Understanding the Dynamics of Vapor Intrusion Processes

Through Numerical Modeling

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What is Vapor Intrusion?

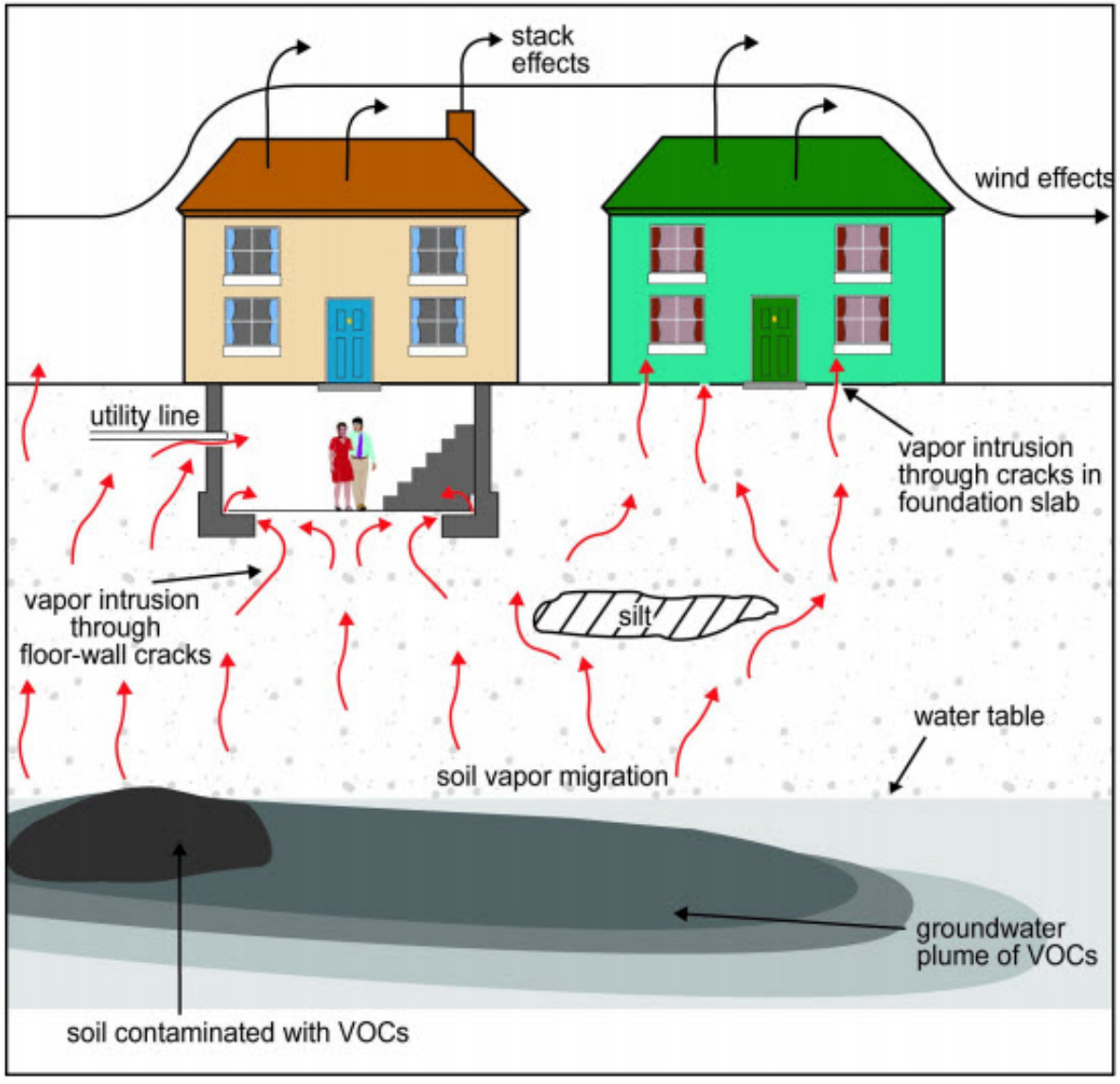


Figure: EPA[1]

Why Should Vapor Intrusion Concern Us?

VI Contaminants

- Volatile organic compounds (VOCs)
- Chlorinated organic solvents
  - Trichloroethylene (TCE) ($2\,\mu g\,m^{-3}$)
  - Tetrachloroethylene (PCE)
- Most of these carcinogenic
- Common at Superfund sites - one site may affect many buildings

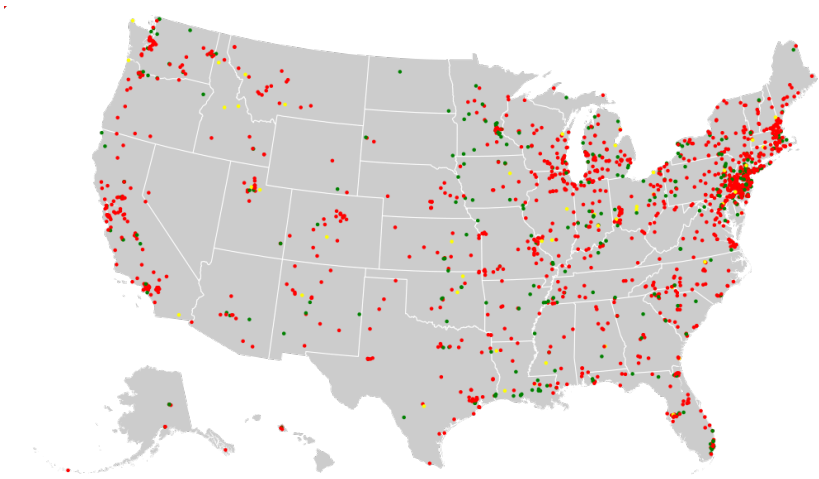


Figure: Superfund sites as of 2013.
Wikipedia CC[2]

Difficulties in VI Investigations

Human concerns

- Liability issues - responsible party
- Intrusive & expensive

Practical concerns

- Concern for indoor sources (false positives)
- VI sites affected by great variability (false negatives)
  - Spatially
  - Temporally
- Requires multiple-lines of evidence (MLE) - spatially and temporally separated samples

Attenuation Factors and Empiricism

Determining VI

- Decrease in vapor concentration from point to point - *attenuation*
- Compare to EPA VI database recommended values ($\alpha_{\mathrm{gw}} \approx 0.001$)
- Does not capture individual site differences - highly empirical approach
- Need to make sense of complex data

Attenuation factor

$$\alpha_{\mathrm{gw}} = \frac{c_{in}}{c_{\mathrm{gw}}}$$

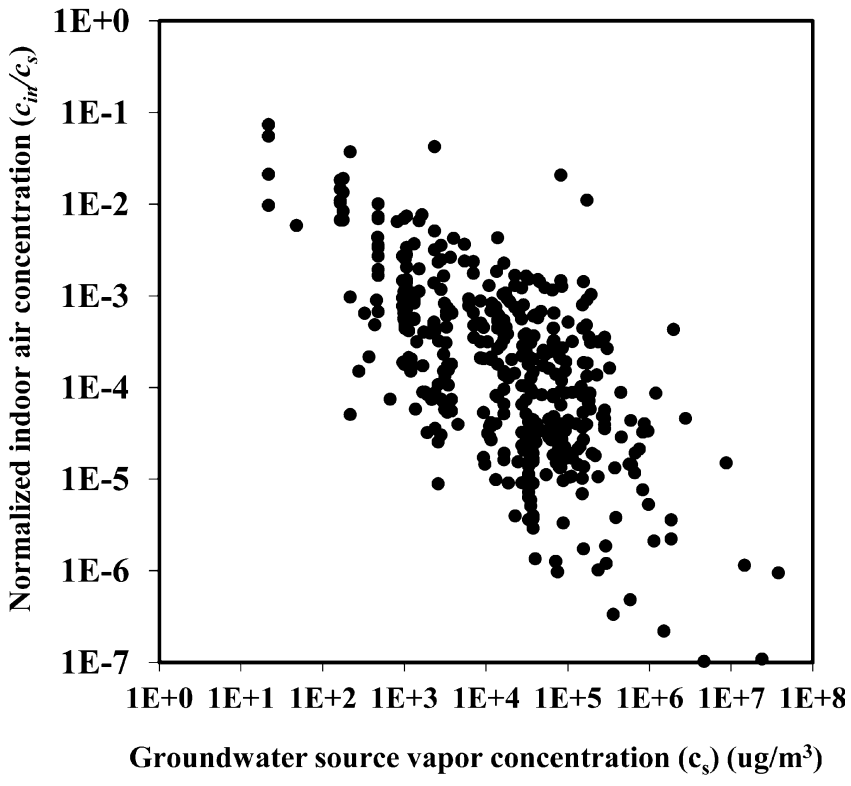


Figure: Yao et al.[3]

Benefits of Modeling in VI

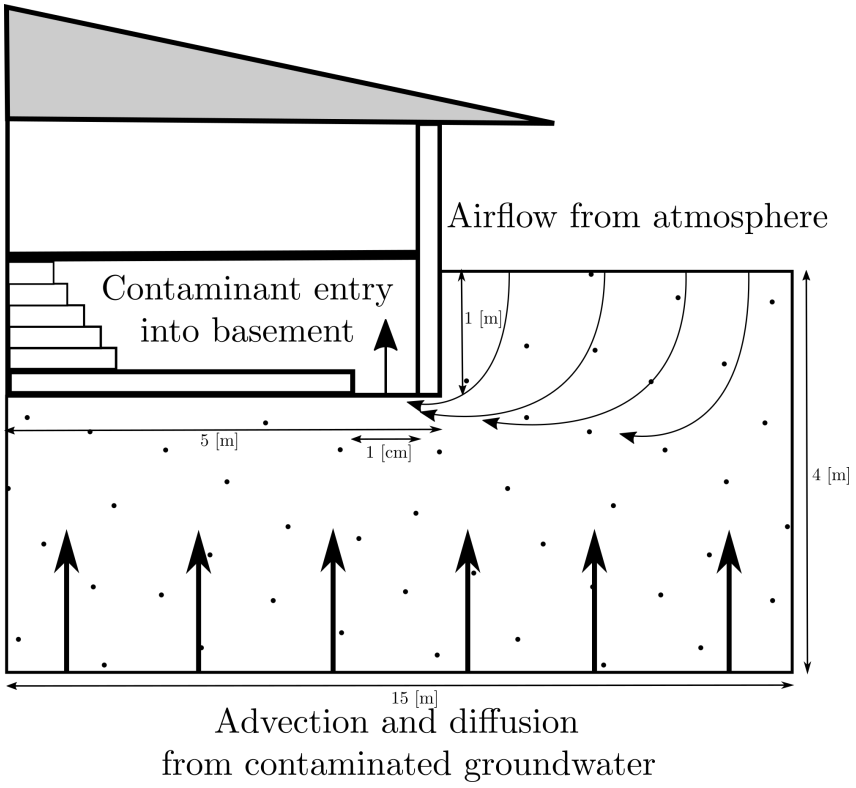
Advance Scientific Understanding

- Can control for any variable/feature
- First-principles explanation of VI - discover new insights
- Hypothetical scenarios

Predictive Tool

- Guide VI investigations
- Evaluate results

Developing a VI Model



Physics

- Indoor environment (CSTR)
  - Contaminant entry through foundation crack
  - Expulsion via air exchange rate
  - (Indoor sources/sorption possible)
- Airflow (Darcy's Law)
- Advection-diffusion in soil
  - Water/vapor/(sorbed) phases
  - Biodegradation
- Soil moisture content
  - Effective permeability
  - Effective diffusivity

Modeling in VI

Analytic models

- Constrained by CSM
- 1D (some 2D)
- Sacrifice physics to be solvable
- Usually steady-state only

Numerical models

- Finite-element method
- 3D
- Adapt/evolve CSM
- Resolve all physics
- Time-dependent supported

The ASU House

Figure: Holton et al.[4]

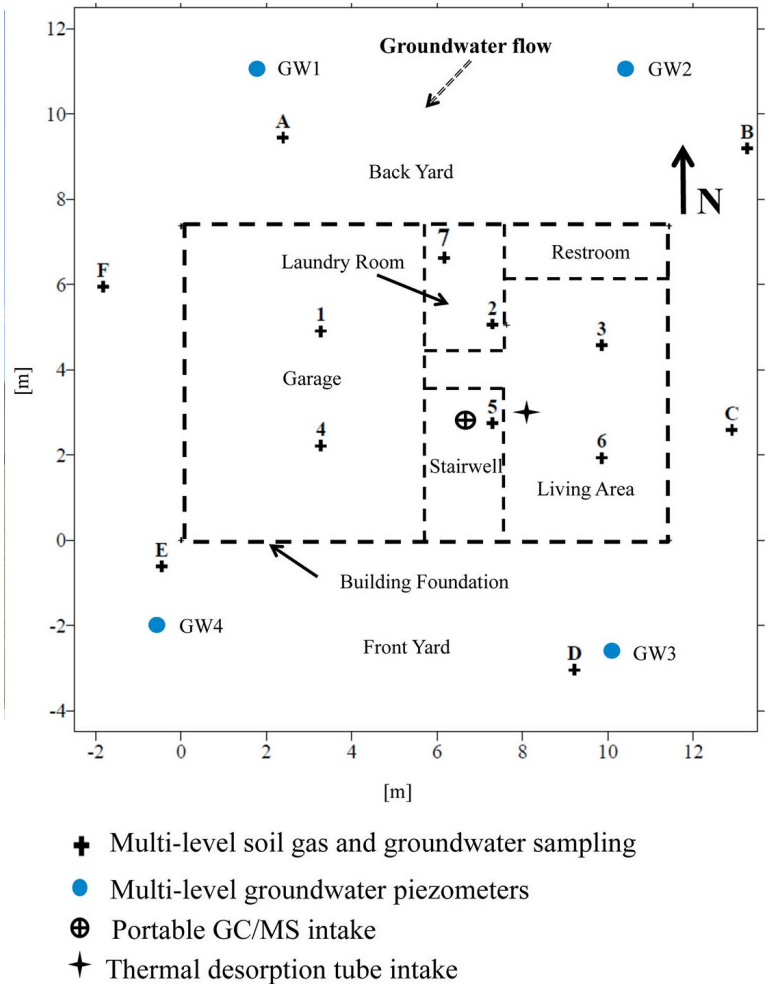


Figure: Holton et al.[4]

- Near Hill AFB in Layton, UT
- TCE contaminated groundwater
- Bought by ASU to study VI & CPM

The Controlled Pressure Method

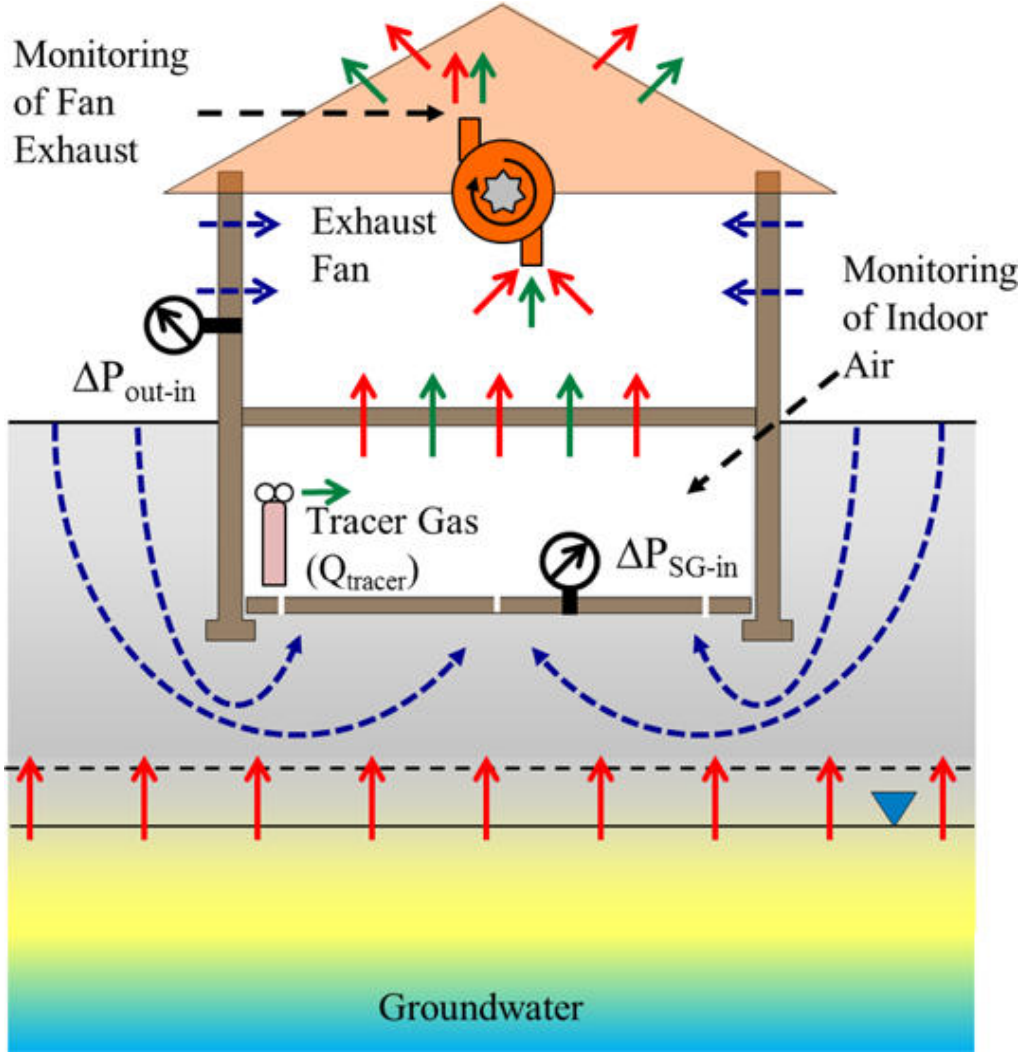
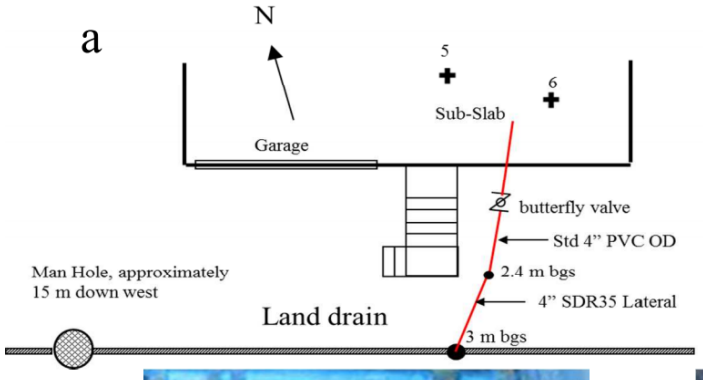


Figure: Holton et al.[5]

- Control contaminant entry via building pressurization
- Identify indoor sources & worst-case scenario

Discovery of a Preferential Pathway



a. Location of the land drain line and lateral foundation drainage.
b. Lateral before butterfly valve installation.
c. Lateral after butterfly valve installation.

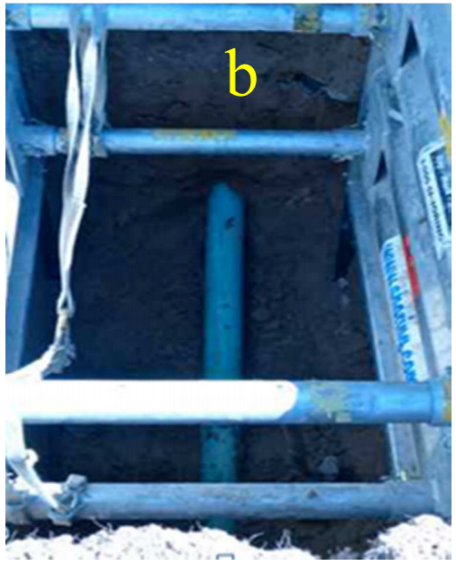
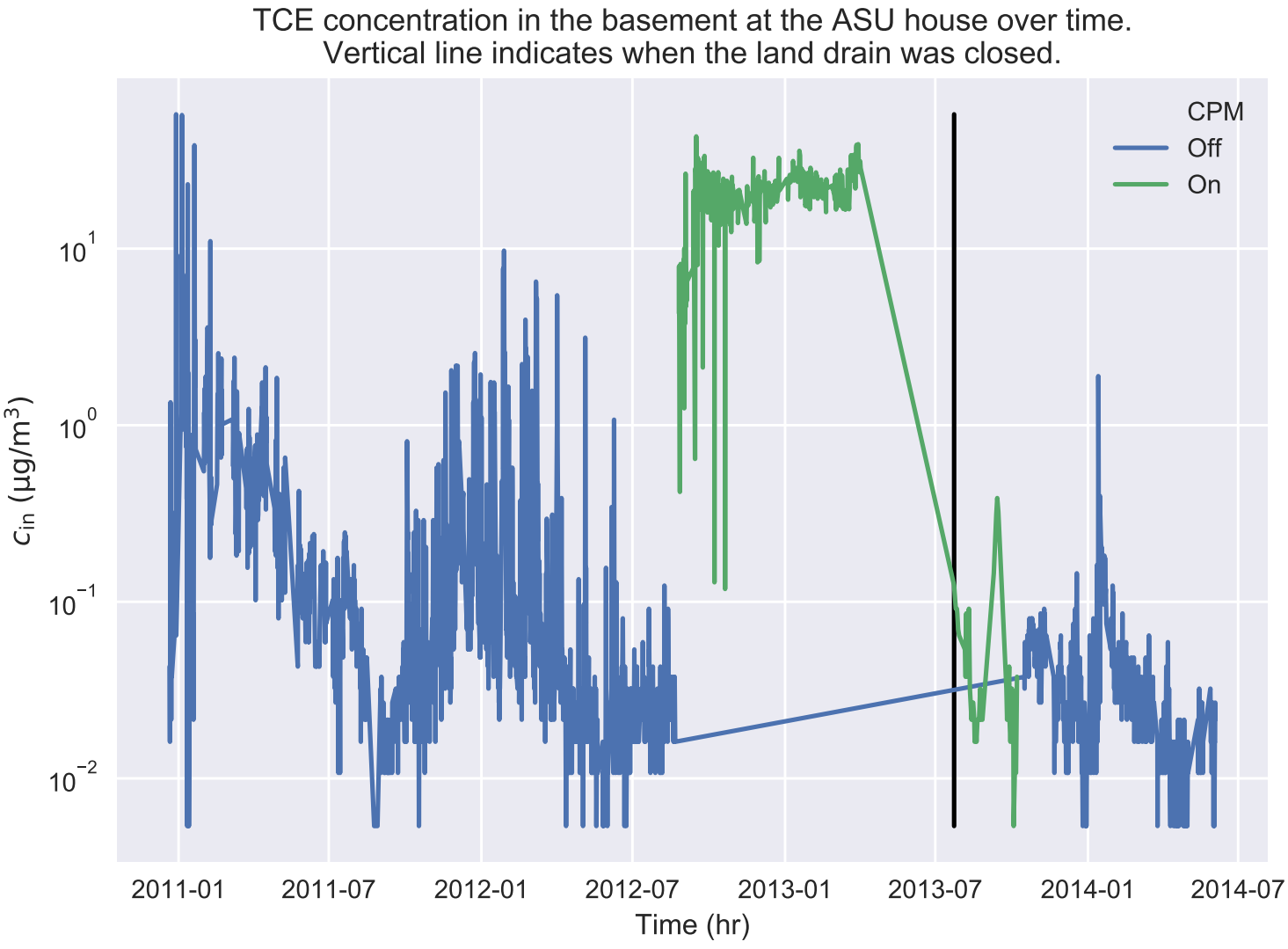


Figure: Guo et al.[6]

Indoor Contaminant Concentration at the ASU House



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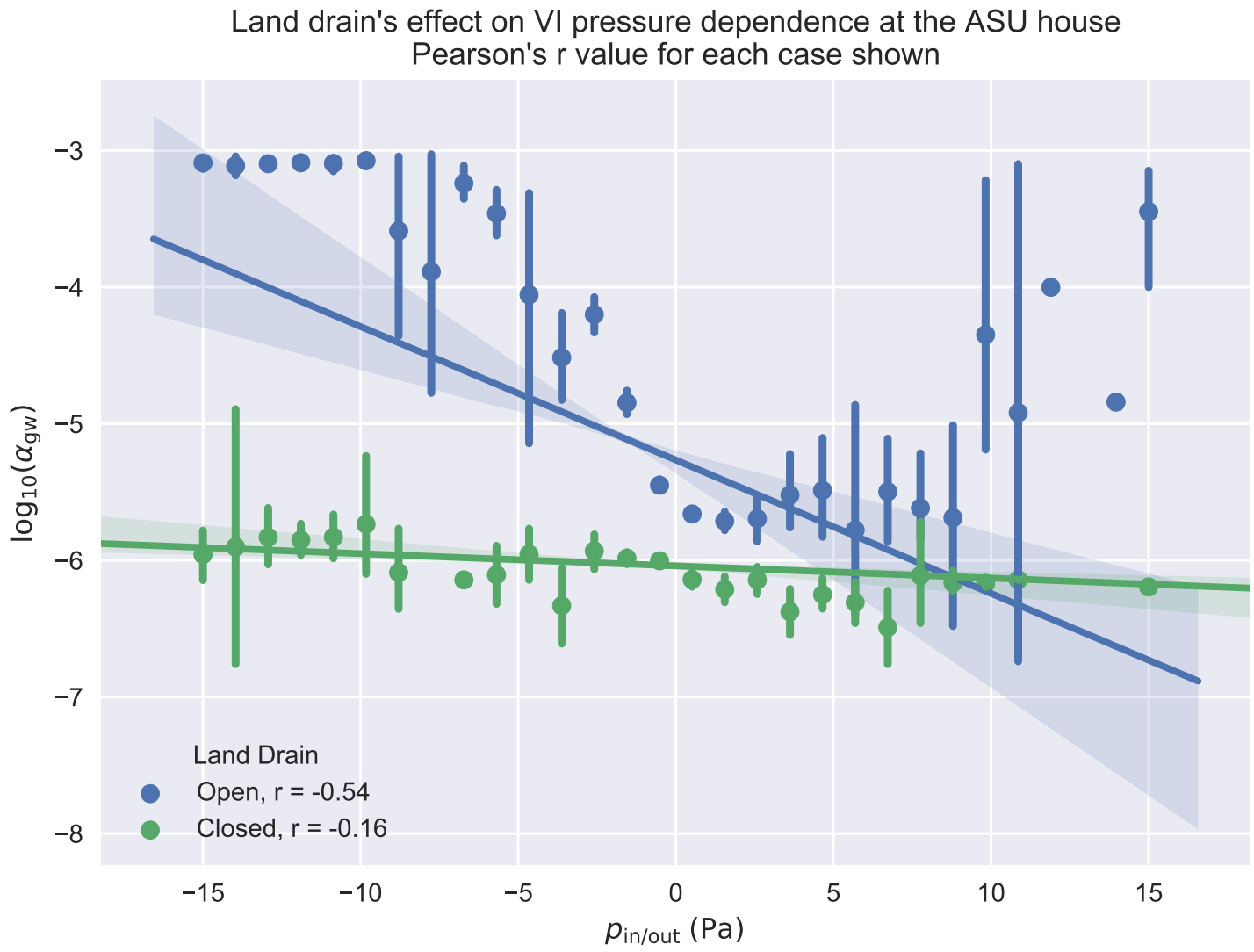
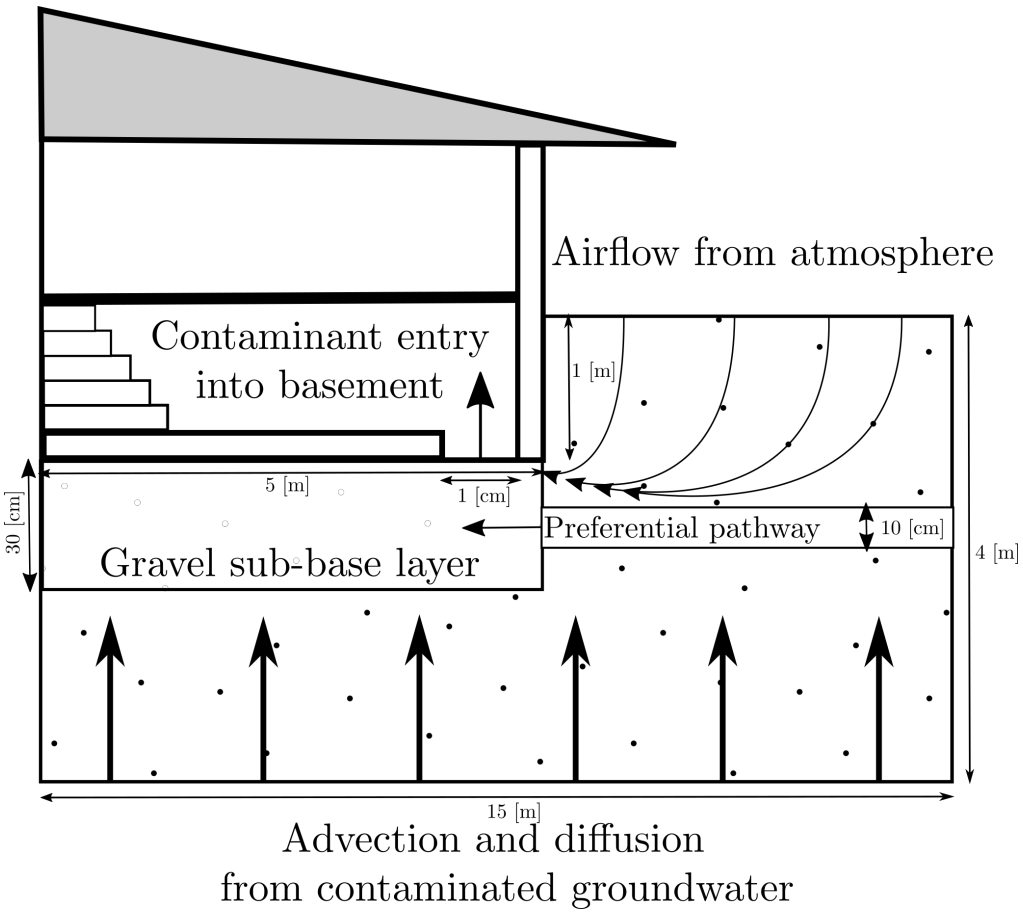


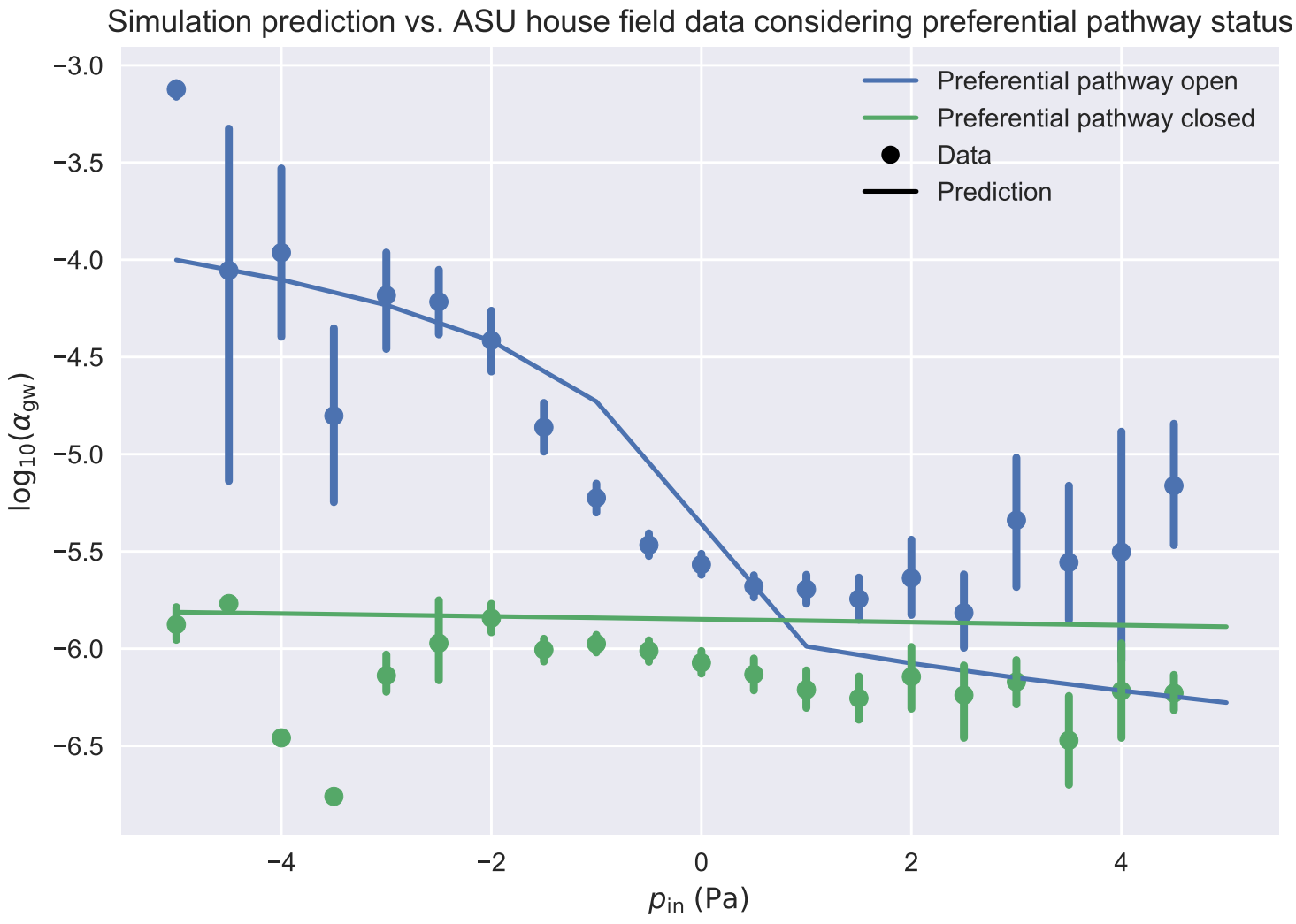
Modeling a "ASU House"-like VI Scenario



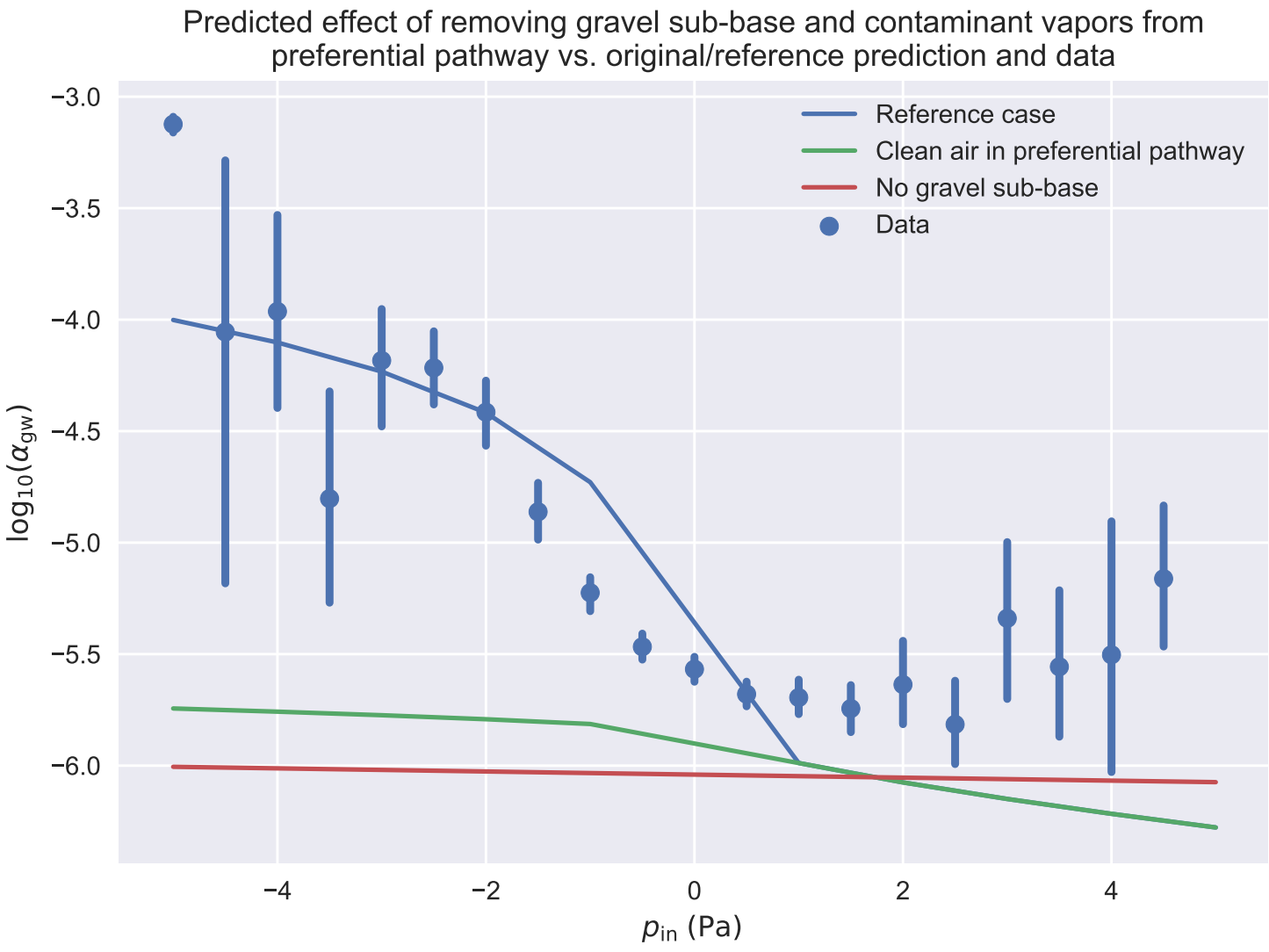
Additions

- Permeable gravel sub-base
- 10 cm pipe filled with contaminant vapors

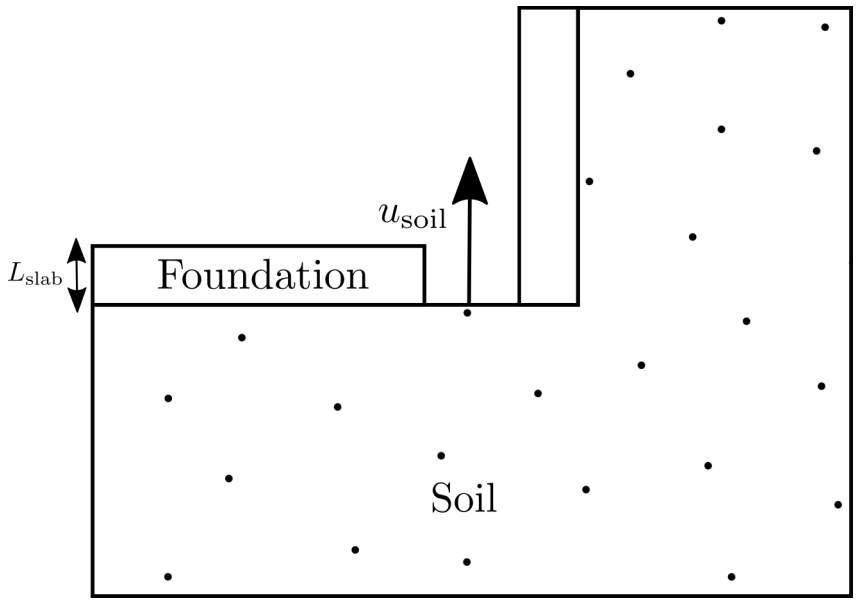
Predicting the Effects of a Preferential Pathway



Preferential pathways: Specific Site Conditions



Péclet Number and Advection

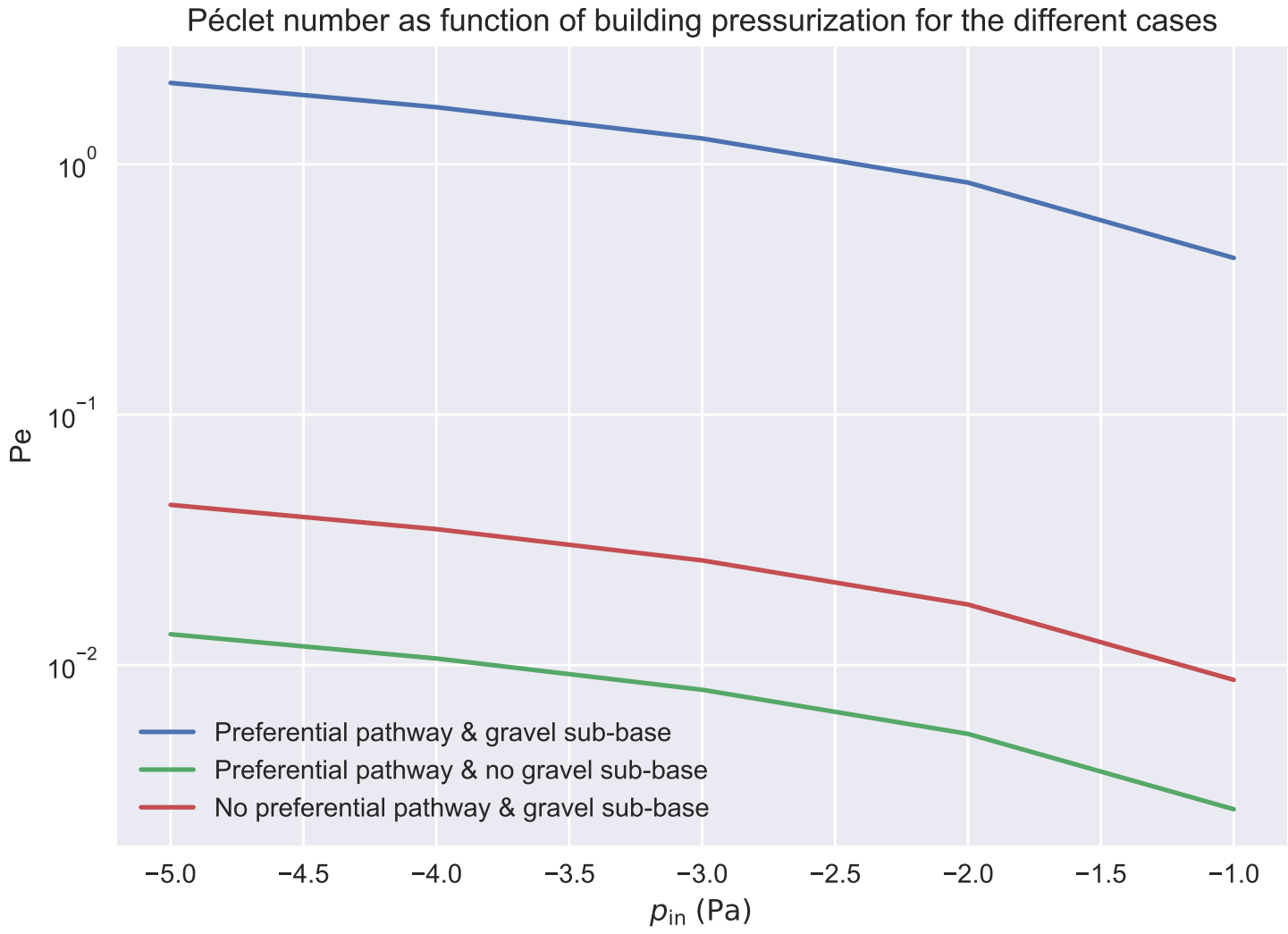


Péclet number for contaminant entry

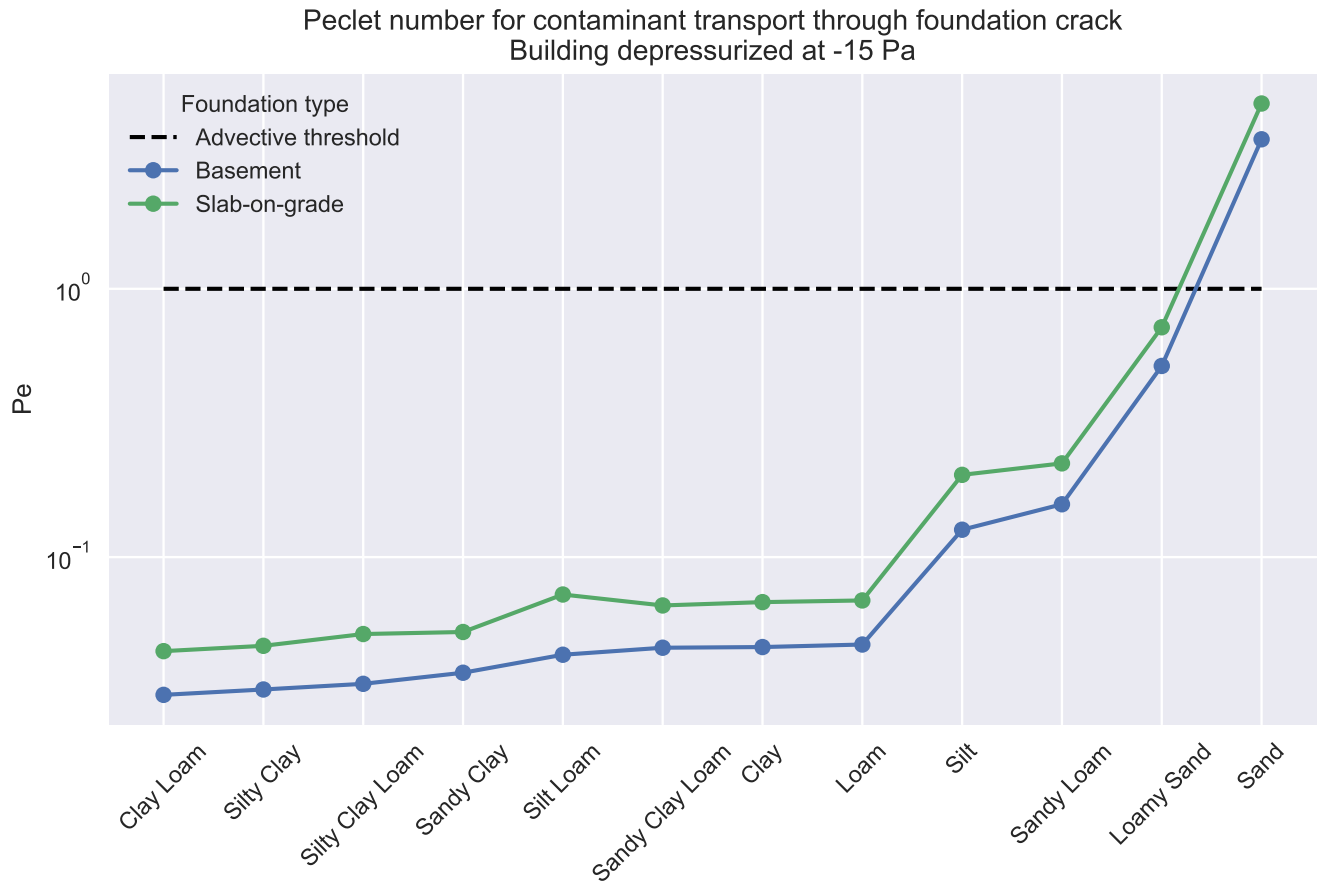
$$\text{Pe} = \frac{\text{advection}}{\text{diffusion}} = \frac{u_{\text{soil}} L_{\text{slab}}}{D_{\text{air}}}$$

$\text{Pe} > 1 \rightarrow$ advection dominated $\quad$ $\text{Pe} < 1 \rightarrow$ diffusion dominated

Péclet Number and Advection



Advection: Considering Soil and Foundation Type



Summary

- Enhanced advective potential explains preferential pathways' significant impact
  - Source of air and contaminant
  - Permeable medium for communication
- Challenging assumptions about advective entry - soils unlikely to sustain sufficient flow rates
- Insights possible through numerical modeling

Thank you!


OLEM US EPA. *What Is Vapor Intrusion?* en. https://www.epa.gov/vaporintrusion/what-vapor-intrusion. Overviews and Factsheets. 00000 Library Catalog: www.epa.gov. Sept. 2015.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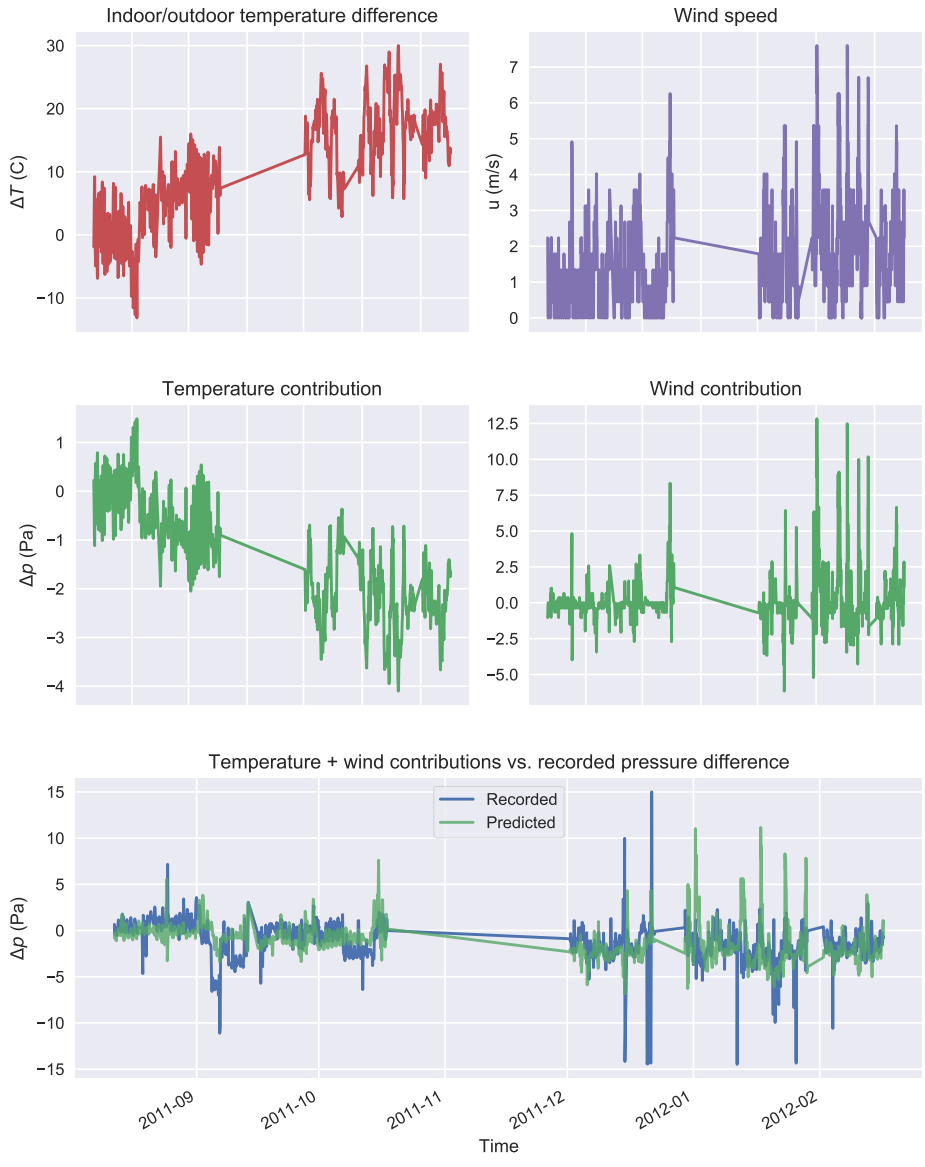
Yuanming Guo et al. "Identification of Alternative Vapor Intrusion Pathways Using Controlled Pressure Testing, Soil Gas Monitoring, and Screening Model Calculations". In: *Environmental Science & Technology* 49.22 (Nov. 2015). 00024, pp. 13472–13482. ISSN: 0013-936X. DOI: 10/f72b6n.

Indicators, Tracers, and Surrogates

Idea

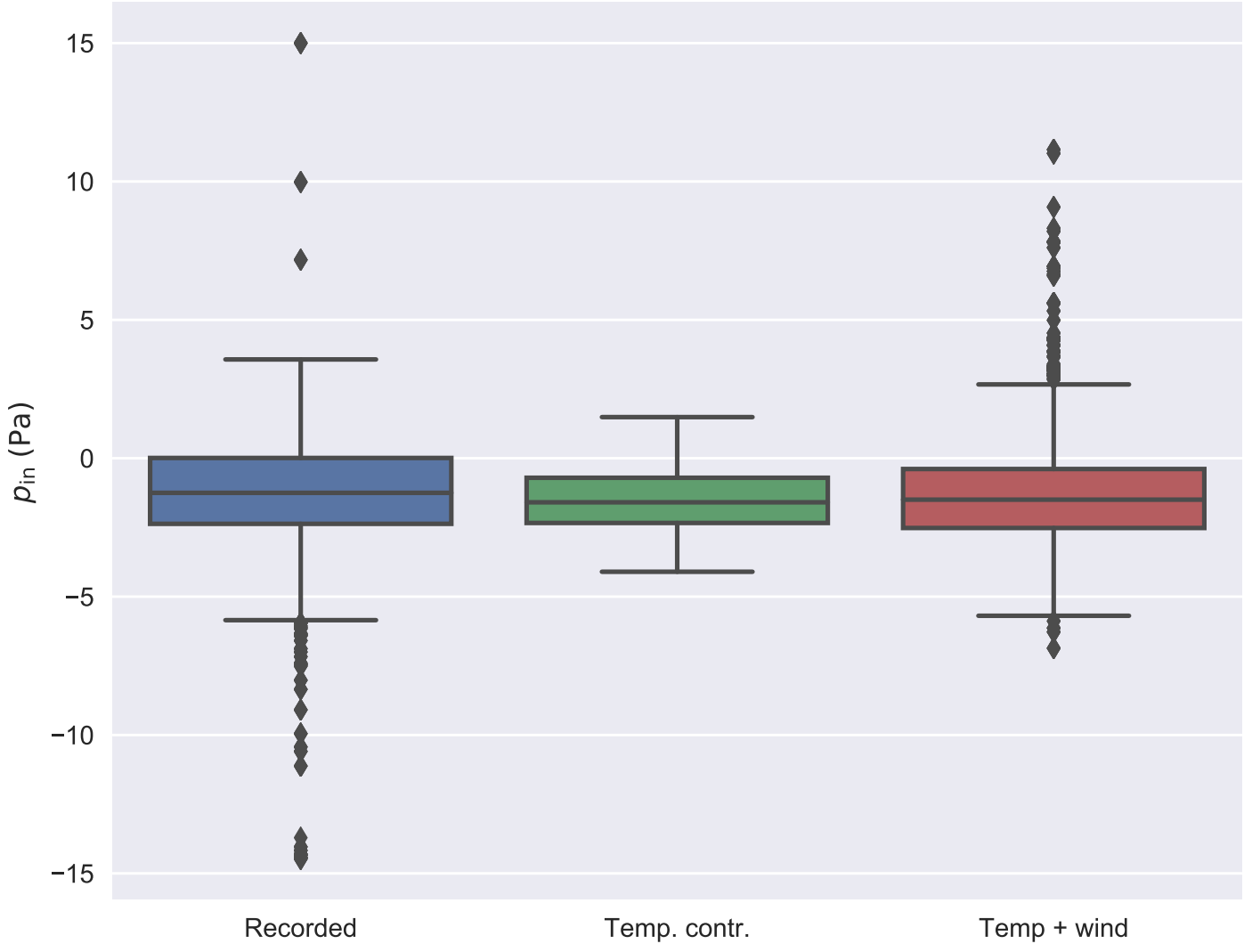
- Use some ITS to predict period when VI is most significant
- Building pressurization good for advection site - determine using weather?

Predicting Building Pressurization

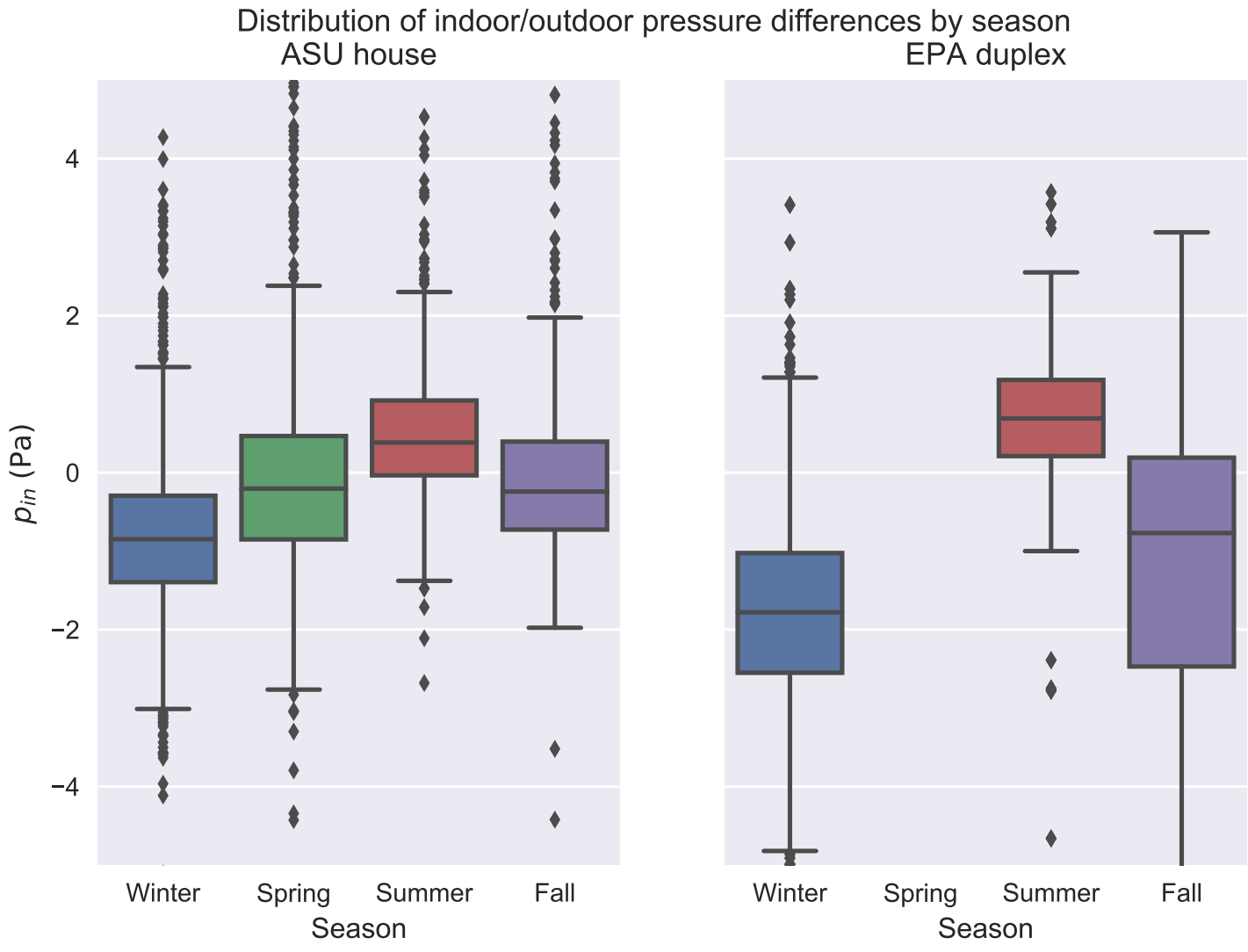


Predicting Building Pressurization

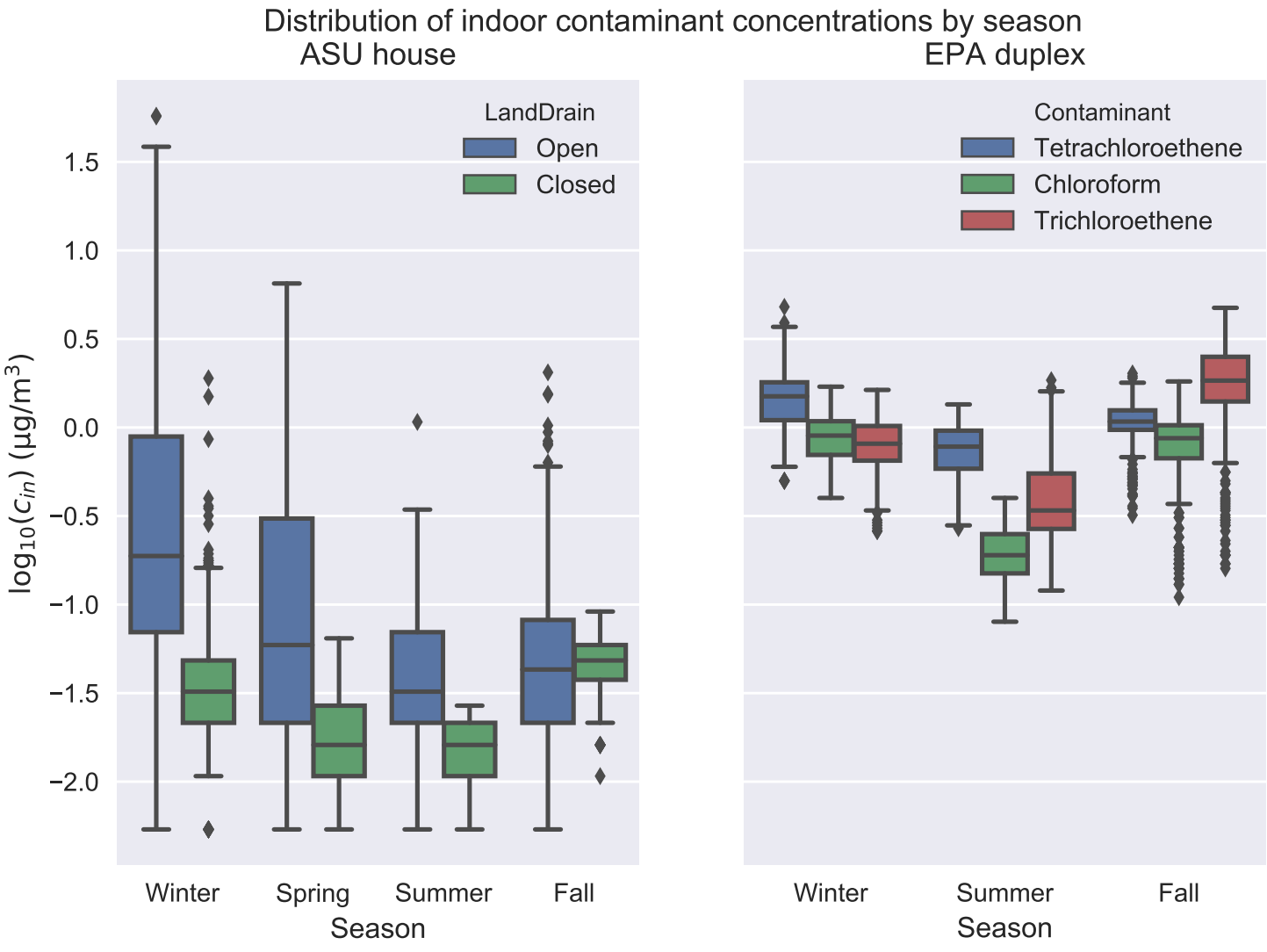
Predicted temperature and wind contribution to building pressurization vs. recorded data at the EPA duplex



Seasonal Pressure



Seasonal Indoor Contaminant Concentration



Key insights

- Building pressurization can quite easily be predicted using weather conditions
- For sites dominated by advective contaminant entry building pressurization can be an effective ITS