIR CONCENTRATION of COMPOUND (mcg/m^3)		
SUB-SLAB VAPOR CONCENTRATION of COMPOUND (mcg/m^3)	< 0.2	0.2 to < 1	1 and above
< 6	1. No further action	2. No Further Action	3. IDENTIFY SOURCE(S) and RESAMPLE or MITIGATE
6 to < 60	4. No further action	5. MONITOR	6. MITIGATE
60 and above	7. MITIGATE	8. MITIGATE	9. MITIGATE

Any subslab concentration of TCE above 60 $\mu g/m^3$ and resistance is futile…
The Indoor air screening level is 2$\mu g/m^3$

$$2/60 = 0.03$$

Conceptual Model and Framework

Conceptual Model of Sub-slab Venting



Qssv

Leakance (B)

Vent pipe

Leakance (B)

Concrete

K', b'

Flow lines (T)

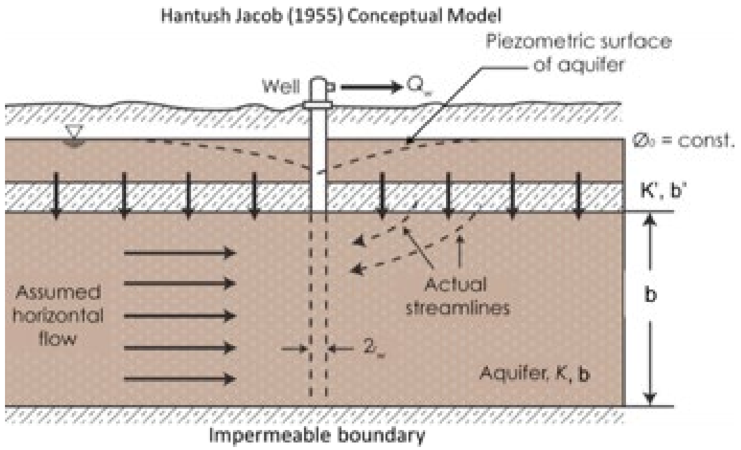
void space

Flow lines (T)

Granular fill

K, b

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.

The Math

Calculated from Model

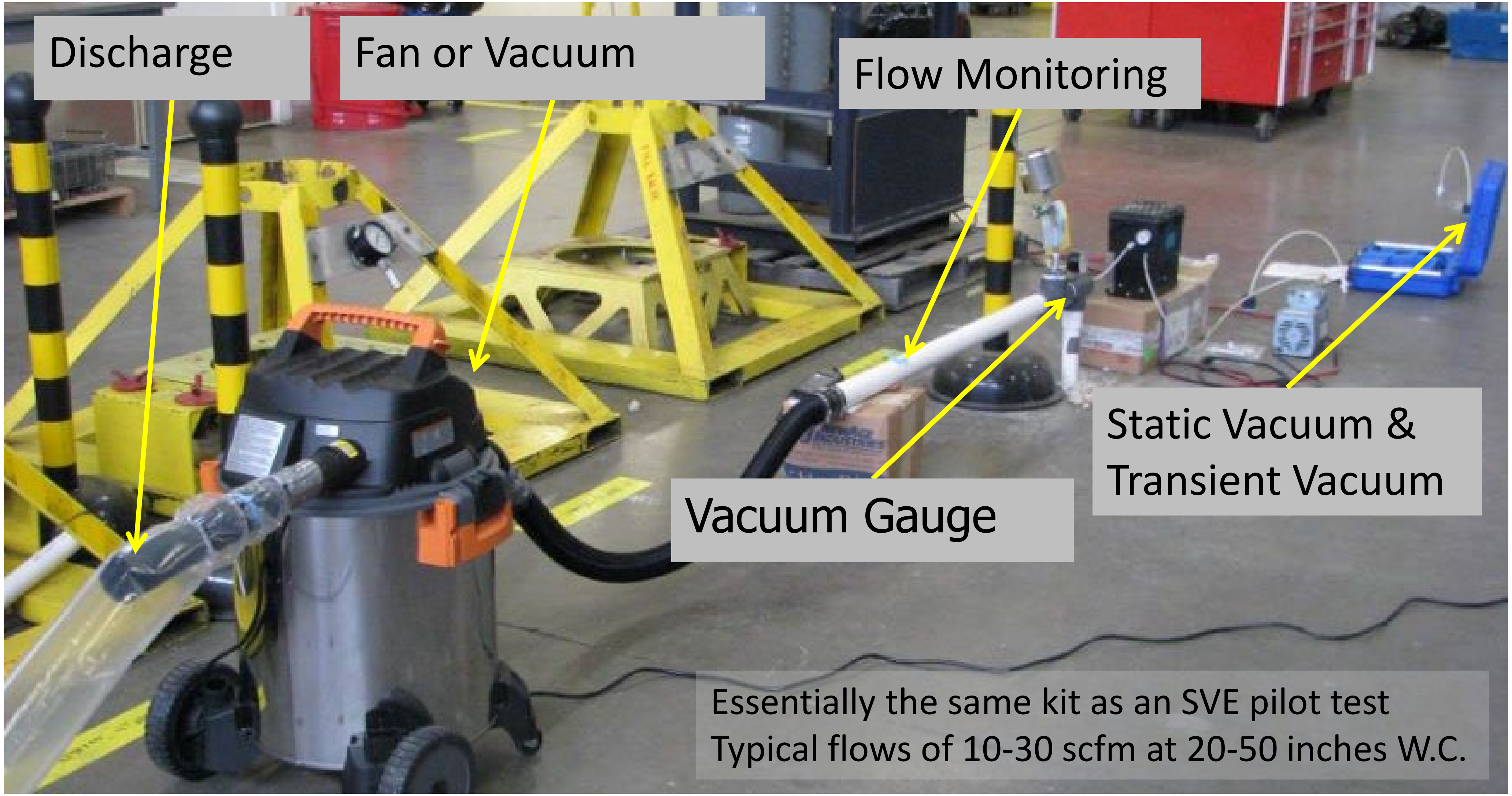
$$AF = \frac{C soil\ vapor}{C indoor\ air} = \frac{Q soil}{Q building} = \frac{K' i\ A}{l\ w\ h\ AER} = \frac{\frac{K b b'}{B^2} \frac{\Delta P}{b'} A}{A\ h\ AER} = \frac{T\ \Delta P}{B^2\ h\ AER}$$

Measured

K′ = bulk vertical pneumatic conductivity of the floor slab (0.08 to 0.9 ft/day)
b′ = floor slab thickness (0.5 ft)
T = transmissivity (54 ft^2/day)
B = leakance (5.5 to 18 ft ft)
ΔP = pressure across the floor slab (0.05 to 0.5 ft of air column)
A = Area of the building footprint (11,000 ft^2)
h = Height of Building = 13.25 ft
AER = Air Exchange Rate = 19 per day (mean for naturally-ventilated)

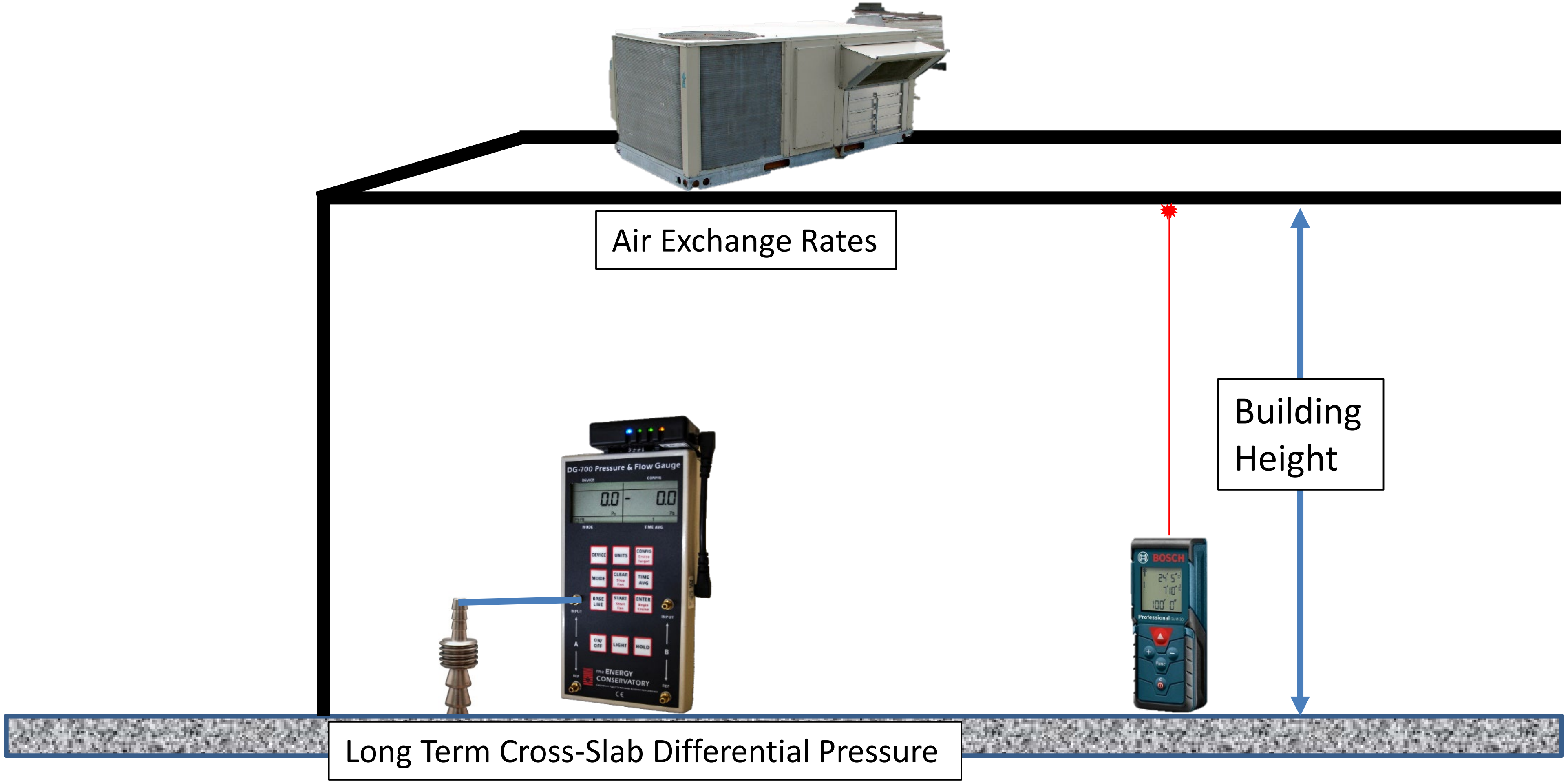
McAlary, T., Gallinatti, J., Thrupp, G., Wertz, W., Mali, D. and H. Dawson, 2018. Fluid Flow Model for Predicting the Intrusion Rate of Subsurface Contaminant Vapors into Buildings, Environmental Science & Technology, 2018, 52(15), pp 8438-8445.

Collection of Field Data



Essentially the same kit as an SVE pilot test
Typical flows of 10-30 scfm at 20-50 inches W.C.

Collection of Field Data

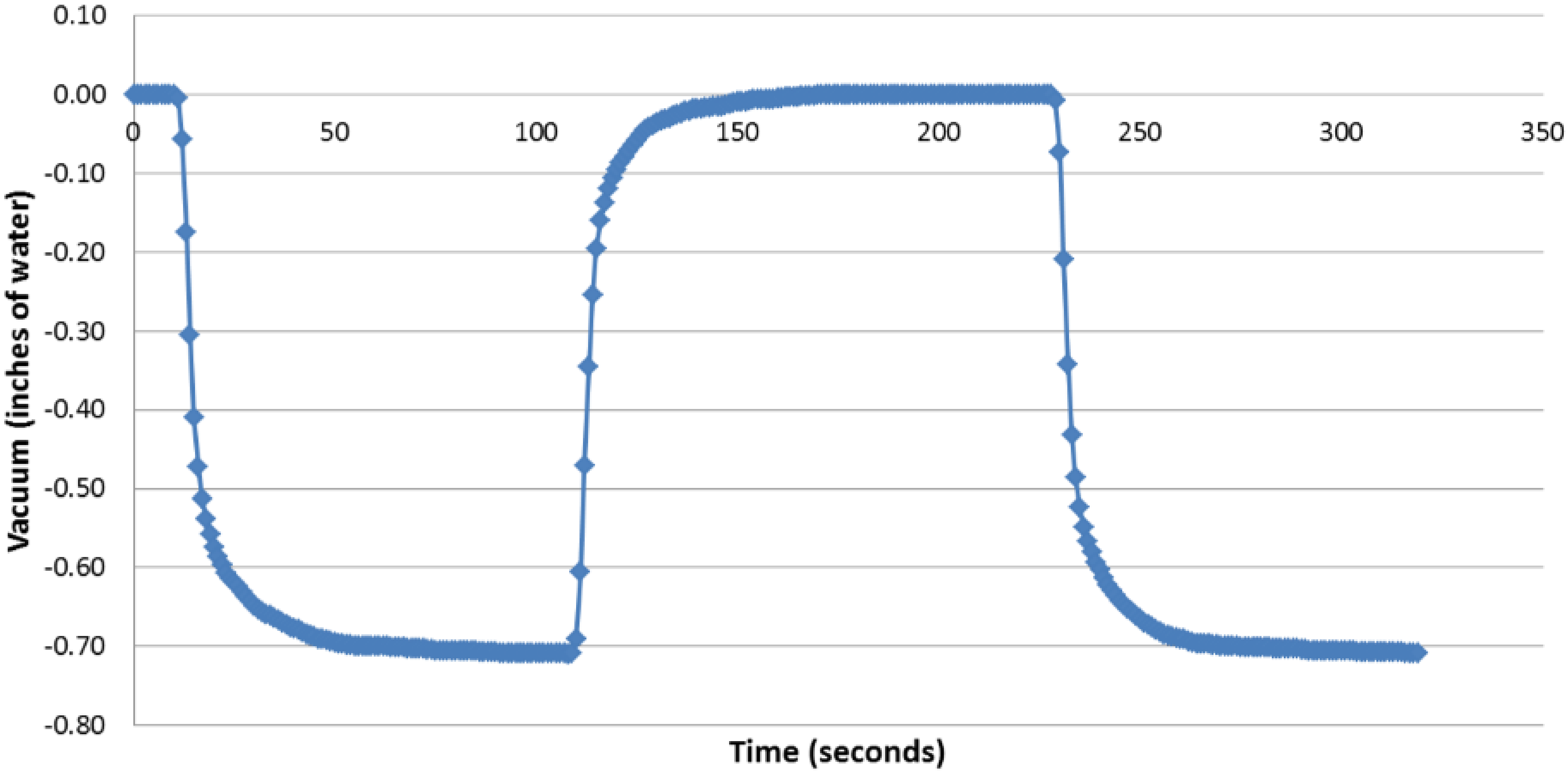


Air Exchange Rates

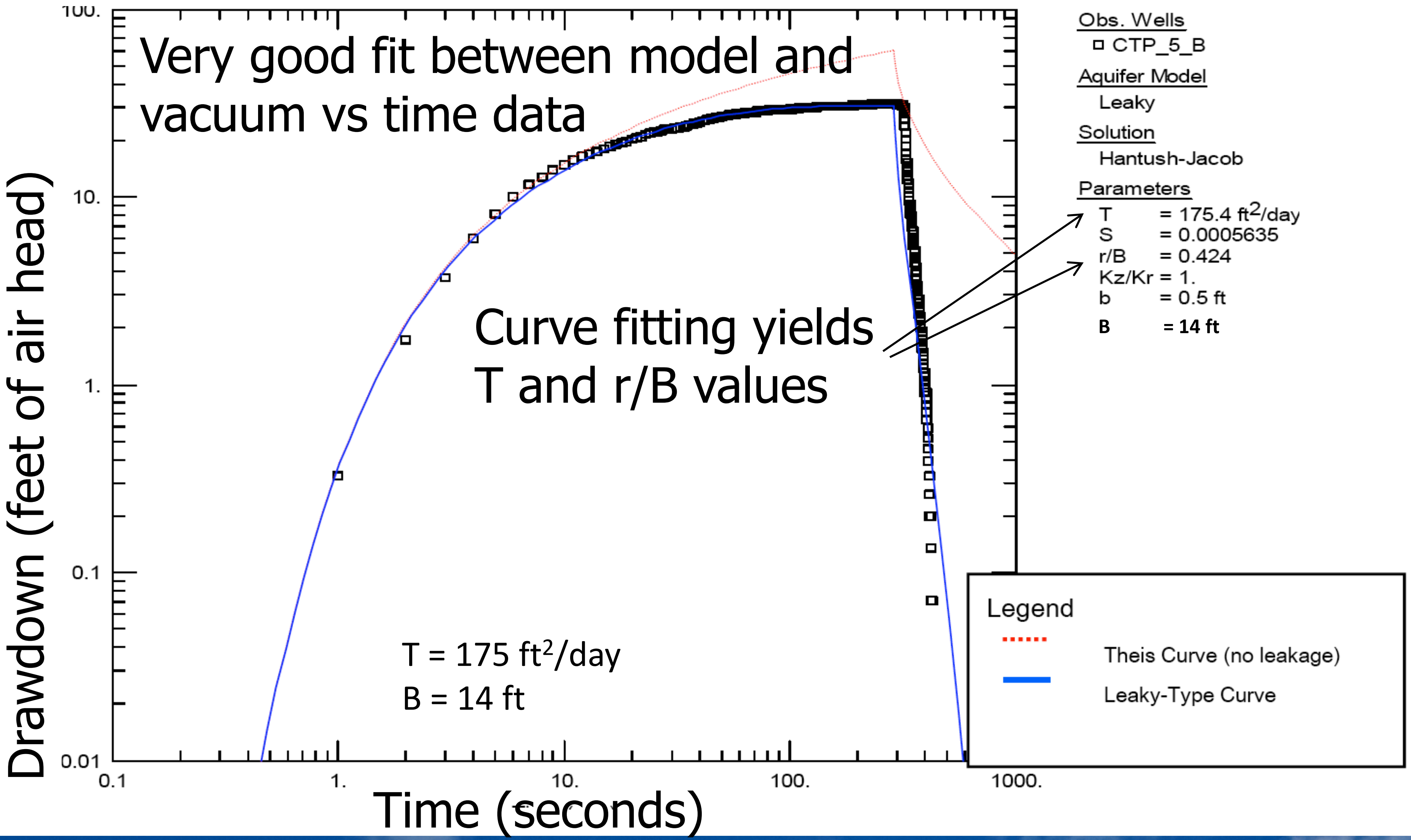
Building Height

Long Term Cross-Slab Differential Pressure

Determination of T & B with Transient Vacuum



Curve Fitting to Time-Drawdown Data

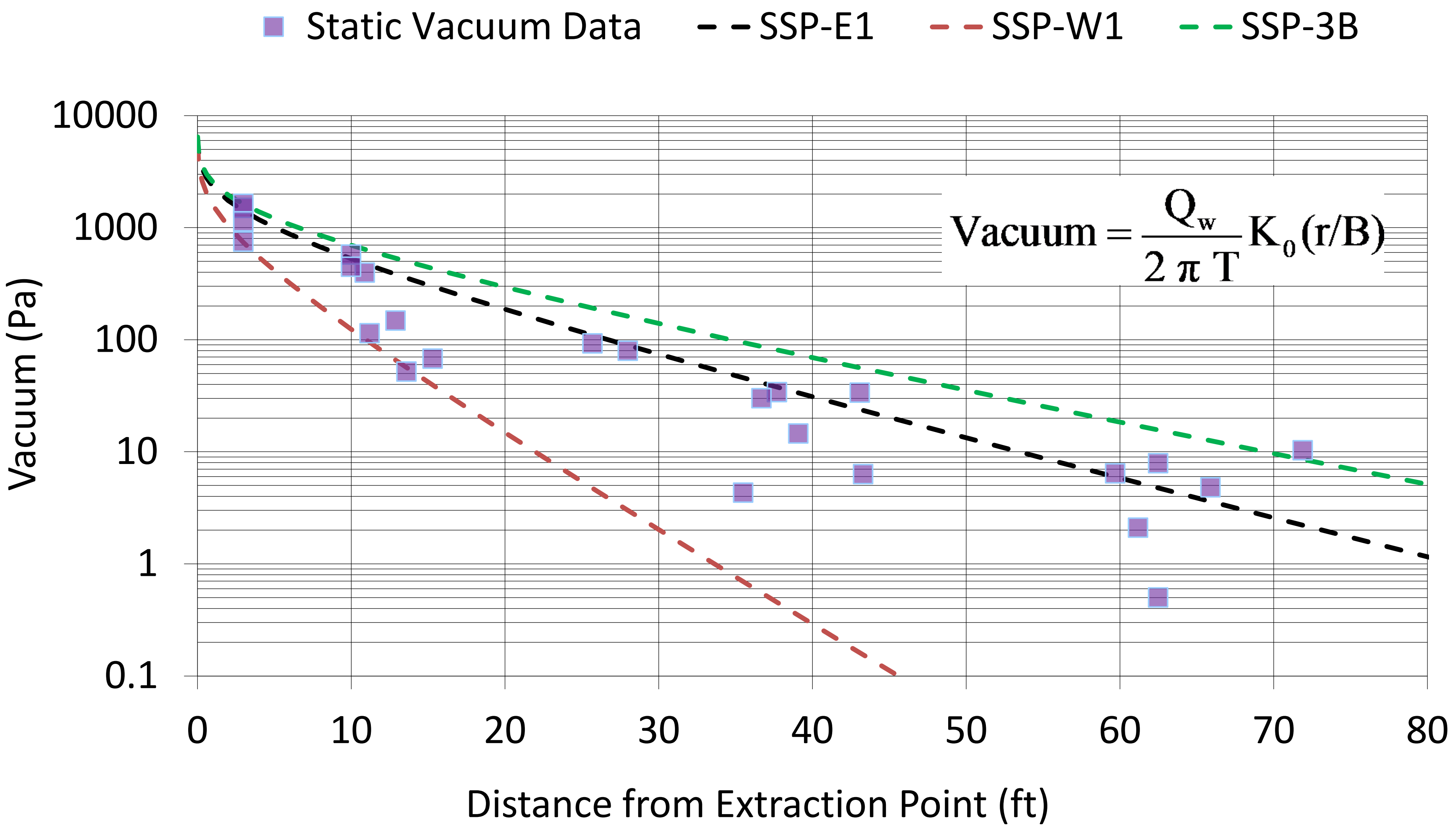


Very good fit between model and vacuum vs time data

Curve fitting yields T and r/B values

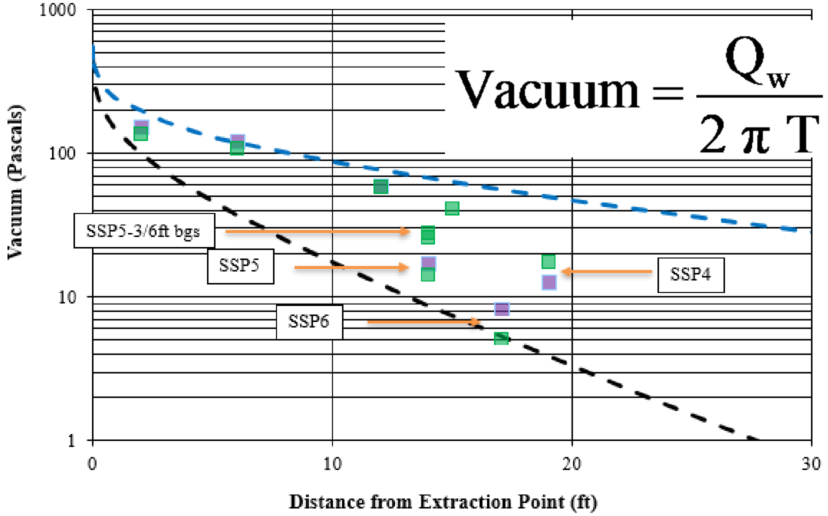
T = 175 ft^2/day
B = 14 ft

Determination of T & B with Static Vacuum

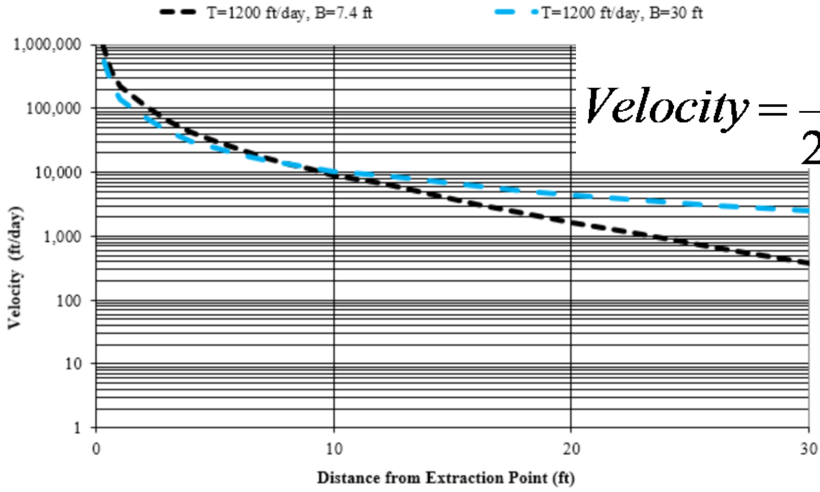


$$\mathrm{Vacuum} = \frac{Q_w}{2\,\pi\,T} K_0(r/B)$$

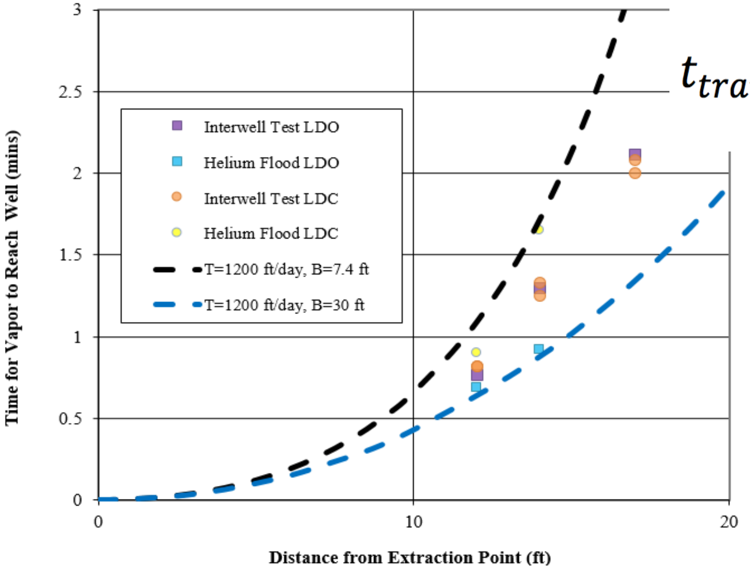
The Model and the Math



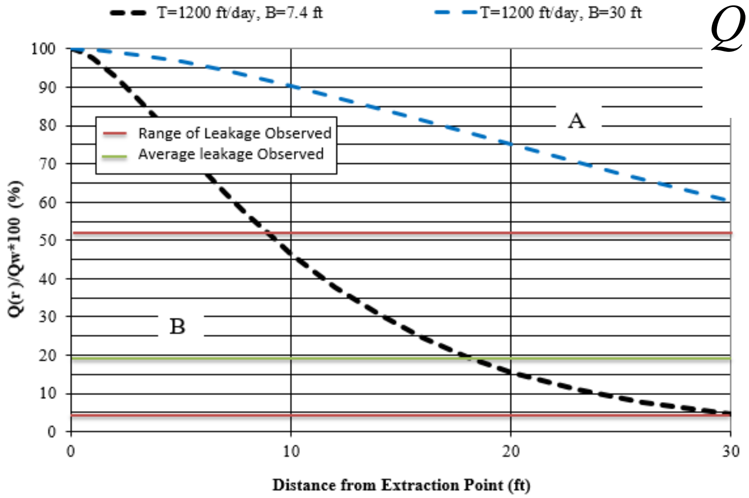
$$\text{Vacuum} = \frac{Q_w}{2\pi T} K_0(r/B)$$



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



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



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

Statistical Look from 121 Tests

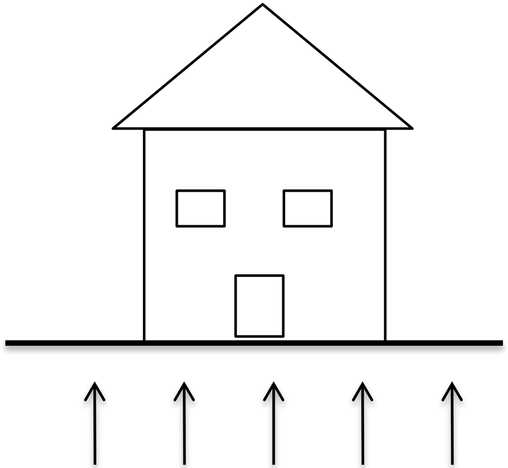
	Transmissivity below the floor (T) (ft^2/day)	Leakage Factor (B) (ft)	AF via Eq 9 (Qsoil/Qbuild) (n=121)	U.S. EPA Empirical Subslab AF (Cia/Css) (n=431)	AF Eq 9 / USEPA AF
Maximum	1000	73	0.25	0.94	0.3
95th %-ile	457	30	0.10	**0.026**	4.0
75th %-ile	70	14	0.020	0.0068	3.0
50th %ile	42	9.1	0.0078	0.0027	2.9
25th %-ile	21	5.8	0.0026	0.0015	1.7
5th %-ile	5.3	3.3	0.00040	0.00032	1.2
Minimum	1.7	0.7	0.00021	0.000025	8.5

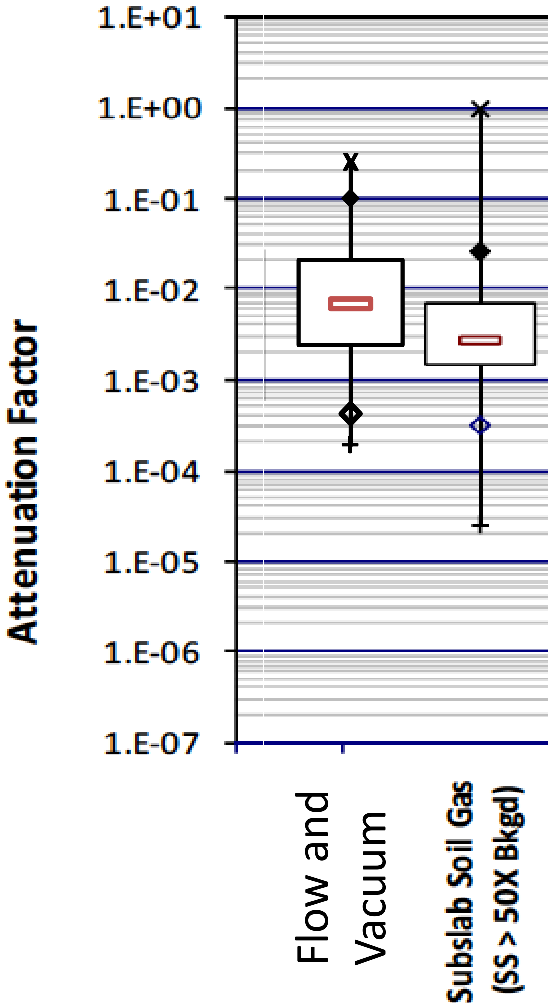
Residential Attenuation Factors

Assume:
ΔP = 4 Pa (1.1 ft air column)
h = 8 ft (2.4 m)
AER = 0.45/hour (USEPA, 2011)

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

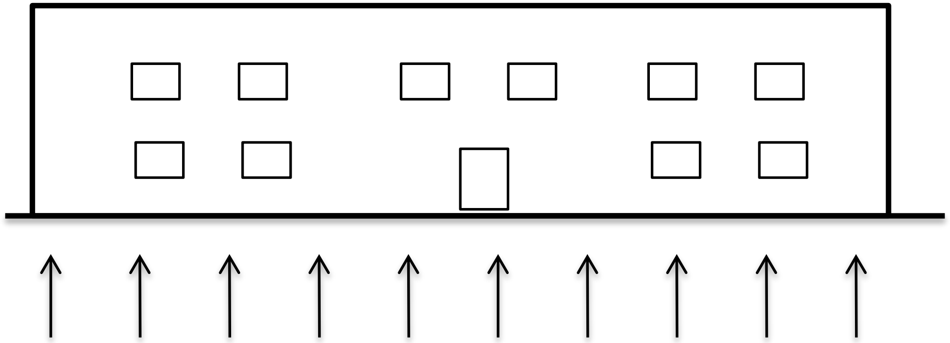
	Alpha via Flow/Vacuum Model (n=121)
Maximum	2.5E-01
95th %-ile	1.0E-01
75th %-ile	2.0E-02
50th %ile	7.8E-03
25th %-ile	2.6E-03
5th %-ile	4.0E-04
Minimum	2.1E-04





U.S. EPA, 2011. Exposure Factors Handbook, EPA/600/R-090/052F

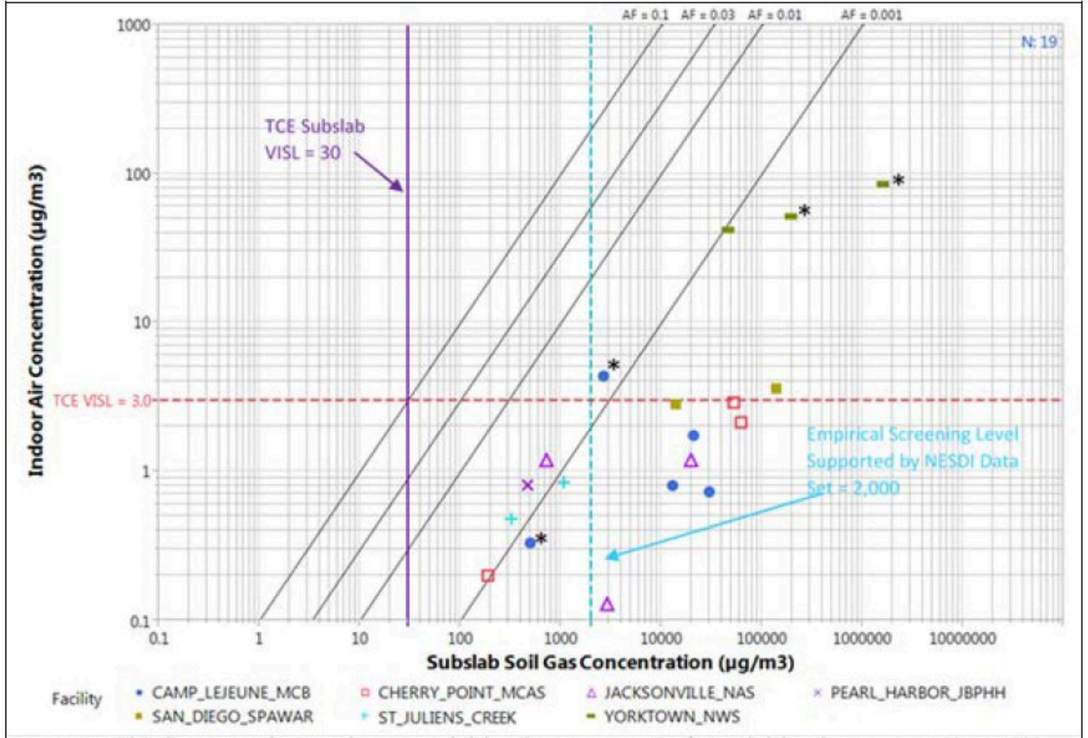
Commercial/Industrial Attenuation Factors



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

Assume:
ΔP = 4 Pa (1.1 ft air column)
h = 15 ft (4.6 m)
AER = 1.5/hour (USEPA, 2011)

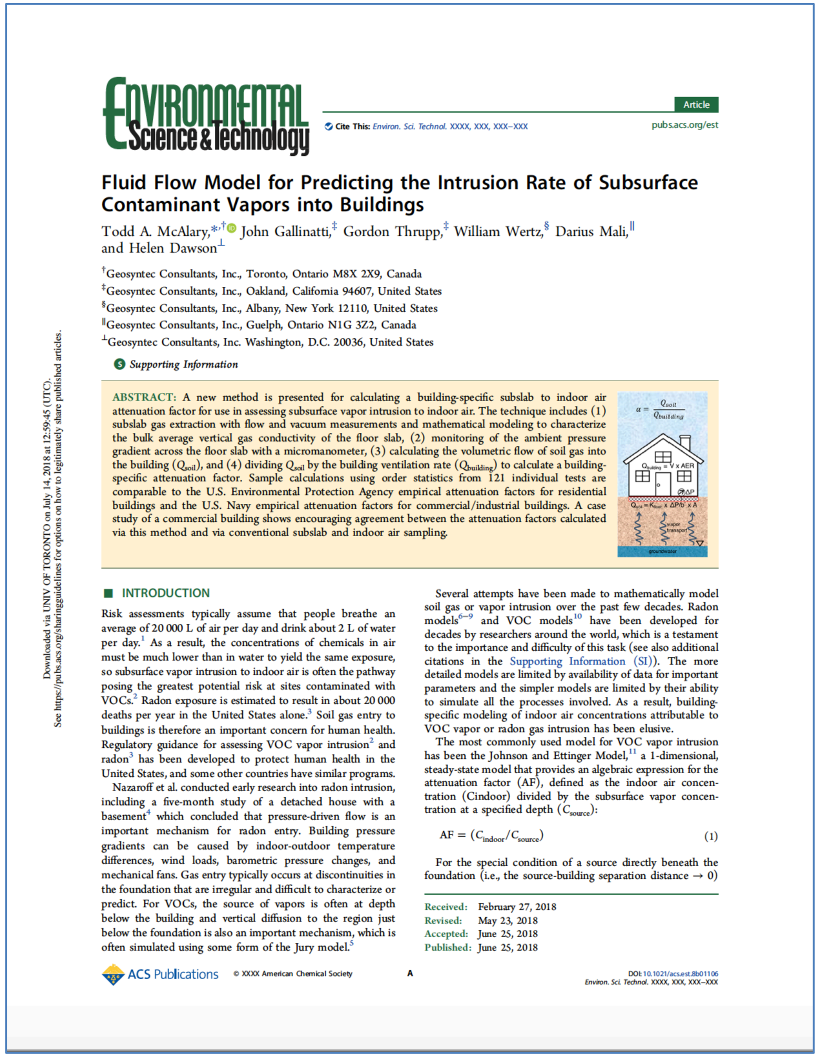
	Alpha via Flow/Vacuum Model (n=121)
Maximum	3.9E-02
95th %-ile	1.6E-02
75th %-ile	3.1E-03
50th %ile	1.2E-03
25th %-ile	4.1E-04
5th %-ile	6.3E-05
Minimum	3.3E-05



Note: asterisk indicates sample zone where max subslab soil gas concentration/min subslab soil gas concentration > 1000

U.S. Navy, 2015. A Quantitative Decision Framework for Assessing Navy Vapor Intrusion Sites, Technical Report TRNAVFAC-EXWC-EV-1603, June 2015.

ES&T Article and ESTCP Final Report



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Fluid Flow Model for Predicting the Intrusion Rate of Subsurface Contaminant Vapors into Buildings

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Supporting Information

ABSTRACT: A new method is presented for calculating a building-specific subslab to indoor air attenuation factor for use in assessing subsurface vapor intrusion to indoor air. The technique includes (1) subslab gas extraction with flow and vacuum measurements and mathematical modeling to characterize the bulk average vertical gas conductivity of the floor slab, (2) monitoring of the ambient pressure gradient across the floor slab with a micromanometer, (3) calculating the volumetric flow of soil gas into the building (Q_{soil}), and (4) dividing Q_{soil} by the building ventilation rate ($Q_{building}$) to calculate a building-specific attenuation factor. Sample calculations using order statistics from 121 individual tests are comparable to the U.S. Environmental Protection Agency empirical attenuation factors for residential buildings and the U.S. Navy empirical attenuation factors for commercial/industrial buildings. A case study of a commercial building shows encouraging agreement between the attenuation factors calculated via this method and via conventional subslab and indoor air sampling.

INTRODUCTION

Risk assessments typically assume that people breathe an average of 20 000 L of air per day and drink about 2 L of water per day.[1] As a result, the concentrations of chemicals in air must be much lower than in water to yield the same exposure, so subsurface vapor intrusion to indoor air is often the pathway posing the greatest potential risk at sites contaminated with VOCs.[2] Radon exposure is estimated to result in about 20 000 deaths per year in the United States alone.[3] Soil gas entry to buildings is therefore an important concern for human health. Regulatory guidance for assessing VOC vapor intrusion[2] and radon[3] has been developed to protect human health in the United States, and some other countries have similar programs.

Nazaroff et al. conducted early research into radon intrusion, including a five-month study of a detached house with a basement[4] which concluded that pressure-driven flow is an important mechanism for radon entry. Building pressure gradients can be caused by indoor-outdoor temperature differences, wind loads, barometric pressure changes, and mechanical fans. Gas entry typically occurs at discontinuities in the foundation that are irregular and difficult to characterize or predict. For VOCs, the source of vapors is often at depth below the building and vertical diffusion to the region just below the foundation is also an important mechanism, which is often simulated using some form of the Jury model.[5]

Several attempts have been made to mathematically model soil gas or vapor intrusion over the past few decades. Radon models[6−9] and VOC models[10] have been developed for decades by researchers around the world, which is a testament to the importance and difficulty of this task (see also additional citations in the Supporting Information (SI)). The more detailed models are limited by availability of data for important parameters and the simpler models are limited by their ability to simulate all the processes involved. As a result, building-specific modeling of indoor air concentrations attributable to VOC vapor or radon gas intrusion has been elusive.

The most commonly used model for VOC vapor intrusion has been the Johnson and Ettinger Model,[11] a 1-dimensional, steady-state model that provides an algebraic expression for the attenuation factor (AF), defined as the indoor air concentration (Cindoor) divided by the subsurface vapor concentration at a specified depth (C_{source}):

$$AF = (C_{indoor}/C_{source}) \qquad (1)$$

For the special condition of a source directly beneath the foundation (i.e., the source-building separation distance → 0)

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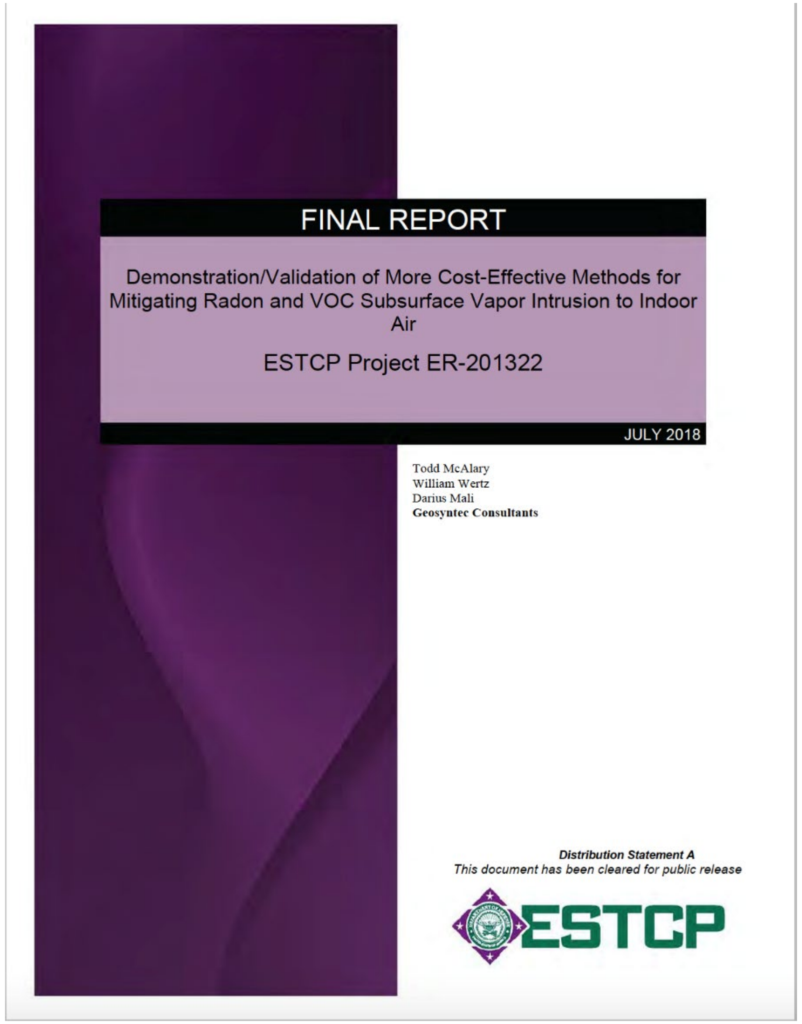

FINAL REPORT

Demonstration/Validation of More Cost-Effective Methods for Mitigating Radon and VOC Subsurface Vapor Intrusion to Indoor Air

ESTCP Project ER-201322

JULY 2018

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Questions?

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