Scenario-Specific Attenuation Factors for Vapor Intrusion Screening

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Matthew A. Lahvis
Principal Consultant
Shell Oil Products US Inc.

Robert A. Ettinger
Senior Principal
Geosyntec Consultants

Rafat Abbasi
Senior Consultant
Geosyntec Consultants

Wayne Jones
Principal Data Scientist
Shell IT International Ltd.

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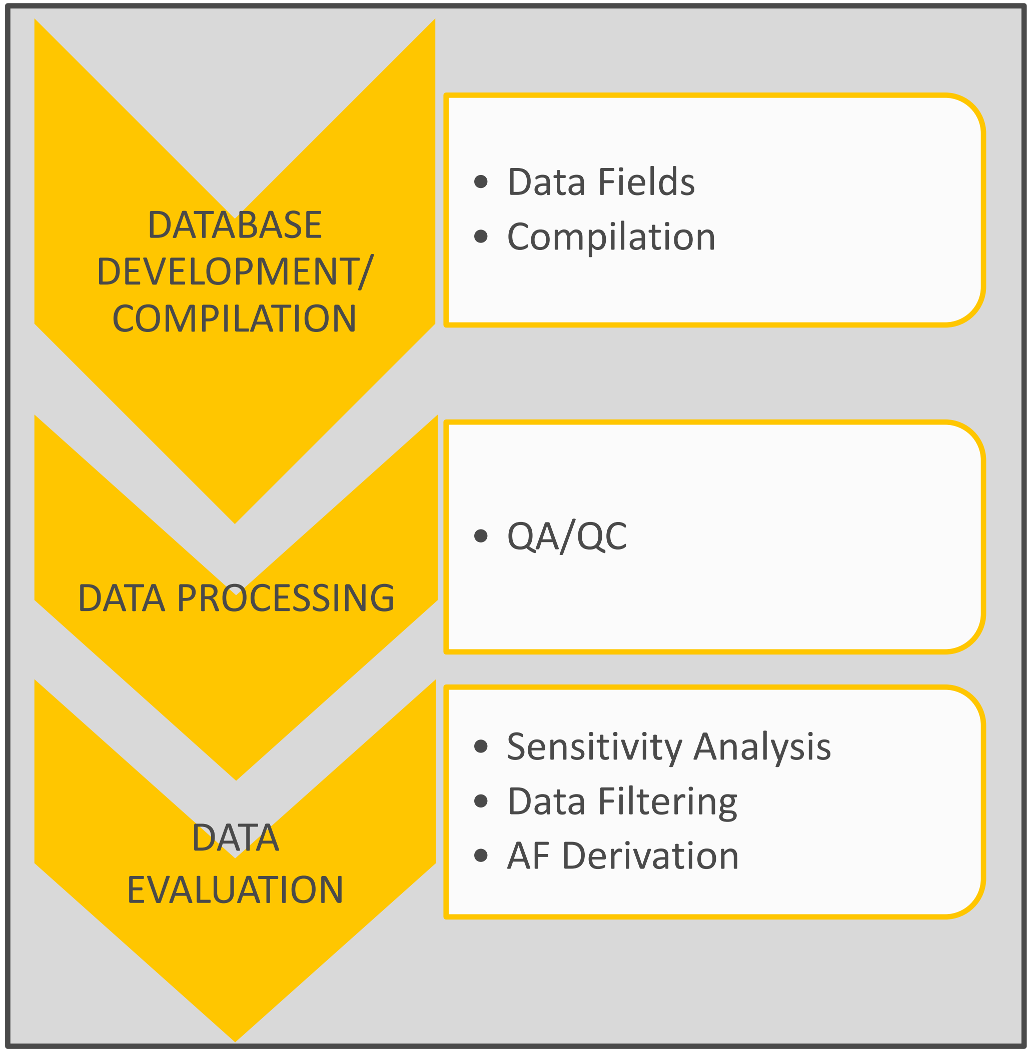
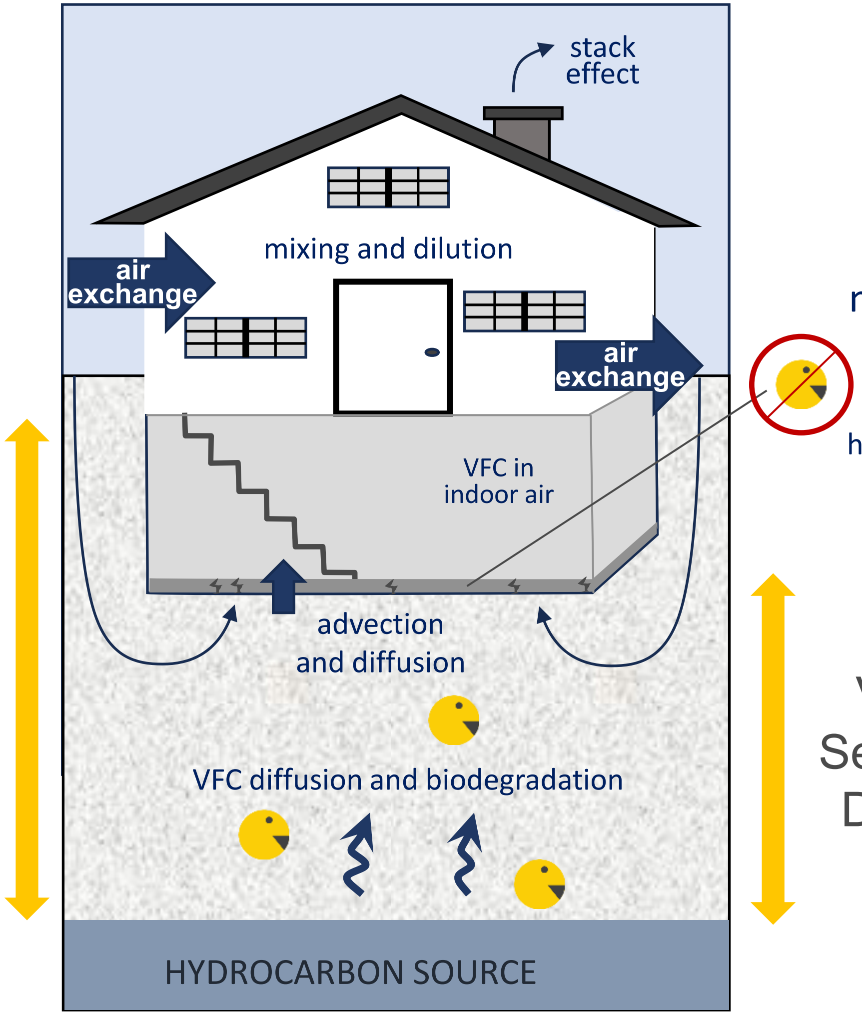
Outline

- Background
  - Motivation and context
  - Database
- Building-Specific AFs
- AF Sensitivity to Key Variables
- Recommended Scenario-Specific AFs
- Conclusions



Outline



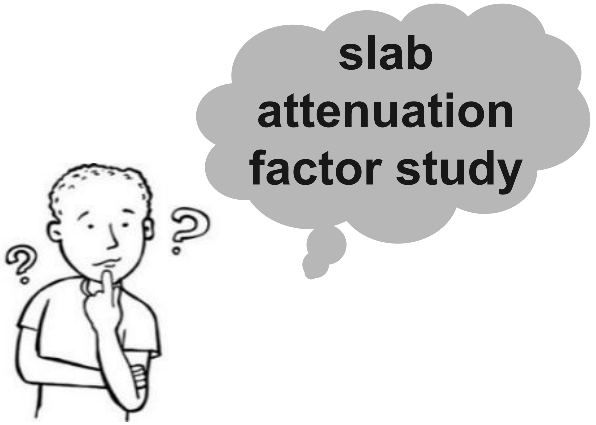
Vertical Screening Distance

no biodegradation within building foundation

(petroleum and chlorinated hydrocarbon transport across slab is similar)

Vertical Separation Distance

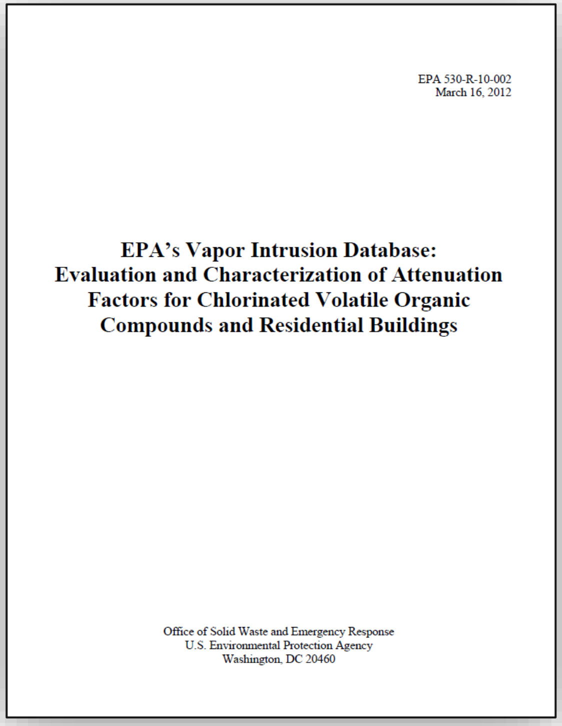
- insufficient source-building separation distance to screen out requires vapor sampling
- risk-based screening levels (RBSLs) for subslab soil gas and indoor can easily be exceeded



Motivation and Context

US EPA 2012 Study

- most regulatory agencies base VI RBSLs in shallow soil-gas on USEPA's default (generic) AF = 0.03 derived from 2012 USEPA empirical study
- concerns exist over data that were ultimately used to derive the AF:
  - only single-family residences, primarily with basement construction (16 % unfinished)
  - no non-residential buildings
  - no soil-gas data
  - nearly 80 percent (342/431 indoor air (C_{IA})/subsurface vapor (C_{SSG}) data pairs) used came from 3 sites subject to relatively cold winter-time temperatures
  - no rigorous evaluation of AF sensitivity to key variables
- the AF is applied to all common building and sampling types and geographies


EPA 530-R-10-002
March 16, 2012

EPA's Vapor Intrusion Database:
Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings

Office of Solid Waste and Emergency Response
U.S. Environmental Protection Agency
Washington, DC 20460

RBSLs = risk-based screening levels; AF = attenuation factor; IA = indoor air; C_{IA} = indoor air concentration; C_{SSG} = subsurface vapor (subslab or soil-gas) concentration

Motivation and Context

Studies Post USEPA (2012)

- several “big data” empirical studies conducted since 2012
- significant differences in AFs compared to USEPA (2012)
- studies generally limited in geographical extent or subject to ambiguities from data pairing at buildings with multiple data pairs

Study	95th %ile Attenuation Factor
USEPA (2012)	0.03
Ettinger et al. (2018)	0.003
Nawikas (2019)	0.006 – 0.01
Hallberg et al. (2021)/Lutes et al. (2021)/ Levy et al., (2023)/DoD (2023a, b)	0.001
DTSC (2021)/Abbasi et al. (2022)	0.0009 – 0.005
Lahvis and Ettinger (2021)	0.0008 – 0.002
Eklund et al. (2022)	0.0003

Groundwater Monitoring&Remediation

Improving Risk-Based Screening at Vapor Intrusion Sites in California

by Matthew A. Lahvis and Robert A. Ettinger

Journal of the Air & Waste Management Association

An alternative generic subslab soil gas-to-indoor air attenuation factor for application in commercial, industrial, and other nonresidential settings

Keri E. Hallberg, Laurent C. Levy, Rodrigo Gonzalez-Abraham, Christopher C. Lutes, Loren G. Lund & Donna Caldwell

SUB-SLAB TO INDOOR AIR ATTENUATION FACTORS DETERMINED FROM RADON DATA

SUZIE NAWIKAS

H&P INC, CARLSBAD, CA

Naval Facilities Engineering and Expeditionary Warfare Center and Naval Facilities Engineering Systems Command

Final

Reanalysis of Department of Defense ... Commercial and Industrial Buildings

November 2021

Christopher C. Lutes, CH2M
Laurent C. Levy, Ph.D., P.E., CH2M
Keri E. Hallberg, P.E., CH2M
Rodrigo Gonzalez-Abraham, Ph.D., CH2M
Donna Caldwell, CH2M
Loren G. Lund, Ph.D., CH2M
Teresie R. Walker, NAVFAC Atlantic
Travis B. Lewis, P.E., NAVFAC EXWC

... Intrusion Attenuation Factor for Industrial Buildings

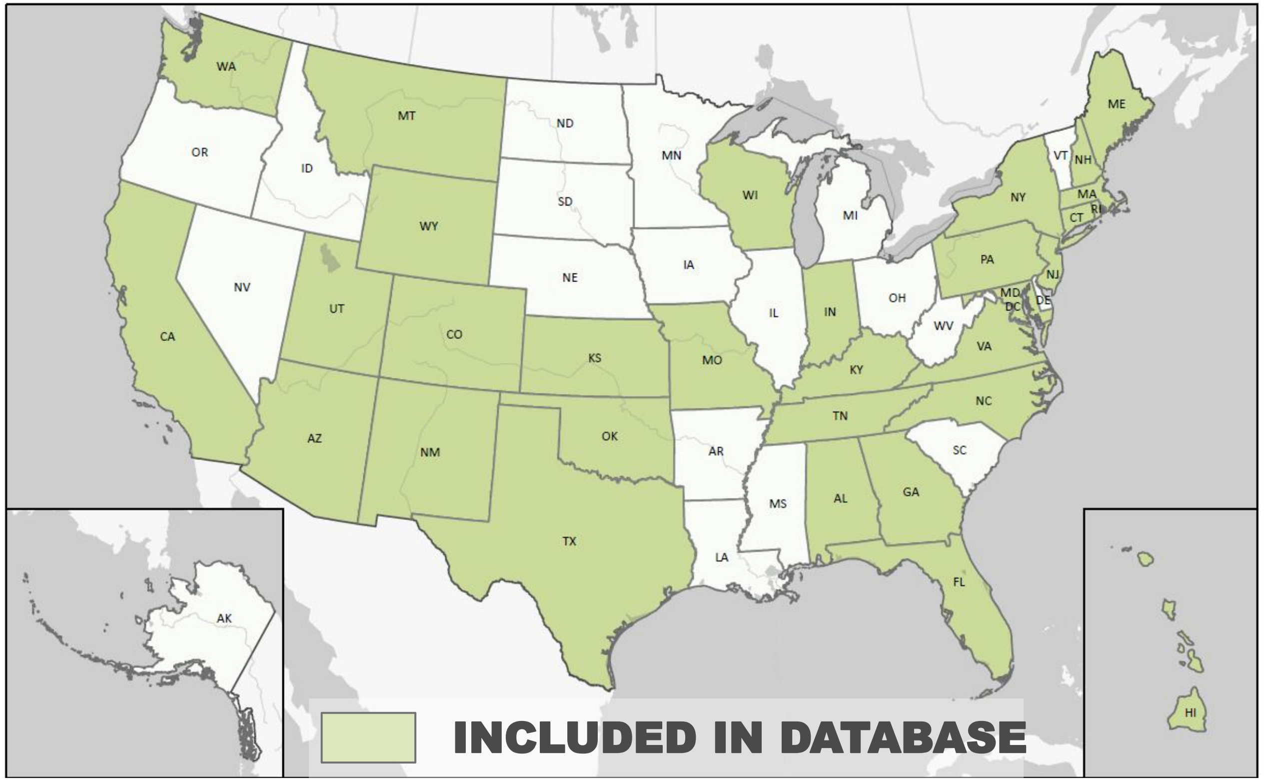
by Bart Eklund, Carly Ricondo, Helen Artz-Patton, Jessica Milose and Chi-Wah Wong

Groundwater Monitoring&Remediation

Empirically Derived California Vapor Intrusion Attenuation Factors

by Rafat Abbasi, William Bosan and Dan Gallagher

National AF Study
General Database Statistics



- over 26,000 vapor data pairs
- broad geographical coverage (26 states)
- database includes data on 37 chemicals from:
  - large empirical studies
  - USEPA (2012)
  - new data (11 consultancies, NCDEQ)
- data on multiple variables

Population	All Chemicals	TCE	PCE	Radon
Sites	330	143	139	157
Buildings	1,467	857	831	192
Data Pairs	26,051	8,144	6,668	277

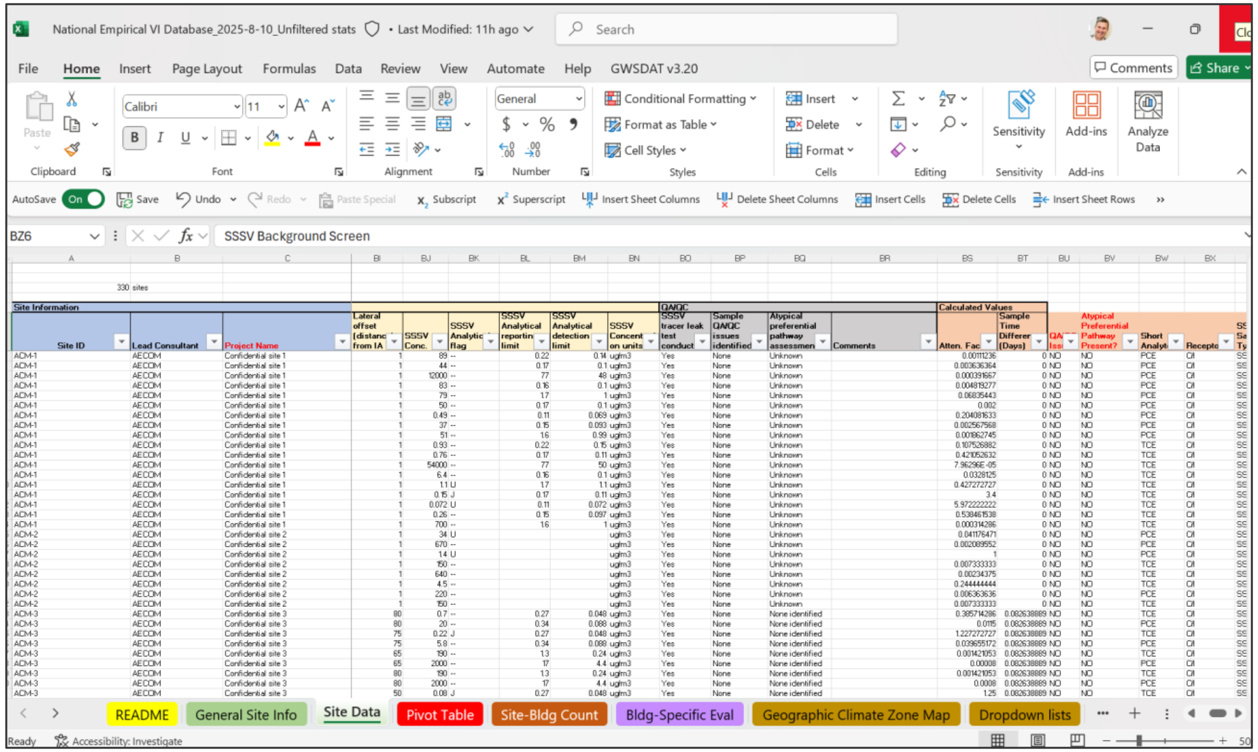
KEY POINT

- **AF database represents the most comprehensive and representative compilation of AFs to date**

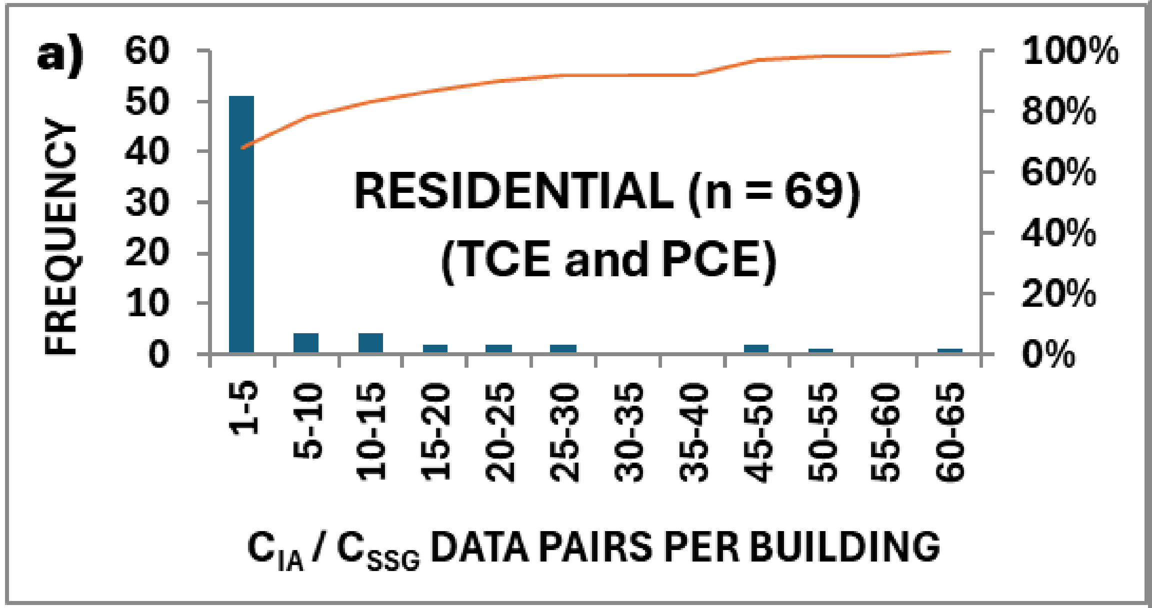
National AF Database Provides Ability to Assess AF Sensitivity to Key Variables

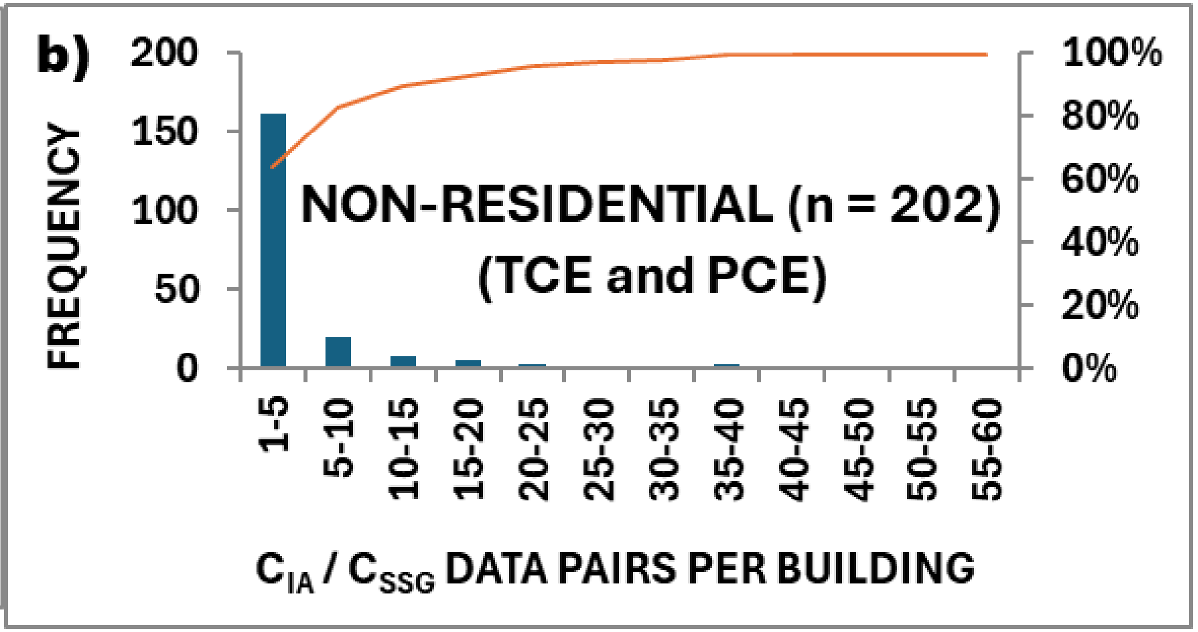
Opportunity to Define Scenario-Specific AFs Depending on Site Conditions

- land use (e.g., residential, commercial, industrial, school)
- climate (geographic) zone
- building age (pre- and post 1950)
- building size
- HVAC operation (on/off within multiple and individual buildings)
- predominant vadose zone soil type
- time between indoor air and subsurface vapor sampling (t)
- distance between subsurface and indoor air vapor sampling (x)
- soil-gas sample depth (z)
- relative source location (shallow soil, deep soil/groundwater)



Numerous Buildings With Multiple C_{IA} and C_{SSG} (Subslab and Soil Gas) Data Pairs (e.g., TCE data)



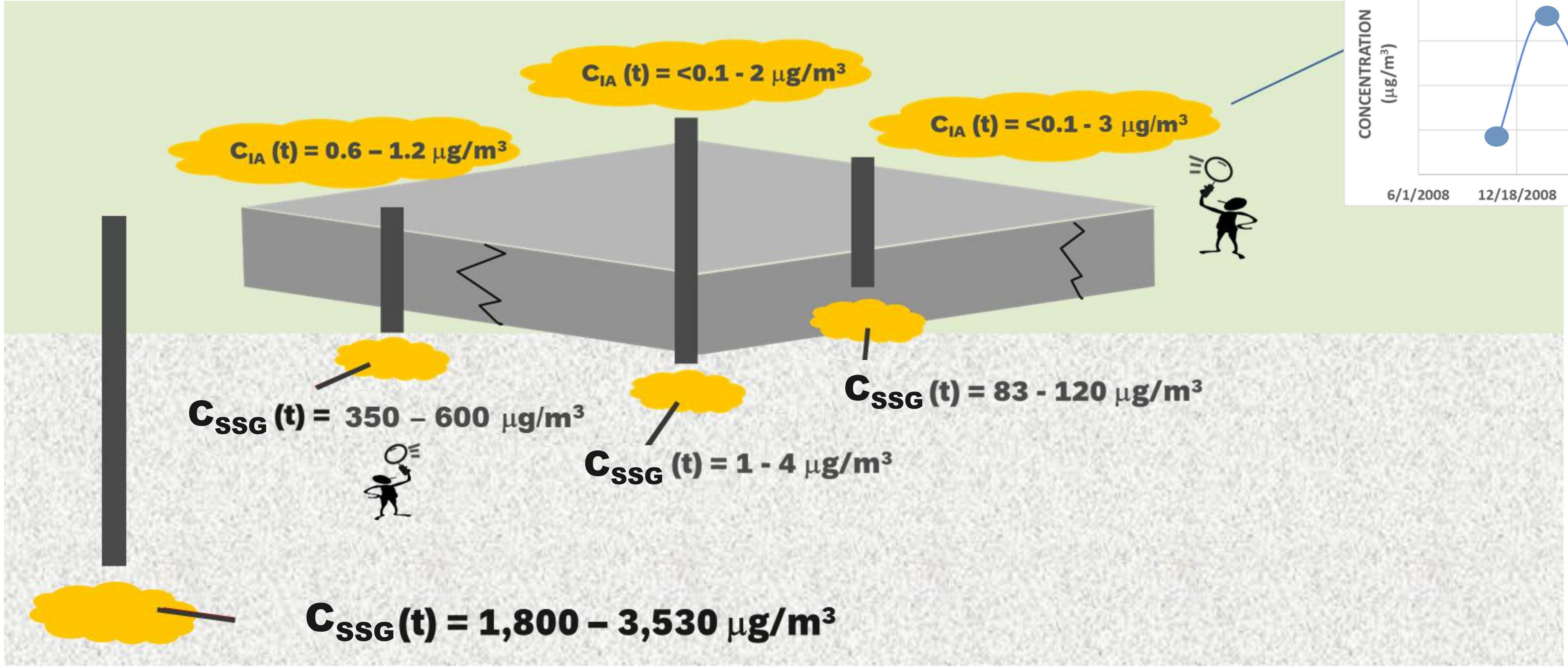


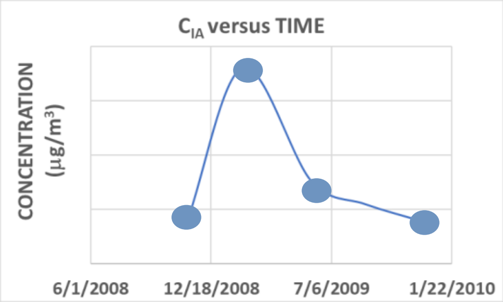
KEY POINT

- multiple C_{IA} and C_{SSG} data pairs from certain buildings has the potential to:
  - introduce ambiguity in AF determinations
  - bias final AF determinations

AFs Ambiguity at Buildings with Multiple Indoor air and Subsurface Data Pairs Can Be Significant

Fictional Data





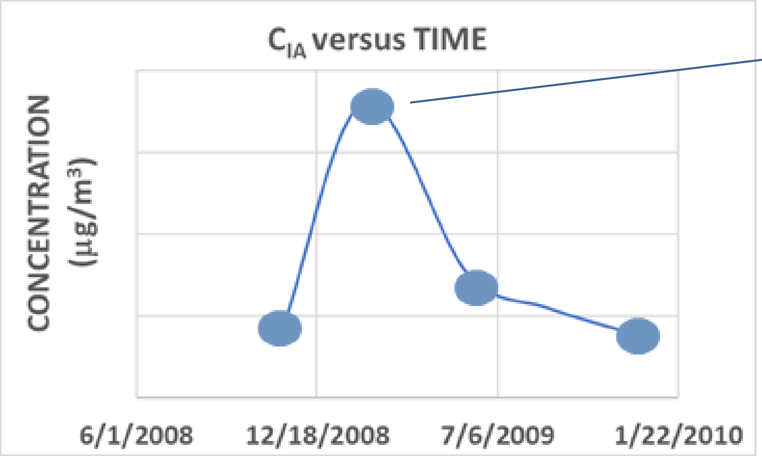
KEY POINT

- AFs for specific buildings can vary by over an order of magnitude depending on C_{IA} (concentration in indoor air) and C_{SSG} (concentration in subsurface vapor data pairing

Development of Building-Specific AFs

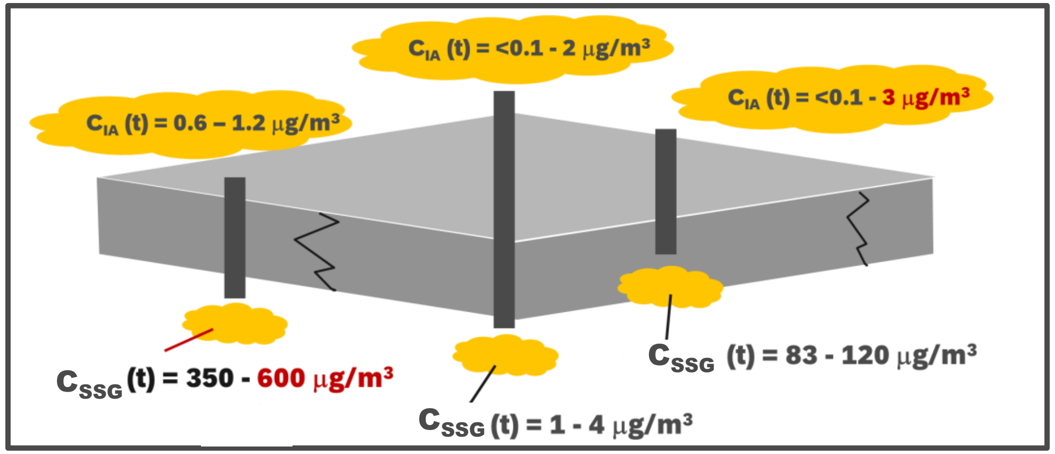
C_{IA} and C_{SSG} Data Pairing

INDOOR AIR (C_{IA})



maximum C_{IA} over time and space (conservative)

SUBSURFACE VAPOR (C_{SSG})



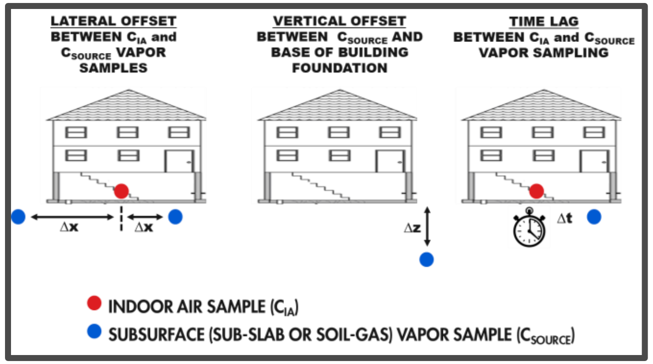
1) maximum C_{SSG} (full measure of slab attenuation) over time and space
2) average C_{SSG} (uncertain points of vapor entry)

KEY POINT

- AFs for site screening derived using relatively conservative assumptions of max C_{IA} and average C_{SSG}
- AF sensitivity to key variables based generally on maximum C_{IA} and maximum C_{SSG}

Data Filtering

- akin to USEPA (2012)
  - QA/QC review (exclude lesser quality data – e.g., lack of leak testing, lack of leak testing, foundations with preferential pathways, excessive slab degradation)
  - indoor air < outdoor air (where reported)
  - low C_{IA} and C_{SSG} more susceptible to bias from background (non-VI) sources
- additional baseline filters intended to improve data quality (underpinned later by sensitivity analyses)
  - lateral separation distance between C_{IA} and C_{SSG} (Δx <= 110 ft)
  - time between C_{IA} and C_{SSG} sampling (Δt <= 92 days)
  - depth below land surface for near-slab soil gas samples (Δz <= 15 ft)



KEY POINT

- **filtered NAF database (96 sites, 271 buildings, 1,474 data pairs, 15 states) is over 4x larger than USEPA (2012) and more representative (60% TCE, 40% PCE)**
- **almost entirely TCE (60%) and PCE (40%); and ~70% from California**

ANOVA - Key Variable Significance

Variable (Degrees of Freedom)	*F*-Value	*P*-Value	Significance Code*
Sample Type (2)	58	<2.2E-16	+++
Building Type (5)	28	<2.2E-16	+++
US Climate Zone (2)	29	3.5E-13	+++
Building Construction Date (2)	24	5.6E-11	+++
Foundation Type (3)	9.1	5.0E-06	+++
Time (Δt) Between C_{IA} and C_{SSG} Sampling (4)	4.7	8.2E-04	+++
Distance (Δx) Between C_{IA} and C_{SSG} Sampling (3)	5.1	0.0016	++
C_{SSG} Sample Depth (Δz) (4)	4.0	0.0072	++
C_{SSG} Source Assumption (1)	4.9	0.027	+
Relative VFC Source Depth (2)	2.3	0.10	
HVAC Operation (2)	1.8	0.17	
Chemical (2)	0.73	0.48	
Predominant Soil Type (2)	0.16	0.85	

* *P*-values < 0.001 = "+++"; < 0.01 = "++"; < 0.05 = "+";≤1 = " "

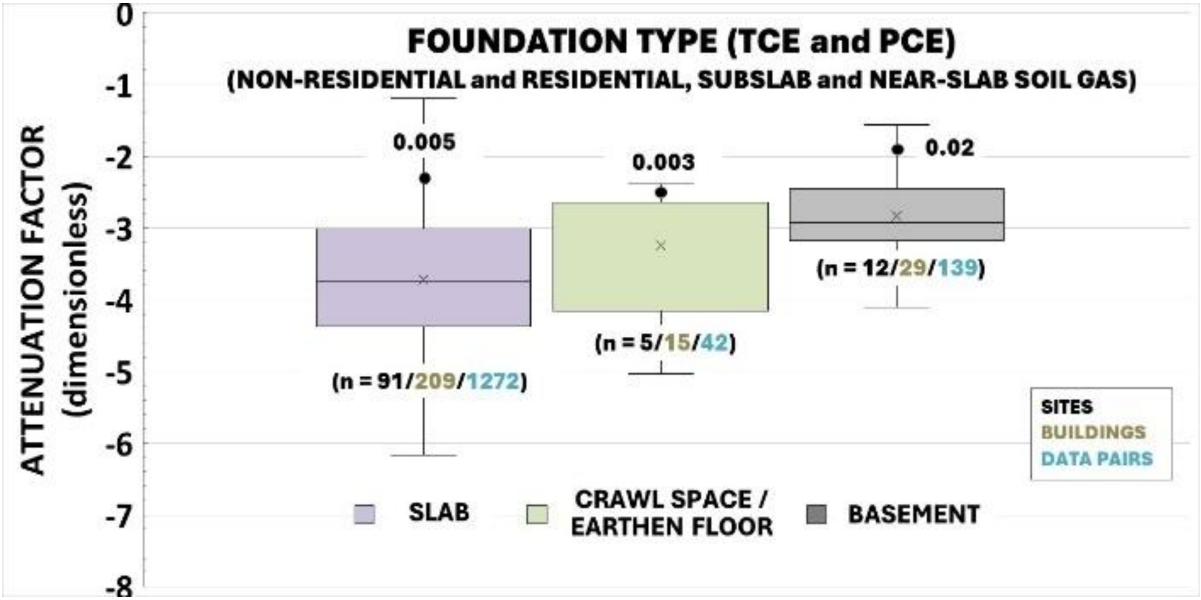
DIFFERENCES IN AFs ARE MORE LIKELY EXPLAINED BY RANDOM CHANCE

KEY POINT

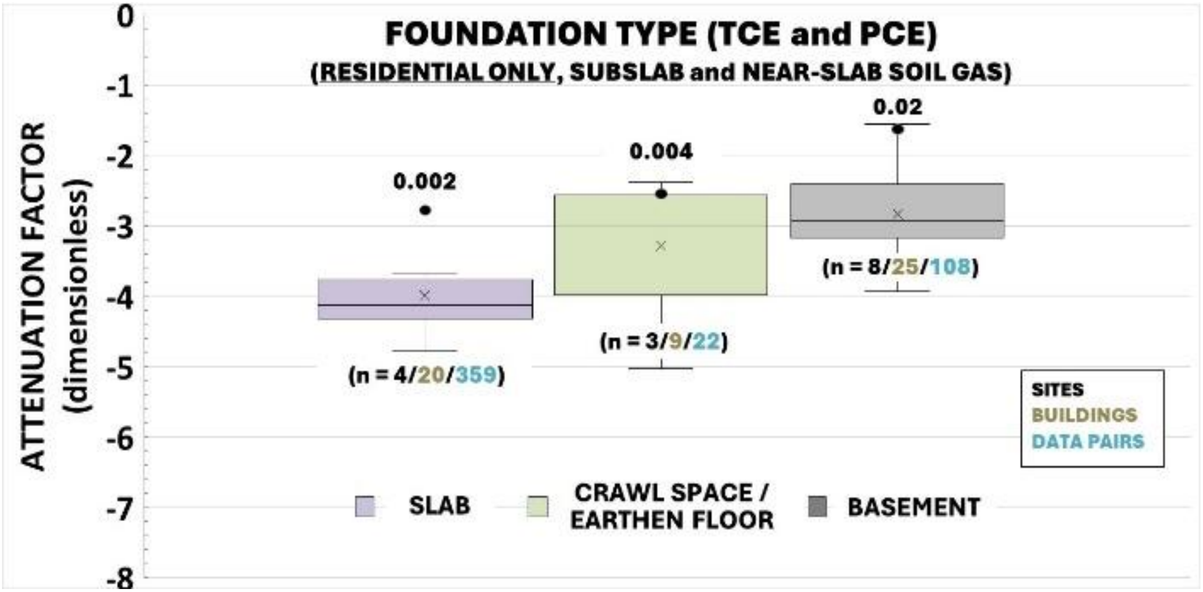
variable significance and impact helps 1) underpin scenarios where different AFs are warranted, 2) sites that are more prone to VI, and 3) inform best practice for data collection

Foundation Type

TCE and PCE, Subslab and Soil Gas



RESIDENTIAL ONLY



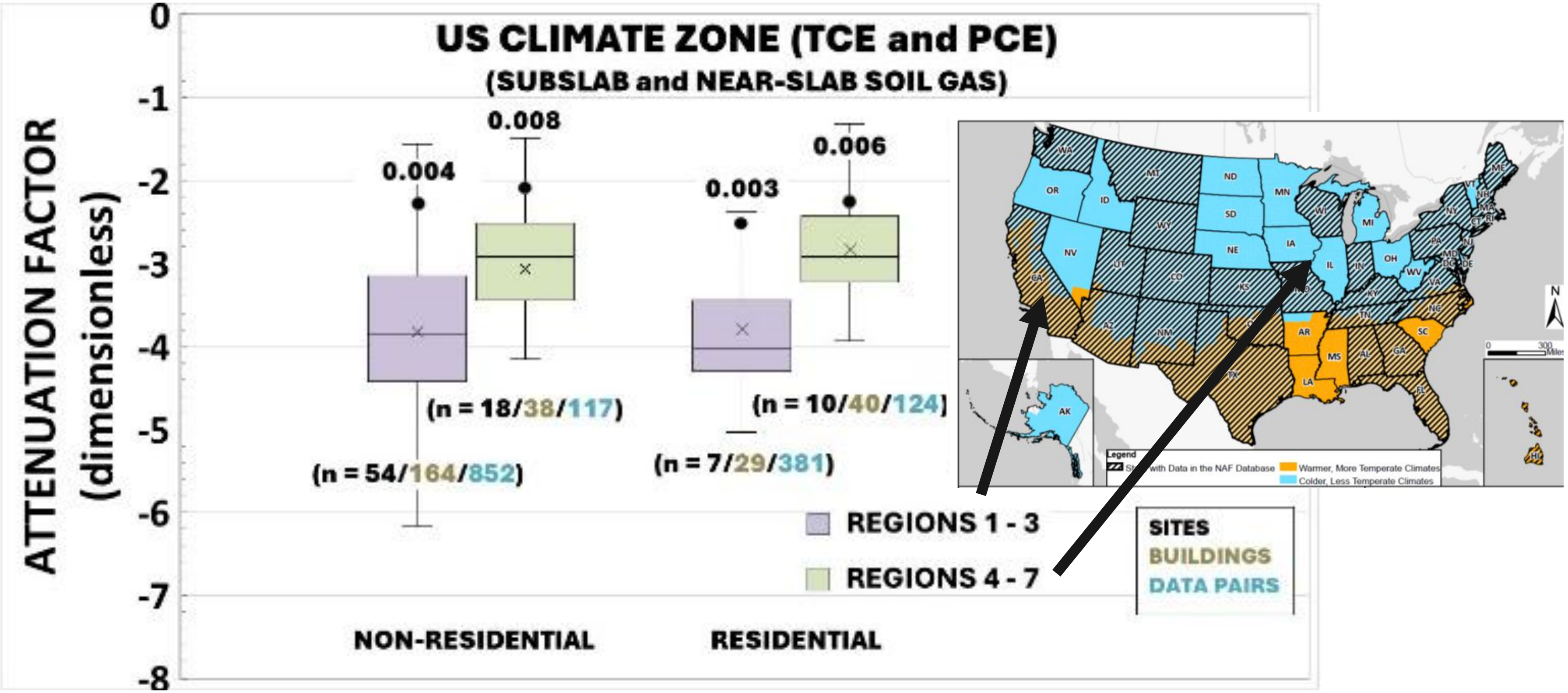
* Crawl space AFs based on soil gas (not crawl space air)

KEY POINT

- median AFs are nearly 10x higher for buildings with basement versus slab-on-grade foundations, potentially attributed to greater VI surface area
- similar differences in AFs are observed for residential-only buildings
- 95th %ile AF for residential-only buildings with basements is consistent with USEPA (2012)

US Climate Zone

TCE and PCE, Subslab and Soil Gas



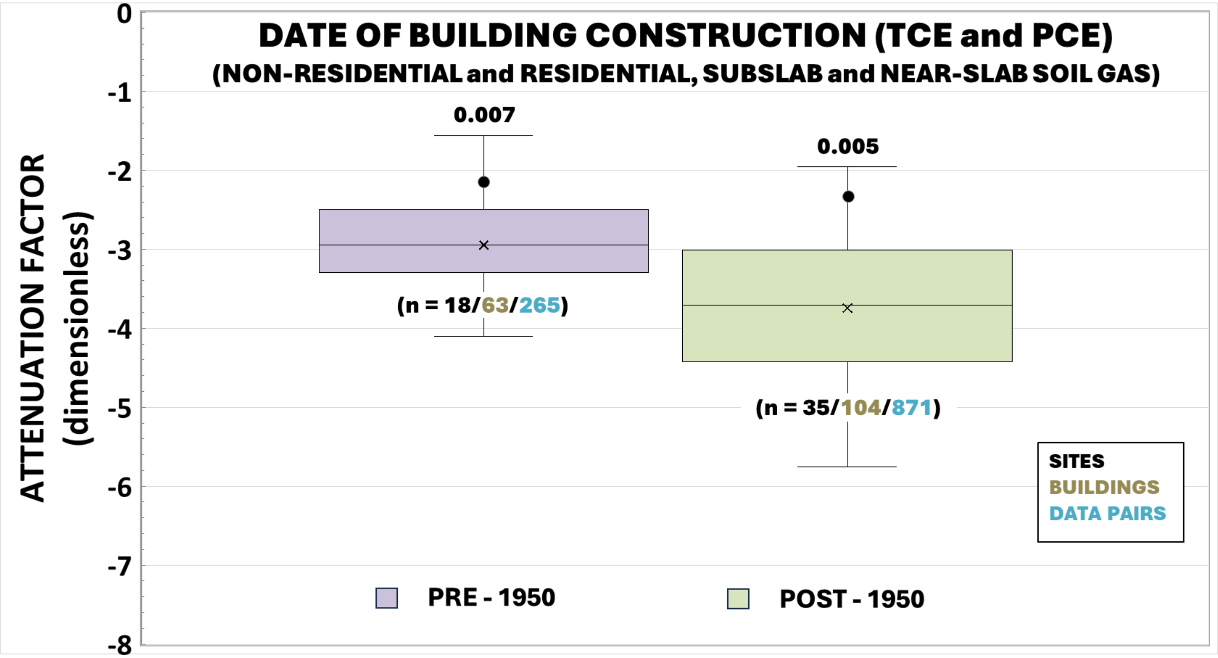
KEY POINT

- median AFs for non-residential and residential buildings are roughly 10x higher in geographic regions of the US more prone to colder winter seasons and less temperate climates
- the effect is largely independent of building type and foundation type, given a) median AFs for non-residential and residential buildings vary by < 1.5x and b) more than 50% of residential buildings had basement foundations and foundation type was a significant variable

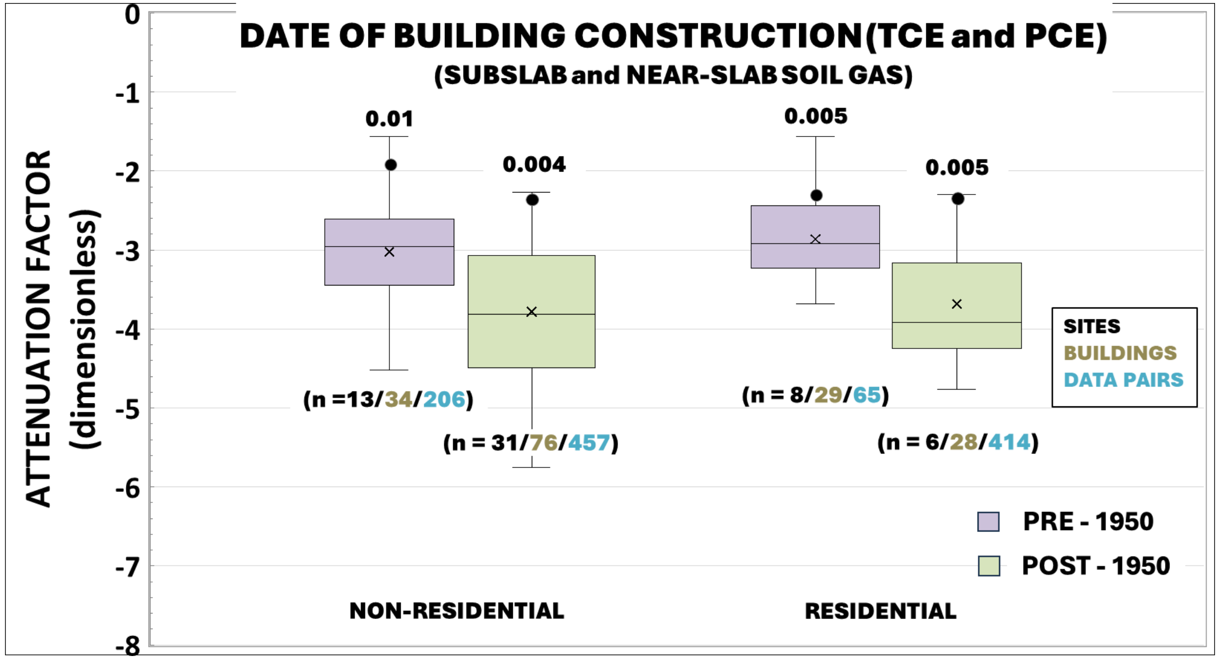
Date of Building Construction

TCE and PCE, Subslab and Soil Gas

PRE-1950 vs. POST-1950



NON-RESIDENTIAL vs. RESIDENTIAL

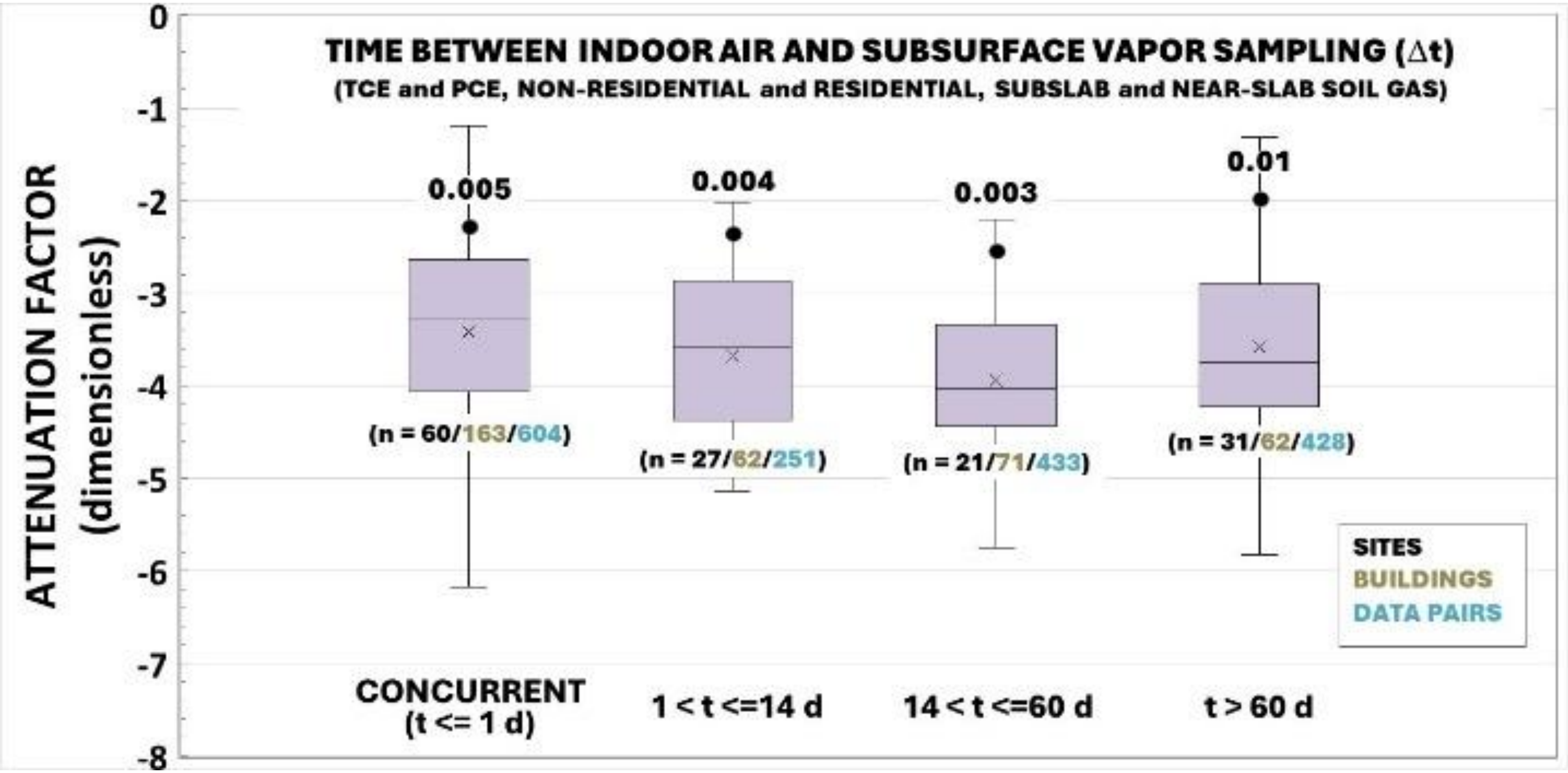


KEY POINT

- median AFs are 8 – 10x higher for buildings built prior to 1950 than after 1950
- similar relations are observed for both non-residential and residential buildings implying the effect is related to building construction and loss of slab integrity

Time Between Indoor Air and Subsurface Samples (Δt)

TCE and PCE, Subslab and Soil Gas, Non-Residential and Residential

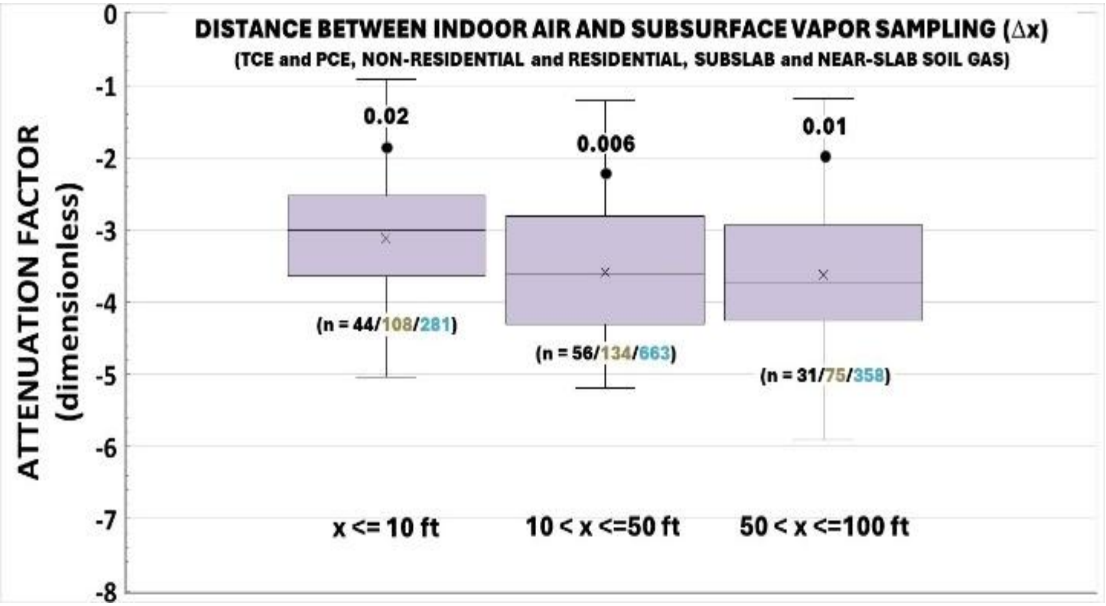


KEY POINT

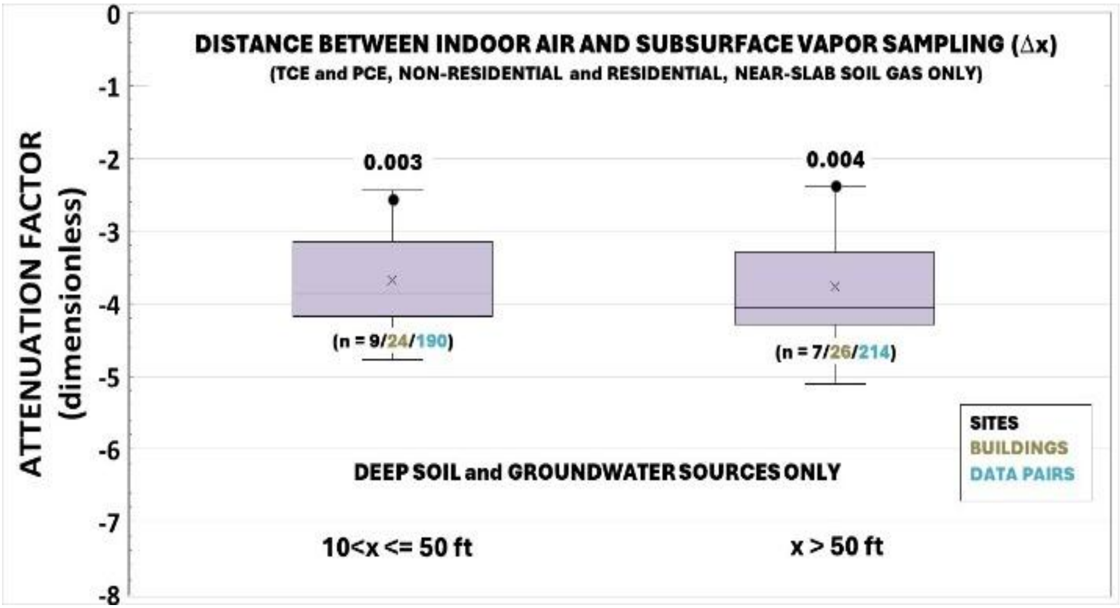
- median AFs do not vary significantly with increasing time (t) between C_{IA} and C_{SSG} sampling, which implies that C_{IA} concentrations remain relatively constant over time in the absence of any source remediation or changes to HVAC

Distance Between Indoor Air and Subsurface (Δx)

TCE and PCE, Subslab and Soil Gas, Non-Residential and Residential



DEEP SOIL/GROUNDWATER SOURCES (SOIL-GAS ONLY)

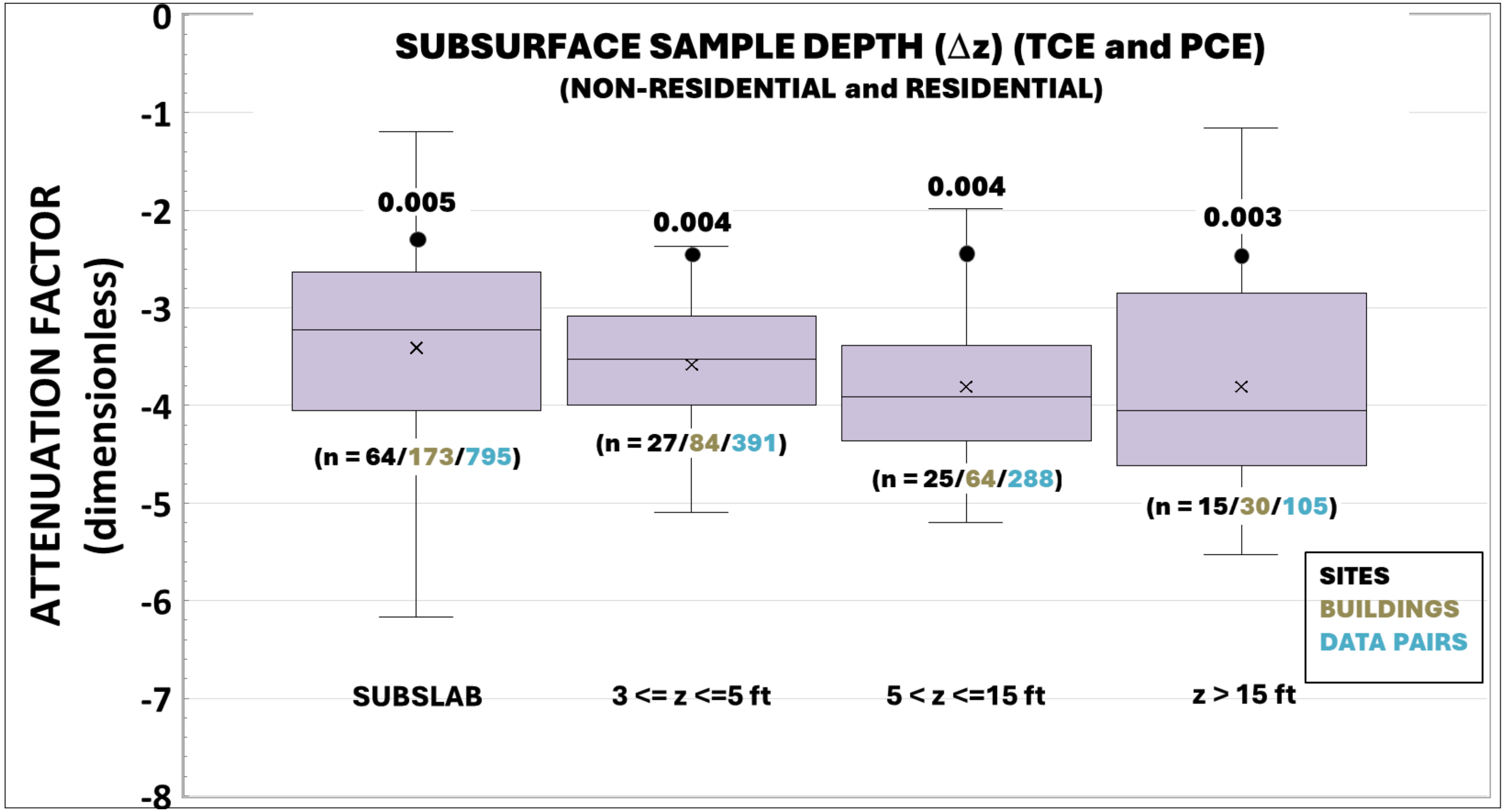


KEY POINT

- median AFs do not vary significantly with increasing distance (Δx) between C_{IA} and C_{SSG} sample locations after 10 ft separation distance
- median AFs do not vary significantly for deep soil/groundwater sources and soil-gas samples, implying that C_{IA} and C_{SSG} samples do not have to be co-located to be representative for VI screening

Subsurface Sample Depth (Δz)

TCE and PCE, Subslab and Soil Gas, Non-Residential and Residential



KEY POINT

- median AFs are up to 8x higher for subslab than near-slab soil-gas; implies additional attenuation caused by vapor transport through the vadose zone

95th Percentiles Based on Average C_{SSG}

Building and Sample Type		US Climate Zones 1 -3 or Post-1950 Building Construction			US Climate Zones 4 - 7 or Pre-1950 Building Construction		
		95th Percentile	Median	Sites/ Buildings/ Data Pairs	95th Percentile	Median	Sites/ Buildings/ Data Pairs
Basement		0.008	0.004	2/8/56	0.02	0.003	9/29/139
Residential	**Subslab Soil Gas**	0.003	0.002	3/3/5	0.005	0.001	3/15/16
	Near-Slab Soil Gas	0.003	0.0001	5/27/377	n.d.	n.d.	n.d.
Non-Residential	**Subslab Soil Gas**	0.006	0.0003	27/48/319	0.01	0.002	17/32/77
	Near-Slab Soil Gas	0.004	0.0001	29/66/293	0.006	0.001	7/11/78

n.d. = no data

KEY POINT

- **95th %ile AFs vary by an order of magnitude and are up to 10x less than USEPA AF = 0.03, depending on screening scenario**
- **95th %ile AFs for residential buildings are less than those for non-residential buildings, consistent with prior studies**
- **AFs with insufficient data could be adjusted based on AF trends across various categories**
- **most sites will exhibit AFs similar to median values**

Conclusions

- study is most comprehensive and representative evaluation of building-specific AFs to date
- study provides an improved understanding of key variables that affect AFs:
  - basis for scenario-specific AFs
  - less significant variables are time and distance between indoor air and subsurface vapor sampling
- resultant AFs:
  - are over an order of magnitude different and up to10x lower than USEPA’s (2015) recommended default (0.03) depending on the screening scenario (i.e., not a one-size fits all AF)
  - results help explain differences between previous studies [US EPA (2012) and post-2012 studies]
  - (NOT SHOWN) broadly supported by multiple methods, radon data
- future studies should target scenarios where data are limited
- study provides regulators and practitioners with scientifically defensible AFs for RBSL development at sites not well represented by USEPA (2012) database

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Gina Plantz – Haley and Aldrich

Suzi Rosen – Partners Environmental Solutions

Robert Traylor – Partners Environmental Solutions

Laura Trozzolo – TRC Companies

Nadine Weinberg – ERM

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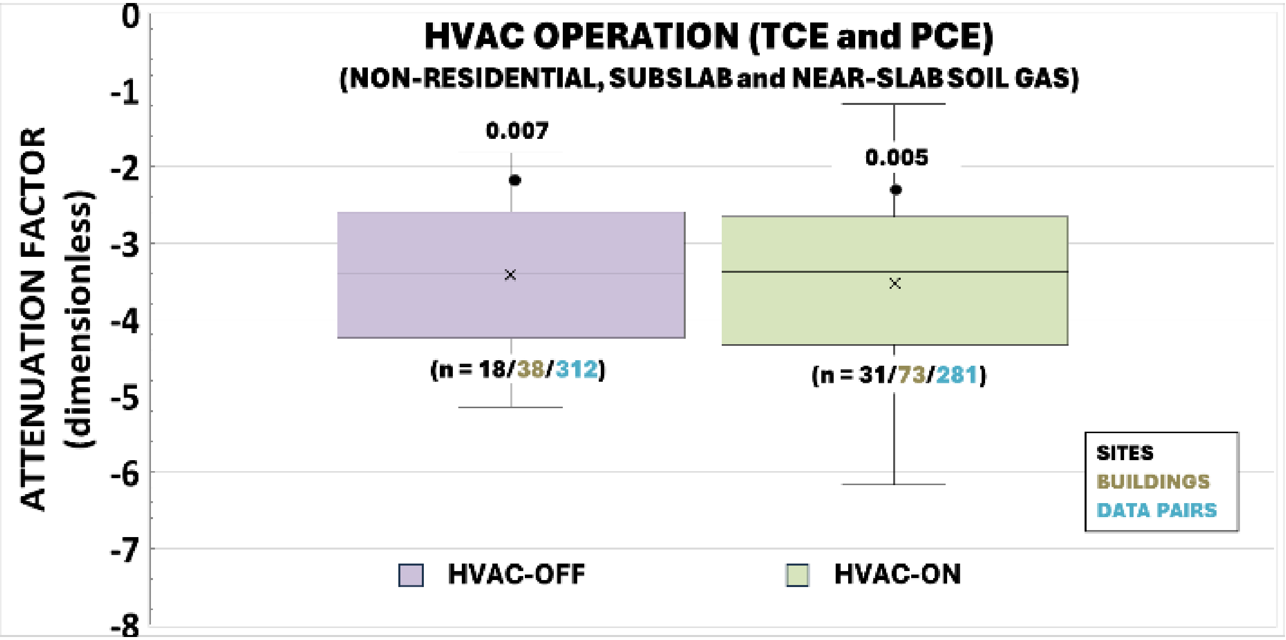
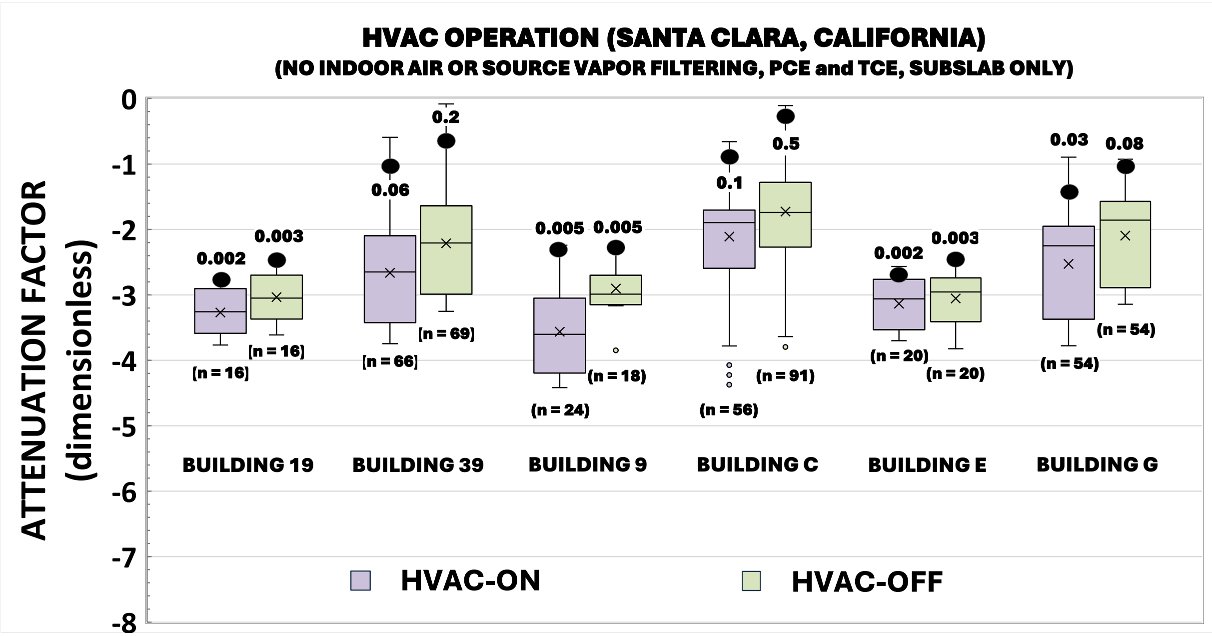
HVAC Operation (All Sites vs. Individual Site)

TCE and PCE, Subslab and Near-Slab Soil Gas, Non-Residential Only

HVAC OPERATION (MULTIPLE SITES/BUILDINGS)



HVAC OPERATION WITHIN SPECIFIC BUILDINGS (INDIVIDUAL SITE)

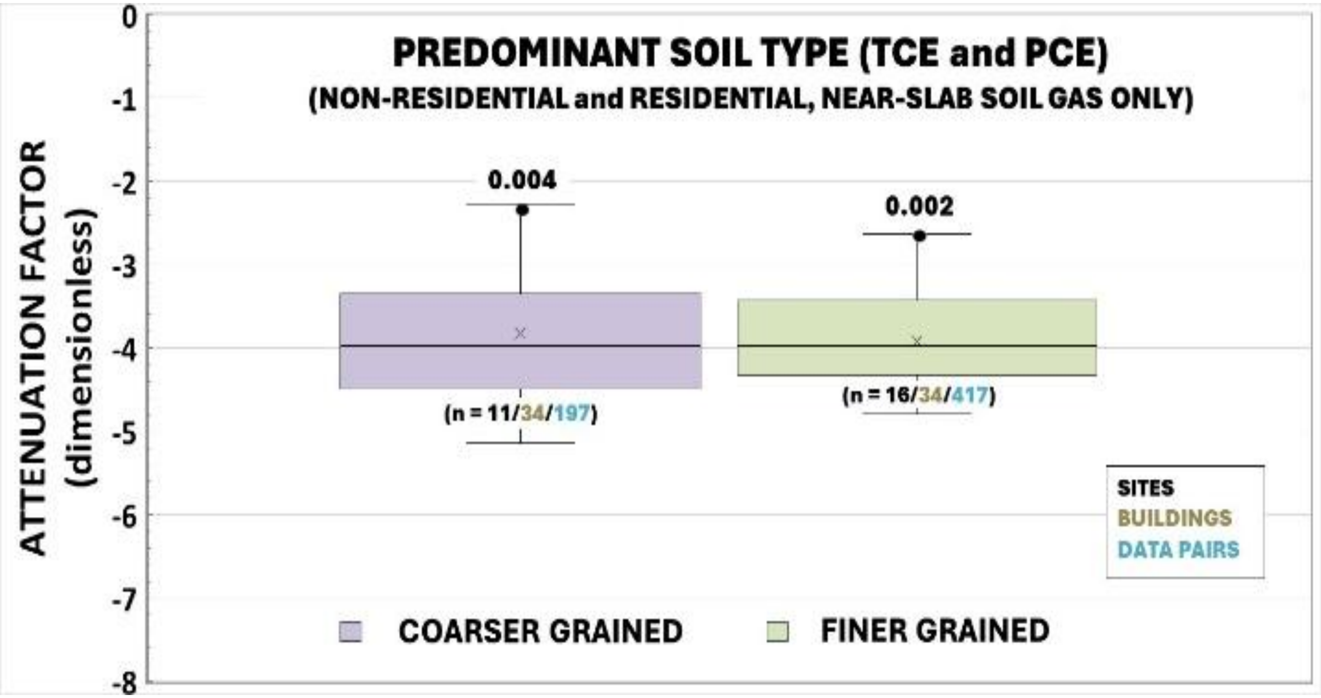


KEY POINT

- HVAC operation appears to have a negligible effect on the AF when evaluated across multiple sites/buildings, yet median AFs can vary up to 4x in individual buildings

Predominant Soil Type

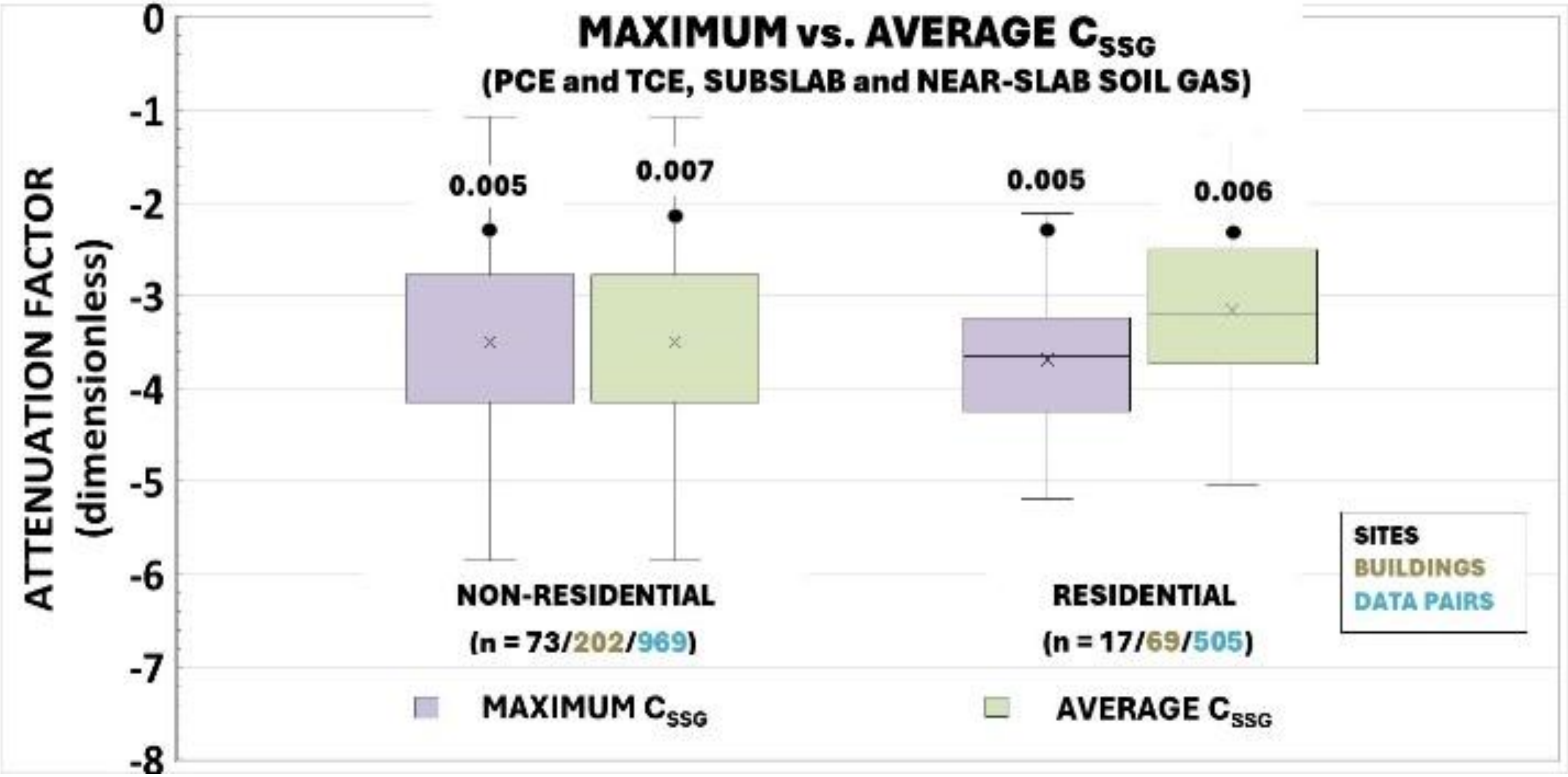
TCE and PCE, Non-Residential and Residential, Near-Slab Soil Gas



KEY POINT

- median AFs are equivalent for vadose zones consisting of predominantly coarse- or fine-grained soil based on soil gas data from sites with deep soil / groundwater sources
- lack of AF sensitivity to soil-type likely results from a high number of sites with mixed soil types
- the lesser variance in AFs observed at sites with finer-grained vadose zone systems may indicate less spatiotemporal variability in C_{SSG} concentrations

C_{SSG} Strength Assumption - Maximum vs. Average
(TCE and PCE, Subslab and Near-Slab Soil Gas)

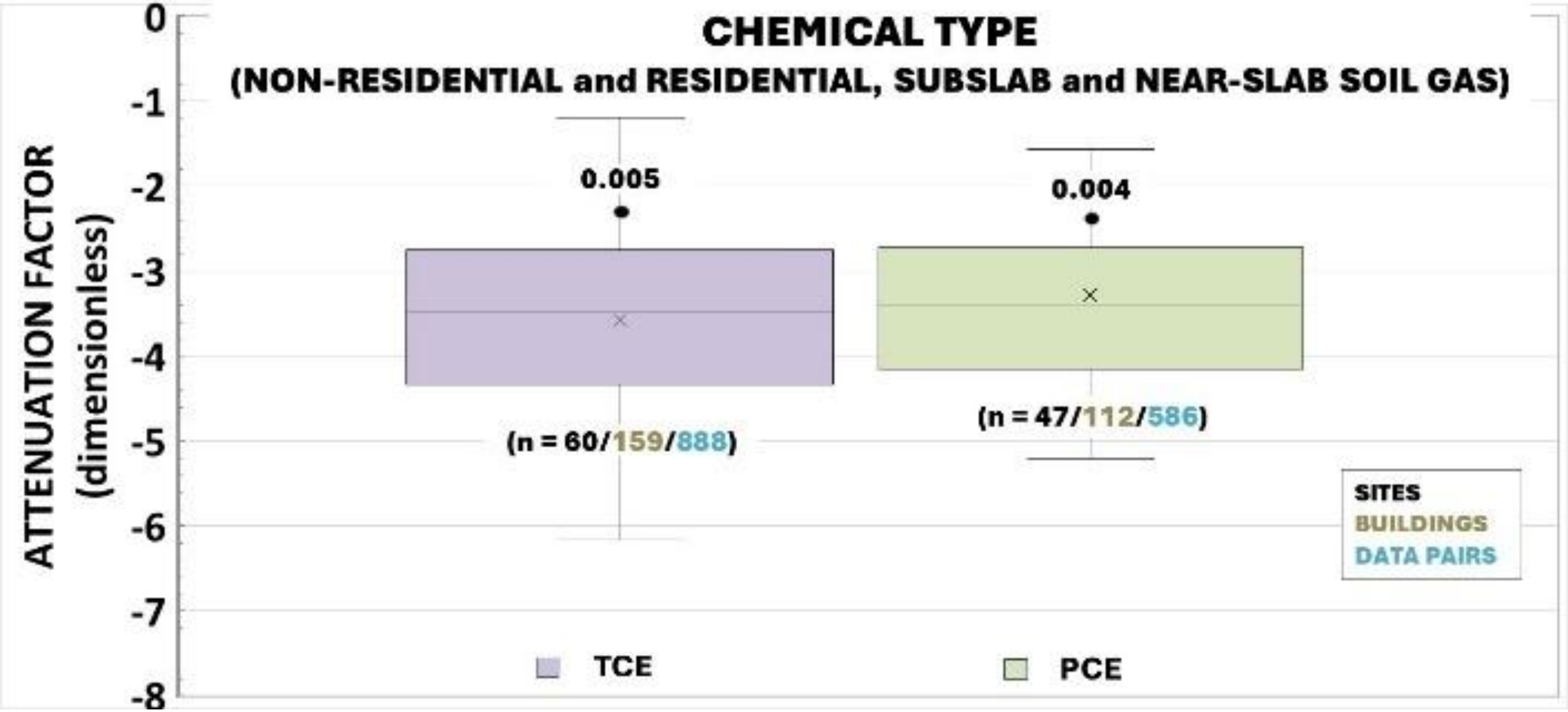


KEY POINT

- median AFs are 1.5x higher for non-residential buildings and essentially equivalent for residential buildings which is consistent with a) limited differences in maximum versus average C_{SSG} concentrations for relatively small C_{SSG} sample populations and b) lesser variability in C_{SSG} concentrations at residential versus non-residential buildings

Chemical Type

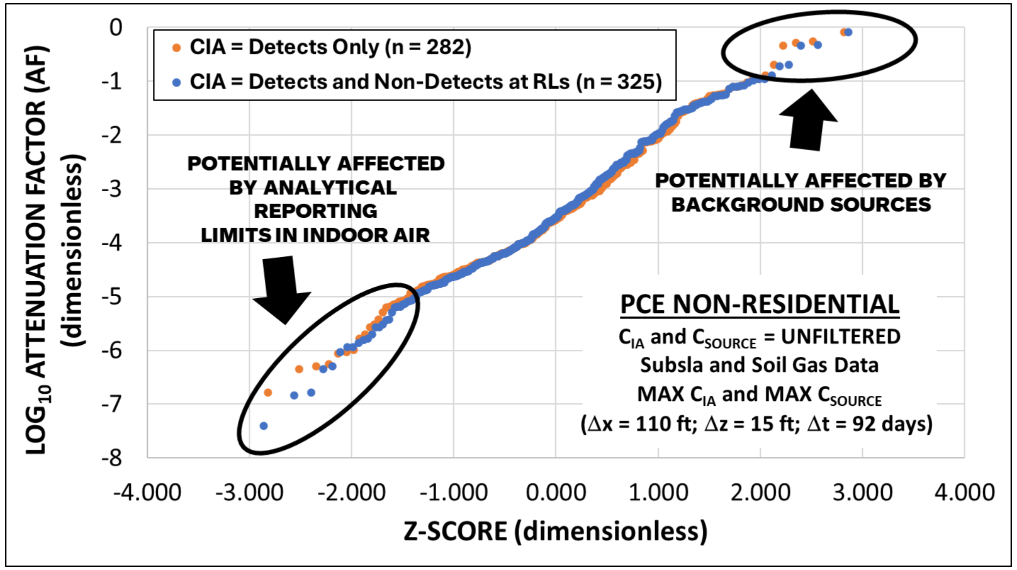
Subslab and Soil Gas, Non-Residential and Residential



KEY POINT

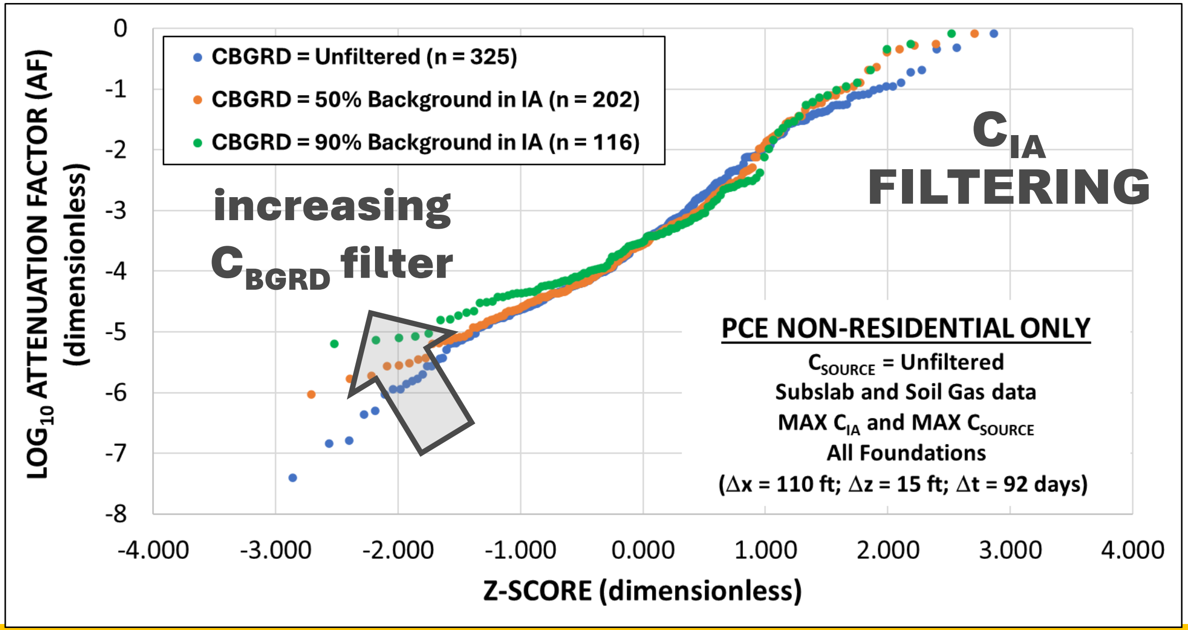
- median AFs are generally unaffected by chemical type allowing the variable to be grouped for AF determinations

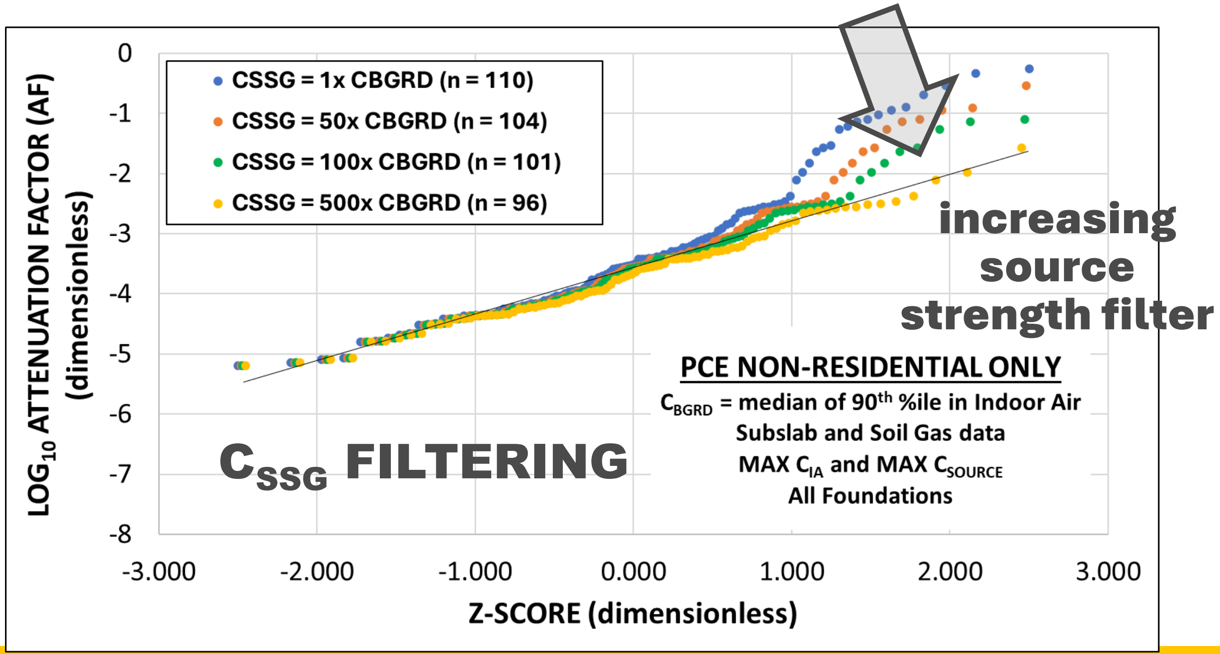
AFs Can Be Affected by Analytical Reporting Limits, Background Sources in Indoor Air



KEY POINT

- increasing C_{IA} filter establishes C_{BGRD} and reduces # of low AFs that are not log-normally distributed; increasing conservatism
- increasing C_{SSG} filter (multiplier of C_{BGRD}) greatly reduces very high AF (weak sources)
- analysis resulted in C_{BGRD} of 90% background in indoor air (same as USEPA 2012) and C_{SSG} filter = 500x C_{BGRD} (10x higher than USEPA (2012)





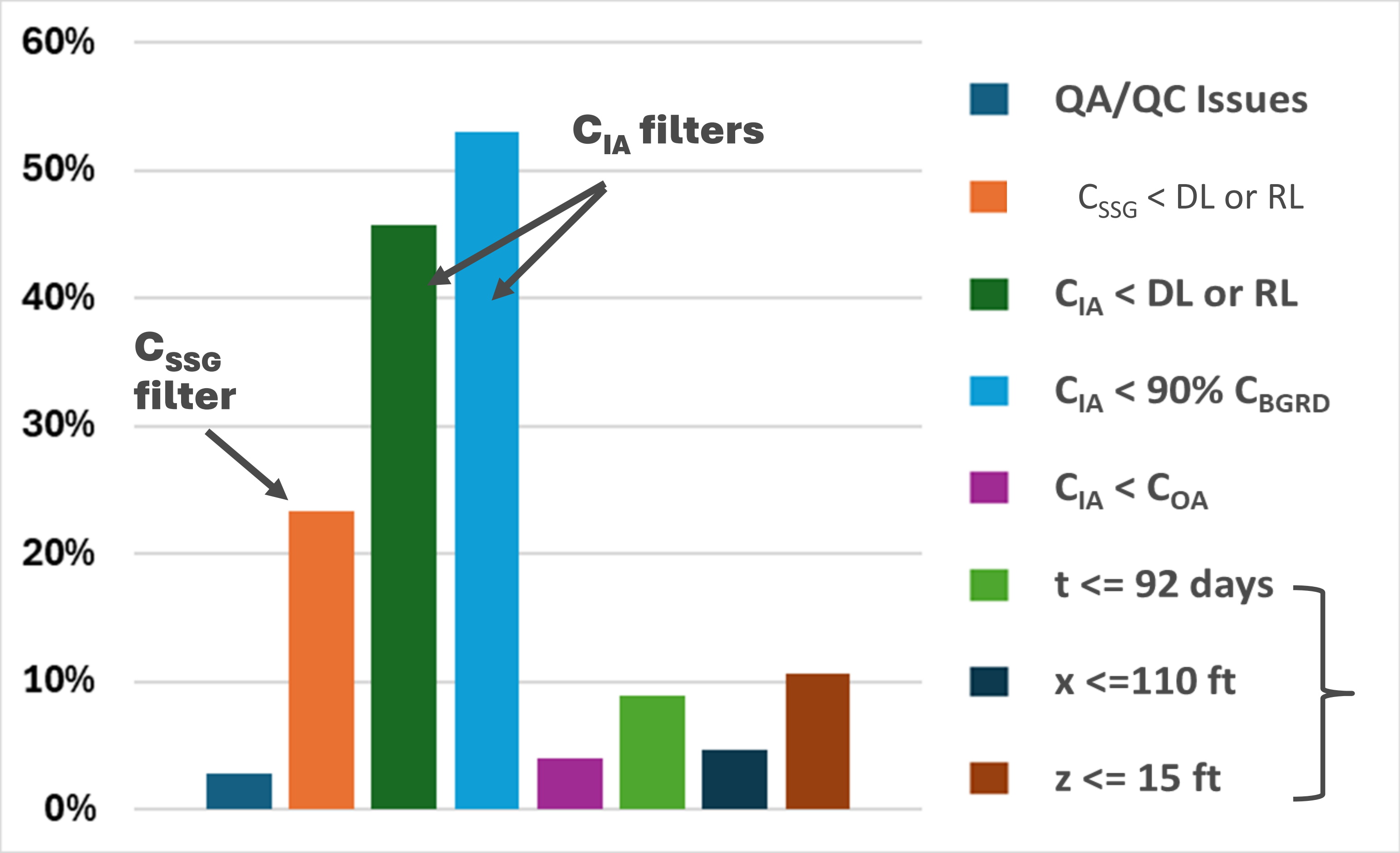
Background: 3 Methods for AF Derivation - Differences

Method	Pros	Cons
Method 1: Descriptive Statistics (e.g. 95th %ile)	Approach ultimately used by USEPA (greater acceptance by wide range of stakeholders) AF sensitivity to specific variables is more easily visualized and assessed	95th %ile AFs can be strongly affected by small #s of data points (e.g., outliers), especially for small data populations AF can be sensitive to data filtering
Method 2: Reliability Analysis	More risk-based (AF defined by its ability to consistently, dependably identify sites where C_{IA} > RBSLs) AF dependence on C_{SSG} and C_{BGRD} filtering is reduced	Draws attention to an "acceptable" % of false negatives – requires agency decision/consensus Requires a relatively large population of data (i.e., cannot be used to assess AF sensitivity to certain variables)
Method 3: Theoretical Relations	Helps show impact of C_{SOURCE} on AF (i.e., AFs affected by background sources)	Difficult to define the AF asymptote if AF data are highly variable

KEY POINT

- **AFs derived using all 3 methods provides a multiple lines of evidence to support a technically defensible AF value**

Reduction in AF Data Population Caused by Data Filtering



baseline filters supported by AF sensitivity analyses

KEY POINT

- **C_{IA} then C_{SSG} filtering; other variables have minor effect**

C_{IA} = Indoor air concentration

C_{SSG} = Source vapor concentration

C_{OA} = Outdoor air concentration

C_{BGRD} = Background concentration in indoor air

AF Sensitivity to Meteorological Events

CONTINUOUS MONITORING @ NON-RESIDENTIAL BUILDING (SAN BERNADINO, CALIFORNIA)

Barometric Pressure (BP)

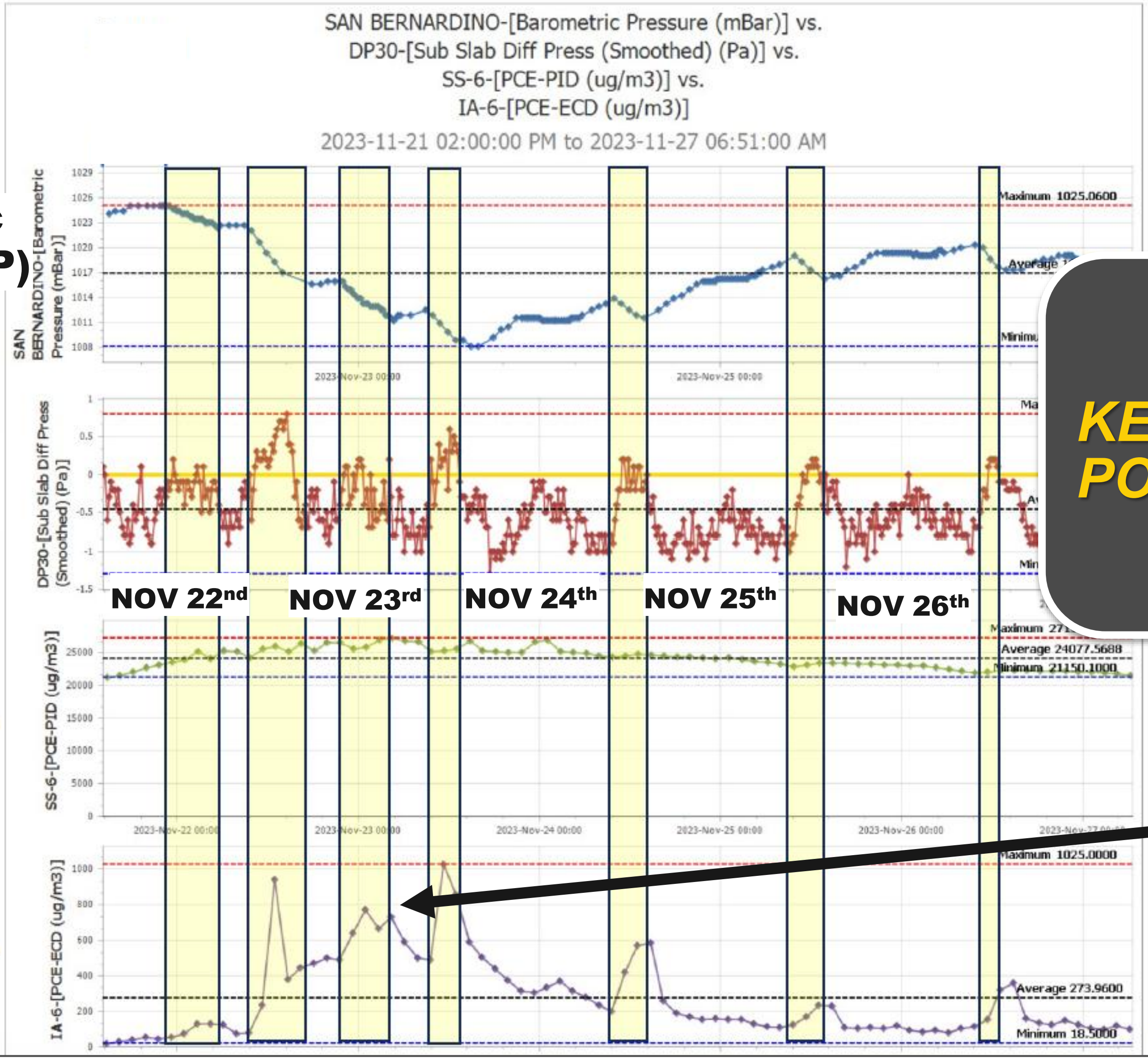
Differential Pressure

C_{SSG}

<10% rise in PCE_{SS} concentrations

C_{IA}

OoM (100 – 1,000 µg/m³) spikes (hrs) in PCE_{IA} concentrations

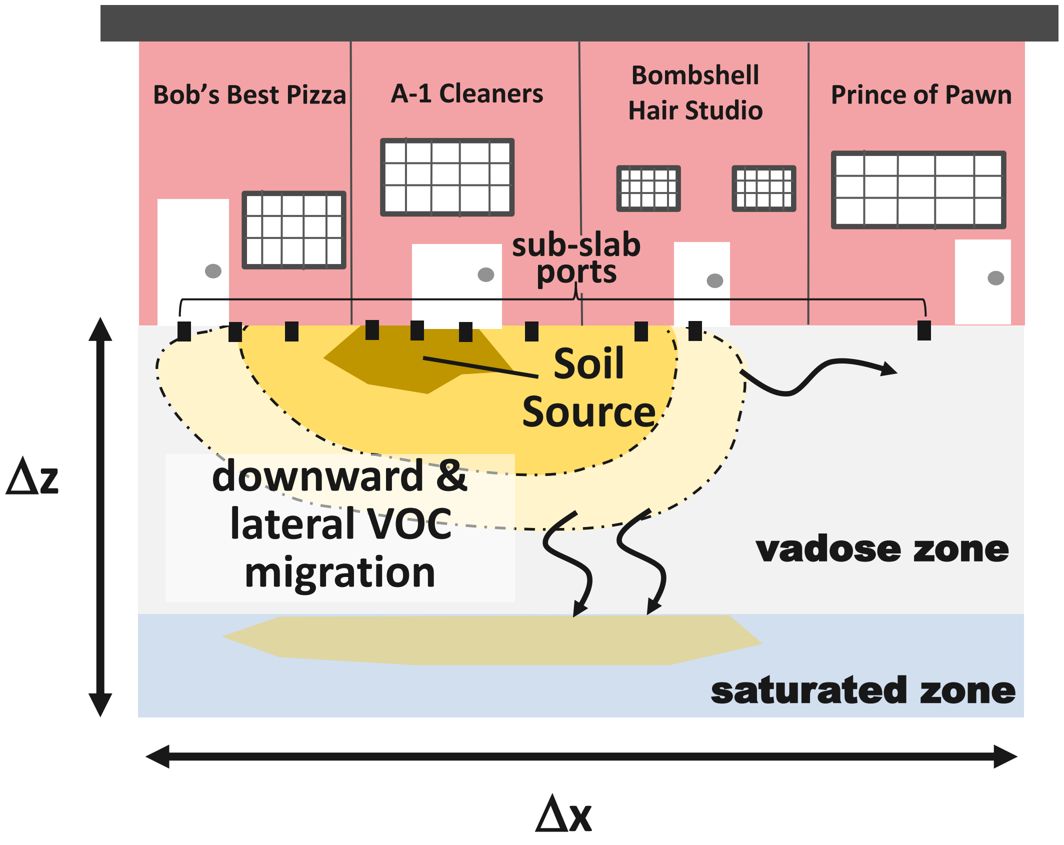


KEY POINT C_{IA} can spike during low and relatively rapid drops in BP, while C_{SSG} remains relatively constant

1-day average = 3.8x 5-day average

Differences in Relative Source Depth Could Affect AF Determinations (Shallow Soil vs. Groundwater Source)

Non-Residential
(shallow soil sources)



Residential
(groundwater sources)