ATTENUATION FACTORS FACT SHEET

A vapor intrusion (VI) attenuation factor (AF) is the ratio of the indoor air concentration to soil vapor or groundwater concentration. AFs are typically used to estimate indoor air concentrations for risk-based decision-making or to calculate subsurface media-specific screening levels, but they may also be used in data evaluation to evaluate the impact of background sources of vapor-forming chemicals (VFCs) in indoor air or evaluating the effectiveness of VI mitigation measures. These AFs are developed empirically or through the use of VI models (see Chapter 9: Modeling). The application of AFs is discussed in several other locations in this guidance, including Chapter 5: Site Screening and Chapter 8: Data Evaluation and Vapor Intrusion Risk Assessment. **The approach and methodology used to determine the applicable AF used for site screening, data evaluation, and risk-based decision-making should be established in consultation with the applicable regulatory agency**.

Empirical Attenuation Factors

Empirical AFs are calculated by relating measured indoor air concentration to either a subsurface soil vapor concentration (AF_{sg}) or groundwater concentration (AF_{gw}) as follows:

$$AF_{sg} = C_{indoor} / C_{soil\ gas} \quad \text{and} \quad AF_{gw} = C_{indoor} / \left(C_{groundwater} \times H' \times 1{,}000 \left(\frac{L}{m^3}\right)\right)$$

where C is the chemical concentration detected in the associated medium (indoor air, soil vapor, or groundwater), and H' is the chemical's dimensionless Henry's Law constant.

A scientifically peer-reviewed U.S. Environmental Protection Agency (USEPA) study compiled a database of VI data from more than 900 buildings and 40 sites and used these data to evaluate empirical AFs (USEPA 2012), which are summarized in Table 1. The results of this data analysis have been used to propose default screening-level AFs. USEPA generally recommends the 95th percentile AFs for initial site screening, with the exception of exterior soil vapor, for which the 75th percentile (0.027) is recommended due to the variability in the soil vapor data set (USEPA 2015). Because these AFs are generally based on the 95th percentile values, they may be conservative in many situations.

Table 1. Summary of attenuation factors from the USEPA attenuation factor database.

Medium	AF Range*	95 Percentile AF*	Median*	USEPA Default Screening AF†
Sub-slab soil vapor	2.5E-05 to 0.94	0.026	0.0027	0.03
Exterior soil vapor	5E-06 to 1.3	0.25	0.0038	0.03
Groundwater (generic)	4.8E-07 to 0.021	0.0012	0.000076	0.001
Groundwater (fine-grained vadose-zone soil)	1.0E-07 to 0.0024	0.00045	0.00005	0.0005
Crawl space	0.057 to 0.92	0.90	0.39	1.0

* Source: USEPA (2012).

† Source: USEPA (2015).

Various studies have identified limitations of the USEPA study (Abbasi et al. 2023; Brewer et al. 2014; Lahvis and Ettinger 2021; Yao et al. 2013; 2018). The concerns are largely rooted in limitations associated with the filtered empirical data set ultimately used by USEPA to derive the AF, namely the following:

- The data ultimately used to derive the AF were collected only at single-family residences, primarily with basement (not slab-on-grade) construction (16 percent unfinished). This presents a significant challenge when using the default AF of 0.03 for buildings with slab-on-grade or crawl-space foundations (Abbasi et al. 2023; Lahvis and Ettinger 2021).
- After data filtering, no nonresidential (commercial/industrial) buildings were included in the AF analysis. Commercial and industrial buildings often have far higher indoor air exchange rates, thicker foundation slabs, and higher ceilings that will attenuate soil vapor more than in a residential setting (Brenner 2010; Eklund and Burrows 2009; NAVFAC 2015a; Shea et al. 2010).
- USEPA identified data quality concerns with the soil vapor data, and ultimately these data were not used as the basis for the default exterior soil vapor screening AF (USEPA 2015).
- Nearly 80 percent (342/431) of the indoor air and sub-slab soil vapor data pairs ultimately used to derive the AF came from only three sites located in Endicott, New York; Raymark, Connecticut; and Aurora, Colorado. Nearly 50 percent (207/431) came from Endicott.
- After data filtering, nearly all the VI sites were located in geographic regions of the United States subject to relatively cold wintertime temperatures where VI could have been enhanced by stack effects during building heating (Abbasi et al. 2023; Lahvis and Ettinger 2021).
- Potential biases from background sources (i.e., not VI-related) could not be fully resolved (Man et al. 2022).
- Duration of indoor air sample collection for each subject building is not provided in the USEPA database, introducing potential sources of error into the data used to derive AFs (Brewer et al. 2014).
- Indoor air samples were randomly timed samples and may not adequately represent reasonable worst-case concentrations (Schuver et al. 2018).
- Approximately 70 percent of the indoor air-to-groundwater pairs in the USEPA database were separated by more than 100 feet, reducing the reliability of AF quantification (Yao et al. 2018).
- Information associated with heating, ventilation, and air conditioning (HVAC) operations was not available for a number of sites.
- Deeper soil vapor data was invalidated; hence, soil vapor AFs were based entirely on sub-slab data.
- No sensitivity analysis was performed to evaluate the impacts of variables including HVAC, building age, climate, concurrency of subsurface with indoor air data, depth of source(s), etc. on AFs.

USEPA recognizes that the distributions of the empirical AFs reported in their study may change as new data are reviewed and the reported AFs “may not apply to new sites with significantly different subsurface and building conditions” (USEPA 2012, 66).

Additional VI studies to assess empirical AFs have been published (Abbasi et al. 2023; Eklund et al. 2024; Hallberg et al. 2021; Lahvis and Ettinger 2021; Lahvis et al. 2025; Levy et al. 2023; NAVFAC 2015b; 2016; 2021; USDOD 2023a; 2023b). These peer-reviewed studies provide empirical VI data for conditions that were not broadly considered in the USEPA 2012 study, including studies focused on sites located in temperate climates (i.e., California) (Abbasi et al. 2023; Lahvis and Ettinger 2021) and evaluating nonresidential buildings (Eklund et al. 2024; Hallberg et al. 2021; Levy et al. 2023; NAVFAC 2015b; 2016; 2021; USDOD 2023a; 2023b). A more comprehensive national empirical VI database (Lahvis et al. 2025) has also been compiled that addresses many of the limitations recognized in previous studies (e.g., geographic distribution, building types, foundation types).

These studies suggest the ranges of AFs are dependent on specific site factors. For example, commercial and industrial buildings often have far higher indoor air exchange rates, thicker foundation slabs, and higher ceilings, which will result in lower AFs than what would be observed for typical residential buildings (Abbasi et al. 2023; Eklund and Burrows 2009; Brenner 2010; Shea et al. 2010; and NAVFAC 2015a). Because these studies use site-specific factors, the building characteristics from these studies may not represent the characteristics of future buildings at a given site, and uncertainties regarding potential building construction should be considered in the selection of the AF for the site in consultation with the applicable regulatory agency. Details of AF studies are summarized in **Table 2**, which includes key findings and limitations, and the median and 95th percentile AFs are summarized in **Table 3** and **Table 4**.

The more recent studies listed above tended to focus on data sets that differ from USEPA's empirical AF evaluation. The limitations of these studies (indicated in **Table 2**) should be considered when using these results for site-specific application for VI assessment.

These studies can potentially provide additional lines of evidence for considering alternative AFs in site-specific VI assessments; however, these studies may not provide sufficient technical justification for a state or federal regulatory agency to deviate from using USEPA-derived AFs for screening or as a line of evidence for site-specific VI assessments. Best practice is to consult with the applicable regulatory agency.

For a detailed discussion on the derivation and use of site-specific AFs from indoor air and soil vapor data, see **Section 8.5.3**.

Table 2. Summary and key findings from empirical studies to derive attenuation factors.

Study	Media	Geographic Distribution	Building Types	Number of Sites / Buildings / Data Pairs	Primary Chemicals	Key Findings	Limitations
USEPA (2012)	• Sub-slab • Exterior soil vapor • Groundwater • Crawl space	U.S.: nationwide, predominantly colder climates	Predominantly single-family residences, basement construction, built before 1945	Sub-slab Unfiltered: 13/424/1,231 Filtered: 12/203/431 Exterior soil vapor Unfiltered: 13/130/213 Filtered: 11//106 Groundwater Unfiltered: 25/658/952 Filtered: 24//774 Crawl Space Unfiltered: 4/11/91 Filtered: 4//41	PCE, TCE	• 95th percentile AF = 0.03 (all residences), 0.03 (residences with basements), 0.01 (residences with slab-on-grade), 0.03 (TCE), and 0.03 (PCE).	• Data were collected at single-family residences, primarily with basement construction (16% unfinished). • 80% of the filtered data came from 3 sites subject to relatively cold winter climates where VI could be enhanced during building heating (nearly 50% of the data were from 1 site in Endicott, NY). • No soil-gas data were ultimately used in the AF derivation.
Derycke et al. (2018)	• Sub-slab • Soil vapor	France	School buildings near industrial facilities; no details on building construction	Unfiltered: 38/51/5,042 Filtered: 24/26/102	Ammonia, BTEX, 111TCA, TCE, C8-C10 aliphatic and C8-C10 aromatic hydrocarbons	• 95th percentile AF = 0.04. • Median AF = 0.0004. • Tracer compounds may aid in data evaluation for low source sites. • Building age identified as key variable to refine AF analysis.	• Low concentration sources are present at most sites. • No source concentration filtering was conducted. • VFCs predominantly not detected in indoor air (17% detection frequency). • No background assessment included (likely important for BTEX and hydrocarbon data analysis).

Study	Media	Geographic Distribution	Building Types	Number of Sites / Buildings / Data Pairs	Primary Chemicals	Key Findings	Limitations
Hallberg et al. (2021)	Sub-slab	U.S.: nationwide	Commercial and industrial buildings at U.S. Department of Defense sites across the United States	Unfiltered: 22/76/3,106 Filtered: 22/76/142	PCE, TCE, c12DCE, 11DCA	• 95th percentile AFs varied based on chemical: AF = 0.003 (TCE), 0.0006 (PCE), 0.0005–0.002 (cis-1,2-DCE), 0.0002 (1,1-DCA), and 0.002 (all VFCs). • Indoor air and subsurface vapor concentrations were weakly correlated.	• The data were collected at commercial/industrial buildings with similar land use and slab-on-grade foundations. • The AFs were independently evaluated for 274 HVAC zones (assumed to be operating at the time of vapor sampling). • Buildings with identified preferential pathways were filtered from the data set. • Similar 95th percentile AFs varied depending on the VFC (the highest AFs were generally observed for TCE).
Lahvis and Ettinger (2021)	• Sub-slab • Exterior soil vapor	California	Residential and nonresidential; predominantly slab-on-grade; numerous residential and institutional (i.e., school) properties with crawl-space construction	Unfiltered: 36/485/8,415 Filtered: 23/71/788	PCE, TCE	• 95th percentile AF = 0.002 (TCE and PCE), 0.001 (TCE), 0.003 (PCE), 0.0008 (reliability analysis), and 0.0009 (indoor air/exterior soil vapor data pairs). • AFs demonstrated little sensitivity to variables typically considered important in VI characterization (partially attributed to relatively weak correlation of indoor air and subsurface vapor concentration data). • Consider reliability analysis for AF evaluation in certain cases.	• Data used to derive the AFs were mainly from nonresidential sites, buildings with slab-on-grade foundations, and sites located in coastal metropolitan areas of California. • Buildings with identified preferential pathways were filtered from the data set.

Study	Media	Geographic Distribution	Building Types	Number of Sites / Buildings / Data Pairs	Primary Chemicals	Key Findings	Limitations
Abbasi, et al. (2023)	• Sub-slab • Exterior soil vapor • Groundwater	California	Residential and nonresidential; predominantly slab-on-grade; numerous residential and institutional (i.e., school) properties with crawl-space construction	Unfiltered: 52/213/4,972 Filtered: 32/82/600	PCE, TCE	• 95^{th} percentile AF = 0.005 (indoor air/sub-slab soil vapor data pairs), 0.0009 (indoor air / exterior soil vapor data pairs), and 0.001 (groundwater data pairs).	Data used to derive the AFs were mainly from nonresidential sites, buildings with slab-on-grade foundations, and 32 sites located in metropolitan areas in California.
Eklund et al. (2023)	Sub-slab	U.S.: Midwest	Industrial buildings	Unfiltered: 1/77/10,7000 Filtered: 1/64/157	PCE, TCE, Freon 12, 111TCA	• 95^{th} percentile AF = 0.0003. • Indoor air concentrations were spatially uniform sub-slab soil-gas concentrations that varied over 4 orders of magnitude but exhibited little temporal variability (i.e., multiple rounds of sub-slab soil vapor sampling would not improve VI risk assessment). • Slightly higher AFs were observed during winter. • AFs were not noticeably affected by building size. • Different AFs should be applied to residential and nonresidential buildings.	The data were from a single industrial site located in the U.S. Midwest with significant seasonal variability in meteorological conditions.

Study	Media	Geographic Distribution	Building Types	Number of Sites / Buildings / Data Pairs	Primary Chemicals	Key Findings	Limitations
Lahvis et. al (2025)	• Sub-slab • Exterior soil vapor	Unfiltered: 32 states Filtered: 15 states	Residential and nonresidential	Unfiltered: More than 26,000 paired measurements of indoor air and subsurface vapor at 1,541 buildings, 330 sites Filtered: 1,474 indoor air and subsurface vapor measurements from 271 buildings, 86 sites	PCE, TCE	• AFs for various site-specific scenarios encountered during site screening (e.g., foundation type, sample type, building type, date of building construction, geographic region) varied by more than an order of magnitude. Individual variables indicated that sample type (sub-slab or near-slab soil vapor), building type (residential or nonresidential), U.S. Climate Zone (Zones 1–3 [warmer, more temperate climates] or Zones 4–7 [cooler, less temperate climates]), date of building construction (pre- and post-1950), and building foundation type (slab-on-grade versus crawl space or basement) were the most statistically significant variables.	The AFs derived in this study for certain residential and basement scenarios with relatively small AF data sets have greater uncertainty. The small data sets arose because of efforts to target AF data with the greatest likelihood of being associated with VI and the calculation of building-specific AFs.

Abbreviations: 111TCA = 1,1,1-trichloroethane; 11DCA = 1,1-dichloroethane; AF = attenuation factor; BTEX = benzene, toluene, ethylbenzene, xylenes; c12DCE = cis-1,2-dichloroethene; HVAC = heating, ventilation, and air conditioning; PCE = tetrachloroethene; TCE = trichloroethene; VFC = vapor-forming chemical; and VI = vapor intrusion.

Table 3. Sub-slab and soil vapor to indoor air attenuation factors.

Study	Sub-Slab Vapor AF Median / 95th Percentile	Soil Vapor AF Median / 95th Percentile	Receptor Scenario	
USEPA (2012)	0.0027 / 0.026	0.0038 / 0.25	Residential	
Lahvis and Ettinger (2021)	0.0001 / 0.0024	0.0001 / 0.001	Residential and Nonresidential	
Abbasi et al. (2023)	0.000067 / 0.0048	0.000043 / 0.00087	Residential and Nonresidential	
Eklund et al. (2024)	0.000093 / 0.00064	Not applicable	Industrial	Not applicable
Hallberg et al. (2021)	0.00007—0.00002 / 0.0002—0.003	Not applicable	Nonresidential	Not applicable
Lahvis et al. (2025)	0.001—0.004 / 0.02—0.008	0.0001* / 0.003*	Residential	
Lahvis et al. (2025)	0.002—0.0003 / 0.01—0.008	0.001—0.0001 / 0.02—0.008	Nonresidential	

* No data for climate zones 4–7.

Table 4. Groundwater to indoor air attenuation factors.

Study	Groundwater Median / 95th Percentile	Receptor Scenario
USEPA (2012)	0.000074 / 0.0012	Residential
Levy et al. (2023)	0.0000007 / 0.00007	Nonresidential
Abbasi et al. (2023)	0.00001 / 0.001	Nonresidential

Modeled Attenuation Factors

VI models typically consider the following components of the VI conceptual site model:

- VFCs present in soil/groundwater will partition (i.e., volatilize) to soil vapor based on chemical-specific properties and the concentration of VFCs in soil/groundwater.
- VFCs migrate in soil vapor by diffusion (i.e., the natural movement of chemicals from areas of high concentration to areas of low concentration) from the source to the sub-slab / ground surface. As a result of the diffusive transport, chemical concentrations near the sub-slab/ground surface are lower than those at the contaminant source.
- Certain VFCs, such as petroleum hydrocarbons and vinyl chloride, may naturally biodegrade in the vadose zone, further reducing their flux to the surface.
- VFCs in sub-slab soil vapor can enter the building through cracks in the foundation or gaps around utility penetrations. The soil vapor entry into the building is typically driven by wind effects, stack effects (caused by heating within the building), or mechanical ventilation (e.g., bathroom fans) that induce a slight depressurization of the building.
- Chemicals entering the building will disperse in indoor air as a result of building ventilation.

VI models calculate the flux through these different zones, and these results may be used to calculate an AF to aid in corrective action decision-making at sites. Note that AFs evaluated using empirical VI databases do not account for the impact of biodegradation of the VI pathway. As a result, some agencies have proposed the application of a biodegradation factor if conditions are shown to be conducive to biodegradation (California DTSC 2023). Additional considerations and limitations on the use of models to evaluate the VI AF are discussed in **Section 8.4**.

The Johnson and Ettinger (1991) model is a screening model that may be used to calculate the VI AF without the consideration of vadose-zone biodegradation. To facilitate modeling using the Johnson and Ettinger model, USEPA and the California Environmental Protection Agency Department of Toxic Substances Control (DTSC) have published spreadsheets that can be easily used by environmental practitioners to perform the Johnson and Ettinger model calculations (California DTSC 2024; USEPA 2017) and calculate site-specific AFs. DTSC's 2024 Johnson and Ettinger update provides sensitivity analysis on AFs based on site-specific variables, including soil types for three distinct layers, and site-specific building parameters.

Other models, such as BioVapor (API 2010) and PVIScreen (USEPA 2016), are better suited to evaluate AFs for biodegradable compounds. Building-specific AFs can also be determined from VI transport modeling (e.g., Johnson and Ettinger 1991), the DTSC Johnson and Ettinger Spreadsheet Update (2024), BioVapor (API 2010), PVIScreen (USEPA 2016), and field measurements using building pressure cycling (McHugh et al. 2012) or other methods.

Alternate modeling approaches include the following:

- A model based on evaluation of vacuum and flow data collected during sub-slab depressurization or high-volume sampling has been developed (McAlary et al. 2018; Nicholson et al. 2021). This model uses the solution of the "leaky aquifer" to calculate the leakance of the building foundation, which is then used to determine the sub-slab to indoor air AF.
- Another model correlates measured indoor air concentrations with barometric pressure gradients to predict the distribution of indoor air concentrations over time (Kram and Solgi 2025).

REFERENCES

Abbasi, Rafat, William Bosan, and Dan Gallagher. 2023. "Empirically Derived California Vapor Intrusion Attenuation Factors." *Groundwater Monitoring & Remediation* 43 (1): 60–68. **https://doi.org/10.1111/gwmr.12559**.

API. 2010. "BioVapor Indoor Vapor Intrusion Model." **https://www.api.org/oil-and-natural-gas/environment/clean-water/ground-water/vapor-intrusion/biovapor**.

Brenner, David. 2010. "Results of a Long-Term Study of Vapor Intrusion at Four Large Buildings at the NASA Ames Research Center." *Journal of the Air & Waste Management Association* 60 (6): 747–58. **https://doi.org/10.3155/1047-3289.60.6.747**.

Brewer, Roger, Josh Nagashima, Mark Rigby, Martin Schmidt, and Harry O'Neill. 2014. "Estimation of Generic Subslab Attenuation Factors for Vapor Intrusion Investigations." *Groundwater Monitoring & Remediation* 34 (4): 79–92. **https://doi.org/10.1111/gwmr.12086**.

California DTSC. 2023. *Supplemental Guidance: Screening and Evaluating Vapor Intrusion*. **https://dtsc.ca.gov/wp-content/uploads/sites/31/2023/02/VI_SupGuid_Screening-Evaluating.pdf**.

California DTSC. 2024. *User's Guide — DTSC Implementation of the Johnson and Ettinger Model to Evaluate Vapor Intrusion into Buildings*. California Environmental Protection Agency, Department of Toxic

Substances Control. **https://dtsc.ca.gov/wp-content/uploads/sites/31/2024/11/DTSC-JEM-User-Guide_2024-October.pdf**.

Derycke, Virginie, Aline Coftier, Clément Zornig, Hubert Léprond, Mathilde Scamps, and Dominique Gilbert. 2018. "Environmental Assessments on Schools Located on or near Former Industrial Facilities: Feedback on Attenuation Factors for the Prediction of Indoor Air Quality." *Science of The Total Environment* 626 (June): 754–61. **https://doi.org/10.1016/j.scitotenv.2018.01.118**.

Eklund, Bart, and Don Burrows. 2009. "Prediction of Indoor Air Quality from Soil-Gas Data at Industrial Buildings." *Groundwater Monitoring & Remediation* 29 (1): 118–25. **https://doi.org/10.1111/j.1745-6592.2008.01220.x**.

Eklund, Bart, Catherine Regan, Rich Rago, and Lila Beckley. 2024. "Overview of State Approaches to Vapor Intrusion: 2023 Update." *Groundwater Monitoring & Remediation* 44 (3): 76–93. **https://doi.org/10.1111/gwmr.12627**.

Eklund, Bart, Carly Ricondo, Helen Artz-Patton, Jessica Milose, and Chi-Wah Wong. 2023. "Development of a Default Vapor Intrusion Attenuation Factor for Industrial Buildings." *Groundwater Monitoring & Remediation* 43 (1): 35–43. **https://doi.org/10.1111/gwmr.12534**.

Hallberg, Keri E., Laurent C. Levy, Rodrigo Gonzalez-Abraham, Christopher C. Lutes, Loren G. Lund, and Donna Caldwell. 2021. "An Alternative Generic Subslab Soil Gas-to-Indoor Air Attenuation Factor for Application in Commercial, Industrial, and Other Nonresidential Settings." *Journal of the Air & Waste Management Association* 71 (9): 1148–58. **https://doi.org/10.1080/10962247.2021.1930286**.

Johnson, P. C., and R. A. Ettinger. 1991. "Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors into Buildings." *Environmental Science & Technology* 25 (8): 1445–52. **https://doi.org/10.1021/es00020a013**.

Kram, M. L., and R. Solgi. 2025. "Empirically-Derived Building-Specific Learning Models for Predicting Occupant Vapor Intrusion Exposures." *Remediation Journal* 35 (2): e70016.

Lahvis, Matthew A., and Robert A. Ettinger. 2021. "Improving Risk-Based Screening at Vapor Intrusion Sites in California." *Groundwater Monitoring & Remediation* 41 (2): 73–86. **https://doi.org/10.1111/gwmr.12450**.

Lahvis, Matthew A., Robert A. Ettinger, Rafat Abbasi, and Wayne R. Jones. 2025. "Scenario-Specific Attenuation Factors for Vapor Intrusion Screening." *Groundwater Monitoring & Remediation*, ahead of print. **https://doi.org/10.1111/gwmr.70012**.

Levy, Laurent C., Keri E. Hallberg, Rodrigo Gonzalez-Abraham, et al. 2023. "An Alternative Generic Groundwater-to-Indoor Air Attenuation Factor for Application in Commercial, Industrial, and Other Nonresidential Settings." *Journal of the Air & Waste Management Association* 73 (4): 258–70. **https://doi.org/10.1080/10962247.2023.2175740**.

Man, Jun, Yuanming Guo, Qing Zhou, and Yijun Yao. 2022. "Database Examination, Multivariate Analysis, and Machine Learning: Predictions of Vapor Intrusion Attenuation Factors." *Ecotoxicology and Environmental Safety* 242 (September): 113874. **https://doi.org/10.1016/j.ecoenv.2022.113874**.

McAlary, T. A., J. Gallinatti, G. Thrupp, W. Wertz, D. Mali, and H. Dawson. 2018. "Fluid Flow Model for Predicting the Intrusion Rate of Subsurface Contaminant Vapors into Buildings." *Environmental Science & Technology* 52 (15): 8438–45. **https://doi.org/10.1021/acs.est.8b01106**.

McHugh, Thomas E., Lila Beckley, Danielle Bailey, et al. 2012. "Evaluation of Vapor Intrusion Using Controlled Building Pressure." *Environmental Science & Technology* 46 (9): 4792–99. https://doi.org/10.1021/es204483g.

NAVFAC. 2015a. *A Quantitative Decision Framework for Assessing Navy Vapor Intrusion Sites*. TR-NAVFAC-EXWC-EV-1603. https://clu-in.org/download/issues/vi/TR-NAVFAC-EXWC-EV-1603.pdf.

NAVFAC. 2015b. *Attenuation Pathways for Munitions Constituents in Soils and Groundwater*. https://www.enviro.wiki/images/5/55/NAVFAC-2015-AttenuationPathways.pdf.

NAVFAC. 2016. "Quantitative Decision Framework for Assessing Vapor Intrusion for Industrial Buildings at Navy Installations." https://exwc.navfac.navy.mil/Portals/88/Documents/EXWC/Restoration/er_pdfs/v/navfacexwc-ev-FS-frmwk-vi-201604.pdf?ver=lq_8h6Qq3XxD1m0Zz8XcQQ%3d%3d&timestamp=1652982994551.

NAVFAC. 2021. "Reanalysis of Department of Defense Vapor Intrusion Database of Commercial and Industrial Buildings." November. https://exwc.navfac.navy.mil/Portals/88/Documents/EXWC/Restoration/er_pdfs/v/Reanalysis_of_DOD_VI_Database_of_Comm_Ind_Buildings_Final_NOV21/Reanalysis%20of%20DOD%20VI%20Database%20of%20Comm%20Ind%20Buildings%20Final%20NOV21.pdf?ver=ujOoxNHDndzSmKvGzP-Q3w%3D%3D&timestamp=1652983111487.

Nicholson, Paul, Darius Mali, and Todd A. McAlary. 2021. "Simplified Approach for Calculating Building-Specific Attenuation Factors and Vapor Intrusion Mitigation System Flux-Based Radius of Influence." *Groundwater Monitoring & Remediation* 41 (2): 122–31. https://doi.org/10.1111/gwmr.12456.

Schuver, Henry J., Chris Lutes, Jeff Kurtz, Chase Holton, and Robert S. Truesdale. 2018. "Chlorinated Vapor Intrusion Indicators, Tracers, and Surrogates (ITS): Supplemental Measurements for Minimizing the Number of Chemical Indoor Air Samples—Part 1: Vapor Intrusion Driving Forces and Related Environmental Factors." *Remediation Journal* 28 (3): 7–31. https://doi.org/10.1002/rem.21557.

Shea, David, Claire G. Lund, and Bradley A. Green. 2010. "HVAC Influence on Vapor Intrusion in Commercial and Industrial Buildings." https://clu-in.org/download/contaminantfocus/vi/HVAC%20Influence.pdf.

USDOD. 2023a. "Development and Application of Groundwater-to-Indoor Air Attenuation Factors for Industrial/Commercial Buildings at DoD Facilities." In *DoD Vapor Intrusion Handbook*.

USDOD. 2023b. "Development and Application of Subslab-to-Indoor Air Attenuation Factors for Industrial/Commercial Buildings at DoD Facilities." In *DoD Vapor Intrusion Handbook*.

USEPA. 2012. *EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings*. United States Environmental Protection Agency. https://www.epa.gov/sites/default/files/2015-09/documents/oswer_2010_database_report_03-16-2012_final_witherratum_508.pdf.

USEPA. 2015. *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*. U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response. https://www.epa.gov/sites/default/files/2015-09/documents/oswer-vapor-intrusion-technical-guide-final.pdf.

USEPA. 2016. *Petroleum Vapor Intrusion Modeling Assessment with PVIScreen*. United States Environmental Protection Agency. **https://nepis.epa.gov/Exe/ZyPDF.cgi/P100TJ1S.PDF?Dockey=P100TJ1S.PDF**.

USEPA. 2017. *Documentation for EPA's Implementation of the Johnson and Ettinger Model to Evaluate Site Specific Vapor Intrusion into Buildings Version 6.0*. Office of Superfund Remediation and Technology Innovation. **https://semspub.epa.gov/work/HQ/100000489.pdf**.

Yao, Yijun, Fang Mao, Yuting Xiao, Huanyu Chen, Iason Verginelli, and Jian Luo. 2018. "Investigating the Role of Soil Texture in Petroleum Vapor Intrusion." *Journal of Environmental Quality* 47 (5): 1179–85. **https://doi.org/10.2134/jeq2018.04.0140**.

Yao, Yijun, Rui Shen, Kelly G. Pennell, and Eric M. Suuberg. 2013. "Examination of the Influence of Environmental Factors on Contaminant Vapor Concentration Attenuation Factors Using the U.S. EPA's Vapor Intrusion Database." *Environmental Science & Technology* 47 (2): 906–13. **https://doi.org/10.1021/es303441x**.