December 2020

Technical/Regulatory Guidance

Technical Resources for Vapor Mitigation Training

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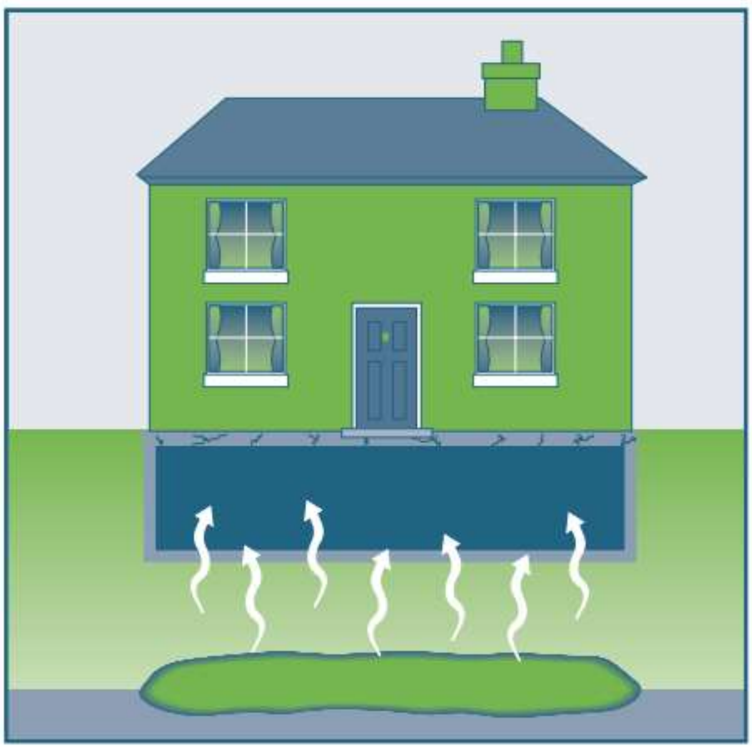


December 2020
Prepared by
The Interstate Technology & Regulatory Council (ITRC)
Vapor Intrusion Mitigation Training Team

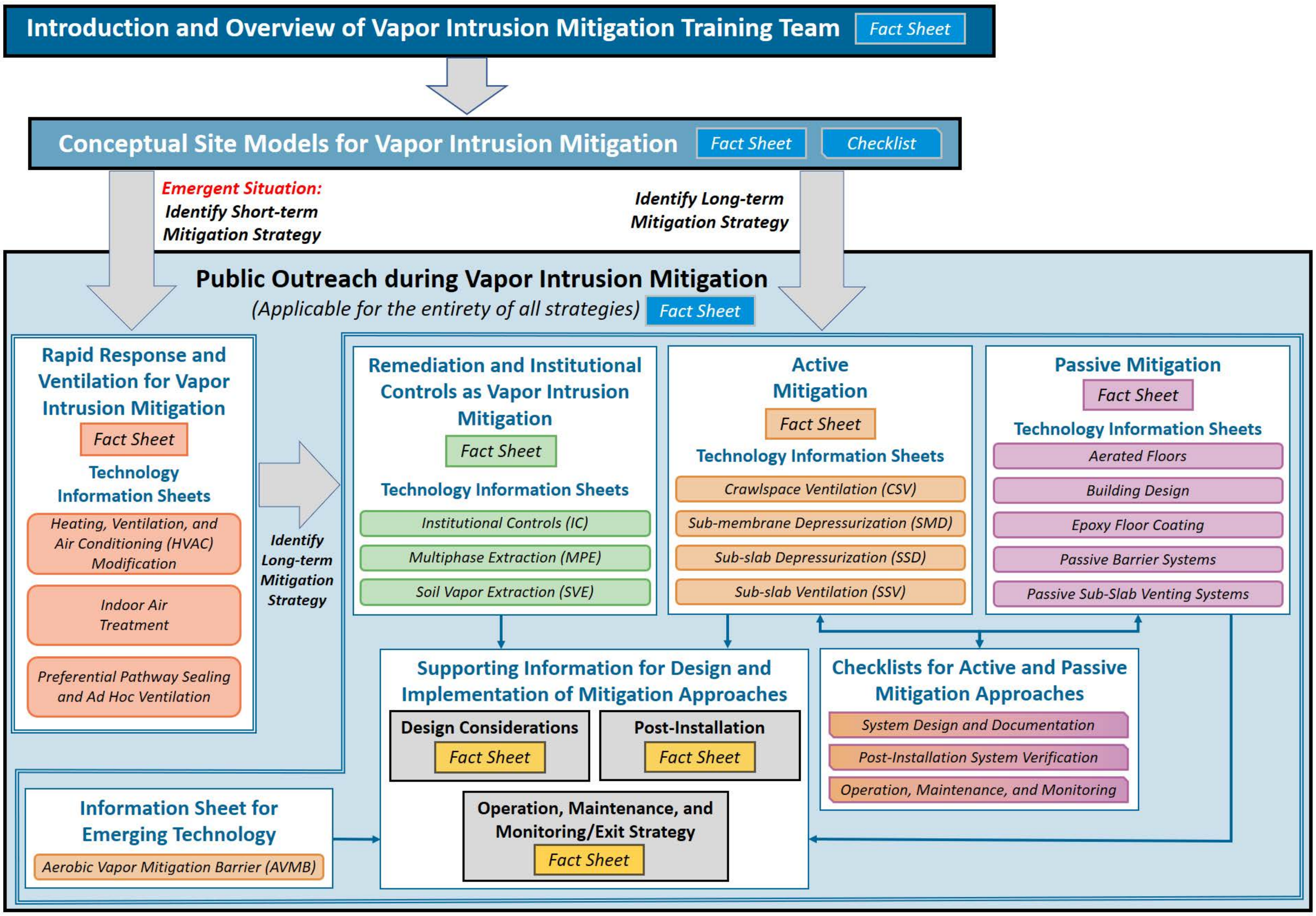
Vapor Intrusion Mitigation Team Interactive Directory

This Interstate Technology and Regulatory Council (ITRC) online documentation includes the Vapor Intrusion Mitigation Team's (VIMT) Fact Sheets, Tech Sheets, and Checklists prepared by the ITRC Vapor Intrusion Mitigation Team. Links within the online document help the reader locate interrelated topics. It is the intention of ITRC to periodically update the document as significant new information and regulatory approaches for VIMT develop. The web-based nature of this document lends itself to updating of key information in this rapidly evolving subject. Each document can be downloaded as a PDF. The documents are designed specifically for state and federal environmental staff, as well as others (including stakeholders, project managers, and decision makers), to gain a working knowledge of vapor mitigation and practice. The document was developed by a team of over 200 environmental practitioners drawn from state and federal government, academia, industry, environmental consulting, and public interest groups. While every effort was made to keep the information accessible to a wide audience, it is assumed the reader has some basic technical background in chemistry, environmental sciences, risk assessment, and vapor intrusion. ITRC has previously produced guidance documents on evaluating the vapor intrusion pathway and petroleum vapor intrusion.

The Interactive Directory below presents the relationship between work products prepared by the VIMT team. Lists of acronyms, glossary terms, and references cited in the fact sheets are also available on this website.

User Instructions for Interactive Directory: Click on the individual buttons within the graphical interactive directory below to navigate to each fact sheet, technology information sheet, or checklist.

Interactive Directory of Vapor Intrusion Mitigation Training Team Work Products



If the graphical interactive directory does not work in your browser, please use the links on the side margin of the VIMT or use the content directory below to find links to each document.

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An Introduction to Vapor Intrusion (VI) Mitigation Fact Sheet

INTRODUCTION

The Interstate Technology and Regulatory Council (ITRC) has developed nine fact sheets and one additional technology information sheet for emerging technology to summarize the latest science, practices, and new approaches for vapor intrusion (VI) mitigation. The fact sheets are intended to address needs of regulatory program personnel regarding sites with known or potential VI impacts. The content is also useful to practitioners (i.e., environmental consultants or engineers) and parties responsible for the release of these contaminants, as well as public and tribal stakeholders. The fact sheets in the series are:

Overarching VI Mitigation Topics

1. Conceptual Site Models (CSM) for Vapor Intrusion Mitigation
2. Public Outreach During Vapor Intrusion Mitigation

VI Mitigation Considerations

3. Design Considerations
4. Post-Installation Considerations
5. Operations, Maintenance, and Monitoring (OM&M) Considerations

VI Mitigation Strategies

6. Rapid Response and Ventilation
7. Active Mitigation Systems
8. Passive Mitigation Systems
9. Remediation and Institutional Controls

Technology Information Sheet for Emerging Technology

10. Aerobic Vapor Mitigation Barrier (AVMB)

Emergency (911) Situations

*This document does **not** cover emergency response actions related to VI creating a combustible, explosive, or other hazardous environment.*

*If strong odors are detected or there is reason to believe that combustible, explosive, oxygen-deficient, or toxic condition exists inside a building, **immediately** evacuate the building and contact first responders.*

This document includes a brief introduction to VI; however, it is assumed that the user has previous knowledge of VI topics, especially related to evaluation of the VI pathway and VI sampling. Knowledge of VI topics provides the foundation to understand the requirements, implementation, and verification of an adequate VI mitigation strategy that protects public health. Therefore, it is highly recommended that users of this document refer to the following references for additional background information regarding VI:

- ITRC – Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management (ITRC, 2014)
- ITRC – Vapor Intrusion Pathway: A Practical Guideline (ITRC, 2007a)
- U.S. Department of Defense – DOD Vapor Intrusion Handbook (USDOD, 2009)

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- U.S. Environmental Protection Agency (USEPA) – Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites, Office of Underground Storage Tanks (USEPA, 2015a)
- USEPA – Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air, Office of Solid Waste and Emergency Response (USEPA, 2015b)

1.1 What is Vapor Intrusion?

Chemical contaminants in soil and groundwater can volatilize into soil gas and migrate through unsaturated soils of the vadose zone. VI occurs when these vapors migrate upward into overlying buildings through cracks and gaps in the building floors, foundations, and preferential pathways (e.g., utility conduits, sewer lines) and contaminate indoor air (see also ***Conceptual Site Models for Vapor Intrusion Mitigation Fact Sheet***). If present at sufficiently high concentrations, these vapors may present a threat to the health and safety of building occupants. VI is a potential human exposure pathway—a way that people may come into contact with hazardous vapors while performing their day-to-day indoor activities (USEPA, 2015b).

VI chemicals of concern (COCs) vary by regulatory agency and may include:

- volatile organic compounds (VOCs) such as hydrocarbons (for example benzene), chlorinated hydrocarbons (for example trichloroethylene (TCE), tetrachloroethylene (PCE), and vinyl chloride), and methane
- select semi-volatile organic compounds such as some polycyclic aromatic hydrocarbons (PAHs), naphthalene, and some polychlorinated biphenyls (PCBs)
- select inorganic compounds, such as mercury (elemental), pesticides, and hydrogen cyanide
- per- and polyfluoroalkyl substances (PFAS)

The Most Common VI Mitigation Approaches Are Active and Passive Mitigation Measures

- *Refer to the **Active Mitigation Fact Sheet** and **Passive Mitigation Fact Sheet***
- ***Rapid Response and Ventilation** measures may be necessary before or concurrently with other VI mitigation approaches.*

Note that background COC contributions to indoor air unrelated to the subsurface may complicate interpretation of indoor air sampling results, such that additional lines of evidence should be considered when generating a site CSM (see also ***Conceptual Site Models for Vapor Intrusion Mitigation Fact Sheet***) or evaluating performance of selected VI mitigation strategies. Conceptual site models for VI are typically developed and modified throughout the investigative process. Examples of generalized VI scenarios that a CSM would be developed for are illustrated in Figure 1-1.

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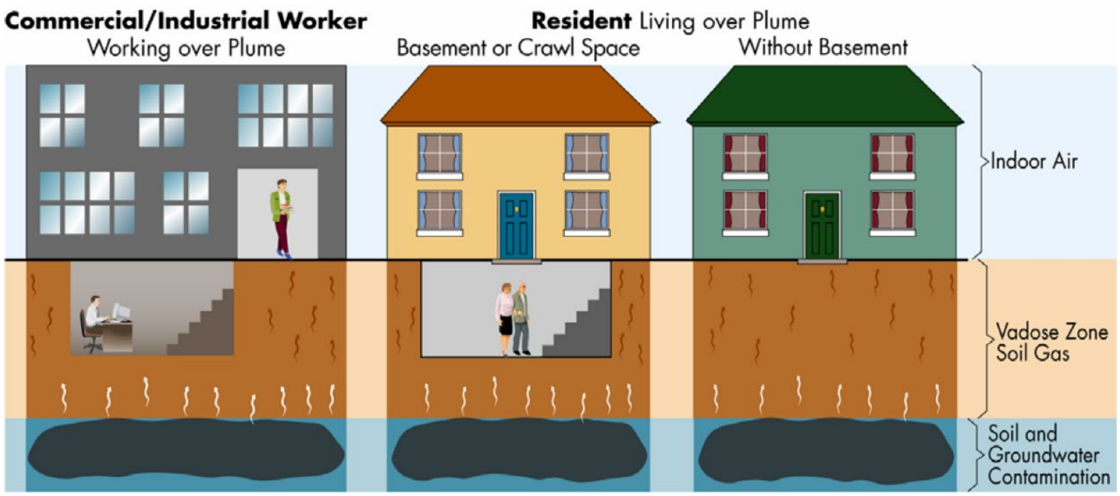

Figure 1-1: Generalized VI scenarios (from ITRC 2007 VI Guidance, Figure 1-1).

1.2 What is the Objective of VI Mitigation?

The objective of VI mitigation is to reduce indoor air COCs due to VI below applicable action or screening levels. This requires modification of the VI pathway to reduce the mass flux of COCs entering the building and/or to reduce indoor air COC concentrations by removal or dilution. Sections 2, 3, and 4 below introduce the user to the fact sheets and what to expect from each document.

As illustrated in the ***Conceptual Site Models for Vapor Intrusion Mitigation Fact Sheet*** figure titled "*Flowchart for Vapor Intrusion Mitigation Conceptual Site Model Development*," mitigation technologies can be applied at different points along the VI pathway to accomplish these goals. Understanding how a mitigation technology is modifying the VI pathway helps us understand 1) whether the technology is compatible with the site conditions and stakeholder objectives (e.g., cost, timeliness, sustainability, etc.), and 2) what information is needed to evaluate the performance of the system over the short and long terms.

Examples of common mitigation technologies applied below the slab[1] (e.g., sub-slab technologies), at the slab (e.g., vapor barriers), and inside the building (e.g., heating, ventilation, and air conditioning [HVAC] controls) are described below, including how they modify the VI pathway and information typically needed to evaluate the suitability and performance of the technology at a site. A similar thought process should be applied to other mitigation technologies that are not discussed below but may be considered at a site, such as technologies to address COC migration into buildings through preferential pathways (e.g., sewer lines or utility tunnels). Refer to the ***Preferential Pathway Sealing***

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[1] Vapor intrusion can occur through any subsurface portion of the building shell, including floor slabs, foundation walls, elevator shafts, sumps and vaults, and any other building component in contact with the ground, including bare soil in basements or crawl spaces. For simplicity, however, we will use the term "slab" in this fact sheet to represent the building/subsurface interface through which vapors can migrate.

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and Ad Hoc Ventilation Technology Information Sheet. See the ITRC VI mitigation technology information sheets included with each VI mitigation approach fact sheet for more detailed information, including recommendations for design and implementation of specific technologies.

In certain instances, radon mitigation providers do not understand how VI is different from radon mitigation and are not installing systems that provide the level of coverage necessary for regulatory acceptance and public health protectiveness. Additionally, many radon mitigation providers do not have the training/experience to design VI mitigation systems for large buildings, such as determining if exhaust controls are required and having licenses to obtain necessary building permits.

Radon Mitigation Systems Are Not Necessarily VI Mitigation Systems

- *It is important to understand that while radon and VI mitigation strategies share many similarities, mitigation systems for VI are typically designed, constructed, inspected, and verified more thoroughly.*
- *However, most active and passive VI mitigation systems will address radon concerns but this must be determined by a professional.*

Pre-emptive VI mitigation is common for new construction and is defined as designing and implementing VI mitigation measures without a requirement or without confirmation that an unacceptable risk is or would be present. While an institutional control (e.g., land use restriction) may be in place for a site that requires VI mitigation for new construction (such as when constructing on an undeveloped site with known contamination), pre-emptive mitigation is commonly selected even when VI impacts do not warrant VI mitigation. Pre-emptive VI mitigation can limit concern that may be related to migration of COCs associated with an existing release or a future release and in some cases, can increase building value.

1.3 How to Use This Document

This document provides regulators, practitioners (i.e., environmental consultants or engineers), and parties responsible for the release of these contaminants, as well as public and tribal stakeholders, with consensus information based on data, research, and experience gained from case studies, to support VI mitigation decision making under different regulatory frameworks. Further, this document is meant to assist regulators in reviewing or determining appropriate VI mitigation strategies and to help practitioners appropriately design and implement VI mitigation strategies.

Figure 1-2 is a graphical depiction of the organization of the fact sheets, technology information sheets, and checklists prepared in support of VI mitigation training.

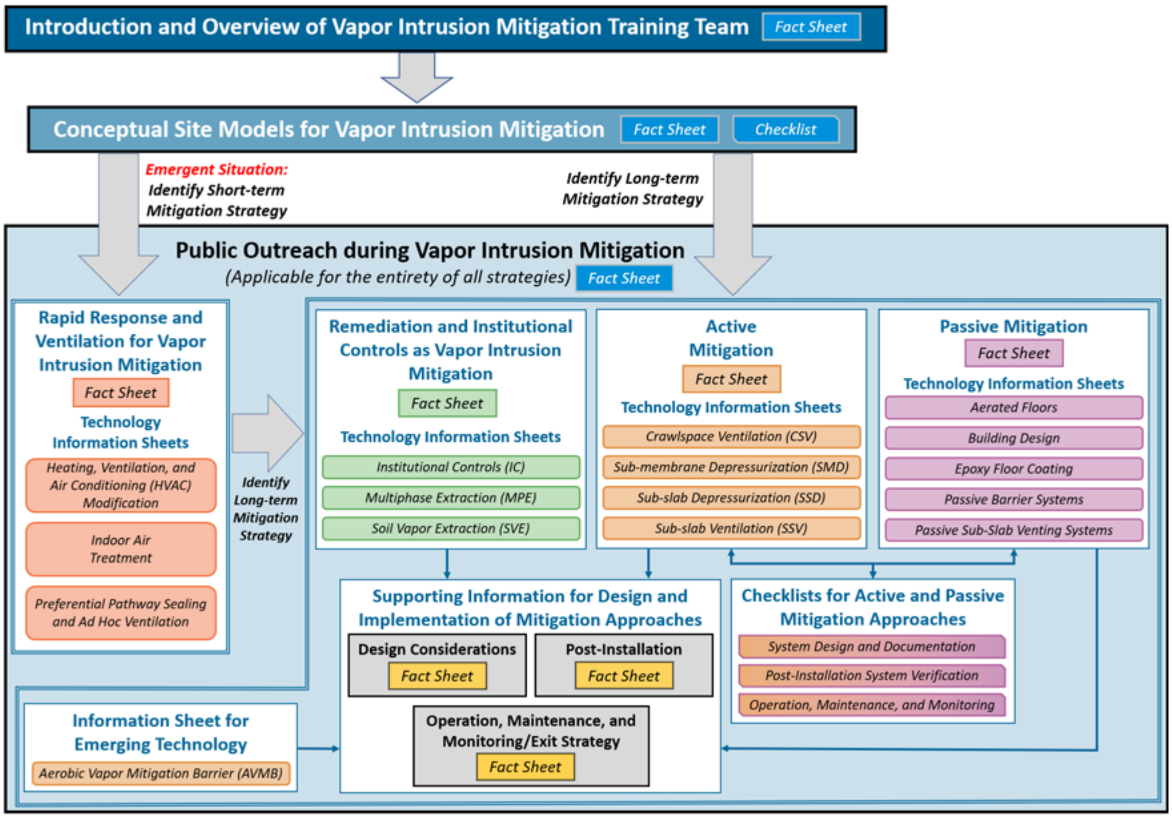

Figure 1-2. Document map for work products prepared by the VI mitigation training team.

Generally, a regulator or practitioner should approach each site by following the step-wise approach outlined in this document by navigating from the materials introduced in Section 2 (Overarching VI Mitigation Topics) and using the ***Conceptual Site Models for Vapor Intrusion Mitigation Fact Sheet*** as guidance for which fact sheets in Section 3 (VI Mitigation Considerations) and Section 4 (VI Mitigation Strategies) are applicable. It's important to note that topics detailed in the ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet*** should be followed at every step in the VI mitigation process—from initial site characterization to follow-up and maintenance for the life of the building.

OVERVIEW OF OVERARCHING VI MITIGATION TOPICS FACT SHEETS

Two fact sheets, ***Conceptual Site Models for Vapor Intrusion Mitigation*** and ***Public Outreach During Vapor Intrusion Mitigation,*** provide information that is relevant throughout the entire mitigation effort. A brief overview of each fact sheet is found below.

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2.1 Conceptual Site Models for Vapor Intrusion Fact Sheet

For the Fact Sheet Click here

The ***Conceptual Site Models for Vapor Intrusion Mitigation Fact Sheet*** provides a general overview of the VI pathway, including the locations and types of vapor sources, subsurface vapor transport mechanisms, foundation and other building conditions affecting the rate of vapor entry, and receptors that could be impacted by VI. The VI Mitigation CSM helps the practitioner evaluate the potential for a complete VI pathway, identify data gaps, and communicate findings and conclusions to other stakeholders.

This fact sheet introduces two tools to help focus the VI Mitigation CSM. The first is a checklist to help guide mitigation planning, and the second is a conceptual flowchart illustrating various VI pathways and strategies that could be employed to control these pathways. VI Mitigation CSMs that use this checklist and flowchart should allow more thorough identification of the specific VI pathways relevant to the site, as well as options for vapor control strategies.

2.2 Public Outreach During Vapor Intrusion Mitigation Fact Sheet

For the Fact Sheet Click here

The ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet*** details the importance and procedure for engaging the public at environmental contamination sites with VI concerns, specifically with the people who own; live, work, or study in; and otherwise occupy the impacted buildings. Their cooperation, not just permission, makes it possible to investigate, remediate, mitigate, and monitor at properties where COCs may be present. Regulators and practitioners may be asking them to agree to allow intrusive activities, such as drilling holes through their floors, attaching fans and piping to their buildings, or rearranging their basements for investigation or mitigation.

Topics covered in this fact sheet include characterizing community concerns, unique topics for the community involvement plan, and logistical considerations for the community involvement plan specifically pertaining to VI concerns. The user of this document should refer to the ITRC ***Risk Communications Plan Toolkit*** (ITRC, 2020) for generic guidance on developing a community involvement plan.

3 OVERVIEW OF VI MITIGATION CONSIDERATIONS FACT SHEETS

Three fact sheets for VI mitigation considerations includes design considerations, post-installation considerations, and operation, maintenance, and monitoring (OM&M) considerations. A brief overview of each fact sheet is found below.

3.1 VI Mitigation Design Considerations Fact Sheet

For the Fact Sheet Click here

Prior to designing a mitigation system, it is common to perform a building survey and predesign diagnostic testing to understand specific issues that will need to be incorporated into any mitigation system design for either an active system (see ***Active Mitigation Fact Sheet)***, passive system (see ***Passive Mitigation Fact Sheet)***, or an environmental remediation technology that will be used as a mitigation strategy (see ***Remediation and Institutional Controls as Vapor Intrusion Mitigation Fact Sheet***). Design considerations detailed in the fact sheet include geology and/or hydrogeology, building survey, new or existing building characteristics, design testing (qualitative verification), permitting, communications, long-term system effectiveness and reliability, operation and maintenance, and exit strategy.

3.2 VI Mitigation Post-Installation Fact Sheet

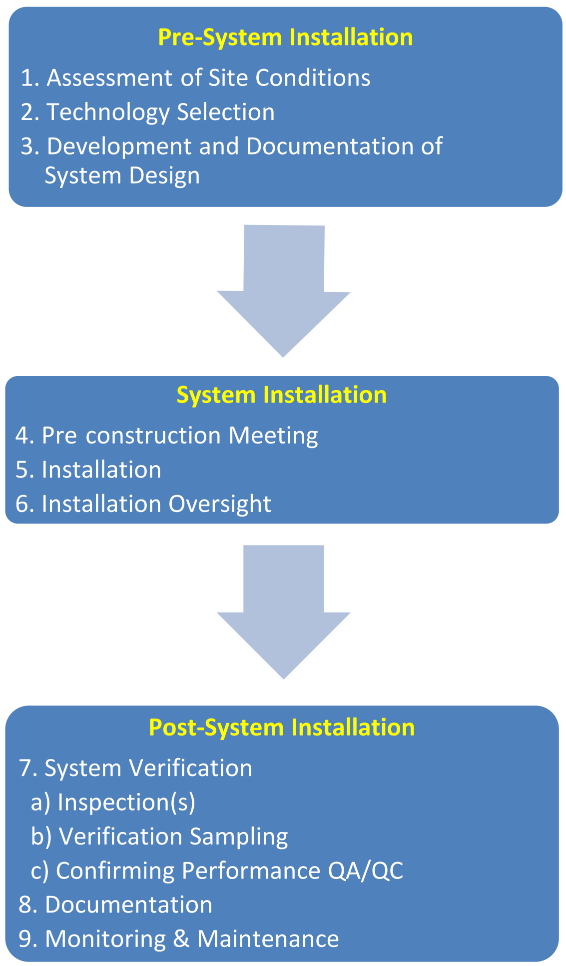
For the Fact Sheet Click here

After the installation of an active (see ***Active Mitigation Fact Sheet***) or passive (see ***Passive Mitigation Fact Sheet***) mitigation system, or implementation of an environmental remedial technology (see ***Remediation and Institutional Controls as Vapor Intrusion Mitigation Fact Sheet***), post-installation verification and testing for confirmation of the design and operating parameters is often required. It is during this time that the system is confirmed to be operating and meeting performance specifications.

3.3 VI Mitigation Operation, Maintenance, and Monitoring (OM&M)/Exit Strategy Fact Sheet

For the Fact Sheet Click here

After a mitigation strategy that addresses an active (see ***Active Mitigation Fact Sheet***) system, passive (see ***Passive Mitigation Fact Sheet***) system, or an environmental remedial technology (see ***Remediation and Institutional Controls as Vapor Intrusion Mitigation Fact Sheet***) has been designed and implemented, the OM&M (see ***Operation, Maintenance, and Monitoring/Exit Strategy Fact Sheet***) of the selected mitigation strategy is critical to ensure long-term effectiveness of the system and protection of public health. Complex mitigation strategies will typically require more complex OM&M procedures. The key to any OM&M is to ensure that the system is operating as designed and that it remains effective in the long-term and until it is appropriate to implement an exit strategy.



The four fact sheets for VI mitigation strategies include rapid response and ventilation, active mitigation measures, passive mitigation measures, and remediation and institutional controls. In general, VI mitigation strategies follow the process flow step diagram, Figure 4-1, noted on this page. A brief overview of each fact sheet is found below.

Figure 4-1. Process flow step diagram illustrating typical VI mitigation strategies.

For the Fact Sheet Click here

4.1 VI Mitigation Rapid Response and Ventilation Fact Sheet

Rapid response is an interim VI mitigation approach that may be appropriate, under certain conditions, prior to implementing a long-term mitigation strategy for an occupied room or building. For the purposes of this document, a rapid response is one that could be easily implemented and verified on a timescale of days to weeks and operated on a short-term basis while more immediate mitigation strategies are implemented. A long-term mitigation strategy will take longer to design, implement, and verify and is intended to operate until the remedial objectives are met. Note that some technologies or mitigation methods characterized in this document as rapid response may also be suitable as long-term mitigation strategies.

For cases where COCs are detected in indoor air at concentrations exceeding short-term exposure criteria, a rapid response is typically warranted. Rapid response actions may also include administrative controls, such as evacuating and eliminating occupant access to the building, or engineering controls that reduce chemical vapor exposure through building ventilation, indoor air treatment, or physically preventing vapor entry into the building.

4.1.1 HVAC and Indoor Air Mitigation Technologies

HVAC adjustments and air purifying units (APUs) are common techniques that can be used to address the presence of COCs in indoor air. Both can be used as rapid response actions to lower indoor air concentrations within a relatively short time frame (i.e., days). Note that neither technique is intended to remediate the VI source.

4.1.2 How HVAC and Indoor Air Mitigation Technologies Work

For buildings equipped with an engineered HVAC system, VI mitigation may be accomplished using HVAC as an engineering control. VI mitigation may be achieved by pressurizing the building—thereby controlling cross-slab pressures and preventing VI—and/or increasing air exchange rates by providing sufficient outdoor air exchange to dilute the effects of VI on indoor air quality.

APUs—commonly adsorption-based units that use a particulate filter and granular activated carbon—can be ducted onto the HVAC system or used as stand-alone, portable or wall-mounted units. APUs are intended to actively circulate indoor air and remove certain COCs present in the air stream.

4.1.3 How to Evaluate Performance

Performance evaluation for both techniques includes their ability to achieve acceptable indoor air concentrations under practical operating conditions and costs. Overall performance is subject to uncertainty, and follow-up indoor air sampling is necessary. Note that background COC contributions to indoor air unrelated to the subsurface may complicate interpretation of indoor air sampling results, such that additional lines of evidence, including differential pressure, airflow, and tracer gases, should also be considered when evaluating performance.

Potential concerns associated with HVAC adjustments include energy intensiveness and technical limitations (e.g., outdoor air is too humid). However, certain buildings with complex layouts or utility networks may achieve indoor air targets through adjustments to their HVAC with less disruption or expense than sub-slab depressurization (SSD) or sub-slab ventilation (SSV) installation, even when long-term operating costs are considered. HVAC adjustments and APUs may also provide temporary VI mitigation prior to installation of other mitigation systems. HVAC adjustments may also augment the performance of other mitigation systems (e.g., reduce SSD operating requirements).

Multiple factors need to be taken into consideration when selecting and sizing APUs (e.g., number of units and individual capacity). The total APU system airflow should be several times the baseline airflow through the space to be treated (e.g., 5–10 air exchanges per hour). COC mass loading and carbon consumption should also be considered. Potential limitations include competition from nontarget COCs (e.g., background sources), moisture, noise, and human interference.

4.2 Active Mitigation Fact Sheet

For the Fact Sheet Click here

Active mitigation technologies are typically applied below the building slab. The most common approaches involve extraction of vapors from the subsurface materials (e.g., soil or gravel) immediately below the structure. Sub-slab depressurization (SSD)[2] and sub-slab ventilation (SSV) are the most commonly installed types. Other approaches detailed in the active mitigation measures fact sheet include sub-membrane depressurization (SMD) and crawlspace ventilation (CSV).

4.2.1 How SSD and SSV Systems Work

SSD uses an electric fan to create a pressure gradient across the building envelope to prevent vapors from migrating from the subsurface into the building through soil gas advection. When a negative pressure differential is present below a building envelope relative to inside the building envelope, any communication between indoor air and the sub-slab soil gas (e.g., through cracks or improperly sealed utilities, etc.) will be one-way, from indoor air to below the slab, mitigating indoor air impacts. The goal for SSV is

[2] Related approaches include sub-membrane depressurization, drain-tile depressurization, and block-wall depressurization.

to reduce vapor concentrations below the floor of a structure's slab to levels that are low enough to maintain acceptable indoor air concentrations above the slab, regardless of whether there is a consistent or even measurable vacuum below the floor. Because SSD and SSV systems both apply negative pressures and induce air flow below the slab, some dilution of COC concentrations and some reduction in upward air flow may occur with both approaches.

In some cases, SSV-type systems may be intended to help maintain oxygen levels below the building (usually at some depth below the building slab) and promote aerobic biodegradation of petroleum hydrocarbons, methane, and other compounds that tend to degrade aerobically in the vadose zone (e.g., vinyl chloride).

Active mitigation is chosen because, although natural forces (e.g., thermal gradients or wind) can induce negative air pressures and air flow below a slab (i.e., passive systems), these forces are generally weaker and much more variable than the pressures and air flows that can be induced by electric fans. While it may be reasonable in some situations to initially operate an installed SSD or SSV system in passive mode, adequate performance should be demonstrated and monitored, and the design should include a contingency for active operation if necessary. Typically, a system designed to operate passively have a different layout than a system designed and intended to operate as an active system.

4.2.2 How to Evaluate Performance

The initial and then continued long-term performance of an active mitigation system is reflected by collecting additional lines of evidence. These lines of evidence include readings from the system (e.g., air flow rate, vacuum, etc.) and how the system is affecting the building (e.g., differential pressure field extension under the slab, indoor air samples, etc.). System performance data are collected both during system commissioning and then periodically during system operation. Frequency of collecting performance data is determined on a site-specific basis. Data can be used both to verify system performance and to understand when a system may no longer be necessary and steps toward evaluating system decommissioning can be taken.

The performance of any mitigation system is ultimately reflected by indoor air concentrations of the COCs over time; however, interpretation of indoor air test results can be confounded by background sources and temporal variability. Therefore, additional and alternate ways to evaluate and monitor system performance can be valuable. SSD system performance is directly related to negative pressures, which can be continually monitored at relatively low cost. SSV system performance can be inferred by sub-slab vapor concentrations that are below screening levels (based on generic or site-specific attenuation factors); higher levels do not necessarily mean that indoor air is impacted, as

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screening levels are typically conservative, but also do not provide confirmation on their own that the system is performing adequately.[3]

4.3 Passive Mitigation Fact Sheet

For the Fact Sheet Click here

Passive mitigation technologies are primarily intended to modify the VI pathway without the use of electrical or mechanical means and commonly involve creating a barrier to vapor migration through the slab, such as barriers placed immediately below slabs (new construction), sealing of cracks and other openings in slabs, and surface coatings. Common passive mitigation barrier systems detailed in the fact sheet includes asphalt latex membranes (ALM), thermoplastic membranes (TM), composite membranes (CM), and epoxy floor coatings (EFC). Other passive mitigation measures detailed in the fact sheet include passive venting systems, such as passive sub-slab venting and aerated floor systems (AFS), and building design specifications, such as raised foundations or vented garages.

4.3.1 Passive Barriers

In most cases, advective flux of COCs across the slab is the dominant transport mechanism of concern. Vapor barriers work by blocking the flow of soil vapor through joints, cracks, or other openings in the slab. Therefore, the quality of the seal between the vapor barrier and foundation and at penetrations through the slab will be most important. In some cases, sub-slab vapor concentrations are high enough for diffusion through the slab to be of concern. In these cases, vapor barriers work by reducing diffusion flux through the slab and the permeance of the barrier to the COCs is important.

Vapor barriers are typically included in the design of SSD systems for new construction, in part to limit the downward flow of building air through the slab, thus decreasing the size and/or number of fans required to depressurize the slab. The vapor barrier also reduces the potential for advective transport of COCs into the building if the fans temporarily shut down. Reduced sub-slab vapor COC concentrations due to sub-slab venting associated with SSD system operation also provide additional protection.

It should be noted that a successful barrier may cause COC concentrations to increase below the slab, unless otherwise controlled (e.g., by venting). This could be of concern if COCs diffuse laterally to other areas, or if future imperfections in the barrier allow sub-slab vapors to enter the building. Passive venting systems are often used in combination with passive barrier systems to prevent these conditions from occurring.

4.3.2 How to Evaluate Performance

As indicated above, the performance of any mitigation system is ultimately reflected by indoor air concentrations of the COCs over time. The integrity of the barrier can be evaluated by vacuum and/or smoke testing after construction, although this provides only

[3] Combined with contemporaneous indoor air data, sub-slab vapor concentrations could potentially be used to develop or modify site-specific sub-slab attenuation factors.

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a qualitative assessment of performance. Measurement of sub-slab vapor COC concentrations may suffice, if concentrations are below screening levels, although this may be unlikely with passive systems. Therefore, indoor air testing may be necessary in many cases to confirm performance of mitigation systems relying solely on vapor barriers.

4.4 Remediation and Institutional Controls as Vapor Intrusion Mitigation Fact Sheet

For the Fact Sheet Click here

In some instances, environmental remediation technologies can serve as VI mitigation. Remedial technologies detailed in the fact sheet include soil vapor extraction (SVE) and multiphase extraction (MPE). Institutional controls can also provide protection and serve as an administrative assurance for mitigation of a known or potential VI concern.

4.4.1 Remediation Technologies for VI Mitigation

For remediation technologies to serve dually as VI mitigation and site cleanup, they must accomplish the same objective as a dedicated VI mitigation system, which is to reduce concentrations of the COCs in indoor air below the applicable regulatory levels. Remediation technologies that can serve that purpose include SVE and MPE. An overview of each of these technologies is detailed in the ***Remediation and Institutional Controls as Vapor Intrusion Mitigation Fact Sheet*** and accompanying technical information sheets. In general, the most common remedial technologies used for VI mitigation include SVE and MPE.

4.4.2 How to Evaluate Performance of Remediation Technologies for VI Mitigation

Similar to performance evaluation for active and passive mitigation measures above, remedial technologies used to address VI are reflected by indoor air concentrations of COCs over time. Measurement of sub-slab vapor COC concentrations over time provides evidence of the effectiveness of the remedial technology approach for VI mitigation.

4.4.3 Institutional Controls (ICs)

ICs are a form of land use controls (LUCs) that provide protection from exposure to site-related contaminants. While ICs consist of administrative or legal restrictions on a site, LUCs can also use physical measures, which are called engineering controls or ECs (e.g., physical barriers). In contrast to ECs, ICs are primarily government controls, proprietary controls, enforcement or permit mechanisms, and informational devices. Planning that protects human health and the environment and uses all aspects of an IC life cycle (ITRC, 2016) is essential for long-term success (e.g., a long-term stewardship plan). As it relates to the VI pathway, ICs can be applied as a stand-alone remedy (for undeveloped lands or restricted use on developed land), as part of an overall remedy selection, or as a permit that requires ongoing monitoring and maintenance of the mitigation system. More details are provided in the ***Institutional Controls Technology Information Sheet***.

4.5 Technology Information Sheet for Emerging Technologies—Aerobic Vapor Mitigation Barrier (AVMB)

For the Technology Information Sheet Click here

The ***Aerobic Vapor Mitigation Barrier Technology Information Sheet*** describes a method for in situ VI mitigation and remediation at sites with existing buildings situated above subsurface sources of VOCs that rapidly biodegrade aerobically—namely, petroleum hydrocarbons and methane. The method involves the delivery of atmospheric (ambient) air below and around a building foundation at rates sufficient to maintain aerobic conditions in the vadose zone that act as a "biobarrier" to VI. The technology can also enhance the remediation of certain shallow subsurface vapor sources. The method represents a cost-effective alternative to other petroleum VI mitigation and remediation technologies (e.g., soil vapor extraction (SVE) and sub-slab depressurization (SSD)) because the technology is applied in situ and does not require expensive vapor treatment or intrinsically safe equipment.

Similar to performance evaluation for VI mitigation strategies described above in Section 4.4, the effectiveness of using AVMB to address VI is reflected by indoor air concentrations of COCs (primarily petroleum hydrocarbons and methane) over time. Additionally, measurement of sub-slab vapor COC concentrations over time provides evidence that the AVMB system is effectively reducing petroleum hydrocarbon and methane COCs.

5 REFERENCES AND ACRONYMS

The ITRC VI Mitigation Training web page includes lists of acronyms, a full glossary, and combined references for the fact sheets. The user is encouraged to visit the ITRC VI Mitigation Training web page to access each fact sheet and supplementary information and the most up-to-date source of information on this topic.

Conceptual Site Models for Vapor Intrusion Mitigation

ITRC has developed a series of fact sheets that summarizes the latest science, engineering, and technologies regarding vapor intrusion (VI) mitigation. This fact sheet describes:

- the importance of understanding the VI pathway and how it can be modified by various mitigation technologies to reduce indoor air concentrations
- information needed to evaluate VI mitigation alternatives by enhancing the VI Conceptual Site Model (CSM)

INTRODUCTION

The value of a conceptual site model (CSM) when evaluating the potential for vapor intrusion (VI) is well established (ITRC, 2007a; ITRC, 2007b; ITRC, 2014). The VI CSM provides a general overview of the VI pathway, including the locations and types of vapor sources, subsurface vapor transport mechanisms, foundation and other building conditions affecting the rate of vapor entry, and receptors that could be impacted by VI. The VI CSM helps the practitioner evaluate the potential for a complete VI pathway, identify data gaps, and communicate findings and conclusions to other stakeholders.

Nevertheless, a VI CSM adequate for evaluating the potential for VI might not provide enough information to select an appropriate mitigation approach. For example, more detailed information related to slab and sub-slab conditions might be required to evaluate the efficacy of sub-slab depressurization (SSD) or sub-slab ventilation (SSV). Similarly, more detailed information related to building conditions might be required to evaluate the efficacy of mitigation that relies on increasing building air exchange rates and/or interior pressure levels. In some cases, more information may be required about the nature of preferential pathways to evaluate mitigation options. Presumably, the existing VI CSM will identify the presence of petroleum VI, but more information might be needed to evaluate the need for off-gas treatment and intrinsically safe equipment. Because CSMs are evolving documents, this additional information should be used to enhance the VI CSM to better evaluate and select an appropriate vapor control strategy for the site.

This fact sheet introduces two tools to help enhance the VI CSM for mitigation decision-making purposes. The first is a checklist to help identify information that might be needed to enhance the VI CSM for evaluation of mitigation alternatives. The second is a conceptual flowchart illustrating various VI pathways to help identify strategies that could be employed to control these pathways that are consistent with the VI CSM.

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As discussed above, the information needed to evaluate the potential for VI might not be sufficient to evaluate mitigation alternatives. This fact sheet is supported by a ***Vapor Intrusion Mitigation Conceptual Site Model Checklist*** of information that may be beneficial to enhance the VI CSM for the purposes of evaluating mitigation alternatives.

2.1 Checklist to Enhance the VI CSM for Evaluation of Mitigation Strategies

This checklist assumes that VI site characterization has been completed and the user has reviewed the existing CSM, confirmed key components, and determined that VI mitigation is necessary. Guidance and CSM checklists for VI site characterization are found elsewhere (ITRC, 2007a; ITRC, 2007b; ITRC, 2014). The purpose of the ***Vapor Intrusion Mitigation Conceptual Site Model Checklist*** is to further develop and emphasize the key considerations of the VI CSM as they relate to mitigation and to identify and characterize site and building conditions as necessary for evaluation of VI mitigation alternatives.

This checklist is a tool to guide mitigation planning and facilitate communication between interested parties. The checklist can be used in various ways. For example, it can be used as a framework for enhancing the VI CSM to include mitigation considerations. It can also be completed by the preparer of the mitigation plan, or used by the reviewer of this plan, to document information contained in mitigation plans and reports. The checklist is organized with mitigation goals at the beginning to help the user focus on site features that are relevant to development of a mitigation plan to meet those objectives. For example, a detailed building-specific evaluation may not be needed if the mitigation goals and subsurface conditions indicate that the VI mitigation effort should be focused on the source area for the chemicals of concern (COC) or pathway outside of the building envelope.

2.2 How Mitigation Technologies Modify the VI Pathway

The objective of vapor control is to reduce indoor air concentrations of VI-related COCs, below applicable action or screening levels. This requires modification of the VI pathway to reduce the mass flux of COCs entering the building and/or to reduce indoor air COC concentrations by removal or dilution.

As indicated on Figure 2-1, measures that can be used to control VI can be applied at different points along the VI pathway to accomplish these goals. Understanding how a mitigation technology is modifying the VI pathway helps us understand (1) whether the technology is compatible with the site conditions and stakeholder objectives (e.g., cost, timeliness, sustainability, etc.), and (2) what information is needed to evaluate the performance of the system over the short and long terms.

Figure 2-1 presents a flowchart that may be used as a tool to guide the user in selecting appropriate exposure scenarios based on information identified in the checklist. The flowchart may also be used in the evaluation of mitigation/remediation alternatives.

The approach recommended for completing this flowchart is as follows:

- Characterize the chemical types, site sources, and relevant exposure pathways using the data and information summarized from the checklist and associated supporting site information to customize the flowchart for the site.
    - ► Check the small checkboxes for every relevant identified source, transport mechanism, and exposure pathway.
- Identify and characterize the relevant indoor air receptor(s) and indoor air criteria.
    - ► Consider land use restrictions and surrounding land use when making this selection, if there are no receptors present, or likely to be present, or if institutional controls prevent exposure from occurring and are likely to stay in place.
- Identify potential mitigation/remediation measures (shown as valve symbols) that will break the lines linking sources, transport mechanisms, and pathways leading to the indoor air receptors. If there are no connected lines and no data gaps limiting the reliability of the VI CSM, there is no exposure and no mitigation measures are required.
    - ► Select mitigation/remediation measures (shown as valve symbols) that will break the lines linking sources, transport mechanisms, and pathways leading to the indoor air receptor(s).
    - ► Adjust the mix of mitigation/remediation measures until no potential exposure routes remain.
    - ► Graphically illustrate the most likely mitigation/remediation measure(s) selected for the site by marking the appropriate valve symbols on the flowchart and recording and detailing the selected action on the right-hand-side of the flowchart.

More specific descriptions for Figure 2-1 follow. Figure 2-1 is a guide, may not be applicable in all situations, and may be modified as appropriate. Other CSM forms, depending on the artistic capability of the preparer, may be used to convey the same information. This can include graphic cartoons, plan views, sections, and/or tables. Although we recognize Figure 2-1 is far more detailed than some CSM diagrams employed for VI, simpler diagrams may not convey some of

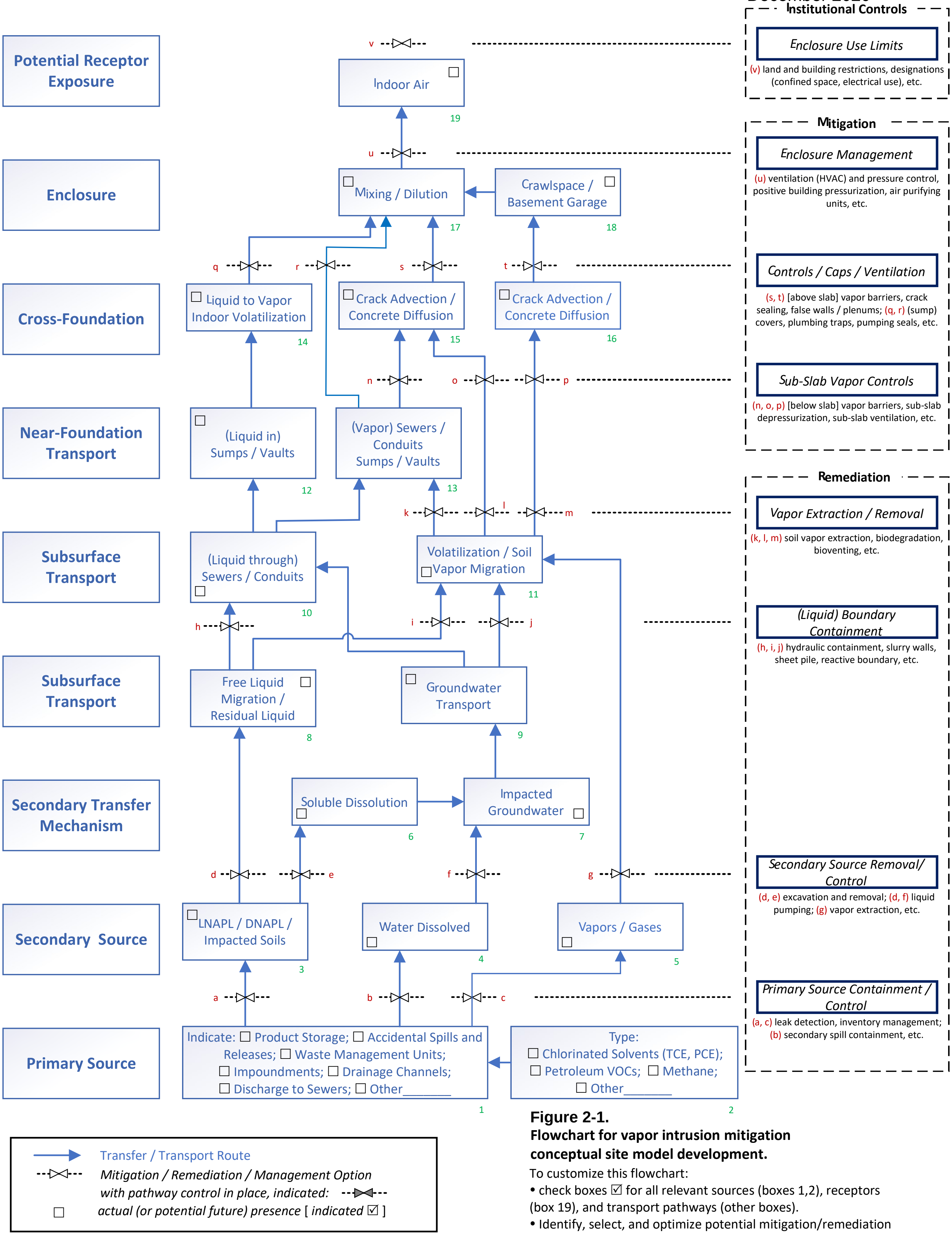

Figure 2-1.
Flowchart for vapor intrusion mitigation conceptual site model development.

To customize this flowchart:

- check boxes ☑ for all relevant sources (boxes 1,2), receptors (box 19), and transport pathways (other boxes).
- Identify, select, and optimize potential mitigation/remediation measures (shown to the right of valve symbols) that will break the lines linking sources, transport mechanisms, and pathways.
- See Section 2.2 for more details.

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the possible complicating (but infrequent) conditions encountered in suspected VI events. As with any CSM diagram completeness and confidence will vary and hopefully will improve as more site-specific information is collected and interpreted.

Compartments:

Primary Source. Indicate the original release (1) and type (2). Additional information may include volumes, date(s) and nature of release, phase, and possible emergency response actions. Indicate composition of the source. Include whether constituents may be of direct concern, advective carriers (methane, water), or both. Source-generated constituents (biogenic gases, intermediate reaction or degradation products) may be included as applicable.

Secondary Source. Nature of the near-release concentrated release (3, 4, 5) in the environment, including delineated areas and/or volumes. Constituent composition may vary between the phase types.

Secondary Transfer Mechanisms. Primarily to indicate demarcation and phase transfer between a delineated residual NAPL (6) and the nearby higher concentration zone of a water-soluble groundwater plume (7).

Subsurface Transport. [lower row]. Includes possible initial transient migration of NAPLs (8) as DNAPL or LNAPL, which should be delineated and monitored (ITRC, 2018) as part of the VI CSM. NAPL migration is transient and will eventually expand to a quasi-steady residual (near-immobile) zone. Water-soluble groundwater transport (9) may include constituent advection, diffusion, dispersion, degradation, and transformation.

Subsurface Transport. [upper row]. Liquid migration through identified subsurface conduits (10), as either water or NAPL (so indicate). Volatile gases or vapors in unsaturated (vadose) soils (11) from either NAPL or groundwater. Transformation, (aerobic) degradation, and attenuation may be included as appropriate.

Near-Foundation Transport. May include subsurface vapor migration through conduits (13) or liquid migration through conduits (12) to the immediate subsurface vicinity of a building enclosure.

Cross-Foundation. Migration of vapors through a foundation interface to a building enclosure, either through soils (16) or through a near-foundation conduit (15). Liquids (NAPL or water) may also migrate directly through a building envelope (14), either through a conduit or directly in contact with the building foundation.

Enclosure. May include indoor space intended for continuous human occupancy (17). Can also include intermediate space such as crawlspaces or basement garages (18) not designed for continuous human occupancy. Specific buildings (or impacts to multiple buildings) may certainly be more complex than indicated in the simple flowchart; add supporting information and more detail as appropriate.

Potential Receptor Exposure. Indoor air enclosures (19) with possible human cohorts of varied designations (residential, commercial, industrial, confined space), including applicable defined gas and vapor criteria levels (acute or chronic toxicity, flammability, etc.) for constituents of concern.

Transport Pathways and Controls:

Transport pathways in the CSM may be connected through a series of compartments from the primary source to indoor air, including a number of "valves" along the route showing remediation, mitigation, or control measures that may be employed to break the exposure pathway. In some situations (such as just after initial notification by a resident of odors, for example) only a portion of the pathway is understood. Selected control measures (indicated adjacent to the Indoor Air compartment, box 19) may still be available in this situation to control exposure even in the absence of complete site-specific information.

Remediation:

The list of remediation measures is not necessarily comprehensive. Other remediation options may also be employed in controlling or eliminating vapor exposure pathways. Note that a portion of the contaminant, outside of the remediated or controlled zone, may remain for a varied time (nominally hours for unsaturated zone vapors, or up to many years for groundwater or NAPL in soils or sediments) and might require further mitigation measures.

Primary Source Containment/Control. Indicated control actions (a, b, c) are intended to ensure the primary release is prevented, detected, terminated, controlled, and/or removed.

Secondary Source Removal/Control. Listed remedial actions (d, e, f, g) may be intended to remove all or part of a secondary source zone, or to eliminate further migration beyond a defined delineated zone.

(Liquid) Boundary Containment. Remedial actions (h, i, j) are intended to control NAPL or impacted groundwater and eliminate further migration beyond a designated containment zone.

Vapor Extraction/Removal. Soil vapor extraction, bioventing, or natural vapor degradation (k, l, m) may limit further migration of vapors, and may also be employed to enhance depletion of some source zones.

Mitigation:

The list of engineered mitigation measures is intended to control or eliminate actual or potential risks in enclosures or indoor air. It is not necessarily a comprehensive list.

Sub-slab Vapor Controls. Measures implemented at and below a new or existing building foundation (n, o, p) to eliminate subsurface vapor migration into air. Active and passive controls (see ***Active Mitigation Fact Sheet*** and ***Passive Mitigation Fact Sheet***) are not differentiated in the diagram and act on the same pathway at the same point.

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Controls/Caps/Ventilation. Includes measures implemented at and above a foundation interface (s, t) to eliminate vapor migration through the foundation, or measures intended to control vapor migration into a building envelope through conduits (q, r).

Enclosure Management. Includes engineered measures to control entry of contaminant vapors into an enclosure or remove them by treatment (u). (For more information, see the fact sheets and associated supporting fact sheets on ***Rapid Response and Ventilation***, ***Active Mitigation***, and ***Passive Mitigation***).

Institutional Controls:

Enclosure Use Limits. Administrative controls (v) up to and including evacuation or condemnation for use, to eliminate human exposure.

REFERENCES AND ACRONYMS

The references cited in this fact sheet are included in a combined list with references cited in other fact sheets and technology information sheets prepared by the ITRC VI Mitigation Training team. This reference list, along with an acronym list and glossary, is available on the ITRC web site.

VAPOR INTRUSION MITIGATION CONCEPTUAL SITE MODEL CHECKLIST

SCOPE AND INSTRUCTIONS

This checklist assumes that vapor intrusion (VI) site characterization has been completed and the user has reviewed the existing conceptual site model (CSM), confirmed key components, and determined that VI mitigation is necessary. Guidance and CSM checklists for VI site characterization are found elsewhere (ITRC, 2007a; ITRC, 2007b; ITRC, 2014). The purpose of this checklist is to further develop and emphasize the key considerations of the VI CSM as they relate to mitigation and to identify and characterize site and building conditions as necessary for evaluation of VI mitigation alternatives.

This checklist is a tool to guide mitigation planning and facilitate communication between interested parties. The checklist can be used in different ways. For example, it can be used as a framework for enhancing the VI CSM to include mitigation considerations. It can also be completed by the preparer of the mitigation plan, or used by the reviewer of this plan, to document information contained in mitigation plans and reports. The checklist is organized with mitigation goals at the beginning to help the user focus on site features that are relevant to development of a mitigation plan to meet those objectives. For example, a detailed building-specific evaluation may not be needed if the mitigation goals and subsurface conditions indicate that the VI mitigation effort should be focused on the chemicals of concern (COC) source area or pathway outside of the building envelope. Click **here** to download a fillable digital checklist.

1. MITIGATION GOALS

Identify the key mitigation goals or risk drivers. States may consider augmenting this checklist with the appropriate mitigation goals or risk drivers for their state or region.

- Describe why mitigation is needed (e.g., primary COCs and action or risk levels in environmental media or indoor air exceeded; other drivers such as redevelopment, property transaction, or pre-emptive mitigation).

- Describe mitigation goals (e.g., rapid response requirement and basis/receptor; reduction/elimination of contaminant mass flux into building via conventional vapor intrusion and/or preferential pathway; primary or secondary subsurface source reduction needed).

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- Describe the land use and land use goal (e.g., residential; commercial; industrial; mixed use).

- Have the appropriate standards and regulations been identified? ☐ Yes ☐ No ☐ Unknown

  If "Yes", summarize below.

  Note: It is the user's responsibility to determine applicable federal, state, and local standards, regulations, and guidance. Be aware that some states have specific guidance for active and passive mitigation systems. Furthermore, design standards such as ANSI/AARST may apply and, in some municipalities, additional plumbing and building codes may also apply for vapor intrusion mitigation systems.

- Identify and describe the obligations of various stakeholders and logistics for site and building access when various stakeholders may be responsible for the proposed mitigation/remediation/management option (e.g., party owning the property vs. party implementing the mitigation).

2. SUBSURFACE CONDITIONS

To complete this section, locate available geologic/hydrogeologic cross sections and other information to put the contamination into context. In the descriptions below, include references to site reports, as necessary, to support the discussion. Copies of figures or other information may be attached to this checklist as appropriate.

- Describe the site geology and hydrogeology (e.g., distinct strata/soil types, moisture content, heterogeneity/homogeneity of soils and lithologic units encountered, depth and lateral continuity of confining units and transmissive units; redox potential of impacted aquifer).

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- Describe the thickness of the vadose (unsaturated) zone, depth to capillary fringe, and phreatic (saturated) zone. Include units and reference point (e.g., depth to saturated zone in feet below ground surface).

- Describe other considerations (e.g., impacts in shallow unconsolidated aquifer vs. deeper aquifers; presence of perched aquifers; seasonal water table fluctuations or changes in flow direction).

3. SUBSURFACE COC SOURCE

Identify the primary or secondary COC source that the mitigation plan addresses. In the descriptions below, include references to site reports, as necessary, to support the discussion. Copies of figures or other information may be attached to this checklist as appropriate.

- Describe the composition (e.g., chlorinated solvents, petroleum hydrocarbons, methane).

- Describe the presence and distribution of subsurface COC sources (e.g., light nonaqueous phase liquid (LNAPL), dense nonaqueous phase liquid (DNAPL), soluble plume, vadose zone soil contamination).

- Describe all impacted environmental media and extent of impacts. Include maps or cross sections, as needed.

- Describe status of source and impacts (e.g., known vs. unknown source; delineation completed vs. ongoing; plume stability).

- Describe status and frequency of source monitoring.

- Describe other considerations (e.g., age of release; remediation planned or in progress; location of underground utilities; presence of impacted media near or within utility lines).

4. SITE SETTING

Characterize contamination in context with areas and buildings where VI mitigation is needed. In the descriptions below, include references to site reports, as necessary, to support the discussion. Attachments to this checklist with, for example, copies of figures may also be provided.

- Summarize the nature of the site and surrounding area (e.g., urban vs. rural; paved vs. unpaved; topography; presence of surface water bodies).

- Describe other considerations that may affect mitigation planning (e.g., climate [rainfall, temperature]).

- Describe proximity of contaminants in the subsurface to existing or future buildings requiring VI mitigation (e.g., contamination in contact with building; separation distance).

- Describe potential preferential pathway issues (e.g., sanitary sewer or utility tunnel intersecting contaminated groundwater or nonaqueous phase liquid (NAPL) zone).

5. BUILDINGS

Locate and map out existing buildings, identify square footage, and identify areas for potential future construction if known. If multiple buildings are being evaluated, tabulation of the following for each building may be necessary. Also, building additions may need to be evaluated separately. Note that a detailed, building-specific evaluation may not be needed if the VI mitigation effort is focused on the COC source area or pathway outside of the building envelope. In the descriptions below, include references to site reports, as necessary, to support the discussion. Attachments to this checklist with, for example, copies of figures may also be provided.

5.1. Structure

- Indicate current building use:

  ☐ Residential

  ☐ Non-Residential

  If non-residential, could future use include residential? ☐ Yes ☐ No ☐ Unknown

  Are land use controls (LUCs), use restrictions, institutional controls, or equivalent in place? ☐ Yes ☐ No

Note: If current or future site use is or could be residential, the most conservative state and federal regulations apply for technology selection and design.

- Indicate structure status:

  ☐ Existing construction

  ☐ New construction

  ☐ Potential future construction

- Describe building configuration (e.g., single-family home, apartment, multistory building, high rise office, strip mall, warehouse, attached garage, multipurpose/use building, building with additions). Include total building footprint (area) and height. Note occupancy status.

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- Describe below-grade portion of the structure (e.g., finished vs. unfinished basement and suitability for occupancy, crawl space, slab on grade, pile-supported, dirt floor; foundation walls; floating slab, edge supported). Include depth below grade and thickness of slab.

- How many foundation sections (i.e., concrete pours, or change in foundation type) are present within the building?

  ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ Other: ___________________

  Is the foundation a monolithic pour or are there post tension reinforcement cables in the slab(s)? ☐ Yes ☐ No ☐ Unknown

  If "No" explain further (for example, stem walls, monolithic footings, column pads at grade, concrete walls, block walls):

  Note any unique structure conditions (for example, concrete reinforcement, wire mesh, rebar post tension slab, mud slab):

- Describe below-grade structure integrity (e.g., degraded, open, or closed joints or cracks, floor sealant present, liner present) and penetrations (e.g., floor drains, sumps, dry wells, perimeter drains; plumbing/utilities; elevator or machine pits).

- Describe sub-slab conditions (e.g., soil/fill type or types, including native/compacted soil, stone, fill material; permeability; thickness; moisture content—wet vs. dry; void spaces; existing ventilation systems or moisture barriers).

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- Is the foundation in close proximity to the water table? ☐ Yes ☐ No
- Identify building- or fire-code requirements for sub-slab ventilation systems (e.g., for methane) or moisture barriers below foundations.

Identify data available for building. Note: measurements may be needed, depending upon mitigation option selected.

☐ Sub-slab soil gas

☐ Indoor/outdoor air

☐ Attenuation factor (indoor air/sub-slab concentration)

☐ Indoor-outdoor differential pressure

☐ Indoor-subslab differential pressure

☐ Diagnostic testing (pressure field extension range, identification of voids)

5.2. Interior Space

- Describe wall type (e.g., wood frame, block wall, poured, drywall).

- Describe utility systems that may present preferential pathways for VI (e.g., electrical, plumbing, communication/phone, mechanical).

- Describe special issues (e.g., elevators, stairwells, trash chutes, utilidors that may present preferential pathways for VI; exhaust fans, fume hoods that may introduce back-drafting potential; gas-fired appliances, building with multiple zones).

- Describe the heating, ventilation, and air conditioning (HVAC) system (e.g., forced air vs. radiant; equipment location(s), for example basement, crawl space, utility closet, attic, roof; source of return air, including inside air, outside air, combination; system design considerations relating to indoor air pressure). Note: positive pressure is often the case for commercial buildings, but should be verified.

6. DATA GAPS AND UNCERTAINTY SUMMARY

Summarize the VI pathway described above. It is recommended that the VI pathway be described using the VI CSM Flowchart, cross sections, or sketches to illustrate the specific pathways and relevant mitigation/remediation/management option(s) to cut off the pathways.

- List key data gaps, if any.

Public Outreach During Vapor Intrusion Mitigation

ITRC has developed a series of fact sheets that summarize the latest science, engineering, and technologies regarding vapor intrusion (VI) mitigation. This fact sheet describes:

- common concerns of communities affected by VI
- specific vapor intrusion considerations for development of a Community Engagement Plan
- references to support preparation of a Community Engagement Plan

1 INTRODUCTION

It is important to engage the public at environmental contamination sites, but at vapor intrusion sites it is *essential* to engage the people who own, live, work or study in, or otherwise occupy impacted buildings. Their cooperation, not just permission, makes it possible to investigate, remediate, mitigate, and monitor properties contaminated with hazardous substances. You may be asking them to agree to allow intrusive or disruptive activities such as drilling holes through their floors, attaching fans and piping to their buildings, or rearranging their basements for investigation or mitigation.

Before the first announcement or knock on a door, the environmental team should implement a Community Engagement Plan that recognizes the unique character of each community and the form of planned investigation or mitigation. While the contents and logistics of a Community Engagement Plan for a vapor intrusion issue are listed separately below, they are integrally related and will need to be developed together.

2 POSSIBLE COMMUNITY CONCERNS FOR THE COMMUNITY ENGAGEMENT PLAN

Characterizing the community and listening to affected parties to determine their concerns are the first steps in developing a Community Engagement Plan. Some common concerns are listed in Table 2-1. The initial characterization will help determine when, where, and how to communicate in the future with the affected parties.

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Table 2-1. Common affected party concerns.

Occupant/Use	Possible Concerns					
	Communication Language Barriers	Operational Impact	Property Value (increase or decrease)	Health and Safety	Cooperation/ Trust	Access/Privacy
Residential						
Homeowner	X		X	X	X	X
Manager	X	X			X	X
Renter	X			X	X	X
Other Stakeholders (e.g., tribal communities)	X		X	X	X	X
Non-Residential						
Commercial/Industrial	X	X	X	X	X	X
Retail Tenants (incl. customers)	X	X		X	X	X
Hospital (incl. patients)	X	X		X	X	X
School/Daycare (incl. parents)	X	X		X	X	X
Place of Worship	X	X		X	X	X
Public Facilities	X	X		X	X	X

Note: X indicates common potential concerns affecting various categories of occupants.

3 UNIQUE TOPICS FOR THE COMMUNITY ENGAGEMENT PLAN

Refer to the ITRC Risk Communication section within *Technical Resources for Addressing Environmental Releases of PFAS – Per- and Polyfluoroalkyl Substances* (https://pfas-1.itrcweb.org/14-risk-communication/)) for generic, but in-depth, guidance on developing a Community Engagement Plan. The risk communication section addresses general topics including Role of Risk Perception; Risk Communication Challenges; and Risk Communication Planning and Engagement Tools.

A Community Engagement Plan specific to vapor intrusion is discussed in detail within section 7.0 of the ITRC Petroleum Vapor Intrusion (PVI) Guidance (October 2014) (https://www.itrcweb.org/PetroleumVI-Guidance/). The community engagement section addresses topics including Stakeholder Concerns; Community Engagement Plans; and Risk Communication. The PVI Guidance includes a robust description of the topics discussed within this fact sheet. However, note that the risk from PVI, which is the focus of the PVI Guidance, is generally lower than the risk from other contaminants such as chlorinated solvents.

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A Community Engagement Plan specific to vapor intrusion may need to address the following concerns:

3.1 Vapor intrusion is a unique and complex topic with which the general public is unfamiliar. When exceedances occur, affected individuals do not have control to reduce the level of contaminants in air, which can cause substantial anxiety. It is important to inform people that screening levels are established to protect the most sensitive populations, often for a long-term exposure. Communicating the difference between acute and chronic exposure and the difference between acute and chronic health effects is important and may need to be done by state and local health department staff who specialize in health risk communication**.** People should not assume exceedances above the screening levels will cause illness in all people**.** Still, those are the levels by which regulators make risk decisions. The inherent variability with vapor intrusion due to so many factors further complicates the topic but must also be communicated. The *terminology* to explain vapor intrusion and health risks is also complex and unfamiliar. It is critical to use everyday language to keep the audience engaged and informed.

An example of a plain language message for an occupant is: "*Odorless toxic chemical vapors can enter a building from the subsurface through cracks and other openings. Breathing the vapors at elevated levels is not healthy and can cause cancer and other diseases if breathed over a long time. Some chemical vapors can cause health issues for you after a short exposure.*"

Public Outreach Example

It is often possible to tailor investigation and mitigation strategies to maximize cooperation between the community and the response team. Here is a recent example:

A groundwater plume with TCE emanating from an industrial facility beneath an environmental justice community put residents at risk for acute exposure to chemical vapors in their homes. After identifying approximately 50 homes with the highest concern, the consultant began requesting access, with limited success. The process to obtain access; schedule and perform sampling; and schedule and install mitigation became cumbersome, delaying necessary activities. In addition, within the area of study, homes first tested revealed indoor air concentrations well above the indoor air screening level for an imminent health risk. Due to the number of confirmed residences with an imminent health risk and the large number of homes still at risk of an immediate health concern, the regulatory agency approved an alternative strategy within an identified area. This strategy included canvasing the neighborhood with environmental regulators and consultants followed by paired air sampling and installation of a mitigation system in the same mobilization, prior to receiving analytical test results. As a result of this approach, critical trust was established, and disruption time decreased. The level of participation and rate of mitigating the exposure increased significantly.

The Agency for Toxic Substances and Disease Registry (ATSDR) and some state health departments have fact sheets written for the general population on individual contaminants to assist with this risk communication. Chapter 4 of ITRC's *Risk Communication Toolkit* Step 5: Identify Messages discusses key components of composing a risk communication message.

The definition of the many vapor intrusion screening levels and the implications on human health are difficult to communicate. It is important to explain how risk to human health requires (1) a completed vapor pathway, and (2) exceedance of indoor air screening levels. Some screening level exceedances (e.g., sub-slab, conduit) do not mean that unacceptable exposure has occurred. For example, people may see high soil gas levels and mistakenly compare them to indoor air screening levels. Explain that mitigation is designed to minimize exposure by interrupting pathways where exposure is occurring, and that this interruption will be verified through monitoring. Consider explaining ways the performance metrics are used to verify that the system is working. Refer to Section 2.4 of the ***Operation, Maintenance, & Monitoring Process/Exit Strategies Fact Sheet*** for the applicable standards and performance metrics. Radon mitigation system resources may also be helpful.

3.3 **Various indoor sources of air contamination can interfere with the vapor intrusion sampling results.** These indoor sources from consumer products are commonly referred to as background sources. Vapor sampling could include monitoring soil gas, sub-slab vapor (soil gas beneath a building), indoor air, crawlspace air, and outdoor air to identify the source(s) of contamination. A diagram may be helpful to explain the difference between a background source and air impacted by vapor intrusion from an exterior contaminant source. If it hasn't been previously communicated, providing a list of interferences, or background sources, to occupants may help explain the pre-existing impacts to indoor air from common consumer products. Emphasize that indoor air sources are not the focus of the vapor intrusion investigation and that most vapor mitigation approaches will not reduce indoor air concentrations due to background sources. Refer to agencies that are responsible for educating about or regulating these background sources (e.g., county or state departments of health).

3.4 **There are situations when rapid response is needed as the vapor intrusion pathway may take time to address and mitigate.** States typically require more aggressive action at properties where short-term exposure risk is applicable due to the concentration of a contaminant. Some states include requirements for rapid response where the trichloroethylene (TCE) screening level is exceeded at locations with specific demographics. Special messaging in conjunction with state and/or local health departments is necessary to address sensitive populations. In some cases, a rapid response (see ***Rapid Response & Ventilation Fact Sheet***) may be appropriate and include relocation of the occupants (e.g., close a school or business) while a long-term plan is implemented. This includes a unique set of concerns for impacted parties.

Mitigation may be long term and affected parties will have questions. Typically, mitigation systems require some form of long-term operation, maintenance, and monitoring (OM&M). At the time mitigation is proposed, it should be clear who is financially responsible for installation, initial OM&M, and long-term OM&M. Enforceable documents are recommended if responsibilities are split (e.g., responsible party performs installation and initial OM&M and property owner performs long-term OM&M).

3.6 **While many are worried about the effects of toxic exposure, people will also be concerned about other impacts to their lives.** For example, at residential properties, residents may be concerned that environmental responders will track mud on carpets or let out pets. At commercial properties, concerns may include interrupting the workday or discouraging business. At schools, officials may want to avoid any environmental work during school hours. The response team should make sure that building owners, managers, and occupants are aware of the incidental impacts of each of the mitigation technologies proposed for that building (e.g., noise, electricity, disruption). Table 3-1 shows how some impacts and concerns apply to mitigation options. In some cases, informed occupants can help response teams tailor their response to affected buildings. The leaders of the response team should make sure that the contractors performing the installation are aware and respectful of the concerns of building occupants, owners, and managers.

Table 3-1. Mitigation-specific impacts and concerns.

	Noise	Aesthetics	Building Contents, Belongings	Cost	Permit	Long-Term Management & Institutional Controls	Property Value (increase or decrease)	Notification for Future Occupants
Sub-Slab Depressurization Systems	X	X	X	X	X	X	X	X
Passive		X	X		X	X	X	X
Air Purifying Units	X	X		X		X	X	X
Heating, Ventilation, and Air Conditioning	X			X		X	X	X
Sealing Floors		X	X	X*		X	X	X
Temporary Relocation			X	X		X	X	X
Barrier/Liner	X	X	X	X	X	X	X	X

***Usually the cost of sealing floors is low compared to other forms of mitigation, but there are exceptions.**

LOGISTICAL CONSIDERATIONS FOR THE COMMUNITY ENGAGEMENT PLAN

The means of communication (e.g., door-to-door outreach [Figure 4-1], public meeting/presentation, flyers) will likely be determined by the goals of the communication, the scope of the project, and consideration of stakeholder/ audience needs as outlined above. Most communication regarding vapor mitigation installation will likely be in the affected structure or a nearby community building as appropriate. The vapor intrusion investigation process should be clearly communicated to the public through public meetings, websites, and social media. Additional efforts are often required to establish the level of trust necessary for an affected resident to grant access to modify their building by installing a mitigation system. The Community Engagement Plan should define the roles and responsibilities of each stakeholder, including responsible parties and their consultants, regulators, state and local health departments, local governments, community advisory groups, etc.

Figure 4-1 – Door-to-door outreach.
Source: Getty Images

Some things to consider:

- Strategy for door-to-door outreach
  - Sometimes visiting a home multiple times is necessary to make contact, as well as to build needed trust. Consistency and persistence are key. With the advent of video doorbells, fewer people may be answering the door if they are not expecting someone.
  - Advance notice is very important. Furthermore, the environmental response team should anticipate such potential inefficiencies or delays when establishing schedules and preparing cost estimates.
  - Use the knowledge of affected parties along with likely concerns for each mitigation type from the attached matrices to anticipate questions. For example, a homeowner may want to know who will pay for the electricity to operate an active vapor mitigation system.
- It is rare that building occupants, managers, or owners know anything about vapor intrusion, which is inherently a complex, technical subject. It may take slow, relaxed discussions at their location or repeated presentations at public meetings to earn their confidence. Multiple forms of communication will likely be necessary.

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- Knowledge of the community will help determine the best time of day to contact residents, occupants, managers, or owners. Some states have specific requirements for the number and timing of communication attempts.
- Timing is important. It is essential to make an effort to directly connect with occupants prior to a media announcement.
- Address cultural language barriers by making sure fact sheets and other sources of information are in languages spoken by the community.
- Address technical barriers by creating fact sheets in layman's language keeping in mind that illustrations are very helpful for understanding what a mitigation system does. Illustrated fact sheets are helpful to leave with affected parties both to reiterate presented information and to provide points of contact for further questions. Various state and federal agencies provide generic and site-specific fact sheets that can be given to the affected parties. Links to several fact sheet examples are provided in Table 4-1.

Table 4-1. Links to example fact sheets.

Government Organization and Reference
Agency for Toxic Substances and Disease Registry (ATSDR) VI Fact Sheet • https://www.atsdr.cdc.gov/docs/atsdr_vapor_investigation.pdf
California Department of Toxic Substances Control (DTSC), California Environmental Protection Agency (CalEPA), VI Public Participation Advisory (Appendix E): • https://dtsc.ca.gov/wp-content/uploads/sites/31/2016/01/VIPPA_Final_03_05_12.pdf
Maryland Department of the Environment, Citizen's Guide to Vapor Intrusion, What You Need to Know: • https://mde.maryland.gov/programs/LAND/MarylandBrownfieldVCP/Documents/LRP%20-%20Vapor%20Intrusion%20Citizens%20Guide%20Fact%20Sheet%20Update_Sept%202019%20(1).pdf
Minnesota Department of Health Vapor Intrusion Website: • https://www.health.state.mn.us/communities/environment/hazardous/topics/vaporintrusion.html
Minnesota Pollution Control Agency Vapor Intrusion Website: • https://www.pca.state.mn.us/waste/what-vapor-intrusion • https://www.pca.state.mn.us/waste/understanding-your-vapor-intrusion-test-results • https://www.pca.state.mn.us/waste/communication-vapor-intrusion-projects
New Hampshire Department of Environmental Services VI Environmental Fact Sheet: • https://www.des.nh.gov/organization/commissioner/pip/factsheets/rem/documents/rem-30.pdf
New Jersey Department of Environmental Protection VI Pathway Website and Community Outreach for VI Sites: • https://www.nj.gov/dep/srp/guidance/vaporintrusion/ • https://www.nj.gov/dep/srp/guidance/vaporintrusion/community_outreach_guidance.pdf

Table 4-1. Links to example fact sheets.
Government Organization and Reference
New York Department of Health VI Fact Sheets: • https://www.health.ny.gov/environmental/indoors/vapor_intrusion/fact_sheets/
Wisconsin Department of Natural Resources VI Resources for Environmental Professionals: • https://dnr.wi.gov/topic/brownfields/vapor.html • https://dnr.wi.gov/topic/Brownfields/Vaporpublic.html
USEPA R9 Triple Site, Sunnyvale, CA Fact Sheet Example • https://cumulis.epa.gov/supercpad/SiteProfiles/index.cfm?fuseaction=second.scs&id=0900265&doc=Y&colid=38595&region=09&type=SC VI Community Involvement Information • https://semspub.epa.gov/work/11/176269.pdf

Where new construction is planned, local governments with planning jurisdiction have a key role. Cities, if they are informed and partner with environmental regulators, can use their building approval authority to reinforce the requirements developed by regulators. In some states, local governments are responsible for conducting and/or approving environmental impact studies that impose conditions on development. Furthermore, local officials are often the first to be contacted by people affected by vapor intrusion investigations, as well as by the media covering such investigations. The requirements for a Community Engagement Plan will evolve over the life of the project. It is important that the environmental team repeatedly assess the effectiveness of the communication tools they are using.

5 REFERENCES AND ACRONYMS

The references cited in this fact sheet are included in a combined list with references cited in other fact sheets and technology information sheets prepared by the ITRC VI Mitigation Training team. This reference list, along with an acronym list and glossary, is available on the ITRC web site.

Rapid Response and Ventilation for Vapor Intrusion Mitigation

ITRC has developed a series of fact sheets that summarizes the latest science, engineering, and technologies regarding vapor intrusion (VI) mitigation. The fact sheets are tailored to the needs of state regulatory program personnel who are tasked with making informed and timely decisions regarding VI-impacted sites. The content is also useful to consultants and parties responsible for the release of these contaminants, as well as public and tribal stakeholders. This fact sheet:

- provides an overview of rapid response as a preliminary method to consider
- describes the typical options related to rapid response
- describes the advantages and limitations of implementing a rapid response
- provides general cost considerations related to rapid response
- describes other special circumstances to consider when deciding if rapid response is applicable

More detailed information on specific rapid response options is included in the ITRC ***Preferential Pathway Sealing and Ad Hoc Ventilation***, ***Indoor Air Treatment***, and ***HVAC Modification Technology Information Sheets***.

INTRODUCTION

Rapid response is an interim VI mitigation approach that may be appropriate, under certain conditions (e.g., high contaminant concentrations and sensitive populations present), prior to implementing a long-term mitigation strategy for an occupied room or building. For the purposes of this fact sheet, a rapid response is one that could be easily implemented and verified on a timescale of days to weeks, whereas a long-term mitigation strategy typically takes longer to design and implement but is more effective, practicable, and often more cost-effective to operate over a long period of time. Some technologies or mitigation methods characterized in this fact sheet as rapid may also be suitable as long-term mitigation strategies. A rapid response may be implemented prior to developing a complete VI conceptual site model. Acceptable rapid response methods can vary based on site

Other Terminology Used to Describe a Rapid Response

- *Depending on the regulatory framework and the measured indoor or subsurface concentrations for the chemical(s) of concern, the term "rapid response" can correspond to one or more of the following:*
    - *accelerated response*
    - *urgent response*
    - *expedited response*
    - *emergency response*
    - *immediate response*
    - *imminent hazard response*
- *For certain regulatory frameworks, several terms are used corresponding to different notification requirements and response time frames.*

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location and building use; however, a good understanding of building occupant demographics and building use is helpful to evaluate the need and type of rapid response. For cases where chemicals of concern are detected in indoor air at concentrations exceeding short-term exposure criteria, a rapid response may be required (Beringer, 2017). Rapid response actions can include administrative controls, such as relocating occupants and eliminating occupant access to the building, or engineering controls that reduce chemical vapor exposure through building ventilation, indoor air treatment, or by physically preventing vapor entry into the building.

The requirement for a rapid response can vary significantly from state to state and among regulatory programs or health agencies. The criteria that may trigger the need for a rapid response and the time frame that qualifies a response as "rapid" also vary among jurisdictions. This fact sheet presents approaches and methods that should be considered when a rapid response has been deemed necessary.

The scope of this fact sheet is limited to scenarios where there may be an acute risk to human health from chemical VI and does not include "emergency" situations (i.e., "call 911" situations) where combustible, explosive, or oxygen-deficient conditions may exist inside a building. If these conditions are believed to be present, first responders should be contacted immediately.

2 OPTIONS FOR RAPID RESPONSE

2.1 Administrative Controls

2.1.1 Notification

Notification is an administrative control that should be considered. Notification is simply the act of communicating information about the VI condition and anticipated actions to various stakeholders (e.g., property owner, tenants, and occupants). This information would include but not be limited to background information on the site and VI, data or information that is triggering the rapid response, how a rapid response differs from a long-term response, what possible next steps might be, and contact information for entities that can provide more information and answer questions. Examples of notification include communications with tenants or inter-agency communication (e.g., the state environmental agency notifies the state health department). For additional information, see ITRC's ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet***.

2.1.2 Temporary Relocation

Temporary relocation of a building's occupants eliminates receptor exposure to the VI-contaminated indoor air. This rapid response action typically includes a high level of public communication (see also ITRC's ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet***); engagement with government agencies with statutory authority to evacuate an occupied building, including private property owners; and coordination and assistance with temporary accommodations until additional interim or final mitigation measures result in improvement to indoor air quality. In some cases, an occupant may decide to temporarily relocate based on personal risk tolerance regardless of whether relocation is being mandated by a regulatory body, or by a property manager, in the case of residential rental properties or commercial/industrial properties. Temporary relocation may not be required for an entire building or building population—for example, temporary workers or infrequent building users. Higher contaminant concentrations can pose greater risk to sensitive populations; therefore consideration should be given to limiting access to certain portions of the building where VI is occurring or temporarily relocating sensitive populations.

Benefits of temporary relocation include:

- can be implemented very quickly
- can be implemented irrespective of building construction or use
- immediately eliminates building occupant exposure

Limitations and requirements of temporary relocation include:

- significant building occupant disruption and potential economic hardship for commercial or industrial building owners
- building occupant communication and coordination is necessary
- does not remediate the source of VI
- typically not accepted as a long-term mitigation strategy
- requires some form of enforcement mechanism
- may require relocating pets, which can limit relocation options and/or increase relocation costs

Temporary relocation often includes weighing the risk of adverse acute health effects with the risks that come with the significant disruption that temporary relocation causes. In many instances, simple measures (such as opening windows) may suffice in the short term. If possible, the decision to temporarily relocate should rest with the individual after they have been informed of the risks. The decision to evacuate a building should consider the thoughts of an individual, but ultimately it is the regulator’s responsibility to protect health and safety.

2.2 Engineering Controls

Engineering controls include those methods or strategies that involve utilizing technology or making physical changes to the building or building systems to reduce concentrations of VI contaminants to acceptable levels or as low as practicable if still above acceptable long-term levels. Engineering controls that could be part of a long-term mitigation strategy (e.g., a sub-slab depressurization system) are addressed in the ***Active Mitigation Approaches for Vapor Intrusion Mitigation Fact Sheet*** and ***Passive Mitigation Approaches for Vapor Intrusion Mitigation Fact Sheet***.

2.2.1 Ad Hoc Ventilation

Ad hoc ventilation can often be done immediately and easily, and does not require special skills or training. Opening a building's doors and windows or turning on existing ventilation fans that bring fresh air into the building are examples of ad hoc ventilation. This type of rapid response is typically short-lived or significantly limited in areas and times of year when climate control is required for building occupancy. Consideration should be given to how ad hoc ventilation may change heating, ventilating, and air conditioning (HVAC) system operation, potentially exacerbating vapor intrusion in other areas of the building. Consideration should also be given to potential issues with humidity, mold, and combustion appliance exhaust that could arise from ad hoc ventilation. See the ***Preferential Pathway Sealing and Ad Hoc Ventilation*** Technology Information Sheet for additional information.

2.2.2 Indoor Air Treatment

Temporarily placing indoor air purification units (APUs) in occupied spaces to filter chemicals of concern in indoor air is also an option that may allow an occupant to stay in their space while a long-term mitigation strategy is put in place (USEPA, 2017). Several APUs available on the market have demonstrated an ability to remove volatile organic compounds (VOCs) from indoor air using carbon adsorption if there is a long enough contact time between the indoor air and carbon media. The ability of APUs to improve indoor air quality is a function of indoor air volume and air flow rate capabilities of the device, allowing indoor air contaminants adequate time to adsorb onto carbon media. The ability of APUs to improve and maintain indoor air quality relies on properly sizing a device for each building area or room, maintaining a power source, and providing routine carbon media maintenance matching the device deployment interval. See the ***Indoor Air Treatment*** Technology Information Sheet for additional information.

Engineering controls listed in this section offer benefits, including:

- reduction or elimination of building occupant exposure
- ability to incorporate into or provide benefit for long-term mitigation strategy (e.g., sealing)

These controls have the following limitations or requirements:

- building occupant communication and coordination is necessary
- these controls do not remediate the source of VI
- mild to moderate disruption for building occupants

2.2.3 Preferential Pathway Sealing

Floor cracks or other openings, including electrical and plumbing conduits and floor drains, can constitute potential vapor intrusion pathways. Such pathways should be identified and sealed whenever they are readily accessible to reduce advective flow of

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soil gas into the building. Sealing these potential VI pathways can typically be done quickly. Sealing will also be beneficial for and likely be part of an effective long-term mitigation approach (USDOD, 2009). See the ***Preferential Pathway Sealing and Ad Hoc Ventilation*** Technology Information Sheet for additional information.

2.2.4 HVAC Modification

It may be possible to mitigate VI by adjusting a building's HVAC system to increase the fresh air intake and/or pressurize the building. Unlike ad hoc ventilation described in Section 2.2.1, this type of response requires some knowledge of building HVAC operations and special skills, certifications, or training. Ventilation and HVAC modification may allow occupants to stay in their building until confirmation sample results verify ventilation efficacy. See the ***HVAC Modification*** Technology Information Sheet for additional information.

3 OTHER CONSIDERATIONS

Rapid response is an interim VI mitigation approach easily implemented and verified on a timescale of days to weeks prior to implementing a long-term mitigation strategy for an occupied room or building. After implementation of a rapid response, efforts should transition to planning and implementing a more permanent, long-term mitigation strategy.

3.1 Verification Testing

Follow-up verification testing/performance monitoring of a rapid response may be appropriate prior to the implementation of a long-term mitigation approach when the severity of the conditions warrant it (e.g., high contaminant concentrations, sensitive populations). Verification testing across differing seasonal conditions is typically not necessary given the timescale of rapid response approaches; however, more than one round of verification testing should be considered if weather conditions change considerably during implementation of a rapid response. Depending on the regulatory framework, indoor air testing may be recommended or required. In addition to indoor air testing, other verification testing may be useful. Regular monitoring of equipment, such as HVAC units or indoor air purifier units, should be conducted to verify operation.

3.2 Costs

The costs and sustainability of implementing rapid response actions are strongly dependent on a variety of factors, including the size of the occupied building, the number of occupants, and building construction. If temporary relocation is required in a commercial or industrial setting, significant business costs could be incurred from lost production or sales. If ventilation and air treatment are implemented, then capital costs may be incurred for equipment. Ongoing operation and maintenance cost (e.g., increased air conditioning) may also be incurred until the long-term mitigation strategy can be implemented.

4 PUBLIC OUTREACH/COMMUNITY ENGAGEMENT

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. Instances that require immediate action should be broached in a more succinct directive without causing undo panic. Transparency in expedited responses may require communicating incomplete information with follow-up as more information becomes available. To build trust, it is better to provide incomplete information immediately, with appropriate caveats, than to withhold it. The increased anxiety from immediate action situations may require repeating information multiple times with multiple follow-ups to directly affected individuals. For more details, see ITRC's ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet***.

5 REFERENCES AND ACRONYMS

The ITRC VI Mitigation Training web page includes lists of acronyms, a full glossary, and combined references for the fact sheets. The user is encouraged to visit the ITRC VI Mitigation Training web page to access each fact sheet and supplementary information and the most up-to-date source of information on this topic.

ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Rapid Response and Ventilation Subgroup

Heating, Ventilating, and Air Conditioning (HVAC) Modification

ITRC has developed a series of technology information sheets that summarize building mitigation technologies related to vapor intrusion (VI). The purpose of this technology information sheet is to:

- provide an overview of HVAC modification as a method to mitigate VI
- describe the typical components related to HVAC systems
- describe the advantages and limitations of implementing HVAC modifications
- provide general cost considerations related to HVAC modification
- describe other special circumstances to consider when deciding if HVAC modification is applicable for VI mitigation

Overview

HVAC systems refer to the mechanical systems that heat, cool, ventilate, filter, humidify, or dehumidify air in a room or building. For some buildings, mitigation of VI can be accomplished using the HVAC system, which when operated appropriately can act as a VI engineering control by pressurizing the building to prevent vapors from entering, and/or by providing sufficient outdoor air exchange to dilute the effects of VI on indoor air quality. A good understanding of a building's HVAC system configuration and operating conditions is crucial to evaluating its influence on VI and potential for VI mitigation. HVAC systems should be evaluated by qualified HVAC engineers, licensed HVAC contractors, or otherwise qualified professionals experienced with assessment of HVAC systems and their relationship to vapor intrusion and indoor air quality.

HVAC influence on VI potential is fundamentally a function of air pressure gradients and air exchange rate (AER). Air pressure gradients across a floor slab, depending on direction, can act to either suppress VI (when indoor air pressure is greater than subslab pressure) or enhance VI (when indoor air pressure is less than subslab pressure). This concept of positive/negative pressure differential is shown in the diagrams below.

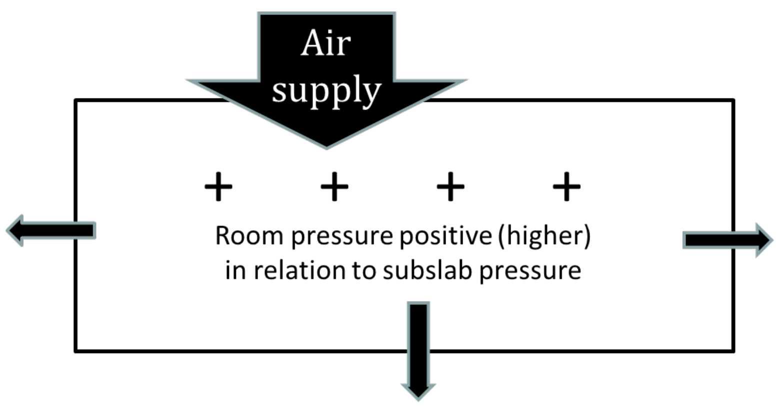

Figure 1 - Positive pressure space conceptualization.
(Source: J. Corsello, Sanborn Head & Associates, Inc., used with permission)

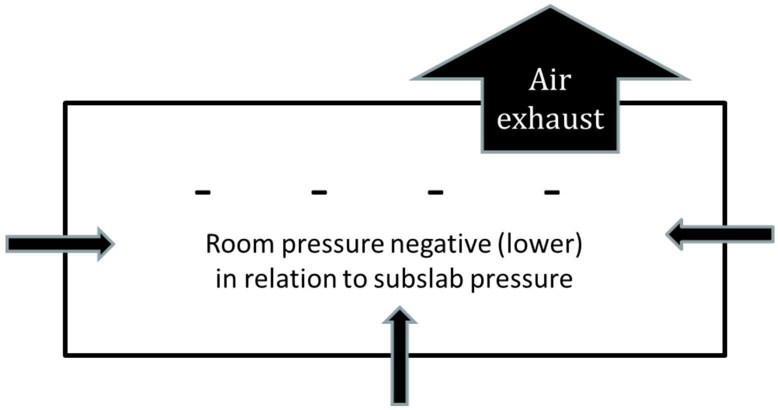

Figure 2 -.
(Source: J. Corsello, Sanborn Head & Associates, Inc., used with permission)

If there is spatial or temporal variability in pressure gradients, either intrusion or suppression of vapor migration may occur in a given location at a certain time within the building, depending on conditions. After VOCs enter a building, air circulation and mixing within the building caused by operation of blowers and fans, or by thermal convection, can act to dilute, transport, and distribute VOCs through the building. Air exchange through mechanical supply of outdoor air can decrease (i.e., dilute) indoor VOC concentrations below levels that would otherwise be present under normal ventilation (e.g., open windows), as may be the case in residential structures, depending on the AER.

While building conditions influencing VI in residential structures do not typically include continuous mechanical ventilation with engineered systems, and are therefore less systematic and less controllable, buildings equipped with engineered HVAC systems represent more controlled environments. Thus, engineered HVAC adjustments can be considered as a component of VI mitigation by either (1) controlling cross-slab pressures by pressurizing the building, or (2) increasing AERs.

Components

The components of an HVAC system will vary depending on the building. In a typical system for a commercial building, outdoor air is drawn into the air handling unit (AHU) and mixed with air recycled from the building space, which is known as return air. The mixed outdoor and return air then passes through filters and across heating and cooling coils before entering the fan, which discharges the conditioned air, known as supply air, to the building space through a network of supply ductwork and diffusers, typically installed in the ceiling. Return air is recycled back to the AHU through a separate duct network connected to intake registers inside the building. In addition, buildings are commonly equipped with separate exhaust fans to serve areas such as laboratories, manufacturing floors, kitchens/cafeterias, mechanical rooms, and restrooms.

HVAC systems can be equipped with special air purifying components/filters to improve indoor air quality. For additional information on other indoor air purification techniques, refer to the ***Indoor Air Treatment*** Technology Information Sheet.

Many variations on this basic description of an HVAC system are in use, and configurations may also vary among multiple AHUs serving different parts of a building. For example, in a variable air volume (VAV) system, often found in office spaces, the amount or “volume” of supply air changes in response to the temperature of the space (e.g., room thermostat). In fact, in a space served by a VAV system, no air pressurization or air exchange will occur if the thermostat is not actively calling for heating or cooling. As a result, building pressurization and AER can vary room-to-room or zone-to-zone depending on VAV status.

A typical HVAC system can potentially be adjusted to mitigate VI through (1) building pressurization, or (2) increase of AERs. Building pressurization is achieved by increasing supply air while decreasing return air. The following actions can be taken to implement building pressurization:

- Adjust outside air/return air damper positions to allow more outside air flow.
- Clean/replace dust filters.
- Increase supply air fan speed, or install a new fan, if needed.
- Re-balance supply/return air.
- Install new supply air ducts and diffusers, if needed.
- Close dampers for return air.
- Decrease/turn off exhaust fans where not needed.
- Seal leaks in building shell.

Increase of air exchange rates within a building is achieved by increasing both the supply air flowrate and building exhaust rate. The following actions can be taken to implement an increase of air exchange rate:

- Adjust outside air/return air damper positions to allow more outside air flow.
- Adjust supply and return air fan speeds, or install new fans, if needed.
- Install new supply and/or return air ducts and diffusers, if needed.
- Increase air exhaust fan capacity.

The HVAC system adjustments described above should be performed by the facility HVAC engineer or a qualified HVAC contractor. Some states may have rules or regulations on who can evaluate/modify HVAC systems to ensure they comply with building and energy code requirements. Any adjustments must maintain the comfort of the occupants.

Advantages

HVAC modification as part of a VI rapid response has several advantages:

- HVAC can be applied to both new and existing buildings.
- Mitigation via HVAC can be used as a rapid response to lower indoor air concentrations quickly, and in some cases, positive pressures can effectively prevent VI.
- Normal HVAC operations in some buildings can maintain acceptable indoor air quality, despite VI potential from sub-slab VOC presence.
- Some buildings subject to VI can be mitigated with HVAC adjustments with less disruption or more favorable cost than sub-slab depressurization (SSD) system installation, even when long-term operating costs are considered.
- Some buildings subject to VI are too technically difficult or costly to mitigate using other mitigation technologies (e.g., active manufacturing constraints, complex subgrade utility networks, complex foundations, very large areas).

Limitations

HVAC modification also has some disadvantages as part of a VI rapid response:

- Mitigation via HVAC does not address/remediate the VI source or pathway.
- These systems are not intentionally designed for VI mitigation.
- This solution leads to dilution of VI rather than prevention, in some cases.
- Many single- or multifamily residences do not have an HVAC system.
- The wide variety of systems (e.g., old, complex) can be challenging.
- There could be many potentially relevant operating parameters to maintain.
- There are multiple points of operating variability/vulnerability.

- This solution is subject to human interference (e.g., building occupants changing system settings for reasons of comfort, operating cost, or other factors).
- Mitigation via HVAC can be energy intensive, resulting in increased cost.
- Manipulating HVAC can alter humidity and cause moisture or mold damage.
- Automatic operating schedules may result in elevated indoor air concentrations when the system is shut off or shortly after it is turned on.
- It can take long periods of time to confirm effectiveness (verification sampling during different seasons).
- An increase in AER can reduce indoor air concentrations only to the degree that AER is increased (i.e., dilution factor is limited by additional available AER).
- For positive pressure systems, the building must have a tight envelope; thus, positive pressure approaches work poorly on older buildings having poor insulation, windows, doors, etc.

Cost Considerations

The costs and sustainability of implementing HVAC modifications are strongly dependent on a variety of factors, including whether existing equipment has available capacity to meet AER or pressurization goals, how air-tight the building may be, and occupant comfort. If new or modified equipment is required, capital costs are building- and space-specific, but can be as much as $100,000 or more for one AHU and some buildings may require multiple AHUs. The building-specific nature of HVAC capital costs is reflected in the cost estimate range of $1 to $15 per square foot published in the ITRC VI-1 guidance (ITRC, 2007a).

Long-term operating costs are also important to consider in evaluating HVAC modifications for VI mitigation. For example, in New England, the average annual cost to condition outdoor air has been reported to range from $6 to $12 per cubic foot per minute (cfm). ITRC reports that additional operating costs to modify HVAC systems to mitigate VI could exceed $1 per square foot annually (ITRC 2007a). Additionally, multiple rounds of verification sampling performed during both the heating and non-heating seasons may contribute to varying costs.

Special Circumstances

HVAC operational variability due to variable air volume systems, automatic variable operating schedule, and the use of economizers present special circumstances that should be considered when implementing HVAC modifications. For example, automatic operating schedules could result in elevated indoor air concentrations when the HVAC system is off and shortly after it is turned on due to less outside air circulating throughout the room. In addition, special indoor air quality or energy conservation requirements (e.g., relative humidity, temperature) based on building use may also need to be considered.

Occupant, Community, and Stakeholder Considerations

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. For more details, see ITRC's ***Public Outreach during Vapor Intrusion Mitigation*** Fact Sheet.

Resources

- Interstate Technology Regulatory Council (ITRC), Vapor Intrusion Pathway: A Practical Guideline, Washington, D.C., January 2007.
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- American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), *Ventilation for Acceptable Indoor Air Quality*, ANSI/ASHRAE Standard 62.1-2019, Atlanta, GA, 2019.

- Shea, D., Lund C., and Green, B., *HVAC Influence on Vapor Intrusion in Commercial and Industrial Buildings*, Platform presentation at the Air and Waste Management Association (AWMA) Vapor Intrusion Conference, Chicago, IL, September 2010.
- Shea, D. and Green, B., *HVAC Systems for VI Mitigation in Large Buildings: Reliability and Long-Term Performance Monitoring Considerations*, Platform presentation at the Fourth International Symposium on Bioremediation and Sustainable Environmental Technologies Conference, Miami, FL, May 2017.
- Shea, D., *Long-Term Performance Monitoring for HVAC Engineering Controls for VI Mitigation of Large Buildings*, Platform presentation at the AEHS Foundation's 27th Annual International Conference on Soil, Water, Energy, and Air, Amherst, MA, March 2017.
- Shirazi, E., Hawk, G. S., Holton, C. W., Stromberg, A. J., & Pennell, K. G. (2020). Comparison of modeled and measured indoor air trichloroethene (TCE) concentrations at a vapor intrusion site: influence of wind, temperature, and building characteristics. *Environmental Science: Processes & Impacts*, 22(3), 802-811.
- Tillman Jr, F. D., & Weaver, J. W. (2007). Temporal moisture content variability beneath and external to a building and the potential effects on vapor intrusion risk assessment. *Science of the Total Environment*, 379(1), 1-15.

Related Links:

For more information and useful links about VI mitigation technologies, go to http://www.itrcweb.org/.

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ITRC Technology Information Sheet
Vapor Intrusion Mitigation Team | December 2020
Rapid Response and Ventilation Subgroup

Indoor Air Treatment
Removing Chemical Vapors from Indoor Air

ITRC has developed a series of technology information sheets that summarize building mitigation technologies related to vapor intrusion (VI). The purpose of this technology information sheet is to describe how air treatment units can be used as a rapidly installed technology to mitigate VI. This sheet provides general applicability and design considerations, typical configurations, advantages and limitations, and cost considerations.

Overview

Air treatment units, commonly referred to as air purifying units (APUs) or air cleaners, can be used to mitigate vapor intrusion (VI) and are most often used when a temporary reduction of volatile organic compound (VOC) concentrations in indoor air is needed while a longer term mitigation and/or source remediation strategy is designed, permitted, and installed (e.g., sub-slab depressurization system). APUs are intended to actively circulate indoor air within a certain room or building area and remove VOCs present in the air stream. They are considered a versatile, easy-to-implement, short-term solution, but still require some oversight.

APUs can be ineffective if not properly selected for the target compounds or sized for building- and site-specific conditions. Considerable variability in effectiveness has been reported, with reductions of VOC concentrations in indoor air ranging from 25 to 99%. For that reason, follow-up verification testing/performance monitoring may be appropriate when warranted by site conditions (e.g., elevated VOC concentrations, sensitive settings, such as daycares or schools) prior to the installation of the long-term mitigation design. In addition, certain regulatory frameworks may require indoor air monitoring to verify that an APU is meeting its performance objectives. Because VOC contributions to indoor air unrelated to the subsurface may complicate interpretation of indoor air sampling results, additional lines of evidence should also be considered when evaluating performance (e.g., assessment of indoor or outdoor background VOC sources).

Components

Classes of commercially available APUs include the following:

- adsorption-based APUs (i.e., treatment using a sorbent bed or layer, commonly granular activated carbon [GAC])
- photocatalytic oxidation APUs (i.e., use of light and catalysts to break down VOCs into water, carbon dioxide, and other compounds)
- other types, including ozone generation, chemisorption (e.g., permanganate), or biofiltration (using plants or microbes)

Adsorption-based APUs are most common and are discussed further in this information sheet. Primary issues associated with the other classes listed above include the potential for the formation of by-products released to the indoor air (e.g., other VOCs, ozone, hydrochloric acid) and overall lack of verification through peer-reviewed case studies.

APUs can be used in different configurations. Stand-alone APUs include portable (Figure 1), wall-mounted, or ceiling-mounted units. APUs can also be installed within the ducts of an existing heating, ventilation, and air conditioning (HVAC) system. The units are often equipped with particulate filters to supplement the VOC adsorbent material.

Figure 1. Examples of portable APUs.
(Sources: Jacobs Engineering Group, U.S. Navy, used with permission.)

Typical design specifications for an APU include airflow (for portable units), pressure drop (for duct-mounted units), VOC removal efficiency, sorbent capacity or lifetime, reliability and uptime, noise levels, power usage, physical dimensions, and weight.

Multiple factors should be considered when selecting the number of units and individual capacity of APUs. These factors include:

- chemical characteristics of the air to be treated (e.g., type and concentrations of target VOCs, presence of nontarget VOCs, particles, other air contaminants)
- physical characteristics of air stream (e.g., humidity, temperature)
- building characteristics (e.g., size of space to treat, air exchange rate [AER])
- occupant characteristics (e.g., frequency of occupancy, noise tolerance, acceptance by occupants)
- other characteristics (e.g., power requirements, equipment theft or tampering concerns, equipment visibility and aesthetics)

The number of APUs and individual flow rate should be such that the total airflow is several times the baseline airflow through the space to be treated. The baseline airflow is the amount of air flowing though the space under ambient conditions and can be estimated using the space volume and baseline AER. Typical AERs range from less than one air change per hour in residential settings to a few air changes per hour in non-residential settings. APUs essentially “increase” AER by recycling clean air within the room several times per baseline AER. The expected reduction in VOC concentration can be estimated from the increased AER and an assumed VOC removal efficiency by the APU (i.e., 100% or a lower level). VOC mass loading and GAC consumption should also be considered. The VOC mass loading rate (i.e., the rate of both target and nontarget VOC mass entering the space to be treated) can be estimated from the indoor air concentrations and baseline AER. This mass loading rate can then be used to estimate the amount of GAC needed for treatment and the expected replacement frequency.

Advantages

Advantages associated with APUs include their versatility and ease of implementation in a variety of settings. APUs are well suited for implementing a rapid response. This approach can quickly lower indoor air concentrations to acceptable indoor air quality levels while long-term VI mitigation is designed and implemented. APUs can also be used to supplement an existing mitigation system or installed within an operating HVAC system.

Limitations

There are numerous limitations associated with APUs, which can be summarized as follows:

- APUs treat indoor air and, therefore, do not cut off the VI pathway or address the VOC source.
- The treatment GAC ultimately needs to be replaced or regenerated, and may create waste, with special disposal considerations in areas of high radon potential.
- APUs can be noisy and subject to human interference (i.e., unit turned off or doors shut, interfering with the treatment of air in other rooms).
- APUs can be maintenance- and power-intensive and costly to operate to meet performance objectives.
- Adsorption performance can be limited by moist environments and competition from nontarget VOCs, which are common in indoor air due to a variety of sources (e.g., cooking, upholstery, consumer products).
- APUs can be ineffective or may not achieve indoor air criteria for VOCs with poor adsorption performance (e.g., vinyl chloride) or when indoor air concentrations are high.
- Overall performance is subject to uncertainty, such that follow-up verification testing and the development of a performance monitoring plan may be appropriate when warranted by the severity of the conditions (e.g., elevated contaminant concentrations, daycare or school settings) prior to the installation of the long-term mitigation design.

Cost Considerations

Portable APUs can be purchased at costs ranging from about five hundred to a few thousand dollars. Replacement GAC filters or particulate filters are typically less than three hundred dollars. The overall price will depend on the number of units needed and filter change-out frequency.

Special Circumstances

As indicated previously, certain classes of APUs use photocatalytic oxidation (in lieu of adsorption) to transform VOCs into water, carbon dioxide, and other compounds. These APUs use ultraviolet light and a catalyst (commonly, titanium dioxide). Laboratory and field studies have shown that VOCs can be effectively broken down, assuming enough air passes (recirculates) through the units. Some studies, however, have also shown the formation of intermediate oxidation products, including acetone, formaldehyde, and others. Because multiple air passes are needed before complete breakdown of the VOCs is achieved, building occupants could potentially inhale these by-products while the APUs operate in the space that is treated.

Occupant, Community, and Stakeholder Considerations

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people’s lives and businesses. For more details see ITRC’s ***Public Outreach during Vapor Intrusion Mitigation Fact Sheet***.

Resources

- Interstate Technology and Regulatory Council (ITRC). 2007a. Vapor Intrusion Pathway: A Practical Guideline, Washington, D.C., January.
- ITRC. 2014. Petroleum Vapor Intrusion, Fundamentals of Screening, Investigation, and Management, October.
- Schumacher, B., J.H. Zimmerman, R. Truesdale, K. Owen, C. Lutes, M. Novak, and K. Hallberg. 2017. Adsorption-based Treatment Systems for Removing Chemical Vapors from Indoor Air. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-17/276, June.
- U.S. Environmental Protection Agency (US EPA). 2018. Residential Air Cleaners: A Technical Summary. Office of Radiation and Indoor Air, Indoor Environments Division, 3rd Edition, EPA 402-F-09-002,

Related Links:

For more information and useful links about VI pathways and mitigation technologies, go to http://www.itrcweb.org/.

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ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Rapid Response and Ventilation Subgroup

Preferential Pathway Sealing and Ad Hoc Ventilation
Rapid Responses

ITRC has developed a series of technology information sheets that summarize building mitigation technologies related to vapor intrusion. The purpose of this technology information sheet is to describe approaches that can often be used preliminarily to mitigate the vapor intrusion pathway and require little to no specialized training. This sheet provides general applicability and considerations, typical configurations, advantages and limitations, and cost considerations.

Overview

Advective flow through cracks and other openings can be the dominant mechanism of vapor intrusion, and diffusion through a concrete slab is a minor component of the flux of vapors into a building. If advection is the dominant vapor intrusion mechanism, sealing preferential pathways can be effective for mitigating vapor intrusion. Sealing preferential pathways should be implemented for all VI mitigation strategies, even when advective flow is not the dominant mechanism. Ad hoc ventilation can be another effective approach to mitigating vapor intrusion. Ad hoc ventilation, which includes opening windows, doors, etc., can increase the fresh air exchange rate for a building, thereby diluting vapors as they enter a building. Sealing preferential pathways and ad hoc ventilation can often be implemented within hours to days, do not require special skills, and can be completed with readily available materials. Sealing preferential pathways and ad hoc ventilation represent a low-cost high-return approach for mitigating vapor intrusion and can typically be completed at low cost relative to other rapid response. Keep in mind, these rapid responses are intended to be just that, and are typically not sufficient as a long-term means of vapor control on their own.

Components

This technology information sheet addresses the following:

- sealing of cracks in floors and foundation walls, drains, conduit entry points, plumbing fixtures, etc.
- ventilation of the area by opening doors or windows, or by activating existing ventilation systems.

Floor cracks or other openings, including electrical and plumbing conduits and floor drains, can constitute potential vapor intrusion pathways. Such pathways should be identified and sealed whenever they are readily accessible. A variety of caulks and sealants can be used. For better sealant support, cracks and conduit openings larger than ½ inch should be filled with a foam backer or other compatible material prior to the application of the sealant.

Sumps can be fitted with vapor-tight lids or sealed around the lid and any piping and electrical penetrations can be sealed using a nonpermanent caulk such as silicone. Loose toilets can be re-seated with new wax rings and also sealed around the base. It is also important to ensure that all plumbing traps contain an adequate amount of water to prevent sewer gas. Another maintenance tip is to put a small amount of vegetable oil in floor drains to help minimize evaporation if the floor drain is not expected to be used for long periods of time. However, note that sewer gas can be a carrier for VOCs due simply to breaks in sewer lines. Also note that utility contractors (plumbing, electrical, etc.) routinely use hollow or "chase" piping to support utilities prior to slab pours; these should be sealed if found.

In older buildings, abandoned piping can be common, and these potential vapor pathways should be cut and capped if possible. This includes water, sewer, electrical or gas lines that are no longer in use. Underground tanks used for storage of heating fuel and all associated piping should be properly removed if no longer in use.

More generally, sealing cracks in the foundation and around utility penetrations, particularly in basement areas, should generally contribute to reductions in advective flow of soil gas into the building. Sealing potential vapor intrusion pathways should therefore be part of an effective long-term vapor intrusion mitigation approach.

Temporarily requesting building occupants and/or their property managers to increase ventilation in occupied spaces can also be used as a rapid response measure (see ***HVAC Modification*** Technology Information Sheet). This includes two categories:

- The first category includes those changes that can be made immediately, easily, and do not require special skills or training, such as opening a building's doors and windows or turning on existing ventilation fans that bring fresh air into the building.
- The second category includes adjusting a building's HVAC system to increase the fresh air intake and requires some knowledge of building HVAC operations and special skills or training. Ventilation may allow occupants to stay in their building until confirmation sample results confirm ventilation efficacy. Adjusting a building's HVAC system may also be an effective long-term mitigation strategy (see ***HVAC Modification*** Technology Information Sheet).

Opening lower floor windows and opening windows on opposite sides of the building can create cross breezes that can also increase ventilation. Care should be taken when opening upper floor windows as this can potentially increase the rate of soil vapor entry due to stack effects. Another item to keep in mind is that ventilation fans such as bathroom and kitchen fans typically only draw air out, thus potentially increasing the possibility of VI. An understanding of air exchange rates as well as an understanding of soil vapor entry rate and location is beneficial. Consideration should also be given to potential issues with humidity, mold, and combustion appliance exhaust that could arise from ad hoc ventilation.

Advantages

The most important advantage associated with preferential pathway sealing and ad hoc ventilation is that it can be done quickly and relatively easily. Preferential pathway sealing can reduce soil vapor entry rates relatively inexpensively and should be part of all VI mitigation approaches. Preferential pathway sealing can also improve the efficacy of ventilation inside the building and underneath the foundation. In many cases, it can be accomplished with little to no interference to the building occupants and simple plumbing upgrades can be done without a licensed plumber. The sealing of potential VI pathways will also be part of an effective long-term mitigation approach. It can also be beneficial for other non-VI building issues, such as moisture control.

Limitations

There are several limitations associated with preferential pathway sealing and ad hoc ventilation, which can be summarized as follows:

- Preferential pathway sealing and ad hoc ventilation do not address the vapor source.
- Some sealants may contain VOCs and therefore complicate future indoor air sampling.
- Some floor cracks or conduit entries may be inaccessible for sealing.
- Crack sealing may not be feasible for extremely deteriorated floors.
- Cracks may not be visible due to floor coverings such as carpet or laminate flooring.
- Ventilation (opening windows or doors) may leave occupants susceptible to undesirable outdoor conditions, including temperature extremes and biological threats.
- Ad hoc ventilation may be susceptible to human interference or create security concerns.
- Neither preferential pathway sealing nor ad hoc ventilation may be sufficient on its own to achieve short- or long-term indoor air action levels.
- Overall performance is subject to uncertainty. Follow-up verification testing and performance monitoring are recommended along with the collection of other lines of evidence demonstrating effectiveness,

Cost Considerations

Preferential pathway sealing and ad hoc ventilation are typically inexpensive methods of mitigating vapor issues. Note that preferential pathway sealing is a necessary component of all VI mitigation strategies and ad hoc ventilation is typically used in addition to other rapid response strategies. Various types of caulking and other expandable sealant products and individual plumbing parts are typically available at most hardware stores for less than $10 each. New toilets or sump systems can be more expensive, ranging from $50 to a few hundred dollars. Additional plumbing materials and accessories such as wax rings and piping are typically inexpensive.

While most individual components involved in crack and conduit sealing are relatively inexpensive, total costs for a significant crack and conduit sealing coupled with major plumbing upgrades can be in the thousands of dollars.

The costs and sustainability of ad hoc ventilation are typically limited to any increase in building heating or cooling costs that may result from high fresh air exchange.

Special Circumstances

Potentially explosive, oxygen deficient, or other extremely hazardous environments constitute emergency situations that should be evaluated by trained professionals (i.e., fire department) prior to rapid response activities to mitigate vapor intrusion. Evacuation and temporary relocation may be necessary.

Some crawlspaces, pits, shafts, or sumps may be considered confined spaces, and may require special permission, training, and equipment to enter. These areas may also need to be adequately ventilated with a blower or fan prior to entry. Federal, state, and local rules or regulations, as well as individual facility-specific rules pertaining to confined spaces, should be consulted.

Occupant, Community, and Stakeholder Considerations

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. For more details, see ITRC's ***Public Outreach during Vapor Intrusion Mitigation*** Fact Sheet.

Resources

- American Association of Radon Scientists and Technologists (AARST). *Soil Gas Control Systems in New Construction of Buildings*, AARST/ANSI Standard CC-1000, Hendersonville, NC, 2018
- Interstate Technology Regulatory Council (ITRC), Vapor Intrusion Pathway: A Practical Guideline, Washington, D.C., January 2007.
- Interstate Technology Regulatory Council (ITRC), Petroleum Vapor Intrusion, Fundamentals of Screening, Investigation, and Management, October 2014.
- United States Environmental Protection Agency (EPA*), Engineering Issue: Indoor Air Vapor Intrusion Mitigation Approaches*, USEPA, Washington DC, 2008
- Washington State Department of Ecology Toxics Cleanup Program. *Draft Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action*. Publication no. 09-09-047. February 2016.

Related Links:

For more information and useful links about ISM technologies, go to http://www.itrcweb.org/.

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Active Mitigation Fact Sheet

ITRC has developed a series of fact sheets that summarizes the latest science, engineering, and technologies regarding vapor intrusion (VI) mitigation. This fact sheet describes the most common active vapor mitigation technologies and summarizes the considerations that go into design, installation, post-installation verification, and operation, maintenance, and monitoring (OM&M). More detailed information on the considerations related to each step of the mitigation implementation process can be found in ITRC's ***Design Considerations Fact Sheet***, ***Post-installation Verification Fact Sheet***, and ***Operation, Maintenance, and Monitoring/Exit Strategy Fact Sheet***.

INTRODUCTION

Active mitigation of the VI pathway involves interception, dilution, or diversion of soil gas entry into a building using mechanical means that are powered by electricity. The performance of active mitigation systems is quantifiable by measurement of vacuum, area of influence, flow rates, mass flux, etc. This fact sheet presents information on the design, installation, and OM&M of active mitigation technologies for both new construction and existing buildings that range from small (i.e., residential) to large (i.e., commercial/industrial) structures. Active mitigation for new construction can be significantly different than for existing buildings due to components of new buildings and control of construction of the system during construction of the building. Details and differences between active mitigation for new construction and existing buildings is listed in this fact sheet and in the ***Design Considerations***, ***Post-installation Verification***, and ***Operation, Maintenance, & Monitoring/Exit Strategy*** Fact Sheets where appropriate.

As presented in the ***Conceptual Site Models (CSM) for VI Mitigation Fact Sheet,*** the mitigation technologies presented in this fact sheet assume the primary means for soil gas entry is via advection, rather than diffusion. Except for situations where very high sub-slab vapor source concentrations (e.g., millions of micrograms per cubic meter [$\mu g/m^3$]) are present, diffusion through the slab is not considered a significant transport pathway. Vapor mitigation systems that are "active" are designed to achieve either depressurization of the sub-slab soil or granular fill relative to indoor air or some degree of air flow and dilution in the sub-slab space. Active mitigation systems designed for depressurization will also achieve some degree of ventilation and vice versa. These two types of technologies (depressurization and ventilation) are not separate and distinct, but they are monitored using different performance metrics and criteria.

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ACTIVE MITIGATION TYPES

This fact sheet includes a brief description of four of the most common types of active mitigation, each of which is also described in a supporting technology information sheet as follows:

- sub-slab depressurization (SSD; see also the ITRC ***SSD Technology Information Sheet***)
- sub-slab ventilation (SSV; see also the ITRC ***SSV Technology Information Sheet***)
- sub-membrane depressurization (SMD; see also the ITRC ***SMD Technology Information Sheet***)
- crawlspace ventilation (CSV; see also the ITRC ***CSV Technology Information Sheet***)

In addition to or in conjunction with the four active mitigation types above, the following active mitigation approaches may also be used to assist in addressing vapor intrusion risk. These methods may be used for temporary mitigation, rapid response mitigation, or in building-specific situations where the main methods (SSD, SSV, SMD or CSV) may not be effective or may not be effective on their own. Some of these technologies are described in other technology information sheets as referenced:

- indoor air filtration (see also the ITRC ***Indoor Air Treatment Technology Information Sheet*** and USEPA *Adsorption-based Treatment Systems for Removing Chemical Vapors from Indoor Air* [USEPA, 2017].)
- aerobic vapor migration barriers (AVMB; see also the ***Aerobic Vapor Migration Barriers Technology Information Sheet***)
- building pressurization/ventilation (see also the ITRC ***Heating, Ventilation, and Air Conditioning Modification Technology Information Sheet*** and ***Preferential Pathway Sealing and Ad Hoc Ventilation Technology Information Sheet***)
- drain tile depressurization (DTD)
- block wall depressurization (BWD)

Existing in-depth standards for the mitigation of most building types have been developed and published by the American Association of Radon Scientists and Technologists (AARST) and the American National Standards Institute (ANSI). Published standards include:

- Soil Gas Mitigation Standards for Existing Homes: ANSI/AARST SGM-SF 2017 (AARST, 2017)
- Radon Mitigation Standards for Multifamily Buildings: ANSI/AARST RMS-MF-2018. (AARST, 2018a)
- Radon Mitigation Standards for Schools and Large Buildings: ANSI/AARST RMS-LB-2018. (AARST, 2018b)
- Soil Gas Control Systems in New Construction of Buildings: ANSI/AARST CC-1000-2018. (AARST, 2018c)

These documents can be viewed/accessed for free at https://standards.aarst.org/.

2.1 Common Active Mitigation Strategies

The following section provides a summary of the primary active mitigation technologies that are typically employed.

Sub-slab depressurization (SSD)—SSD uses an electric fan/blower to create a negative pressure beneath the building envelope, relative to inside the building envelope, to prevent vapors from migrating from the subsurface into the building through advection. When a negative pressure is present within the building envelope relative to surrounding soil, advective gas flow from the soil into the indoor air can occur. Soil gas entry pathways can be cracks through the slab or wall(s), improperly sealed utilities, etc. Depressurizing the soils below the slab with an SSD system will create a low pressure that reverses or alters the direction of soil gas flow, thus mitigating vapor intrusion. The types of fans/blowers used for SSD can vary depending on sub-slab material permeability, as well as the building type, construction quality, and size of the building being mitigated. SSD may be limited to the portion of the floor slab where volatile organic compound (VOC) vapor concentrations exceed generic or building-specific action levels. Depending on the vapor concentrations, emission rates, and proximity of receptors, air pollution controls may be needed.

Sub-slab ventilation (SSV)—SSV is an active engineering control employed to mitigate buildings at or near vapor intrusion sites. The goal for SSV is to reduce vapor concentrations below a structure's slab to levels that are low enough to maintain acceptable indoor air concentrations above the slab, regardless of whether there is a consistent or even measurable vacuum below the floor. Generally, this is practical where the material below the slab has a high permeability, including coarse-textured granular fill materials, drainage mats, and aerated floors, resulting in high airflow below the slab. SSV is also generally practical where the sub-slab concentrations are low to begin with and reduction to concentrations below generic or building-specific screening or building-specific action levels is easily achieved. Depending on the vapor concentrations, emission rates, and proximity of receptors, air pollution controls may be needed.

Sub-membrane depressurization (SMD)—For buildings or portions of buildings built over accessible dirt-floor crawlspaces (or dirt-floor basements), an SMD system can be used for active mitigation. SMD relies on the ability to install a durable membrane over the exposed soil in the crawlspace (or basement) to enable a negative pressure to be generated below the membrane. SMD is applicable if the basement or crawlspace will not be accessed (or will not be accessed frequently) so that the membrane is not disturbed or damaged. Prior to placing and sealing the membrane, a venting mechanism (e.g., perforated pipe, soil gas collection mat, etc.) is installed under the membrane and connected to a vertical section of solid piping, leading to a fan located outside the occupied building envelope. The types of fans/blowers used for SMD will vary depending on the size of the crawlspace/basement, how well sealed the membrane is, and the size and age of the building being mitigated.

Crawlspace ventilation (CSV)—For buildings with crawlspaces that are too shallow to enter, CSV may be warranted. This technology focuses on moving a minimal amount of air out of the crawlspace to create a modest but consistent air exchange rate for the space. As crawlspaces tend to not be sealed and are usually connected to other parts of the basement, or connected to the living space above, this venting strategy is used because it may not be possible, practical, or desirable to remove enough air from a crawlspace to create a significantly depressurized space. Ventilation may consist of opening existing vents around the crawlspace, if present, and usually includes connecting an exterior mounted fan to piping that is extended into the crawlspace. Care is needed to avoid freezing water lines in cold climate areas.

2.2 Other Active Mitigation Strategies

The following section provides a summary of other mitigation technologies that may be employed either on their own or in conjunction with the four main mitigation technologies detailed above.

Indoor Air Filtration—Indoor air filtration involves portable filtration units equipped with granular activated carbon, zeolites, or other filter media to remove vapor contamination from the indoor air. Indoor air filtration is primarily used for immediate response actions as a temporary way to reduce indoor air levels until a more permanent vapor mitigation technology can be implemented. Indoor air filtration can also be used as a supplemental degree of protection for SSD/SSV systems in the early stages if active mitigation systems are being installed to mitigate high sub-slab concentrations. See EPA's *Adsorption-based Treatment Systems for Removing Chemical Vapors from Indoor Air* (USEPA, 2017) and the ***Indoor Air Treatment Technology Information Sheet***.

Aerobic Vapor Migration Barrier (AVMB)—AVMB is a combination in-situ VI mitigation and remediation technology for sites with aerobically degradable compounds (e.g., petroleum hydrocarbons, methane and vinyl chloride). AVMB involves the slow delivery or circulation of atmospheric (ambient) air at low pressure or negative gauge pressure (i.e., sub-slab extraction combined with ambient pressure air inlets) below and around a building foundation through either sub-slab vents or horizontal wells installed below the building foundation. The delivery of ambient air creates elevated oxygen (O_2) conditions in the shallow soil around the foundation that are favorable for aerobic biodegradation. A successful AVMB will mitigate the potential for VI by aerobically biodegrading compounds susceptible to the enhanced aerobic conditions. See the ***Aerobic Vapor Migration Barrier Technology Information Sheet.***

Building Pressurization/Ventilation**—**Building pressurization/ventilation involves using the building's heating ventilation and air conditioning (HVAC) system to pressurize the building interior space sufficiently to prevent vapor intrusion or provide sufficient make-up air to reduce indoor air concentrations to acceptable levels. See ***EPA's Indoor Air VI Mitigation Approaches Engineering Issue*** for a summary of building pressurization/ventilation (USEPA, 2008). Pressurization is typically only feasible for commercial or industrial buildings with controlled door and window access so the positive building pressure can be maintained. Buildings with garage bay doors that open frequently or where tenants have free access to open and close doors and windows will not be able to consistently maintain building pressurization. This approach requires regular air balancing and maintenance and may have high operation and maintenance costs related to heating and air conditioning. Industrial building ventilation without controls may also increase fugitive emissions and recirculation of contaminants back into the building. See the ***Heating, Ventilation, and Air Conditioning Modification Technology Information Sheet*** and ***Preferential Pathway Sealing and Ad Hoc Ventilation Technology Information Sheet.***

Drain Tile Depressurization—Drain tile depressurization is similar to ***SSD***; however, it uses the presence of sub-slab sumps and associated drain tile systems to depressurize beneath the building slab to mitigate the potential for vapor intrusion. If the drain tile system is not adequate to reach all portions of the building needing mitigation, SSD can typically be used to supplement this method, except where the water table is very shallow. See *EPA's Indoor Air VI Mitigation Approaches Engineering Issue* for more information on drain tile depressurization (USEPA, 2008).

Block Wall Depressurization—Block wall depressurization uses an electric fan connected to the voids and the network within hollow block walls to create a depressurized zone to mitigate the potential for vapor intrusion through foundation walls. Uniform depressurization of block walls can be difficult. This approach is typically only recommended to supplement a traditional SSD system if the SSD is not addressing vapor intrusion through the foundation walls and it is believed that this pathway is significantly contributing to indoor air concentrations. See *EPA's Indoor Air VI Mitigation Approaches Engineering Issue* for a more information on block wall depressurization (USEPA, 2008).

3 CONSIDERATIONS FOR ACTIVE MITIGATION

Many considerations and decisions are necessary to select, design, install, operate, and eventually decommission an effective active mitigation system. The approach outlined below provides a summary of information to consider during each step in the active mitigation process. More details regarding each consideration can be found in the overall Process Fact Sheets, which include:

- ***Design Considerations Fact Sheet***
- ***Post-installation Verification Fact Sheet***
- ***Operation, Maintenance, & Monitoring/Exit Strategy Fact Sheet***

The Process Fact Sheets are written to include all VI mitigation technology types and go into more detail as to the considerations to be made at each point in the stepwise process and the relative impact each consideration may have for each type of mitigation technology.

3.1 Design Considerations

Prior to mitigation system design, it is common to perform a building survey and predesign diagnostic testing to understand building-specific issues that will need to be incorporated into the system design. The larger and more complicated a building, the more predesign work is likely to be performed to create an effective system design. Design considerations for new large buildings should comport with ANSI/AARST (AARST, 2018b; ARST, 2018c).

For many small buildings (for example, single-family homes), it may be common to do very little predesign work prior to design and installation of a mitigation system. This occurs because it is often mistakenly assumed that single-family homes can be actively mitigated with a single fan and single suction point. This may be true for homes with a smaller footprint and with concrete and sub-base that are in good condition, but care should be taken because this may not be applicable in all cases. Design considerations for new buildings should comport with

ANSI/AARST (AARST, 2017). Below are common considerations that professionals may review or tests they may complete prior to or in conjunction with preparation of an active mitigation system design.

For systems installed during new building construction, design considerations may be different, as there is much more control over the building and its infrastructure. Design considerations for new buildings should comport with ANSI/AARST (AARST, 2018a).

Special design considerations may also be needed if looking to convert and modify a previously installed passive system to an active system. The practitioner or designer must understand the air flow and the potential for short circuiting prior to converting a passive mitigation system to an active system. Designs should account for more than just adding a fan/blower to a passive system's vent stack(s).

The ***Design Considerations Fact Sheet*** provides details of factors that could be considered for various VI mitigation approaches, including active mitigation, passive mitigation, remediation, and rapid response. Factors that could be considered for active mitigation include:

- VI CSM considerations
  - vapor source
  - geology and hydrogeology
  - building conditions
- Design investigation and diagnostic testing
  - sub-slab diagnostic tests
  - barrier or liner material tests
  - building HVAC tests
- Mitigation system design
  - design basis
  - design layout and components
  - permit requirements
  - stakeholder requirements
- System construction and implementation
  - system effectiveness and reliability
  - operation and maintenance considerations
  - exit strategy considerations

A ***System Design and Documentation Checklist*** has also been created to provide a guide through the considerations relative to both active and passive mitigation strategies.

During this stage in the mitigation process, the installation and installation oversight of the system should be considered as it relates to the design and the components of completing a design (e.g., implementability, permitting, construction quality objectives, etc.). Additional installation considerations will be summarized in the post-installation verification process step.

3.2 Post-Installation Verification Considerations

Following design and installation, the mitigation system will be turned on and verification will be needed to document that the system is operating according to the objectives set out in the design. Verification of system installation and effective operation may include multiple criteria. It is also important during this step, as well as in the future during OM&M, to validate the CSM for which the system was designed. Below is a summary of possible post-installation verification considerations that may be needed for active mitigation approaches.

Initial system commissioning data may be collected immediately upon start-up and system balancing. It is also common to collect (or recollect) commissioning data and rebalance the system if needed, up to 30–90 days after system start-up. This is due to changing conditions in the subsurface soils where soils may dry out and/or sub-slab vapor concentrations may be reduced. Often this process results in more permeable soils and an increase in the distances of the pressure field extension (PFE) for an active system (SSD, SMD and SSV). If indoor air samples are going to be collected as part of verification testing, the time frame for sampling may be different than initial system commissioning flow and vacuum data collection. Some states have recommended data collection time frames in their VI guidance to be followed as applicable.

For systems installed during new building construction, post-installation verification testing may be easier to perform prior to building occupation, especially if any retrofits are needed to enhance system performance. These verification methods (i.e., system parameter readings, PFE tests, tracer tests, checking for leaks, etc.) can be performed relatively quickly in an empty building to minimize delay in the continued construction and occupancy schedule.

The ***Post-Installation Verification Fact Sheet*** provides details of those factors that could be considered for active mitigation and includes:

- groundwater elevation
- building information and survey
- system design and specification confirmation considerations
- confirmation testing
- permitting
- communications
- OM&M planning

Please also see the ***Post-Installation Verification Checklist*** for a checklist guide to verification considerations.

3.3 OM&M Considerations

An OM&M plan provides instructions for system operation and upkeep and should be prepared for each installed mitigation strategy. Details of a typical OM&M plan can be found in Section 6.3 and Appendix J.5 of the ITRC PVI Guidance (ITRC, 2014). The goal of OM&M is to verify performance of the system as compared to performance during system commissioning and to inspect and, if needed, repair issues with the system due to system malfunction (i.e., system not operating to meet performance objectives) or due to system equipment life expectancy.

The ***Operation, Maintenance, & Monitoring Checklist*** includes a list of considerations that may be reviewed, inspected, and/or measured during an OM&M site visit. Considerations during OM&M inspections of active mitigation systems may also need to include OM&M of any passive components to VI mitigation activities completed at the property, such as maintenance of passive membranes or maintenance of crack sealants or preferential pathway sealants that were installed/completed in combination with the active mitigation approach. Passive OM&M considerations are included in the ***Operation, Maintenance, and Monitoring Checklist*** and are also discussed in the ***Operation, Maintenance, and Monitoring/Exit Strategy Fact Sheet***.

The ***Operation, Maintenance, and Monitoring/Exit Strategy Fact Sheet*** provides details of those factors that could be considered for active mitigation and includes:

- mitigation system operation
- system start-up and shutdown
- building conditions and use
- system inspections and performance metrics
- communication and reporting

3.4 Exit Strategy

A key concept throughout the process of designing, implementing, and operating an active mitigation strategy is evaluating options for assessing and implementing exit strategies. The source of VOC vapors may be remediated or may biodegrade within the life cycle of a mitigation strategy and therefore, in some cases, render the system unnecessary. There are also cases where mitigations systems are operated out of an abundance of caution, but are not actually necessary, as a result of uncertainties associated with spatial and temporal variability in sampling and analysis of data, background sources, and/or conservative regulatory guidance. The details for exit strategy considerations can be found in the ***Operation, Maintenance, and Monitoring/Exit Strategy Fact Sheet***.

In each step of the active mitigation strategy process (from design to installation to OM&M) the exit strategy (also referred to as decommissioning or system closure) should be considered and planned. A review of existing VI regulatory guidance documents (Eklund et al., 2018) included an evaluation of various state provisions for exit strategies. States such as Massachusetts (MADEP, 2016), New York (NYSDOH, 2006), New Jersey (NJDEP, 2018), and Wisconsin (WDNR, 2018) include recommendations for certain data collection efforts to support the closure decision, such as:

- verification sampling and analysis of sub-slab vapors and/or indoor air and outdoor air and comparison to protective screening levels
- temporary shutdown of system operation prior to the verification sampling, to allow vapor concentrations to rebound to potential levels that might be expected after system closure
- multiple verification monitoring events to account for temporal variability
- operation of the system between verification monitoring events, or indoor air monitoring to maintain protectiveness

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These approaches can effectively demonstrate that system operation is no longer necessary. It may be appropriate to prepare a work plan that outlines the exit strategy prior to implementation of shutdown efforts.

Research into additional approaches for VI assessment and mitigation design and performance monitoring has been demonstrated and validated through Environmental Security Technology Certification Program (ESTCP) projects. These methods can also be used to assess the continued need for a mitigation system or if the system may be considered for decommissioning. For example, the goal of ESTCP (2018) was to demonstrate and validate a more rigorous and cost-effective process for design and optimization of VI mitigation systems to reduce the capital and long-term operating costs. The mass loading and mass flux assessment methodologies applied in ESTCP (2018 and 2020) can also be used to understand if the rate of mass removal from a system has resulted in decreased concentrations of VOCs to levels below the risk-based screening level for mass loading and therefore no longer pose a risk for VI (McAlary et al., 2018; McAlary et al, 2020).

The selection of an appropriate exit strategy and whether vapor sources remain that present a risk for VI will depend on site-specific conditions and should be approached as a process, rather than as an event. The transition can be planned to proceed through multiple steps. Exit strategy considerations are detailed in the exit strategy subsection of the ***Operation, Maintenance, and Monitoring/Exit Strategy Fact Sheet***. It includes descriptions of the following:

- types of monitoring and timing
- stepdown strategies
- decommission considerations
- communication

SUMMARY

Active mitigation involves the use of energized controls (e.g., a fan/blower) to maintain acceptable indoor air quality by mitigating the potential for VI into a building. As described in this fact sheet there are multiple different methods for active mitigation with the most common methods being:

- sub-slab depressurization (SSD)
- sub-slab ventilation (SSV)
- sub-membrane depressurization (SMD)
- crawlspace ventilation (CSV)

Building structures vary widely in their size, function, and use. Because of this variability, implementation of active mitigation technologies will also vary widely, depending on the type of building structure and the design objectives for the VI mitigation system. This fact sheet and associated Process Fact Sheets summarize the many considerations for the design, installation, verification, and OM&M of each of the most common active mitigation technologies as they relate to some of the more common building types and uses. Depending on vapor concentrations, emission rates, and proximity of receptors, air pollution controls may need to be installed.

The details and considerations discussed are a part of the long-term stewardship of active VI mitigation systems. Systems should not only be carefully designed and installed but procedures or guidance (or in some cases, institutional controls) should be put in place to maintain the operation of these systems until such a time that the system can be considered for shutdown.

REFERENCES AND ACRONYMS

The references cited in this fact sheet, and the other ITRC VI mitigation fact sheets, are included in one combined list that is available on the ITRC web site. The combined acronyms list is also available on the ITRC web site.

ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Active Vapor Intrusion Mitigation Systems Subgroup

Crawlspace Ventilation (CSV)
Active Mitigation Systems (uses electric fan/no sealed membrane barrier)

This ITRC Technology Information Sheet provides basic information for using a fan to ventilate a crawlspace for mitigating vapor intrusion into the occupied space of a building. The design objective of CSV is to dilute crawlspace vapors to concentrations less than levels of concern. Controls on the location and volume of air removed from the crawlspace are needed to avoid significant heating or cooling impacts to the residents above the crawlspace. Consequently, CSV is typically used when other technologies are not feasible. Only experienced practitioners should provide services for this mitigation technology.

Overview

Crawlspace ventilation mitigates vapor intrusion (VI) through dilution of VOC concentrations in crawlspace air. Ventilation of a crawlspace may be achieved by removing air from the crawlspace and replacing it with fresh air. As crawlspaces tend not to be sealed, and are usually connected to other parts of the basement and/or the occupied space above, CSV is more common than crawlspace depressurization because it may not be practical or desirable to remove enough air from a crawlspace to create a significantly depressurized space. CSV typically involves the opening of existing exterior vents, if present, around the crawlspace to provide a source of supply air. There are varying considerations for design and implementation of CSV depending on whether the crawlspace is accessible (from inside the building or from outside) or inaccessible. CSV may be more challenging to implement in an inaccessible crawlspace. When the crawlspace is accessible crawlspace sub-membrane depressurization may be a better option than CSV.

CSV design should achieve the movement of the minimum amount of air out of the crawlspace to create a modest, but consistent, air exchange rate (AER) for the space that is sufficient to dilute crawlspace vapor concentrations to below levels of concern. The AER may vary, but a typical range is between 1 and 3 air exchanges per hour. Additionally, sealing of openings in the floor separating the crawlspace from the above occupied space should be considered to minimize the volume of indoor air drawn across the floor and into the crawlspace prior to the atmospheric discharge through the CSV process. Sealing of cracks/openings between the crawlspace and the occupied space can minimize additional energy costs when building air is heated or cooled.

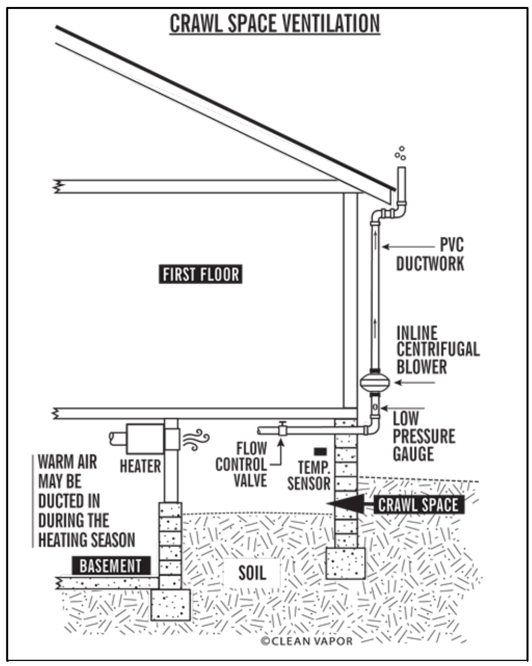

Figure 1. Example crawlspace ventilation system with fan located outside.
Source: Clean Vapor, LLC, used with permission.

The CSV design should also explicitly avoid the risk of back drafting combustion appliances. Back drafting may occur if combustion gases are prevented from atmospherically venting and instead are drawn into building and/or crawlspace air spaces, thereby creating unsafe conditions. National consensus standards, such as those published by the American Association of Radon Scientists and Technologists/American National Standards Institute (AARST/ANSI), and applicable national and local building codes should be consulted with regards to back drafting requirements.

Depending on the size of the crawlspace, several methods can be used for ventilation. One method involves installing solid piping into the crawlspace, sealing the annular space around the piping penetration, and extending the piping to an exterior-mounted fan that discharges ventilated air above the roofline and away from building openings. Alternatively, smaller crawlspaces with existing exterior vent openings may be adequately vented using a crawlspace ventilator fan. See Figure 1 for an example CSV system configuration.

For new buildings in areas with VI potential, it is preferable to mitigate vapors in a crawlspace using sub-membrane depressurization (SMD) systems rather than CSV because the combination of depressurization and a barrier can typically be engineered to provide for a more effective mitigation solution. See the ITRC ***Sub-Membrane Depressurization Technology Information Sheet*** for more information.

Components

This technology requires a fan or blower connected via piping to the crawlspace. See Figure 1 for an example photo of piping exiting a crawlspace. Other features of a CSV include:

- system piping, including a sampling port for accessing system air velocity/flow data and for obtaining effluent samples to quantify chemical concentrations, if needed. These data may be used to estimate chemical mass flux in vented crawlspace air.
- valves or other means for adjusting the airflow. This may be achieved by installing a flow control valve or fan motor speed controller, or through sizing of the piping and fan.
- instrumentation (either permanent or included during operations, maintenance, and monitoring (OM&M) visits) to measure pressure differentials between the crawlspace and adjacent occupiable spaces.

Heating season contaminant of concern concentrations in the crawlspace should be known and targeted AER and pressure differential values between the crawlspace and surrounding occupiable space should be established as part of the design and implementation process. There will be a variable seasonal relationship between pressure differential values and the volume of air exhausted from the crawlspace. In cold climates, design considerations should also include utility insulating, temperature monitoring, heat tracing of pipes, and ducted warm air that is thermostatically actuated to keep pipes from freezing. Freezing of condensation in ventilation pipes or non-CSV-related utilities that contain water may be of potential concern.

Advantages

CSV has the following advantages:

- This is a readily deployable engineering control.
- CSV works in crawlspaces with limited accessibility.
- It is possible to monitor performance using metrics that are readily measurable (i.e., airflow rates).
- A CSV system can easily be connected to remote monitoring and control technologies.

Figure 2. Example piping into a crawlspace area.
Source: C. Regan, ERM, used with permission.

Limitations

CSV has the following limitations:

- Installation and OM&M may require confined space training depending on crawlspace construction and if entry is needed.
- A thorough health and safety evaluation should be completed, and potential hazards addressed prior to entering a crawlspace. In some cases, crawlspace entry may not be necessary or possible. All applicable protocols for confined space entry must be followed for crawlspaces.
- Potential impacts to occupants of the building being mitigated from operation of the CSV ventilation system should be considered, including the potential for heat loss in the livable space above the crawlspace or the potential for increased energy costs from operating the system.
- The presence of asbestos in the crawlspace may require removal or abatement prior to CSV installation and activation. In certain circumstances, the presence of asbestos may eliminate CSV as a mitigation strategy.

- CSV may not be used if atmospherically vented combustion appliances are present within the crawlspace.
- A high energy penalty may be incurred due to the potential for removal of conditioned air from the building space above the crawlspace.
- Extensive sealing may be required between the crawlspace and basement (if present) and the crawlspace and building space above the crawlspace to isolate the crawlspace.
- In cold climates, design considerations should include measures to keep pipes from freezing, as described above.

Cost Considerations

The primary factors that affect the overall cost of a CSV system include:

- the presence of heating/cooling ductwork
- water piping
- size of the building (indirectly as it relates to crawlspace size and length of pipes needed)
- size of the crawlspace
- tightness of the floor between the crawlspace and the overlying occupied space
- presence of exterior vents
- remote monitoring
- OM&M requirements

The approximate costs for installation of this technology range from $2 to $4 per square foot of crawlspace These costs are typically for installation only and do not necessarily include the costs of predesign testing; preparation of a work plan, design and specifications; installation monitoring; regulatory agency and stakeholder liaising; post-installation verification testing; and reporting.

Cost factors include but are not limited to the following:

- size of the crawlspace
- system components
- climate and need for insulation
- means of controlling and monitoring the system's performance

Energy cost for CSV systems can be calculated by understanding the power draw of the blower, the building energy demand based on climate (i.e., the heating degree days) to estimate heat loss, and the local costs for power.

Special Circumstances

Special circumstances for construction of a CSV include:

- CSV should be considered when SMD is not practical due to lack of access to the crawlspace (typically shallow crawlspaces).
- Installation of warning placards may be appropriate at the entrance to the crawlspace to notify entrants of the possible presence of vapors within the crawlspace and of the importance of maintaining a sealed crawlspace entrance.
- Designs should avoid excess air removal from crawlspaces to protect against the potential for back drafting, minimize the potential for freezing of pipes located within the crawlspace, and minimize increases in heating/cooling costs.
- CSV typically requires opening of exterior crawlspace vents when present.
- To the extent possible, a barrier should be placed across the ground surface of the crawlspace, even if the barrier cannot be fully sealed or the entire crawlspace extent accessed.
- Instrumentation and equipment to regulate and measure air flow rates to achieve a targeted ventilation rate should be conducted by an individual who is experienced in this practice.
- In cold climates, temperatures should be monitored so actions can be taken to avoid freezing pipes.

Occupant, Community, and Stakeholder Considerations

It is essential to develop and implement a site-specific community involvement plan that addresses how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. For more details see ITRC's ***Public Outreach during Vapor Intrusion Mitigation Fact Sheet***.

References and Resources

- ITRC Technical and Regulatory Guidance Document, Vapor Intrusion – A Practical Guideline, 2007.
- ITRC Petroleum Vapor Intrusion, Fundamentals of Screening, Investigation and Management, 2014.
- Soil Gas Mitigation Standards for Existing Homes, 2017, AARST Consortium on National Radon Standards, ANSI/AARST SGM-SF 2017.

Related Links:

For more information and useful links about VI pathways and mitigation technologies, go to http://www.itrcweb.org/ .

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ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Active Vapor Intrusion Mitigation Systems Subgroup

Sub-membrane Depressurization (SMD)
Active Mitigation Systems (uses electric fan)

This ITRC Technology Information Sheet provides basic information when using a fan to depressurize soil or a small air space below a sealed membrane barrier, usually placed on the exposed dirt floor of a crawlspace (or dirt floor basement) to mitigate potential vapor intrusion (VI) into a building. SMD is a common engineering control used for buildings at or near VI sites. Although this technology is more commonly applied to residential buildings (due to building construction features that create spaces where SMD can be used), SMD can also be used in commercial and industrial buildings. Depressurization occurs when a negative pressure differential is extended below the installed membrane relative to the indoor air space above the membrane.

Overview

SMD is a commonly used engineering control for mitigating VI in buildings that are built over a crawlspace-style foundation. SMD may also be applicable for dirt floor basements and basements with compromised concrete floor slabs with consideration to whether frequent access to these spaces are needed. The types of fans/blowers used for SMD vary, depending on the size of the area, how well sealed the membrane is, and the size and age of the building requiring mitigation. SMD relies on the ability to access and install a durable membrane over the exposed soil (or slab, in some cases) in the crawlspace/basement that enables a negative pressure to be generated below the membrane. Prior to placing and sealing the membrane, a venting mechanism (e.g., perforated pipe, geocomposite soil gas collection mat) should be installed and connected to a vertical section of solid piping, leading to a fan mounted exterior to the occupiable building envelope. The vertical section of pipe should convey soil gas to a discharge point above the roofline and away from building openings. Following installation and commissioning, performance of the SMD can be measured by collecting differential pressure readings from below the membrane relative to the area and/or building indoor air.

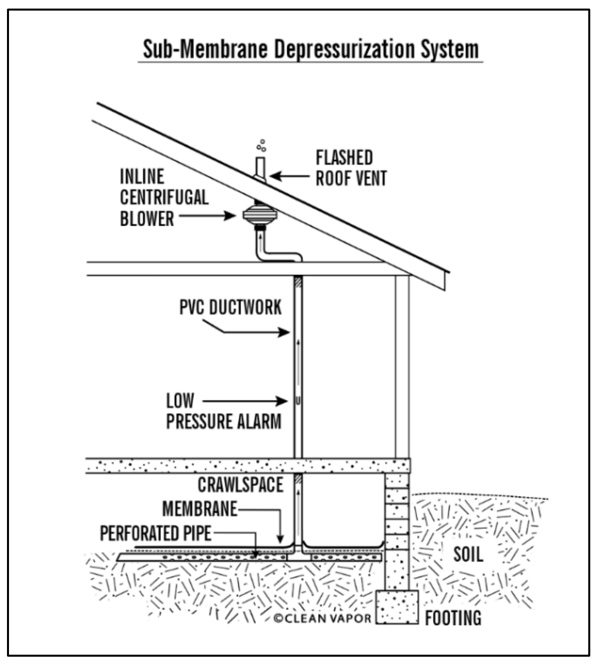

Figure 1. Typical sub-membrane depressurization system in a residential building (fan outside occupiable building envelope)
Source: Clean Vapor, LLC, used with permission.

Components

This technology requires a fan or blower connected via piping to the space directly below the membrane (see Figure 1). The electric fan or blower can be installed on either the outside or inside of a building, depending on access and the locations available. Typically, fans are installed on the outside of the building due to access issues, both for system installation and for ongoing system operation, maintenance, and monitoring (OM&M). Fans installed on the outside of a building are subject to changing weather conditions and, depending on the geographic region, may experience condensate issues and/or additional wear on the fan. Fans installed in interior spaces (for example, attics) must be fully excluded from occupied and/or insulated interior spaces (i.e., fans need to be located outside the occupiable building envelope) to mitigate the potential for leaks in the fan's vent from entering the occupied space. Fans installed in protected spaces, such as attics, have a longer and more consistent operating life because they are protected from extreme weather conditions, but also require access to be granted by the property owner and occupants for each OM&M visit. Qualified personnel should oversee the design, installation, and OM&M of SMD systems.

Other features of an active SMD system may include:

- system piping, including a sampling port for conducting system diagnostic testing (i.e., vacuum and air velocity/flow) and sample collection for analysis of VOC concentrations in effluent or sub-slab vapor flux concentrations
- permanent u-tube manometer, vacuum gauge, or pressure sensor on the system piping to monitor system pressures
- balancing valves on the system piping, which allow adjustments to system flow when installing multiple suction points through the membrane, when multiple crawlspaces or multiple basement areas are present, and/or when combining SMD with sub-slab depressurization (SSD) or other active mitigation methods. Balancing valves may help reconfigure the system footprint as vapor concentrations diminish over time. Blowers that have variable speeds may also be used to balance or rebalance a system over its operational life.
- monitoring points through or below the membrane, for the purpose of monitoring the extent of the vacuum. At least one port should be located distant from the applied vacuum point to verify influence at remote extents.

Advantages

SMD as an active mitigation technology has the following advantages:

- SMD is a readily deployable engineering control.
- This is a cost-effective mitigation method for crawlspaces and preferred over crawlspace ventilation (CSV) if access to the crawlspace is possible. See ***CSV Technology Information Sheet*** for more information.
- SMD generally allows use of lower-vacuum, in-line radon fans to achieve SMD.
- Installing and sealing a membrane barrier makes it less likely in comparison to a CSV system that indoor air will be drawn down into the crawlspace.
- Performance can be reliably monitored through telemetry connected to sub-membrane monitoring point(s).

Limitations

SMD as an active mitigation technology has the following limitations:

- A thorough health and safety evaluation should be completed, and any potential hazards addressed (including possible confined space entry) prior to entering a crawlspace/basement for installation activities.
- Installation of an SMD system requires coordination with and cooperation of the building occupants during both system installation and ongoing OM&M.
- This method relies on the installation and maintenance of a sealed barrier, which may be difficult to achieve in some crawlspace/basement configurations due to uneven walls, numerous supports or pipes to seal around, conditions of the walls to support a membrane seal, and limitations on access.
- Vertical space limitations can make installing and sealing the membrane barrier more difficult.
- Padding or other protective measures, such as geotextiles, may be needed to prevent damage to the barrier if infrequent access to the area is needed (e.g., OM&M visits, building repairs, access to building piping).
- Access limitations may be needed (include labeling) to prevent damage to the barrier from property owners walking on the membrane. Coordination with the property owner/occupant will be needed to prevent items from being stored on top of the membrane, which could limit effectiveness and potentially damage the membrane. For high traffic areas on top of the barrier, a protective covering (such as

- For some properties, it may be difficult to prevent property owners from tampering with and possibly damaging system components.

Cost Considerations

The primary factors that affect the overall cost of an SMD system include the membrane and multiple factors associated with installing the membrane, including the area/footprint of crawlspace/basement, height of crawlspace/basement, type of foundation, age of foundation, cleanliness of area, and presence of obstacles.

Approximate costs for installation of this technology range from $3 to $6 per square foot. These costs are typically for installation only and do not necessarily include the costs of predesign testing; preparation of a work plan, design and specifications; installation monitoring; regulatory agency and stakeholder liaising; post-installation verification testing; and reporting.

Cost factors include, but are not limited to, the following:

- vapor membrane material
- protective geotextile
- piping or drainage mat used under the membrane for soil vapor conveyance
- protective matting, such as EPDM, used in areas where people may need to walk for access
- sub-membrane pressure differential sensors or ports
- adhesion methods and materials to attach membrane to side walls, columns, and pipes
- confined space, low clearance, lighting, health, and safety practices
- means of controlling water intrusion, if present
- long term OM&M

Special Circumstances

Special circumstances for construction of an SMD system include:

- If vertical height is limited, CSV may need to be considered (see ***CSV Technology Information Sheet*** for more information).
- Insulation with or without heat trace may be warranted to prevent freezing of condensate in pipes and fans in cold climates, or to dampen noise.
- Placards may be appropriate at the entrance to the crawlspace/basement to notify entrants of the membrane in place and limit access to the area to only essential activities (e.g., access to the system for maintenance or access to building piping as needed for maintenance).
- Sumps and water drainage accommodations may need to be installed to manage water accumulation if the crawlspace/basement allows water to infiltrate through the dirt floor.
- Rodents and household pets can cause damage to membrane barriers.

Occupant, Community, and Stakeholder Considerations

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. For more details, see ITRC's ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet***.

References and Resources

- ITRC Technical and Regulatory Guidance Document, Vapor Intrusion – A Practical Guideline, 2007.
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ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Active Vapor Intrusion Mitigation Systems Subgroup

Sub-slab Depressurization (SSD)
Active Mitigation Systems (uses electric fan)

This ITRC Technology Information Sheet provides basic information when using a fan to depressurize the sub-slab environment to mitigate the potential for vapor intrusion at a given building. SSD is the most common engineering control installed in buildings at or near vapor intrusion sites. The operational objective for SSD systems is to create a negative pressure below the building slab. Depressurization occurs when the pressure below the slab is less than that of indoor air.

Overview

SSD uses an electric fan to create a pressure gradient across the subgrade portion of the building to mitigate the potential for vapor intrusion from the subsurface into the building. When a negative pressure is present within the building envelope relative to surrounding soil, advective gas flow from the soil into the indoor air can occur. Soil gas entry pathways can be cracks through the slab or wall(s), improperly sealed utilities, etc. Depressurizing the soils below the slab with an SSD system will create a low pressure that reverses or alters the direction of soil gas flow, thus mitigating vapor intrusion. The types of fans/blowers used for SSD can vary depending on sub-slab material permeability, as well as the building type, construction quality, and size of the building being mitigated. SSD may be limited to the portion of the floor slab where volatile organic compounds (VOC) vapor concentrations exceed generic or building-specific screening action levels for VI.

General Design

SSD suction points can be constructed by coring through the slab or foundation, trenching in the slab, directional drilling from outside the building, or other methods of accessing the sub-slab soil. Typical system schematics are shown in Figures 1 and 2. Most commonly, a vertical pipe of 3- to 6-inch nominal diameter is installed through a cored hole in the floor. A suction pit or cavity is created below the floor by removing approximately 1 cubic foot of soil or fill material to reduce resistance to flow and enhance vacuum propagation. The piping is sealed to the slab or foundation at the connection point with the cavity using durable caulking or air-tight pipe fittings. The permeability of the subgrade soils and the presence of cracks and openings in the building floor slab will affect the performance of the SSD. Best performance is obtained when the suction pit is left open (and not backfilled with stone or other material) and cracks/openings in the floor are sealed. Practitioners should understand vacuum, air flow, pressure differential(s), and the effects each has on the system design and operation.

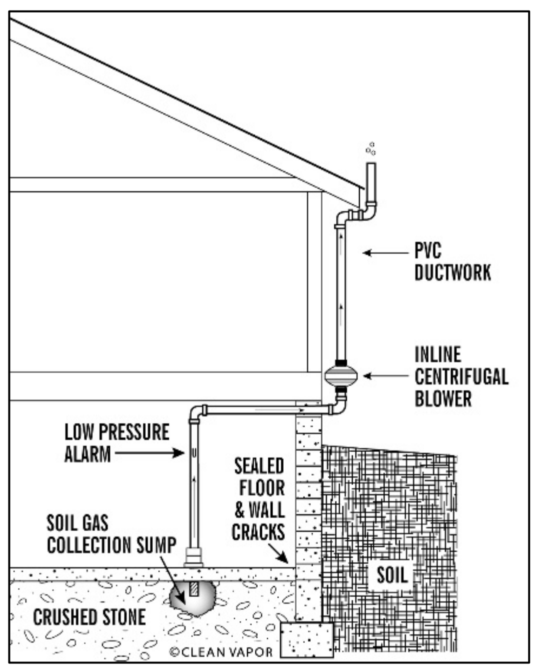

Figure 1. Example SSD system (fan outside).
Source: Clean Vapor, LLC, adapted from EPA (1993)

Detailed design specifications for design and construction of SSD systems are beyond the scope of this technology information sheet, but information regarding design and operation can be found from the American Association of Radon Scientists and Technologists (AARST, 2017) and the Environmental Security Technology Certification Program (ESTCP) (McAlary et al., 2018). The ANSI/AARST standards are consensus-based standards by which certified installers of radon and soil gas mitigation systems in new buildings may be held accountable. ESTCP resources provide technical information that can inform mitigation system design and operation.

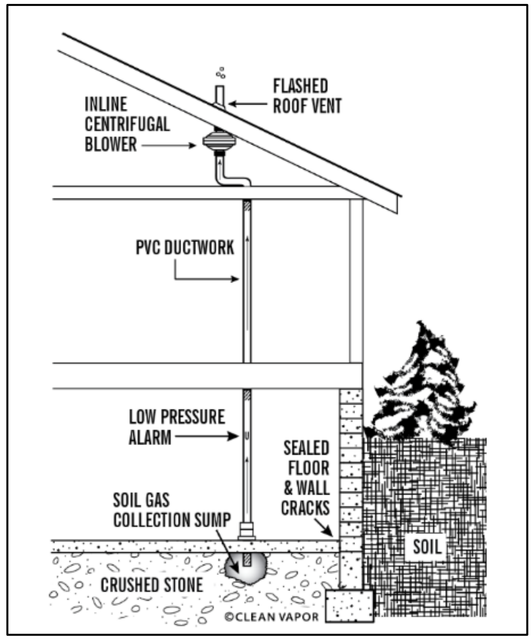

Figure 2. Example SSD system (fan in attic, outside living building envelope).
Source: Clean Vapor, LLC, adapted from EPA (1993), used with permission.

New Building Design

SSD can also be incorporated into the design and construction of a new building. The radon mitigation industry has a long history of using radon-resistant construction techniques (USEPA, 1994) (summarized in https://www.epa.gov/radon/radon-resistant-construction-basics-and-techniques), which may also be appropriate for mitigation of the VI pathway for VOCs. These techniques include installation of some or all of the following: a permeable sub-base (or aerated slab with drainage mat or specialized forms), perforated collection piping, construction-grade geomembrane, solid riser piping (extending above the roofline of the building to an appropriate discharge location), sub-slab probes or tubing run to exterior weatherproof box to monitor sub-slab concentrations from outside as a substitute, and accommodations (i.e., electrical connections) for future fan installation. For new construction, a passive fan (e.g., wind-driven turbine) may not be installed initially, but accommodations should be made for fan installation if required in the future.

The need for installation of a fan and operation of the SSD system in a newly constructed building is often assessed and determined by postconstruction air and vapor sampling and analysis. Other options, depending on regulator acceptance, may include:

- temporary operation of active mitigation, which may consist of running the system as a pilot test (e.g., attaching a wet/dry vacuum or temporary fan to a riser pipe), in combination with the sampling and analysis of the vapor extracted from below the constructed building. The vapor concentrations, along with system performance data, are used to assess the need for active operation of the system (McAlary et al., 2018).
- Collection of sub-slab vapor samples prior to venting after the riser pipes have been capped for a minimum of 30 days (NJDEP, 2018), the building is constructed, and the heating, ventilation, and air conditioning (HVAC) system is operational. Capping the riser pipe(s) simulates “worst-case” conditions because some air exchange occurs by passive venting when the riser pipe(s) are open.

If active mitigation is determined to be necessary for new construction, in-line fan(s) can then be installed on the exterior system piping or interior piping that is outside the heated/occupied building envelope. Vacuum influence is then measured at sub-slab monitoring points (located centrally and at the remote extents), and these data, combined with flow rates, mass removal rates tracer tests, and/or other lines of evidence, may demonstrate system effectiveness. A detailed design standard used for radon mitigation that is applicable to active mitigation system design and operation for VOCs can be found in the ANSI/AARST CC-1000-2018 (AARST, 2018c). Additional information is posted by USEPA (USEPA, 1994). A benefit of including a roughed-in active SSD system during new construction is lower cost compared to a retrofit. Also, a highly transmissive sub-floor, in combination with SSD, requires less reliance on the performance of a resistive layer (i.e., a concrete floor and/or vapor membrane).

Membranes Used with SSD Active Mitigation

Although membranes are not typically installed with an SSD system for an existing structure, installation of a membrane should be considered when SSD is implemented during new construction. The thickness and type of membrane selected and installed will depend on soil vapor VOC concentrations, design objectives, and construction logistics.

Vapor membranes can reduce leakage across the floor, which enables the vacuum field to propagate farther and with less applied force (and less electricity consumption) than in cases where the concrete slab alone is the barrier reducing long-term operation costs. The inclusion of a membrane may also provide some protection in the event that the fan(s) are not operational.

For newly constructed buildings where lower VOC concentrations are expected to be present in sub-slab soil gas, a relatively thin membrane consistent with radon mitigation practice may be considered for active systems. For reference, membranes for use with radon systems are specified in the ANSI/AARST Standard for New Construction (AARST, 2020) and ASTM International (ASTM, 2017). The standards for radon commonly call for a membrane (typically reinforced polyethylene or polyolefin) with a thickness between 6 and 15 mils. Caution should be applied in the selection of liners with thicknesses of 10 mils or less because they may be prone to damage during the construction process and are difficult with which to achieve a reliable seal. Additionally, the interaction with VOCs with the membrane will need to be considered. Installation of the vapor membrane should include sealing at seams, pipes, and other penetrations, and sealing to the perimeter stem wall using sealants compatible with the selected membrane (AARST, 2018a).

For newly constructed buildings where higher VOC concentrations are expected be present in the sub-slab soil gas, installation of a more robust membrane should be considered for active systems. Soil vapor VOC concentrations may be considered high when concentrations are an order of magnitude or higher than an applicable sub-slab screening level. A more robust membrane would include products that are more resistant to diffusion of site-related VOCs (e.g., seamed, sheet-applied membranes that are installed with documented quality control procedures). More information can be found on those types of liners in the ***Passive Mitigation Approaches for Vapor Intrusion Mitigation Fact Sheet*** and associated supporting technology information sheets.

Figure 3. Blower installation outside building.
Source: C. Regan, ERM

Components

Active SSD technology requires an electric fan/blower connected via piping to the space directly below the floor slab. The electric fan/blower can be installed on either the outside (Figure 1 and Figure 3) or inside (Figure 2 and Figure 4) of a building, depending on locations available. Typically, fans are installed on the outside of the building due to access issues both for system installation and for ongoing system operation, maintenance, and monitoring (OM&M). Fans installed on the outside of a building are subject to changing weather conditions and, depending on the geographic region, this may cause condensate issues and/or additional wear on the fan. Fans installed in interior spaces (for example, attics) must be fully excluded from occupied and/or insulated interior spaces (i.e., fans need to be located outside the occupiable building envelope) to mitigate the potential for leaks in the fan's vent from entering the occupied space. Fans installed in weather-protected spaces such as attics have a longer and more consistent operating life because they are protected from extreme weather conditions, but also require permission from and coordination with the property owner to obtain access for each OM&M visit.

Figure 4. Blower installation inside attic, outside occupiable building envelope.
Source: Clean Vapor, LLC

The vent pipe from the fan/blower is exhausted above the roofline and away from building openings to avoid re-entrainment of exhausted vapors (AARST, 2017). Optional components depending on operational and regulatory considerations include vapor-liquid separators or moisture knockout tanks upstream of blowers to manage significant entrained liquids and air emissions treatment (i.e., activated carbon) downstream of blowers.

Other features typical of an active SSD include:

- system piping, including a sampling port for conducting system diagnostic testing (i.e., vacuum and air velocity/flow) and for collecting samples to measure VOC concentrations in the effluent in support of sub-slab vapor flux calculations, if desired
- permanent u-tube manometer (Figure 5), vacuum gauge, or pressure sensor on the system piping to monitor system pressures
- balancing valves on the system piping, which provide an efficient way to adjust system flow from multiple suction points, to account for increased pressure gradients due to drying out of the subsurface soils, and/or to reconfigure the system footprint as sub-slab vapor concentrations diminish over time. Blowers that have variable speeds may also be used to balance or rebalance a system over its operational life.

Figure 5. Typical U-tube manometer.
Source: R. Saari, Arcadis, used with permission.

Advantages

SSD as an active mitigation technology has the following advantages:

- SSD is an easily deployable engineering control that is often considered the most reliable and protective mitigation method.
- Performance can be reliably monitored by measuring sub-slab pressure differential at central and remote extents, reducing the need for expensive sampling during OM&M.
- Continuous performance can be reliably monitored through telemetry connected to sub-slab monitoring point(s).
- SSD systems mitigate vapors from entering indoor air rather than relying on dilution or filtering of the vapors after they have entered indoor air.
- In-line fans, which can be used in most buildings with small footprints or higher permeability sub-slab soils, use a small amount of electricity and require no routine maintenance; therefore, OM&M costs are low.
- Systems are designed to minimize the disturbance/removal of indoor air; therefore, these SSD systems have a low impact on heating and cooling costs.
- Systems can also protect buildings from radon gas and reduce moisture levels in damp basements.
- SSD systems can be implemented on most building types, including existing and new construction, residential homes, and larger commercial and industrial buildings.

Limitations

SSD as an active mitigation technology has the following limitations:

- Installation of SSD systems impacts the occupants of the building in that coordination with and cooperation of the building occupants is needed during system installation (for existing buildings) and ongoing OM&M (both new construction and existing buildings).
- SSD systems will not be continuously effective during high water table conditions where groundwater is in contact with the slab or within inches of the slab and occupies the pore spaces in the permeable subgrade materials.
- Low permeability soils below the slab negatively affect the pressure radius of influence, requiring the installation of additional suction points and/or use of higher vacuum fans.
- Poor concrete slab construction, excessive cracks in the slab, or utility penetrations/floor drains/pipes may create short circuiting of air flow and potentially have a high energy penalty through loss of conditioned indoor air to the sub-slab. A substantial amount of sealing to limit indoor air from being drawn into the system and to enable overall system effectiveness may therefore be needed. Sealants may require OM&M as well.
- High permeability soils below the slab may not allow measurement of large negative pressure differentials away from a suction point(s), providing a false indication that the system is not working.

- Installation of vapor exhaust controls may be necessary depending on the VOC concentrations in the subsurface, site type, and/or state air permitting regulations. Installation of these controls may require the use of more robust blower systems, air permitting, and additional OM&M requirements for discharge monitoring and media changeout.
- SSD systems may not meet performance requirements when required design and construction practices are not followed. Important differences in mitigation design, treatment of exhaust, and practitioner qualifications for VOC and radon VI mitigation should be recognized and accounted for to achieve effective project implementation.
- For some properties, it may be difficult to prevent property owners from tampering with and possibly damaging system components.
- SSD systems will not necessarily prevent diffusion of VOCs across slabs and some vapor barriers if very high concentrations (e.g., millions of $\mu g/m^3$) are present immediately below the slab. This condition is more likely to occur at existing buildings where solvent-impacted soils are present immediately below the slab and is less likely to occur in new construction where clean materials (e.g., gravel) are placed below the slab.
- Sub-slab utilities, pipes, or drains may result in "short circuiting" or preferential pathways that may reduce the system radius of influence.

Cost Considerations

The primary factors that affect the overall cost of an active SSD system include whether an existing or new building is mitigated, building size, building height, building use, tightness of the soils, depth to water, building HVAC, condition of the slab, number of building additions, size and total number of blowers or fans, permitting, exhaust control (if required), remote monitoring, and OM&M.

Approximate costs for this technology generally range from $4 to $9 per square foot (this range applies to both existing and new building mitigation). These costs are typically for installation only and do not necessarily include the costs of predesign testing; preparation of a work plan, design and specifications; installation monitoring; regulatory agency and stakeholder liaising; post-installation verification testing; and reporting. Additional cost factors may include but are not limited to the following:

- sub-slab vacuum field extension
- the number of suction points
- type and number of blowers
- electrical requirements
- building construction features
- aesthetic considerations
- exhaust filtration
- permitting, regulatory, and legal oversight

A large open building with permeable sub-slab fill material and a concrete slab with good integrity would be on the lower end of the per square foot cost range, while a residential home with a low-clearance, exposed-soil crawlspace, stone foundation, and water intrusion issues would be on the upper end of the per square foot cost range.

Special Circumstances

Special circumstances for construction of an SSD include:

- Insulation incorporating heat trace cable may be warranted to prevent freezing of condensate in cold climates or to dampen noise.
- High water tables or perched water where water is present directly beneath the building slab may require additional measures to achieve SSD system performance objectives.

- If there is high air flow below the building, the technology implemented may be fully or partially sub-slab ventilation (SSV; see also ***SSV Technology Information Sheet***) rather than SSD. Although SSV can be as effective as SSD, there are different factors to consider when determining the efficacy of venting versus depressurization.
- Qualified personnel should conduct design, installation, and OM&M of control systems.
- Precautions should be taken to ensure that new tenants and/or construction activities (e.g., sub-slab utilities, service pits) do not damage the SSD system.

Occupant, Community, and Stakeholder Considerations

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. The ITRC fact sheet on ***Public Outreach During Vapor Intrusion Mitigation*** provides additional information.

References and Resources

Related Documents:

- ITRC Technical and Regulatory Guidance Document, Vapor Intrusion – A Practical Guideline, 2007.
- ITRC Petroleum Vapor Intrusion, Fundamentals of Screening, Investigation and Management, 2014.
- New Jersey Department of Environmental Protection. 2018. VI Technical Guidance. January.
- Soil Gas Mitigation Standards for Existing Homes, 2017, AARST Consortium on National Radon Standards, ANSI/AARST SGM-SF 2017.
- Soil Gas Control Systems in New Construction of Buildings. 2018. AARST Consortium on National Radon Standards, ANSI/AARST CC-1000-2018.
- US EPA 402-R-93-078 Radon Mitigation Standard (revised 04-01-1994)

Related Links:
For more information and useful links about VI pathways and mitigation technologies, go to http://www.itrcweb.org.

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ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Active Vapor Intrusion Mitigation Systems Subgroup

Sub-slab Ventilation (SSV)
Active Mitigation System (uses electric fan)

This ITRC Technology Information Sheet provides basic information when using a fan to ventilate the sub-slab environment to prevent and/or reduce sub-slab vapor concentrations and mitigate the potential for vapor intrusion at a given building. Any system that draws gas from below a floor slab for the purpose of sub-slab depressurization (SSD) will also result in some degree of sub-slab ventilation (SSV). SSV can be installed in buildings, at or near vapor intrusion sites, where the permeability of the material below the floor is high, such that ventilation reduces sub-slab concentrations to levels too low to pose a potential indoor air quality concern. Ventilation will occur at these properties even in areas where the sub-slab vacuum is too low to be reliably measured considering instrument sensitivity and baseline fluctuations. The key differences between SSD and SSV are the performance goals and metrics, and the importance of the relative permeability of the floor slab and the material below the slab.

Overview

SSV is an active engineering control employed to mitigate potential vapor intrusion (VI) for volatile organic compounds (VOCs) into buildings. The difference between SSV and sub-slab depressurization (SSD) is that the design objective for SSV is to reduce vapor concentrations below a structure's slab to levels that are low enough to maintain acceptable indoor air concentrations above the slab, regardless of whether there is a consistent or measurable vacuum below the floor. Generally, this is practical where the material below the slab has a high permeability (e.g., coarse-textured, granular fill materials, drainage mats, aerated floors) that allows high air flow rates to be induced below the slab with minimal applied vacuum. SSV is best suited to cases where sub-slab vapor concentrations are relatively low to begin with, and reduction to concentrations less than levels of concern can be readily achieved.

SSV occurs to some extent during the operation of an SSD system and vice versa. The ITRC ***SSD Technology Information Sheet*** should also be reviewed for additional information that may apply to SSV systems. SSV performance may not be quantified if performance monitoring only involves measurements of vent-pipe vacuum or cross-slab differential pressures. If the ventilation rate (i.e., flow rate) below the slab is sufficient to reduce the VOC concentrations to very low levels, then an occasional reversal of the cross-slab pressure gradient will not result in substantial VOC transport into the building. As such, continuously maintaining the more conventional minimum sub-slab vacuum pressure differentials may not be necessary to prevent unacceptable exposures due to VI.

SSV systems can be used in both existing and new construction. For existing buildings, SSV is most suitable where the sub-slab fill material is highly permeable to allow for appreciable air exchange rates (AERs) below the slab and where there are minimal constraints to sub-slab ventilation, such as grade beams or wall footings that may restrict horizontal vapor flow below the floor slab. In a new construction scenario, SSV systems include many similar components of SSD systems, including gas-permeable layers (or aerated floors), horizontal perforated pipes, and/or vapor barriers. New construction SSV systems are designed similarly to SSD systems, although an SSV system may include the addition of air inlets to allow dilution air to enter below the slab if leakage across discontinuities in the floor slab is inadequate for air supply. Sufficient dilution air is needed to reduce sub-slab

VOC concentrations to levels less than mitigation criteria (e.g., building-specific sub-slab screening levels). In many cases, SSV is also capable of reducing sub-slab vapors to concentrations less than generic sub-slab screening levels published by states or other regulatory entities.

Selection of a membrane for new construction SSV is similar to that process discussed for new construction in the ***SSD Technology Information Sheet***. The addition of a properly installed membrane should reduce cross-slab leakage and expand the radius of influence of each SSV suction point. For existing buildings, it is valuable to consider sealing the floor, particularly at expansion joints, floor drains, and obvious stress fractures.

Components

SSV system components are essentially the same as SSD system components (a fan or blower connected to piping that is engineered to evacuate air from the sub-slab area). The main difference between SSD and SSV is in the performance objectives (reducing concentrations below the slab instead of reducing pressure) and associated monitoring (concentrations and mass emissions rather than static vacuum). The electric fan or blower can be installed on either the outside or inside of a building, depending on access to available locations. Typically, fans are installed on the outside of the building to facilitate access during both system installation and ongoing operations, maintenance, and monitoring (OM&M). Fans installed on the outside of a building are subject to changing weather conditions that, depending on the geographic region, may result in condensate issues and additional wear on the fan. Fans installed in interior spaces (e.g., attics) need to be to fully excluded from occupied and/or insulated interior spaces (i.e., outside the occupiable building envelope) to mitigate the potential for leaks in the fan's vent from entering the occupied space. Fans installed in protected spaces, such as attics, have a longer and more consistent operating life because they are protected from extreme weather conditions, but also require permission from the property owner to obtain access for each OM&M visit.

When the subfloor materials are not very permeable, it will be easier to impose a vacuum. Conversely, appreciable flow can be achieved at vacuum levels that may be too low to measure when subfloor materials are highly permeable. An SSV system can also be integrated with other technologies, such as an aerated floor, to reduce air flow resistance in the sub-slab zone.

Components of SSV include:

- High-permeability materials below the floor slab, to allow for high vapor flow velocity and AERs below the floor, which can be measured using pneumatic and tracer tests (McAlary et al., 2018).
- System piping, including a sampling port for conducting system diagnostic testing (i.e., vacuum and air velocity/flow) and for collecting samples to measure VOC concentrations in the effluent to support mass removal rate calculations.
- Fan(s) or blower(s) capable of high flow rates.
- Air inlet pipes if the rate of air leakage across the floor slab is too low to achieve adequate sub-slab AERs.
- Permanent u-tube manometer, vacuum gauge, or pressure sensor on the system piping to monitor system vacuum where and if appropriate.
- Balancing valves on the system piping, which provide an efficient way to adjust the system flow from multiple areas and/or reconfigure the system footprint over time if needed. Blowers that have variable speeds may also be used to balance or rebalance a system over its operational life.
- Qualified personnel to conduct design, installation, and OM&M of control systems.

Advantages

SSV as an active mitigation technology has the following advantages:

- SSV is an easily deployable engineering control.
- In higher permeable sub-slab soils, small, low-vacuum, high-flow fans or blowers can be used.
- Many different types of fans and blowers are available, making system applications widespread.

- Energy cost for operation are usually low because the highly permeable material below the floor imposes minimal resistance to flow.
- Performance monitoring devices can easily be connected to remote telemetry technologies.
- SSV can readily be installed with other engineering controls on or around the building.
- If sub-slab concentrations are reduced to levels that pose no risk to indoor air quality, it may not be necessary to collect indoor air samples for performance monitoring, which avoids potential forensic analysis of background sources and disruption to occupants.

Limitations

SSV as an active mitigation technology has the following limitations:

- Installation of an SSV system impacts the occupants of the building in that coordination with and cooperation of the building occupants is needed during system installation (for existing buildings) and ongoing OM&M (both new construction and existing buildings).
- Low permeability soils below the slab will limit ventilation rates and radius of influence. SSD is a more appropriate technology in these cases.
- Sub-slab differential pressure measurements may not be useful for direct measurement of system performance (i.e., air flow and/or sub-slab ventilation rates are required). Additional communication may be needed with the local agency if they are expecting differential pressure readings because SSVs need to be evaluated with other performance criteria.
- Poor concrete slab construction, excessive cracks in the slab, or utility penetrations/floor drains/pipes may create short circuiting of air flow and potentially have a high energy penalty through loss of conditioned indoor air to the sub-slab. A substantial amount of sealing to limit indoor air from being drawn into the system and to enable overall system effectiveness may therefore be needed.
- SSV may not be continuously effective during high water table conditions if water is in contact with or within a few inches of the slab.
- SSV systems may not meet performance requirements if required design and construction practices are not followed. There are important differences in mitigation design and practitioner qualifications for VOC and radon VI mitigation that should be recognized.
- For some properties, it may be difficult to prevent property owners from tampering with and possibly damaging system components.
- SSV systems will not necessarily prevent diffusion of VOCs across slabs and some vapor barriers if very high concentrations (e.g., millions of $\mu g/m^3$) are present immediately below the slab.

Cost Considerations

The approximate costs for installation of this technology range from $2 to $4 per square foot. These costs are typically for installation only and do not necessarily include the costs of predesign testing; preparation of a work plan, design and specifications; installation monitoring; regulatory agency and stakeholder liaising; post-installation verification testing; and reporting.

Factors affecting cost include but are not limited to the following:

- sub-slab permeability and floor leakage rates
- building size
- the number of suction points and the type and number and size of fans or blowers
- ducted fresh air supply to the sub-slab (if needed)
- electrical power requirements and local utility rates
- building construction features
- aesthetic considerations
- exhaust filtration (if needed)
- monitoring and reporting requirements

- permitting, regulatory, and legal oversight

A large building with an aerated floor, engineered plenum (e.g., continuous void space under the slab), or highly permeable sub-slab fill material, and a high-integrity concrete slab would be on the lower end of the per square foot cost range. A residential home with moderately permeable sub-slab fill material would be on the upper end of the per square foot cost range.

Special Circumstances

Special circumstances for construction of an SSV include:

- In new construction, SSV systems can be designed using engineered plenums or aerated floors to facilitate air flow.
- In existing construction, the permeability of the material below the floor is fixed, and may or may not be adequate for SSV, in which case it may be necessary to design an active SSD system instead of SSV.
- It may be challenging to gain regulatory acceptance and approval of SSV systems because performance is documented using metrics that may be different than standard acceptable SSD system performance metrics. The use and acceptance of SSV systems appears to be increasing.
- Precautions should be taken to ensure that new tenants and/or construction activities (e.g., accessing sub-slab utilities, service pits) do not damage the SSV system.
- Precautions to understand and monitor changes in building use/building modifications should also be taken.

Occupant, Community, and Stakeholder Considerations

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. For more details see ITRC's fact sheet on *Public Outreach During Vapor Intrusion Mitigation.*

References

- McAlary, Todd, W. Wertz, and D. Mali. 2018. Demonstration/Validation of more cost-effective methods for mitigating Radon and VOC subsurface Vapor Intrusion to Indoor air, Environmental Security Technology Certification Program (ESTCP). Project ER-201322, July 2018. https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues/ER-201322
- ITRC Technical and Regulatory Guidance Document, Vapor Intrusion – A Practical Guideline, 2007.
- ITRC Petroleum Vapor Intrusion, Fundamentals of Screening, Investigation and Management, 2014.

Resources

For more information and useful links about VI pathways and mitigation technologies, go to http://www.itrcweb.org/ .

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ECOS

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Passive Mitigation Fact Sheet

ITRC has developed a series of fact sheets that summarizes the latest science, engineering, and technologies regarding vapor intrusion (VI) mitigation. This fact sheet describes the most common passive mitigation technologies and considerations that go into the design, installation, post-installation system verification and documentation, and operation, maintenance, and monitoring.

1 INTRODUCTION

Passive mitigation of the VI pathway involves interception, dilution, diffusion, or diversion of soil gas entry into a structure without the use of mechanical means. These systems physically block the entry of vapors into a building and/or rely on natural mechanisms, such as chemical diffusion and thermal- or wind-induced pressure gradients to divert volatile organic compounds (VOCs) and soil gas, around the building (e.g., to riser pipes). Passive mitigation systems require a high degree of documentation during the installation process, as well as establishing and planning methods that will confirm the system's effectiveness, such as using surrogates and tracers. This document introduces the three most common categories of passive mitigation technology—passive barrier systems, passive venting systems, and building design—and explains instances where such systems can be installed (i.e., new construction, existing structures, etc.).

As presented in the ***Conceptual Site Models for VI Mitigation Fact Sheet,*** the mitigation technologies presented in this fact sheet assume the primary means for soil gas entry is via advection rather than diffusion. Except for situations where very high sub-slab vapor source concentrations (e.g., millions of micrograms per cubic meter ($\mu g/m^3$)) are present, diffusion through the slab is not typically considered a significant transport pathway.

2 PASSIVE MITIGATION TYPES

This fact sheet and associated documentation focuses on three general categories of passive mitigation technologies:

- common passive barriers systems
    - asphalt latex membranes (ALM)
    - thermoplastic membranes (TM)
    - composite membranes (CM)
    - epoxy floor coatings (EFC)
- common passive venting systems

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  - passive sub-slab venting
  - aerated floor void space systems (VSS)
- building design approaches
  - raised foundations (RF)
  - vented garages (VG)

2.1 Common Passive Barrier System Technologies

This section provides a summary of the common passive barrier system technologies that are typically employed.

Asphalt Latex Membranes
(See also the ***Passive Barrier Technology Information Sheet***)

The primary component of an ALM passive barrier system is the spray-on asphalt latex material. These materials are water based, free of VOCs, and used in combination with other layers to create a barrier to advective flow and diffusive transport of VOCs. A typical ALM passive barrier system consists of a base layer, a spray-applied ALM, and a cap sheet. ALMs can be modified to site-specific goals by changing one or more of the components to achieve site-specific performance criteria.

The spray-on ALM adheres directly to concrete and penetrations without the need for additional system components for fastening. The ability of the ALM to adhere to most substrates makes it ideal for sealing to penetrations and to wall terminations. This results in a fast installation by reducing the time spent on detailing when compared to TM barriers.

Thermoplastic Membranes
(See also the ***Passive Barrier Technology Information Sheet***)

TMs are composed of plastic resins formed into uniform membranes and can also be referred to as geomembranes or plastic liners. TMs most commonly consist of high-density polyethylene (HDPE), but variations such as linear low-density polyethylene (LLDPE) are also available. The physical characteristics of TMs can vary between manufacturers as resin blends are specific to each manufacturer and each type of resin blend provides unique physical and chemical resistance properties.

Thickness and installation procedures differentiate TMs from common vapor barriers. “Vapor barrier” is the term most associated with thin-mil plastic liners (e.g., 6–15 mils) that are used to mitigate moisture transmission through concrete. Vapor barriers used in standard construction practices are not typically designed to mitigate chemical vapor transmission (NJDEP, 2018).

Composite Membranes
(See also the ***Passive Barrier Technology Information Sheet***)

Advancements in technology have led to the development of CMs, which incorporate a variety of materials that can reduce diffusion rates of chemical vapors from volatile organic compounds (VOCs), petroleum hydrocarbons, methane, and radon. CMs use a variety of different passive barrier materials to create a multilayered barrier system designed to improve chemical resistance, constructability, and durability. Currently available CMs for vapor intrusion control are typically 20 mils or thicker.

Epoxy Floor Coatings
(See also the ***Epoxy Floor Coatings Technology Information Sheet***)

Epoxy products can be used for a variety of industrial, commercial, and residential applications. EFCs can be applied to concrete foundations in existing buildings and new construction. EFCs are most often used to protect existing concrete surfaces or provide a decorative finish; however, EFCs can also be applied to existing concrete slabs as a passive barrier system.

When applied, the epoxy cures by a chemical reaction that changes the material from liquid to solid. During the conversion from a liquid to a solid state, EFCs become highly adhesive, which allows EFCs to bond with the concrete floor to seal porous concrete. EFCs can be strong, durable, and chemically resistant to the VOC or other vapor contaminants. As a result, EFCs can reduce the potential for advective and diffusive transport.

2.2 Common Passive Venting Systems

This section provides a summary of passive venting systems that are often employed in conjunction with one of the four common passive barrier system technologies detailed above.

Passive Sub-slab Venting System
(See also the ***Passive Sub-slab Venting Technology Information Sheet****)*

The goal of a passive sub-slab venting system is to vent contaminant vapors to the exterior atmosphere and prevent accumulation beneath a structure. Combined with a passive barrier system, contaminant vapors are blocked and rerouted through a passive sub-slab venting system to prevent contaminant vapors from entering the building and accumulating within the indoor air environment.

Passive sub-slab venting systems rely on wind effects, thermal effects, and pressure differences to induce airflow that moves contaminant vapors that accumulate beneath a building through vents to the atmosphere outside of the structure. A passive sub-slab venting system is most easily installed prior to building construction. Successful passive sub-slab venting systems have been designed for existing structures; however, their effectiveness relies on the presence of a subsurface permeable layer or venting system media and adequate access to allow for the installation of a substantial venting network. Venting system media can include gravel, perforated pipes, geogrids, or combinations of these materials. The venting system should generally underlie the entire vapor barrier between foundation structures.

Aerated Floor Void Space Systems
(See also the ***Aerated Floor VSS Technology Information Sheet****)*

Aerated floor VSS are concrete slabs with a continuous void space beneath the slab that can be used for passive and active sub-slab venting or depressurization in lieu of a sand or gravel venting layer commonly associated with traditional mitigation systems. Because the void space has very low resistance to air flow, vacuum levels and air exchange rates in the void space are generally higher and more uniform than in sand or gravel layers. Aerated floor VSS are most applicable to new construction, although aerated floors can also be used for complete floor replacement or placed over existing slabs if a higher finished floor elevation can be accommodated.

2.3 Building Design Approaches
*(See also the **Building Design for Passive Vapor Intrusion (VI) Mitigation Technology Information Sheet**)*

This section provides a summary of common approaches that address VI concerns passively using building design. These common building design approaches are sometimes employed in conjunction with other passive technologies and systems detailed above or with active systems.

Raised Foundations

The primary purpose of buildings designed with raised foundations, such as buildings with block and beam construction and/or crawlspaces (also referred to as podium construction), is typically to prevent water vapor from entering the building. However, a raised foundation can also be an effective means of preventing VI. If the raised foundation is designed with sufficient ventilation, this approach can offer a sustainable, effective, and low-cost method of passive VI mitigation. This approach to passive VI mitigation is most applicable in:

- geographic locations where raised building foundations are the preferred building style
- existing buildings constructed with a raised foundation
- buildings slated for construction on contaminated sites where the potential VI risk is determined to be low
- sites with petroleum hydrocarbons impacts.

Vented Garages

When garages are constructed below occupied spaces, venting of the garage is likely to reduce the potential for VI in overlying units by dilution of VOC concentrations below the units and by normal HVAC controls that prevent garage air from entering the building. In many cases, concentrations within the garage itself may be reduced below levels of concern commensurate with garage exposure conditions. Vented garages are typically constructed in city settings on properties where a vapor source is present and space is limited, making placement of a garage under the building economically feasible.

3 CONSIDERATIONS FOR PASSIVE MITIGATION SYSTEMS

Careful consideration should be given to several factors in order to select, design, install, and maintain an effective passive mitigation system. The approach outlined below provides a summary of information to consider during each step in the passive mitigation process. More details regarding these factors can be found in the overall Process Fact Sheets listed below.

- ***Design Considerations Fact Sheet***
- ***Post-installation Fact Sheet***
- ***Operation, Maintenance, and Monitoring/Exit Strategy Fact Sheet***

The fact sheets listed above describe the VI mitigation technology types covered within the collective scope of the ITRC VIMT documents and provide additional detail about considerations to be made at each point in the passive mitigation process.

3.1 Design

Prior to passive mitigation system design, it is common to evaluate construction plans for buildings proposed for construction or to perform a building survey for existing buildings. Designing a passive mitigation system for a building prior to construction allows for a greater degree of selection of available passive mitigation technologies and ultimately lower installation costs when compared to retrofitting an existing building with a passive mitigation system. This is due to a greater level of control over the building construction sequence and access during installation of the mitigation system components. For retrofitting, factors such as access, accommodating work schedules of building tenants, and structural integrity of the foundation and floor slab of existing buildings are limitations that may result in increased installation time frames and a narrower selection of cost-effective passive mitigation technologies. An explanation and summary discussion of common design considerations for passive mitigation systems is provided in the ***Design Considerations Fact Sheet***. Factors considered to have a significant impact on design of passive mitigation systems are listed below.

- VI conceptual site model (CSM) considerations
    - vapor source
    - geology and hydrogeology
    - building conditions
- design investigation and diagnostic testing
    - barrier or liner material tests
- mitigation system design
    - design basis
    - design layout and components
    - stakeholder requirements
- system construction and implementation
    - system effectiveness and reliability

The ***System Design and Documentation Checklist*** provides a list of considerations when assessing factors that may affect passive mitigation system design.

3.2 Post-Installation System Verification

Once the passive mitigation system has been designed and installed, mitigation system verification during the construction process will be needed to document that the system is functioning as designed. Verification of system installation and effective operation may include multiple criteria. It is also important during this step, as well as in the future during OM&M, to validate the CSM for which the system was designed. Below is a summary of possible post-installation verification considerations that may be needed for passive mitigation systems.

The type of post-installation system verification testing approaches should be based upon the type of passive mitigation technology installed. For instance, smoke and tracer gas testing are appropriate for assessment of passive barrier systems and passive sub-slab venting systems, and can be used to verify the integrity of the barrier (especially at locations where another roll of barrier is overlapping and sealed) and to assess the adequacy of sealing around the areas of liner repairs, perimeter edges, and utility penetrations. Smoke and tracer gas testing may also be appropriate for assessing the adequacy of pipe fitting connections and/or the presence of any obstructions within sub-slab venting systems. In addition to conducting smoke and tracer gas testing, coupon sampling is an important verification testing approach appropriate for spray-on liners such as ALM to confirm liner thickness meets the design specification and may be required by certain ALM manufacturers. In many situations, a passive system may be designed such that it can be made active if needed. Pilot testing of the sub-slab venting system, after pouring the concrete slab, is common to verify that an electrical fan or blower can adequately depressurize/influence the remote extents of the system. Time frames required for collection of system verification information vary depending upon state requirements. Check with your state regulatory agency regarding requirements for the type and time frames for collection and submittal of post-installation system verification data.

An explanation and summary discussion of common post-installation system verification considerations for passive mitigation systems are provided in the ***Post-installation Fact Sheet***. Factors considered to have a significant impact on post-installation system verification of passive mitigation systems are listed below.

- building information and survey
- confirmation testing
- communications

The ***Post-installation System Verification Checklist*** provides a list of considerations when assessing which data to collect to verify whether the system is effectively mitigating the VI pathway.

3.3 Operation, Maintenance, & Monitoring

An OM&M plan provides instructions for proper system operation and maintenance required for an installed mitigation system. An OM&M plan should be prepared for each mitigation system installed, regardless of the mitigation technology implemented. Details of a typical OM&M plan are provided in Section 6.3 and Appendix J.5 of the ***2014 ITRC PVI Guidance*** (ITRC, 2014). The goal of OM&M is to ensure the ongoing function of the mitigation system as designed following system installation and performance verification. This goal is achieved through performing routine inspections, as well as identification and completion of system repairs due to system malfunction (i.e., system not operating to meet performance objectives) or due to system equipment life expectancy. Indoor air and/or sub-slab soil gas testing, or other means of demonstrating continued performance of the passive barrier, may be required over time.

An explanation and summary discussion of common OM&M considerations for passive mitigation systems is provided in the ***Operation, Maintenance, and Monitoring/Exit Strategies Fact Sheet***. Factors considered to have a significant impact on OM&M of passive mitigation systems are listed below.

- mitigation system operation
- building conditions and use

- system inspections and performance metrics
- communication and reporting
- exit strategy

The ***Operation, Maintenance, and Monitoring Checklist*** includes a list of questions designed to assess vapor intrusion mitigation system (VIMS) operation and the need for corrective actions identified during regularly scheduled VIMS inspections.

3.4 Exit Strategies

A key concept to consider throughout the process of effective implementation of a passive mitigation technology is assessment of viable exit strategies. In the event the vapor source no longer poses an unacceptable risk to the receptors within the building, the VIMS may no longer be necessary. Situations may also arise when VIMS are installed out of an abundance of caution, such as presumptive mitigation to expedite property redevelopment or due to uncertainties associated with spatial and temporal variability, background sources, and/or conservative regulatory guidance. Exit strategies should be considered when these types of situations arise. The details for exit strategy considerations can be found in the ***Operation, Maintenance, and Monitoring/Exit Strategy Fact Sheet***. It may be appropriate to prepare a short work plan that outlines the exit strategy prior to implementation of system decommissioning efforts.

Recent review of existing VI regulatory guidance documents (Eklund et al., 2018), includes an evaluation of various state provisions for VIMS closure. States such as Massachusetts (MADEP, 2016), New York (NYSDOH, 2006), New Jersey (NJDEP, 2018), and Wisconsin (WDNR, 2018) include recommendations for certain data collection efforts to support the closure decision, such as:

- verification sampling and analysis of sub-slab vapors and indoor air and outdoor air and comparison to protective screening levels
- multiple verification monitoring events to account for temporal variability
- operation of the system between verification monitoring events, or indoor air monitoring to maintain protectiveness

These approaches can effectively demonstrate that VIMS operation is no longer necessary. In cases where conventional approaches result in inconclusive outcomes, alternative approaches may be considered. Recent research for VI assessment and mitigation design and performance monitoring have been demonstrated and validated through Environmental Security Technology Certification Program (ESTCP) projects. For example, the goal of ESTCP 2018 was to demonstrate and validate a more rigorous and cost-effective process for design and optimization of systems for mitigating VI for VOCs and radon to reduce the capital and long-term operating costs (McAlary et al., 2018).

The selection of an appropriate exit strategy and whether vapor sources remain will depend on site-specific conditions, and should be approached as a process, as opposed to an event. The transition can be planned to proceed through multiple steps. An explanation and summary discussion of common exit strategy considerations for passive mitigation systems is provided in the ***Operation, Maintenance, and Monitoring/Exit Strategies Fact Sheet***.

4 SUMMARY

Passive mitigation involves the use of one or more technologies that inhibit sub-slab soil vapor from entering the interior of a building without the use of mechanical means. There are three general categories of passive mitigation technologies: passive barrier systems, passive venting systems, and building design.

Successful implementation of passive mitigation technologies greatly depends upon the appropriateness of the system design to account for site-specific conditions. This fact sheet summarizes the many considerations that go into the design, installation, verification, and operation of each of the most common passive mitigation technologies.

The details and considerations discussed above are part of a long-term plan for passive VIMS. Systems should not only be carefully designed and installed, but procedures or guidance should be put in place to maintain proper operation of these systems as designed until such time that the vapor source no longer poses an unacceptable risk at the site.

5 REFERENCES AND ACRONYMS

The references cited in this fact sheet, and the other ITRC VI mitigation fact sheets, are included in one combined list that is available on the ITRC web site. The combined acronyms list is also available on the ITRC web site.

ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Passive Vapor Intrusion Mitigation Systems Subgroup

Aerated Floor Void Space Systems (VSS)
a component of vapor intrusion mitigation

This ITRC Technology Information Sheet provides a general description of aerated floor VSS and their use as a vapor intrusion (VI) mitigation method. Aerated floor VSS are a design component for sub-slab ventilation (SSV) or sub-slab depressurization (SSD) systems. Included is an overview of the aerated floor VSS, conditions for applicability as a VI mitigation method, and advantages and limitations of utilizing aerated floor VSS. An approximate cost of the aerated floor VSS and a list of additional resources are also provided.

Overview

Aerated floor VSS are concrete slabs installed with a continuous void space under the slab that can be used for sub-slab venting or depressurization in lieu of the sand or gravel venting layer commonly associated with traditional mitigation systems. Because the void space has very low resistance to air flow, vacuum levels and air exchange rates in the void space are generally higher and more uniform than in sand or gravel layers. Aerated floors can be constructed in various ways, including open void spaces below structural slabs and permeable geocomposite in place of gravel, but are more typically constructed using proprietary plastic forms that are placed on the subgrade prior to pouring of the concrete slab. Therefore, this Technology Information Sheet will focus on proprietary concrete forming systems that create a void network below a slab.

Aerated floor VSS are most applicable to new construction, although aerated floors can also be used for complete floor replacement or placed over existing slabs if a higher finished floor elevation can be accommodated. Aerated floor VSS are appropriate for residential, commercial, institutional, and industrial building designs.

Proprietary forms typically shape the bottom of the concrete slab to create a network of interconnected dome shapes. The slabs are supported at the points between the domes (i.e., where the concrete contacts the ground) but can also be constructed as fully structural, post-tensioned slabs. The forms vary in height from about 2 inches to 30 inches but are most commonly approximately 10 inches high. Welded-wire mesh is typically placed over the forms for reinforcement, and the concrete thickness above the top of the forms is typically 2.5–3 inches for residential buildings and 5–7 inches for commercial buildings. The slab thickness can be increased to support larger loads as necessary. The domes create an orthogonal grid of arches in the bottom surface of the slab that distribute loads and place the slab under compression; as a result, the volume of concrete is similar to, or may be less than, the volume of concrete required for a traditional flat slab with the same load capacity.

For VI mitigation, aerated floor VSS can be designed for SSV or SSD operation (in the former case, air inlets are typically provided to increase air flow rates) and operated in either active and passive venting modes, depending on the degree of venting or depressurization needed to mitigate VI. Long-term operation, maintenance, and monitoring (OM&M) costs are lower than for traditional mitigation systems constructed with gravel venting layers, because fewer and/or smaller fans are required to depressurize and/or vent the void space. In addition, the vacuum level in an aerated floor is generally higher than in gravel and is relatively uniform across the slab. As a result, confirming and monitoring performance of aerated floor SSD systems is simpler and less expensive than for SSD systems installed in gravel. In addition, mitigation systems using aerated floor VSS require fewer riser pipes, relative to an equivalent traditional (i.e., gravel) approach, to remove subsurface vapors. Because aerated floor VSS allow air to directly contact the subgrade below slabs, this technology can enhance oxygen levels and may promote increased aerobic biodegradation of petroleum hydrocarbons.

Figure 1
Cupolex aerated floor void space system. *Source: ITRC PVI-1 Guidance Document, used with permission.*

Components

Aerated floor VSS are generally divided into the following components:

- proprietary plastic forms (various types based on function)
- concrete and reinforcement (placed over plastic forms, as required by structural design)
- riser pipes, inlet pipes, and monitoring ports (as required by the venting design)
- boots installed around all penetrations (similar to boots used for sheet membrane liners)
- caulking/sealing of perimeter and control joints

Advantages

Advantages of using aerated floor VSS for SSV and SSD include:

- higher air flow rates for SSV, and higher and more uniform vacuum levels for SSD than typical sand/gravel venting media
- lower operating costs due to the very low resistance to air flow
- lower costs for system installation due to elimination of gravel layer, sub-slab gas collection pipes, and liner (note: the costs for concrete, steel, and imported fill may also be reduced.)
- relatively quick assembly and installation when compared with the time required for gravel and liner placement
- a single small (e.g., 20-watt) fan can typically provide a relatively high (0.1” water column or greater) and uniform vacuum across buildings up to 20,000 square feet
- separate vapor or moisture barrier not required in most cases due to the presence of the void space and plastic forms when combined with booting and sealing of penetrations through the floor and caulking of perimeter joints.
- useful for mitigating existing buildings with high water table conditions that prevent depressurization under the existing floor slab

Limitations

Limitations of using aerated floor VSS include:

- less use and familiarity in the United States relative to other countries
- less applicable to existing buildings, unless replacing the existing floor slab or placement over the existing floor slab is acceptable

- might not be sufficient when vapor concentrations are high and buildings are negatively pressurized (potentially requiring active venting)
- may increase cost in some circumstances if additional site grading is required to accommodate the void form thickness.
- unfamiliar to many architects, engineers, regulators, and contractors

Cost Considerations

The cost for supply, delivery, and installation of the proprietary forms required for a typical aerated floor system with new construction is typically $2–$3 per square foot, depending on factors such as the size and location of the building. Estimated costs do not include any additional protective barriers, to the extent required by regulatory agencies, or construction overlays ($2–$4 per square foot), although this is not anticipated through normal construction practices. The cost for riser pipes will be lower than for traditional gravel mitigation systems, all else being equal. If the passive mitigation system is upgraded to active, the addition of fans would represent an extra cost. The cost for operation and maintenance would be lower than a traditional (gravel/membrane) system due to smaller or fewer fans. Typically, monitoring costs savings (per square foot of building area) will be greater as building size increases. Costs may differ when retrofitting existing buildings.

Occupant, Community, and Stakeholder Considerations

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. For more details, see the ITRC ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet***.

Resources

Related ITRC Documents:

- ITRC (Interstate Technology & Regulatory Council). 2014. *Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management*. PVI-1. Washington, D.C.: Interstate Technology & Regulatory Council, Petroleum Vapor Intrusion Team. http://itrcweb.org/PetroleumVI-Guidance.

Related Links:

- Pontarolo Engineering. *Venting System Design Guide*. Las Vegas, NV https://cupolex.ca/downloads/Technical%20Reports/Cupolex%20VI%20Venting%20Design%20Procedure.pdf

For more information and useful links about the vapor intrusion pathway and mitigation technologies, go to http://www.itrcweb.org/

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ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Passive Vapor Intrusion Mitigation Systems Subgroup

Building Design for Passive Vapor Intrusion (VI) Mitigation
Vented Garages and Raised Foundations

Effective passive VI mitigation can sometimes be accomplished through building design. Building design for passive VI mitigation includes the construction of vented parking garages or raised foundations between a subsurface source of vapors and an occupied space intended for living or working. Building design for VI mitigation does not include barriers (e.g., asphalt latex membrane, composite membranes, thermoplastic liners) or venting (e.g., aerated floors, sub-slab venting). This ITRC technology sheet provides basic information about relying upon building design for passive mitigation of VI and discusses advantages, limitations, and associated cost considerations of building design to mitigate VI risks. This Technology Sheet also describes the basic components of building design for the purpose of VI mitigation, design considerations, and verification of ventilation when constructing buildings designed to mitigate potential VI risks.

General Overview

Mitigating potential VI passively through building design with certain foundation features such as a vented garage, a raised foundation, or a crawlspace (also referred to as podium construction) is not a new concept, but it is not as well-documented as other passive VI mitigation methods (e.g., vapor barriers).

Vented Garages: According to international and domestic building codes, vented garages, or enclosed parking structures using enhanced building construction for natural ventilation and/or mechanical ventilation techniques associated with vehicle exhaust mitigation, as shown in Figure 1, are required to meet certain minimum air exchange rates (AERs). These are intended to limit exposure to carbon monoxide (CO), nitrogen dioxide (NO_2), volatile organic compounds (VOC), and particles from the automobile exhaust within the enclosed parking garages and within occupiable spaces that are connected (both adjacent and above). When vented garages are constructed below occupied spaces that are intended for living or working, these structures may provide mitigation of VI from subsurface sources because of the high AER required by code. Demonstration of VI mitigation may be achieved by documenting continued compliance with building code requirements and that the designed AER is sufficient to reduce the potential that vapors further migrate into a structure.

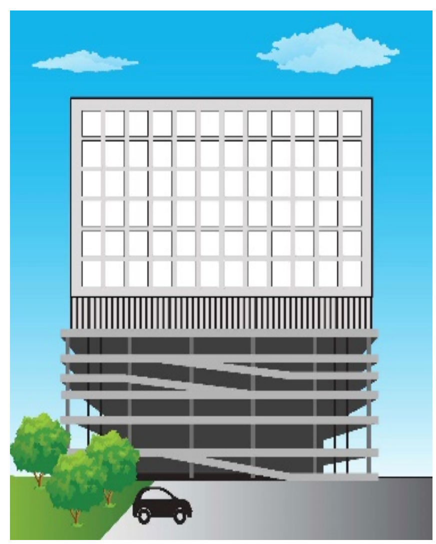

Figure 1. Schematic of a vented garage.
(Source: J. Kasunic, used with permission.)

This passive VI mitigation method uses natural or mechanically enhanced ventilation to mitigate potential VI risks, and it can be applied in most VI risk scenarios unless the method is determined to be unacceptable. These types of systems are most commonly used for vapor mitigation in city settings where there is a subsurface source of vapors and space is limited, making placement of a garage under the building economically feasible.

Raised Foundations/Crawlspaces: Buildings with raised foundations such as block and beam construction (Figure 2) or buildings constructed with a crawlspace (Figure 3) are more prevalent in the southern United States, where high water tables and flooding are common and/or where temperatures are mild throughout the year (i.e., no extremely cold winters). It is well documented that this type of building can effectively mitigate potential water vapor (moisture) from wet soils below buildings which, if not addressed, may result in mold growth or other structural damage to the buildings.

This passive VI mitigation method uses natural or mechanically enhanced ventilation to mitigate potential VI risks and is most applicable within: (1) geographic locations where a raised building foundation is the preferred style of foundation construction; (2) existing buildings with a raised foundation; or (3) new buildings slated for construction on top of contaminated sites where lower potential VI risks are determined to be present, especially at sites impacted with petroleum hydrocarbons.

Figure 2. Schematic of a block and beam foundation.
(Source: J. Kasunic, used with permission.)

Components

The basic components (e.g., openings, ventilation systems, foundations, vent sizes and spacing) for these types of passive VI mitigation methods are often specified in federal and state building codes.

For vented garages, the following components may be a part of the system:

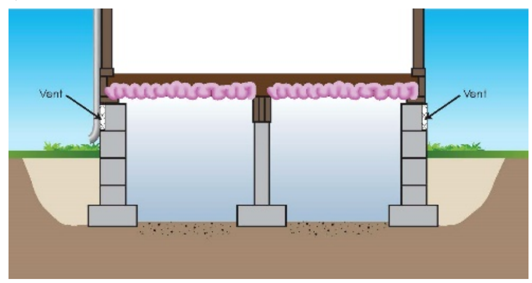

Figure 3. Schematic of a building with a crawlspace.
(Source: J. Kasunic, used with permission.)

- Natural ventilation is provided by openings at the perimeter of the garage. Specifications for openings should include details such as uniform distribution of openings, the number of sides with openings and their orientation, the area of openings in relation to the total perimeter area, and the dimensions of the openings.
- Mechanical ventilation systems typically consist of multiple fans and air inlets typically equipped with real-time exhaust chemical monitors. Mechanically vented garages are usually sealed to increase energy efficiency.
  - Fan systems draw air from the interior of the garage structure and discharge that air to the atmosphere. Makeup air is supplied via intake vents located on the exterior walls of the structure.
  - Ventilation rate specifications are provided in terms of volume per square foot of the floor area.
- Mechanical ventilation often includes real-time monitoring to assess concentrations of automobile exhaust gases such as CO and/or NO_2 within the garage structure. These monitoring systems can be programed to adjust ventilation rates after concentrations of exhaust gases reach threshold concentrations within the garage structure.

For raised foundations, the following components may be a part of the system:

- Block and beam and crawlspaces should be designed and constructed in accordance with applicable building codes.
- Vents for raised foundations that are naturally or mechanically vented should be designed to achieve target ventilation rates specified in applicable building codes. Usually, a target ventilation rate is twice the AER recommended by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE, 2013).
- For mechanically vented raised foundations, mechanical systems such as fans, wiring, and possibly automated systems that control operation of the fan system are also included.

Advantages

Designing buildings to minimize or mitigate potential VI risk has the following advantages in comparison to other technologies:

- Requirements for design, ventilation rate, and sometimes monitoring are often written into enforceable building code.
- Standards and procedures are generally familiar to, and closely followed by, construction contractors.
- Relatively low cost, particularly when implemented using natural venting.
  - Code-required ventilation may provide VI mitigation without any additional capital improvements.
  - Permit-required building inspections and maintenance verify compliance with code.
  - Long-term post-installation performance monitoring is expected to be minimal when designed correctly and the target ventilation rate is achieved.
- Designing for VI mitigation can be combined with other technologies, if necessary.

Limitations

Designing buildings with vented garages or raised foundations to mitigate potential VI risk may have the following limitations:

- In some circumstances, buildings with raised foundations may be less preferred by developers or homebuyers compared to those with slabs or basements.
- Extra efforts (e.g., extra insulation) may be necessary to make buildings with a raised foundation as energy efficient as other types of buildings.
- Ventilation rates may need to be calculated to verify that code-required minimum ventilation rates are sufficient for VI mitigation. If insufficient, a higher ventilation rate should be to be incorporated into the ventilation system design.
- For mechanically vented garages or crawlspaces, additional effort may be needed to ensure mechanical systems function properly.
- When used for VI mitigation, a mechanical venting system may need to run continuously.
- Although field data have been collected from crawlspaces that demonstrate their effectiveness at VI mitigation, dedicated research studies on the effectiveness of mitigating VI with this method are not currently available.
- Building design may not mitigate VI risk associated with certain preferential pathways that are unable to be sealed, such as VI transport via an elevator shaft or stairwells.

Cost Considerations

Compared to active VI mitigation systems and the other passive mitigation systems, these passive mitigation systems have much lower capital expense and minimal operating expense, although the cost for constructing a building with a crawlspace or vented garage can be more expensive than that with a slab.

Designing a garage or raised foundation with enough ventilation for simultaneously controlling accumulation of automobile exhaust gases and moisture and chemical vapors intruding from the subsurface is possible if the mechanical ventilation is operated continuously. Since ventilation rates are written in building codes for vented garages, the incremental costs associated with controlling VI are limited:

- It may be necessary to demonstrate that the ventilation rate is protective for VI (e.g., mass flux calculations or AER monitoring) and maintain the ventilation rate.
- There may be an incremental additional electricity cost if a ventilation rate for VI mitigation is greater than the ventilation rate required by code.

- In some cases, routine maintenance of the mechanical ventilation system may be more frequent for VI mitigation than is required by code.
- If necessary, inspection of the openings that provide natural ventilation for VI mitigation may be more frequent than those required by code.

Special Circumstances

The following special circumstances may apply:

- Demonstration that the ventilation rate is high enough to mitigate VI based on VOC flux measurements, AER measurements, or air concentration measurements may be required.
- Installation of VOC sensors with telemetry capabilities can be used to monitor and demonstrate effectiveness, if possible and available.
- Regulators may require air phase data to demonstrate effectiveness even if long-term monitoring is not otherwise necessary.
- All routine operation, maintenance, and monitoring (OM&M) procedures for mechanical venting systems dictated in building code should be conducted and documented.
- If natural ventilation is used to mitigate VI concerns, all regular inspections should be conducted and documented to ensure that the openings are not obstructed.
- Elevator shafts and stairwells in garages may require additional design components to prevent vapor migration to upper spaces via these potential preferential pathways.
- Below-grade structures may also require waterproofing. Some waterproofing membranes can also protect against VI (see also the ***Passive Barriers Technology Information Sheet***).

Occupant, Community, and Stakeholder Considerations

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. For more details see the ITRC ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet***.

Resources

Related Links:

- ANSI/ASHRAE (American National Standards Institute/American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc). 2013. Standard 62.1-2013. 2013 for Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA, U.S.
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- USDOE (United State Department of Energy) Building Energy Codes Program. 2009. Details for Mechanically Vented Crawlspaces-Code Notes. Building Energy Codes Resource Center, Washington D.C., U.S.

For more information and useful links about VI pathways and mitigation technologies, go to http://www.itrcweb.org/

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ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Passive Vapor Intrusion Mitigation Systems Subgroup

Epoxy Floor Coatings (EFCs)

This ITRC Technology Information Sheet provides an overview of EFCs. EFCs are chemically resistant coatings that form a seal over existing concrete. EFCs can serve as a vapor intrusion mitigation system (VIMS) for existing structures. This technology information sheet will help you better understand the various components of EFCs.

Overview

Epoxy products can be used for a variety of industrial, commercial, and residential applications. EFCs can be applied to concrete foundations in existing buildings and new construction. EFCs are most often used to protect existing concrete surfaces or provide a decorative finish, but they can also be applied to existing concrete slabs as a passive vapor intrusion (VI) barrier.

Epoxy is an organic compound derived from petroleum. The name refers to the epoxide functional group of thermosetting polymer resins. Most EFCs for VIMS are created using two components: a resin and a curing or hardening agent, which are mixed before application. When applied, the epoxy cures by an exothermic chemical reaction that changes the material from liquid to solid. After the two components are mixed, the application becomes time-sensitive before the product hardens. The rigidity and strength of the epoxy coatings are created during the curing process. The curing agent can be adjusted to address project objectives and performance requirements. Curing is significantly affected by temperature, and cold temperatures can impede the curing process.

During the conversion from a liquid to a solid state, EFCs become highly adhesive, which allows them to bond with the concrete floor and seal porous concrete. As a result, EFCs can be strong, durable, and chemically resistant, but performance will vary based on the type of epoxy resin selected. When evaluating epoxies, the following properties should also be considered:

- adhesion of the epoxy bond to the floor material
- resistance to abrasion, to determine how durable the EFC will be for the anticipated wear
- impact resistance
- compatibility and resistance to chemicals that may come into contact with the EFC

EFCs are commonly applied in one or two coats using a roller or squeegee to obtain the proper thickness. Application thickness can vary, but thicker coatings reduce the potential for defect and typically increase the durability of the finished surface. Many EFCs require a 24- to 48-hour curing time between coat applications. The curing time will vary between manufacturers; be sure to consult the manufacturer's instructions and recommendations regarding cure time and foot traffic during the curing process.

An EFC may fail if applied to damp concrete or other surfaces with high moisture vapor emission rates. This type of failure is known as delamination. Removal of moisture within the concrete slab is typically achieved through ventilation, heating, and dehumidification. The primary aesthetic disadvantage of some EFCs is discoloration over time due to exposure to sunlight.

The use of EFCs as a vapor barrier requires the concrete surface to be clean, free of debris, and slightly porous. Before application, shot/sandblasting, diamond grinding, or chemical etching (muriatic acid or buffered phosphoric acid) may need to be used for an existing concrete slab in poor condition. All major cracks, patches, and chips in the concrete slab surface must be repaired before the application of an EFC. Newly poured concrete must be cured sufficiently before application of an EFC. Generally, a 30-day cure time for the concrete is recommended prior to the application of the EFC, but much faster cure times can be achieved if required. To prevent delamination post-installation, measuring relative humidity (RH) prior to EFC application to determine the moisture condition of the concrete slab is recommended. Each RH test has advantages and disadvantages; consult the epoxy coating manufacturer's instructions to determine the most appropriate RH test for the application. Three standard methods for testing RH are:

- ASTM F2170—Relative Humidity Test
- ASTM F1869—Calcium Chloride Test
- Hand-held Concrete Moisture Meters

The application approach should include quality assurance procedures to ensure the proper installation of the EFC. It is recommended that manufacturer-certified installers be used to install EFC for VI mitigation. Surface preparation is one of the most critical factors to ensure proper bond strength. Certified installers are experienced at creating the correct concrete surface profile (CSP) necessary to provide a robust mechanical bond between the EFC applied and the concrete substrate. Most EFC manufacturers will specify the CSP required for the installation.

To ensure the specified EFC thickness is achieved, installers must compare the published manufacturer coverage rates to the desired application area. For example, 1 gallon of resin may be specified to cover 1,600 square feet to achieve a 1-mil-thick coating. If the specification calls for a 10-mil thick EFC, 1 gallon of resin will cover 160 square feet. Installers should use a wet mil gauge to verify applied mil thickness throughout the application. Please note that concrete substrates are not perfectly flat; therefore, periodic inspection of the installation is necessary to ensure appropriate application rates.

Components

EFCs consist of two components, typically described as a part A resin and a part B hardener. The part A resin can be either a clear or pigmented solid-containing material. The hardener is compatible and added to the resin. Together, they cure to form a solid material. Once cured and bonded to the substrate, it will function as prescribed by the manufacturer's technical data sheet. For VI applications, it is essential to select materials that have very low to no VOCs. No VOCs is preferred. Additional materials such as expansion joints, moisture mitigation primers, backer rods, and decorative elements may also be required based on the application.

Advantages

Advantages of using EFCs as a passive mitigation strategy include:

- They are broadly applicable to industrial, commercial, and residential settings.
- They are quick curing for time-sensitive projects.
- EFCs produce a strong and durable product.
- They provide a chemically resistant surface.
- EFCs protect the concrete foundation.
- EFCS are easy to clean and require little maintenance.
- The aesthetics of EFCs are easily manipulated through the use of colors, patterns, and finishes.

Limitations

The effectiveness and reliability of EFCs for VI mitigation can be significantly improved with passive venting. Other limitations of using EFCs as a passive mitigation strategy include:

- EFCs are susceptible to delamination in settings where concrete slabs retain high moisture content.
- Several days may be needed before EFCs can accept traffic.
- Scarification of concrete will almost always be required to prepare the substrate properly.
- Routine maintenance is required to ensure the epoxy coating remains intact, especially if the building experiences differential settling.
- Removal of all building contents is necessary to achieve a complete seal of the concrete surface. This may require substantial coordination with the building occupants.
- Measurements of performance are limited to periodic indoor air sampling.

Cost Considerations

Several factors affect the cost of installing EFCs. Labor represents a large portion of the total project cost. Proper installation typically requires a professional contractor, especially when retrofitting an existing building. Labor costs to install EFCs for new concrete slabs may be less than retrofitting an older concrete slab with an EFC. The condition of an existing concrete slab can affect the amount of preparation required (e.g., physical or chemical scarification, removing stains, repairing damaged concrete, RH testing). Product lifetime should be considered as part of the overall cost and will vary by manufacturer. Charges for labor, materials, and installation of EFCs range from approximately $3 to $12 per square foot.

Industrial and commercial buildings may also have higher costs due to a need for an EFC with greater durability and traction properties. EFCs with these properties may significantly increase material costs. Aesthetic design considerations such as color and pattern, especially for commercial buildings, will also increase costs.

Special Circumstances

Special circumstances associated with the application of EFCs as a passive mitigation strategy are described below:

- Design for function—Epoxies can be readily modified to enhance specific attributes in addition to the primary performance objective as a sealant. End-use and site conditions will dictate the materials and tools needed for installation.
- Weather—Extreme temperatures may affect the curing of the epoxy. Hot temperatures will limit the time available for application; cold temperatures may lengthen curing time.
- Relative humidity of concrete—The project scope should include measuring RH, especially in conditions where excessive moisture is encountered. Additional tasks may need to be performed to dry the concrete to prevent the delamination of the EFC.
- The surface condition of the existing concrete slab—The surface of the concrete must be clean, dry, and free of cracks, chips, and stains. Poor surface conditions detrimentally affect the adhesion of the epoxy.
- Newly installed concrete—New concrete slabs must be allowed to cure before the application of EFCs. Curing times depend on materials and site conditions and should be evaluated before implementation.
- Vertical surfaces—Concrete masonry unit (CMU) block, cast-in-place concrete, or other vertical wall materials specifically designed for wet adhesion would follow similar application approaches to horizontal concrete slabs.

Occupant, Community, and Stakeholder Considerations

- Buildings should not be occupied during EFC installation. If vacating the building is not possible, occupation should be relocated to areas of the building away from the work area, which must be well ventilated until the product has fully cured (typically 24–48 hours following application).

- The materials, equipment, and traffic control measures needed by the professional firm contracted to install EFCs may temporarily disrupt residential neighborhoods.
- It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win the trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. For more details, see ITRC's ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet***.

Resources

- ITRC. 2014. Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management, Washington, D.C.: Interstate Technology & Regulatory Council, Vapor Intrusion Team.
- ASTM. 2016. Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride. ASTM F1869-16a
- ASTM. 2019. Standard Test Method For determining Relative Humidity in Concrete Floor Slabs Using in situ Probes. 2019. ASTM F2170-19a

For more information and useful links about VI pathways and mitigation technologies, go to http://www.itrcweb.org/

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ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Passive Vapor Intrusion Mitigation Systems Subgroup

Passive Barriers

This ITRC Technology Information Sheet provides a general technical overview of several common types of passive barrier technologies used to prevent and/or reduce the entry of vapors into a building. The information contained in this document is designed to provide guidance on the appropriate application of each passive barrier technology listed, as well as considerations for selecting, designing, and installing a passive barrier system.

Overview

Types of Passive Barriers

Passive barriers use one or more layers of materials installed below a building foundation to physically block or divert the entry of vapors into a building. While use of passive barriers in new construction is more common, passive barriers may be installed within existing buildings when site conditions allow. This document provides a general technical overview of several common types of passive barrier technologies used to mitigate buildings at sites with vapor intrusion (VI) risks. Most passive barrier technologies fall under two categories known as asphalt latex membranes (ALMs) and thermoplastic membranes (TMs). Advancements in TM technology have resulted in the creation of a third category known as composite membranes (CMs), which incorporate a combination of barrier materials to improve the performance of the passive barrier. Passive barriers are generally used in conjunction with passive venting systems to enhance their ability to prevent vapors from entering and accumulating beneath a building. When a passive barrier is used in conjunction with a passive venting system, the collective system is referred to as a passive VI mitigation system (VIMS). In some cases, passive barriers are used in conjunction with active venting systems or other building control technologies.

A brief technical overview of ALMs, TMs, and CMs is provided below. More information about passive venting systems can be found within the ***Passive Sub-slab Venting Systems Technology Information Sheet***. Additional information about active venting systems can be found within the ***Active Mitigation Fact Sheet*** and supporting technology information sheets.

Best Practices

Selection of Passive Barrier Technologies

Not all passive barrier system manufacturers provide performance data for their individual products or passive barrier technologies. Users should inquire with the passive barrier system manufacturer to request performance data and assess the appropriateness of individual products or systems for their project.

Pre-system Installation

Passive VIMS documentation should include drawings prepared by a qualified environmental professional, a site-specific quality assurance/quality control (QA/QC) plan consistent with manufacturer recommendations that addresses barrier inspection procedures and methods to prevent damage to the barrier during and after placement, and if required, an on-going monitoring plan. The ***Operations, Monitoring, and Maintenance***

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Checklist provides recommendations of items to include in an operation, maintenance, and monitoring (OM&M) plan.

A properly trained or certified VIMS installation contractor should be selected. Manufacturers can provide lists of contractors that are certified to install their systems. Each member of the contractor's crew should be trained in the proper procedures for successful installation of the VIMS.

Installation Oversight

A qualified environmental professional properly trained and authorized by the manufacturer in the application and inspection of the passive VIMS should be selected and appointed as the QA/QC inspector by the appropriate party. Ideally, the inspector should always be present during the installation of the VIMS; however, this is usually not feasible. Typically, the more oversight the inspector can perform, the smoother the installation process will go because the inspector can prevent improper installation procedures or correct improper installation procedures shortly after they are performed. During installation, the inspector should confirm all aspects of proper installation of the VIMS.

System Installation Inspections

- QA/QC tests are commonly conducted during installation, including smoke, vacuum, or leak tests to confirm proper installation and material quality.
- Any deficient area of the installation should be properly documented and called to the attention of the applicator to address.
- Site inspectors should confirm and document required repairs.
- Site inspectors should prepare a final report verifying the VIMS installation.

Post-system Installation

After installation, a passive VIMS should be properly inspected and commissioned for use. The ***Post-Installation Verification Fact Sheet*** and associated checklist describe best practices for ensuring a passive barrier system is functioning as intended.

Asphalt Latex Membranes (ALMs)

Technology Description

The primary component of a passive ALM VIMS is a continuous seamless layer of spray-on asphalt latex material. ALM materials used for VIMS should be water based and free from volatile organic compounds (VOCs) and used in combination with other layers to create a barrier to VI. A typical ALM passive VIMS consists of a base layer, a continuous seamless layer of spray-applied ALM, and a cap sheet.

ALMs are applied to a carrier layer, referred to as a base layer, that consists of either a geotextile—a thin textile-backed plastic film—or a CM. The base layer serves as a carrier substrate for the spray-on membrane, increasing the tensile strength of the system and in some cases increasing the system's resistance to chemical attack or vapor diffusion.

The ALM is applied at a specified mil thickness to the base layer. The asphalt emulsion and latex polymer blend is mixed with a catalyst material at the tip of a spray wand. This creates a reaction resulting in the instantaneous formation of a uniform seamless ALM. The membrane typically reaches 90 percent of its full properties within 15 minutes. After the ALM has been applied, a different geotextile is applied on top of the spray-on membrane. This is typically referred to as the cap layer or protective layer. The cap layer serves to protect the ALM from construction damage that might be caused by subsequent trades. Additionally, the nonwoven fibers of the cap geotextile get embedded into the concrete that is poured on top of the ALM. This allows for the ALM to be integrally bonded to the concrete, providing protection from VI even if the soils settle away from the bottom of the slab.

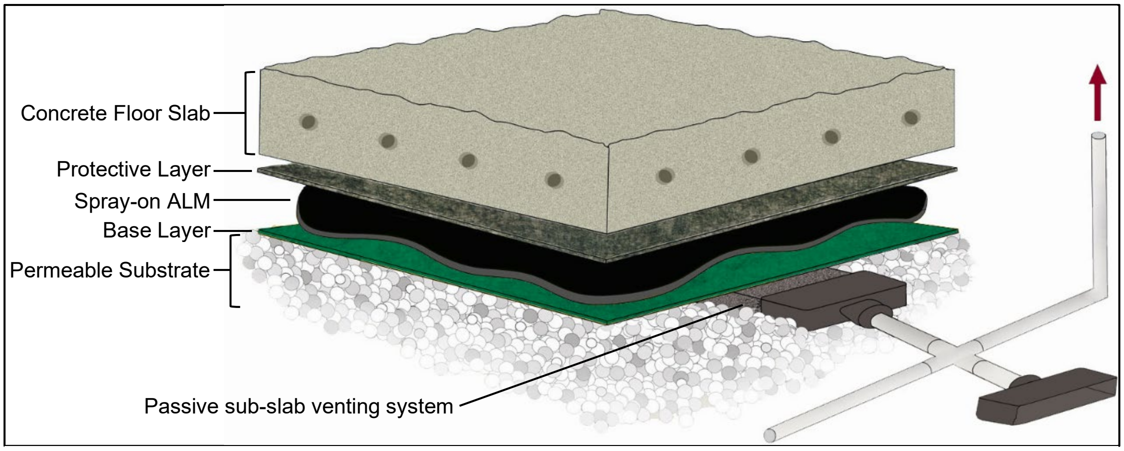

Figure 1. Illustration of a typical asphalt modified latex (ALM) passive barrier and passive venting system.
Source: Adapted from CETCO

When terminating the system to building footings, grade beams, stem walls, etc., the spray-on ALM adheres directly to concrete, thus removing the need for mechanical fastening. The spray-on ALM is also used to seal penetrations without the need for preformed boots. The ability of the membrane to adhere to typical substrates makes it ideal for sealing to penetrations such as polyvinyl chloride (PVC), steel, wood, and concrete terminations at its perimeter. This results in a fast installation by reducing the time spent on detailing.

Advantages

ALM VIMSs can be used for a wide range of chemicals of concern due to the variety of base and cap materials available.

- ALMs adhere to most surfaces, which eliminates mechanical fastening and caulking at penetrations and terminations.
- ALMs are spray-applied and cure in place, and therefore provide a seamless layer of protection. This reduces the risk of a membrane failure at seams, which tend to be the weakest points in seamed systems.
- ALMs that use a protective geotextile may bond to the concrete poured on top of them. This ensures protection even in the event of soil settling. The geotextile also protects the ALM from aggregate damage.
- ALMs are composed of very low permeability materials, which protect against diffusive and advective flow of vapors. If configured properly, an ALM can provide the additional benefit of moisture protection.
- ALMs can be combined with CMs. These combined systems can offer a higher level of protection from chemical diffusion.

Limitations

- ALMs are primarily limited to new construction or foundations that do not have an existing slab.
- ALMs should not be used if they are expected to be in direct contact with pure liquid-phase solvents.

Cost Considerations

Costs for passive ALM VIMSs are typically $2—$5 per square foot, including materials and installation. Cost will vary depending on the project location, size, complexity, and construction sequencing.

Design & Installation Considerations

Contaminant Types

Passive ALM VIMSs can be used for a wide range of contaminants because of the wide variety of base and cap materials that are used in conjunction with the spray-on membrane. Manufacturers generally provide suggestions for the contaminant classes that their systems may be appropriate for. An additional consideration is for the compatibility of the ALM with contaminants that are expected to contact the barrier in a separate liquid phase. These chemicals in their pure form may not be compatible with the ALM or the base and cap layers. If the barrier is expected to be in contact with these chemicals in their pure liquid phase, other remedial actions may be needed on site before redevelopment.

Performance

Performance of an ALM is a function of the materials that it is made from and the quality of the installation. Selection of the most appropriate ALM, based on the contaminant types, concentration, and risk, should consider the performance of the ALM. Chemicals move through a barrier by advection and diffusion. Advective flow is dominated by imperfections in the barrier that coincide with cracks or other openings in the slab, illustrating the importance of the installation of the barrier. The rate of chemical diffusion through the barrier is dependent on the material type. Certain types of materials are better at controlling diffusion. An ALM that incorporates CMs in the base provides higher reductions in chemical diffusion through the barrier.

QA/QC

A QA/QC plan should be implemented on all ALM applications. This may include destructive testing or coupon samples cut at a predetermined frequency. Coupon sampling is the collection of samples cut from the ALM to verify that the membrane thickness meets the project requirements. Areas that are cut for sampling should be repaired with the appropriate methods.

Additionally, a smoke test should be used to inspect the ALM for imperfections. Nontoxic theatrical smoke may be pumped below the membrane prior to placement of concrete to allow for visual identification of holes in the membrane. This allows the entire ALM to be inspected for imperfections that are not visible to the naked eye. Manufacturers can provide standard procedures for conducting these tests. Reports documenting the QA/QC testing should be part of the project records.

Thermoplastic Membranes (TMs)

Technology Description

TMs are composed of plastic resins formed into uniform membranes. They can also be referred to as geomembranes or plastic liners. TMs most commonly consist of high-density polyethylene (HDPE), but variations such as linear low-density polyethylene (LLDPE) and other materials are also available. The physical characterizes of TMs can vary between manufacturers as resin blends are specific to each manufacturer and each type of resin blend provides unique physical and chemical resistance properties.

Since most passive barrier applications also require the use of a sub-membrane vapor collection system, TMs are commonly installed over a gravel substrate. To prevent damage during the installation process it is common to install a non-woven geotextile (between 6 and 12 ounces per square yard in weight) under the TM.

A welding device is used to thermally seal the seams of the TM together. Heat welding methodologies can vary depending on the thickness of the TM. Thicker TMs will require more robust equipment to achieve the goal of a uniform and continuous welded seam. Prefabricated “boots” made of the same TM material are used to seal around pipe penetrations and protrusions. Steel clamps and sealants are used to create a compressive seal between the penetration and the TM.

When terminating the TM to building footings, grade beams, stem walls, etc., a termination bar is mechanically fastened over the edge of the liner and onto the concrete substrate. The termination bar's purpose is to create a compressive seal between the desired substrate and the TM because TMs have no adhesive properties. Proper compression between the termination bar and the termination substrate is required to create an effective seal. Stainless steel termination bars are generally specified due to their longevity, physical strength, and resistance to moisture and chemicals. To promote and maintain uniform adhesion, the lag bolts and washers should be the same material as the termination bar.

Additional considerations must be taken if the geotechnical report indicates that settling may occur underneath the structure. Soil settlement will compromise the integrity of a TM at seams and terminations by no longer providing support for the TM. Manufacturers of TMs provide modifications to TMs to mechanically bond (anchor) the TM to the concrete slab.

Thickness and installation procedures differentiate TMs from common vapor barriers. "Vapor barrier" is the term most associated with thin mil plastic liners (e.g., 6–15 mils) that are used to mitigate moisture transmission through concrete. Vapor barriers used in standard construction practices are not typically designed to mitigate chemical vapor transmission (DNREC-SIRB, 2007).

Advantages

- TMs may provide factory QA documentation, ensuring uniform quality of the base material.
- The material cost for a TM can be low when compared to the material cost of ALM.
- Puncture resistance can be increased by using thicker membranes.
- Independent testing demonstrates that HDPE has a relatively high level of chemical resistance compared to other geomembrane materials.
- ATSM standards provide a standard for field QA/QC.

Limitations

- The use of TMs is primarily limited to new construction projects.
- TMs typically require heat-welded seams and mechanical fastening and sealing at penetrations and terminations, which are the areas more prone to develop leaks.
- While the material cost of a TM may be relatively low, the labor to install the TM is relatively high, when compared to ALMs.
- Thicker TMs decrease the likelihood of damage during the construction process; however, they are more difficult to install properly. Generally, large flat open areas are more conducive to TM installation.
- TMs can be susceptible to thermal expansion and contraction, thus potentially compromising penetration and termination seals.
- TM effectiveness can be compromised if proper compression is not achieved between the termination bar, the TM, and the substrate.

Cost Considerations

- Costs for TMs are typically $5–$10 per square foot, based on HDPE, PVC, or other field-constructed thermoplastic liner systems (Kilmer et al., 2016).
- Cost will vary depending on the project location, size, complexity, and construction sequencing.

Design & Installation Considerations

TM should be designed considering foundation complexity, contaminants of concern, and weather conditions at the anticipated time of installation. The most common ASTM QA standards are:

- ASTM D5820—Conductive Geomembrane Spark Test
- ASTM D4437—Air Lance Test
- ASTM D4437—Vacuum Box Test

- ASTM D5820—Standard Practice for Pressurized Air Channel Evaluation of Dual Seamed Geomembranes

Other forms of quality control include:

- smoke test—the process of injecting nontoxic smoke underneath the membrane, checking for any smoke penetrating the membrane, and then patching the membrane to ensure no more smoke penetrates the membrane. Care should be taken when using a smoke test of a passive VIMS with taped seams. Pressure from the smoke test can cause the seams to separate.
- mechanical point stress test—testing the integrity of each seam using a handheld seam probing tool.

Composite Membranes (CMs)

Technology Description

Advancements in TM technology have led to the development of CMs. These CMs incorporate a variety of materials that can reduce diffusion rates of chemical vapors from VOCs, petroleum hydrocarbons, methane, and radon. CMs use a variety of different passive barrier materials to create a multilayered system designed to improve chemical resistance, constructability, and durability.

Examples of materials used in CMs include ethylene vinyl alcohol (EVOH) embedded between layers of polyethylene. These systems combine the functionality of polyethylene with improved chemical resistance of EVOH (McWatters and K. Rowe, 2018). Other advanced CMs may include metallized films or foils made of metals, such as aluminum, to achieve improved chemical resistance. The inner barrier of CMs may be protected by multiple layers.

Multiple layers provide redundancy and improved diffusion rates for a variety of chemicals, including various VOCs and petroleum hydrocarbons. The redundancy of multiple layers also provides improved durability against construction traffic. Seams may be sealed using various methods, such as heat welding, taping, or spray-on emulsions. Terminations and penetrations are typically sealed using either mechanical fastening and caulking, tapes, or spray-on emulsions.

Advantages

- Using a combination of barrier materials can offer improved chemical resistance.
- Multiple layers may improve long-term durability.
- CMs may provide protection against a broad range of chemicals.
- CMs can provide greater protection and improve installation times using thinner mil systems.
- CMs can be combined with ALMs. Combined systems can offer a high level of protection from chemical diffusion.

Limitations

- New technologies may require regulatory approval. Some CMs may not meet minimum mil thickness regulatory requirements.
- Smooth CMs may pose challenges during installation due to lack of adhesion to concrete and may require mechanical fasting around penetrations and perimeter terminations.
- Taped-based CMs may be subject to delamination in high moisture environments and may have difficulty passing a smoke test.

Cost Considerations

Installed costs for CMs typically range from $1 to $5 per square foot, depending on building type, building size, and warranty requirements. Cost will vary depending on the project location, size, complexity, and construction sequencing.

Design & Installation Considerations

Design and installation considerations for CMs are similar to other passive barriers. The primary methods for design evaluation should focus on chemical resistance, constructability, and cost. The evaluation for chemical resistance should include diffusion testing for representative chemical contaminants. In addition, other testing methods should be used in combination with chemical resistance testing to evaluate the following parameters of CMs:

- composite mil thickness
- tensile strength
- tear strength
- puncture resistance
- elongation

These physical properties should be used in combination with diffusion testing to create a better understanding of the overall robustness of the CM. These barriers will be installed in construction traffic environments and must demonstrate sufficient durability to prevent punctures and/or tears prior to concrete slab pour. Installation is best completed by certified installers who are familiar with the application of the CM. In addition, it is best practice to have third-party inspectors present during installation to ensure the installation is performed per the designed technical specification.

Typical Barrier Selection Considerations

Thickness

The barrier material, properties, and application affect the appropriate thickness and these factors should be considered when selecting a barrier for any particular purpose. It should also be noted that some VI guidance documents do not specify an appropriate minimum thickness, but state that passive barriers should be thick enough to withstand construction and diffuse the chemicals of concern. State and federal VI guidance documents that do suggest an acceptable minimum thickness vary from 30 to 100 mils. A thickness of 40 mils is commonly referenced for TMs and 60 mils for ALMs. A 30-mil minimum thickness is referenced in some guidance (USEPA, 2008). Vapor barriers less than 30 mils are more prone to puncture, tearing, and incomplete seals, thus limiting their effectiveness. However, membranes less than 30 mils may be appropriate when combined with active systems.

Chemical Resistance and Diffusion

Universally accepted standards do not exist for the chemical resistance to chemical vapor or diffusive properties of passive barrier materials. Existing ASTM standards used to evaluate water vapor barriers (ASTM E96) or short-term free product chemical exposure do not adequately address the intended use of VI barrier systems, and may differ due to the molecular size and attraction of the solvent vapor barrier material (Wilson et al., 2014). Manufacturers of VI barrier products publish chemical vapor resistance testing and/or diffusion results. These tests should be evaluated on their own merits. While testing methodologies can vary between manufacturers, there are independent laboratories and universities, such as Geokinetics of Irvine, California, and Queens University in Ontario, Canada, using standard protocols to determine chemical diffusion rates for various commercially available passive barriers.

Puncture and Tensile Strength

Testing the strength of a membrane system helps predict a membrane's ability to resist damage during the construction process. Damage to membranes after they are installed often occurs when small objects (hand tools, rebar, etc.) are dropped onto the membrane. Puncture resistance by ASTM D1709, which measures the amount of force required to fully penetrate the membrane material, is commonly used (NJDEP, 2018).

Tensile strength (ASTM D882) is a measure of a material's resistance failure due to stretching (NJDEP, 2018). Tensile strength can be used to evaluate a membrane's ability to resist failure due to tension that may be caused by differential settlement of the underlying soil.

Constructability

Constructability of a passive barrier system is a subjective term that attempts to convey to users how easy a passive barrier is to install versus its ability to withstand the construction process as well as its usability in a wide variety of situations. TMs are typically provided in large rolls. The material's stiffness and thickness make it more difficult to work with in areas requiring a lot of detail work. However, the large rolls facilitate a fast installation in open areas not requiring detailing. ALMs are efficient for use in areas that require detail work because they are spray-applied and rapidly seal to the substrate. In large open areas ALMs typically take longer to install than TMs.

Special Circumstances

The presence of a high water table or perched aquifer may adversely affect the performance of both passive and active mitigation systems installed within structures constructed below grade. While slab-on-grade structures are not often affected unless they are built in a flood zone, below-grade structures will need protection against both water and VI. Local building code requirements will dictate a building owner's ability to artificially lower the water table to an elevation that does not affect the foundation or mitigation system; however, in many cases this is not economically feasible when contaminated groundwater is encountered. When dewatering systems are used, a passive barrier with waterproofing capabilities should still be used in the event of dewatering system failure, and to prevent the migration of nuisance water. Water intrusion into the structure indicates that a potentially complete VI pathway exists. Waterproofing materials used on contaminated sites must also demonstrate effectiveness to contaminated vapor.

Settlement of soils beneath structures may occur for a variety of reasons. Therefore, passive barriers should demonstrate their ability to adhere directly to the concrete slab, as this will prevent the barrier from settling with the soil. Likewise, peel adhesion and tensile stress on the passive barrier material and its seals and seams may compromise the system.

Occupant, Community, and Stakeholder Considerations

Occupants of buildings with existing passive barriers should be made aware of potential VI risks and that the barrier provides a level of protection designed to prevent VI from occurring. Occupants should be instructed to avoid modifying the concrete slab to prevent affecting the function of the passive barrier. When planning modifications to a building with a passive barrier, consideration should be given to whether the modifications will affect the integrity of the barrier.

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. For more details see ITRC's ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet***.

Resources

- ASTM. 2016. Standard Test Methods for Impact Resistance of Plastic Film by the Free-Falling Dart Method. American Society for Testing and Materials. 2016. ASTM D1709-16ae1

- ASTM. 2017. Standard Specifications for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs. American Society for Testing and Materials. 2017. ASTM E-1745-17
- ASTM. 2018. Standard Test Method for Tensile Properties of Thin Plastic Sheeting. American Society for Testing Materials. 2018. ASTM D882-18
- ASTM. 2018. Standard Practice for Nondestructive Testing (NDT) for Determining the Integrity of Seams Used in Joining Flexible Polymeric Sheet Geomembranes. American Society for Testing and Materials. 2018. ASTM D4437 / D4437M-16(2018)
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For more information and useful links about VI pathways and mitigation technologies, go to http://www.itrcweb.org/

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ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Passive Vapor Intrusion Mitigation Systems Subgroup

Passive Sub-slab Venting Systems

This ITRC Technology Information Sheet describes passive sub-slab venting systems for mitigation of vapor intrusion (VI). Passive venting systems differ from sub-slab ventilation (SSV) systems in that the former are not electrically powered and rely on temperature and pressure differences between the building and atmosphere to induce airflow. A brief overview, along with advantages and disadvantages, is provided below.

Overview

The goal of a passive sub-slab venting system is to vent to the exterior atmosphere contaminant vapors that have accumulated beneath a structure. Combined with a passive barrier, contaminant vapors are captured and rerouted through a passive venting system to prevent contaminant vapors from entering the building and accumulating within the indoor air environment.

Passive sub-slab venting systems rely on wind effects, thermal effects, and pressure differences to induce airflow. This airflow moves contaminant vapors, which may accumulate beneath a building, through vents to the atmosphere. The amount of venting attributed to natural airflow and the resulting vapor concentrations below the passive barrier depend on site-specific conditions and the resistance of the venting material or the subsurface to air flow. A passive venting system is most easily installed prior to building construction. While effective passive venting systems have been designed for existing structures, their effectiveness relies on the presence of a permeable subsurface layer and the ability to install an adequate network of conveyances for venting along with an adequately sealed floor slab. Passive venting of existing structures is often limited by the permeability of the sub-slab materials and the lack of a perforated pipe or vent strip conveyance system. Therefore, passive venting is most commonly used in new construction. A typical way to vent sub-slab soil gas in new construction is using a perforated ventilation network, consisting of pipes or low-profile vents that run beneath the slab and direct the vapors to a centrally located plenum box or pipe header. Another effective sub-slab ventilation option is an aerated floor void space system (VSS); details of a VSS are provided in the ***Aerated Floor Void Space Systems (VSS) Technology Information Sheet***.

Existing structures may be retrofitted with passive venting systems using vertical vent points installed through the floor slab, or by installing a network of horizontal vent piping trenches constructed beneath the existing floor slab. This approach requires modifications and repairs to the existing concrete floor slab.

Passive sub-slab venting systems are generally used in conjunction with passive barriers. The venting system reduces contaminant concentrations in soil gas beneath the barrier and the potential impacts of vapor migration through barrier conduits into a building. Passive barriers improve the capture efficiency of a venting system by eliminating air flow between the interior of the structure and the vented space (see also ***Passive Barrier Systems Technology Information Sheet***). Passive barriers also prevent vapor entry when passive venting systems are not evacuating air from the sub-slab environment (e.g., during high atmospheric pressure or when there is little to no air flow). When passive venting systems are used in conjunction with passive barriers, the collective systems are referred to as passive sub-slab vapor intrusion mitigation systems (VIMS). Some passive venting systems are designed to introduce ambient air into the network to dilute contaminant vapor concentrations prior to discharge to the atmosphere. This is accomplished by installing dilution header pipes that collect ambient air from areas outside of the contaminant zone or building envelope. Inclusion of dilution piping is more common in passive vent systems for new construction where more space is available to install the dilution pipe headers.

Passive sub-slab venting systems differ from sub-slab depressurization (SSD) systems (as described in the ***Sub-slab Depressurization Technology Information Sheet***) in that passive systems may not create a measurable or consistent pressure differential across a slab. Performance metrics should focus on evidence of airflow in the vent and riser piping rather than pressure measurements. Measurement and evaluation of vapor-phase contaminant concentrations in the sub-slab and indoor air environments are other performance metrics used to evaluate the efficiency of a passive VIMS.

Following system installation, post-installation verification should be conducted to document that flow is not obstructed through the system. Refer to the ***Post-Installation Verification Checklist*** for a complete list of system construction and operational parameters to monitor following installation. Operation and maintenance of a passive sub-slab venting system is generally limited to periodic verification of flow through the riser pipes and monitoring. Refer to the ***Operation, Maintenance, and Monitoring Process/Exit Strategy Fact Sheet*** and ***Operation, Monitoring and Maintenance (OM&M) Checklist*** for more information on OM&M of passive sub-slab venting systems

Components

Passive sub-slab venting systems for new construction consist of a network of horizontal vent piping surrounded by a layer of permeable fill material below the concrete slab or foundation of a building. The vent piping may consist of perforated pipe or low profile-venting material, which is a highly permeable strip of geotextile matting (see Figure 3). The lateral vent pipes or low-profile vent material are connected to vertical vent piping that routes contaminant vapors through the building to the atmosphere. The fill material surrounding the vent piping or low-profile venting below the concrete slab must be permeable enough to allow for adequate flow of air and contaminant vapors into the horizontal vent piping or low-profile vent material.

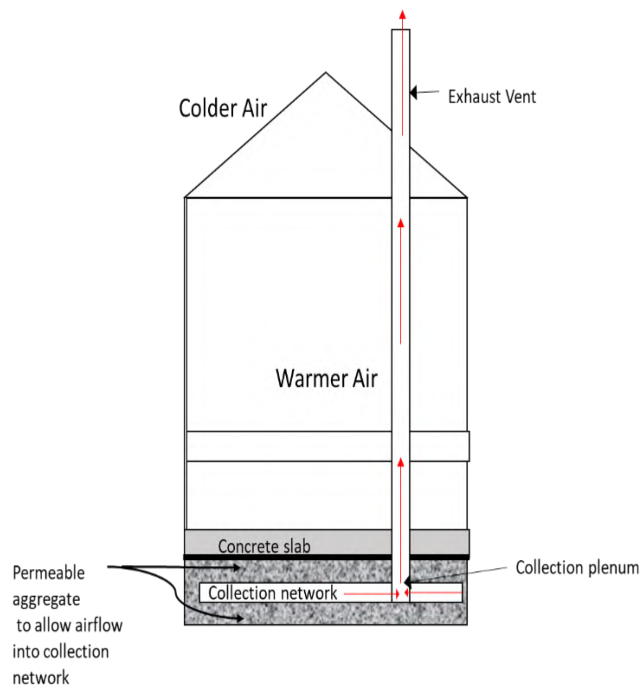

Figure 1. Passive mitigation system components. Airflow is greatest during colder weather when less-dense, warmer air rises through the vent pipe. Some systems will use individual collection sumps in lieu of a collection network.
Source: S. McKinley, used with permission.

Pressure differences and airflow rates within a passive vent system will be dramatically lower and more inconsistent than in an active system with a fan. Therefore, passive systems require a well-connected network of slotted or perforated piping or low-profile vents, a permeable sub-slab layer to allow airflow into the piping, a competent seal between foundation and walls, and a competent slab to minimize leakage. Compared to an active system, passive systems may require multiple collection points, a more extensive horizontal network of vent piping, and a collection plenum or header to be effective. The basic system components shown in Figures 1 and 2 include:

- high permeability material beneath a competent slab or barrier (e.g., AASHTO M 43 No.57 or 67 stone). See Figures 2 and 3.
- venting network of slotted/perforated collection pipes, low-profile vent material, or aerated mats beneath the slab. Schedule 40 polyvinyl chloride (PVC) or standard dimensional ratio (SDR) 35 slotted or perforated (factory- or field-drilled) pipe is typically used for vent piping. See Figure 4.

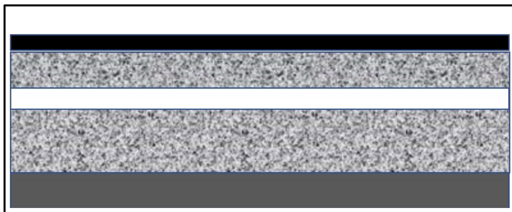

Figure 2. To be effective, passive venting systems need a high permeability layer to promote airflow and an impermeable barrier to provide a seal between the vent and the slab. *Source: S McKinley, used with permission.*

- collection plenum box, typically constructed of hollow concrete blocks turned on their sides with an empty space in the center. It vents the sub-slab collection system to the outside atmosphere through a vertical riser. A pipe header can also be used to connect the vent piping to the riser. See Figure 5.
- impermeable barrier as necessary to provide continuous protection from vapor entry between the slab and venting network. The barrier should be resistant to the site contaminants of concern (COCs) and adequately sealed; typical moisture barrier or even radon barrier systems may not provide necessary chemical resistance. See Figure 2 and refer to the ITRC ***Passive Barrier Systems Technology Information Sheet*** for more information.
- exhaust vent(s), which are riser pipe(s) that extend through the slab, roof, or wall of the structure to the outside. Most of the riser pipe length must be in a conditioned area so that the warmer air inside the pipe will rise through the structure and vent the subsurface through thermal venting. See Figure 1.
- design components, such as fans and associated controls, to upgrade to active mitigation if necessary. See the ITRC ***Sub-slab Ventilation Technology Information Sheet***.

Figure 3. Photograph of a low-profile vent and vent pipes.
Source: CETCO

Figure 4. Photograph of mitigation system piping.
Source: A. Rodak, Duncklee & Dunham, used with permission.

Advantages

Because passive sub-slab venting systems do not have a fan, they reduce the risk of mobilizing soil gas to the vent riser stack, which would create a point source for outdoor air contamination. In addition, passive sub-slab venting systems offer several other advantages:

- Users avoid long-term costs for mechanical part maintenance and operation.
- They have energy-efficient function (i.e., green and sustainable technology).
- This type of system does not rely on a power source for continuous operation.

- Depending on the permeability of subsurface soil, passive sub-slab venting systems can often capture vapors over a large surface with minimal pipe coverage area.

Limitations

Compared to active venting, passive systems may not be able to reduce concentrations of sub-slab soil gas COCs to less than regulatory screening or indoor air quality levels over the same time period. Other limitations of passive sub-slab venting systems include:

- They may show reduced performance, when compared to active systems, due to the absence of an electrical fan or blower to induce continual airflow and by stack effects that are more influential in cooler weather periods
- Effective coverage area of each riser pipe may be limited. Passive venting systems tend to “breathe” in and out, and therefore vapors cannot travel great distances without the use of an electrical fan or blower.
- Performance may depend on the integrity and life of the seal above the sub-slab venting system.
- Performance may be affected by building foundation settlement.
- Presence of concrete footers or sub-slab wall extensions may require additional vent piping
- Some states may not allow passive venting systems.
- An effective system may require a larger number of riser pipes than active systems.

Figure 5. Photograph of a header for mitigation system piping. *Source: Duncklee & Dunham, used with permission.*

Cost Considerations

- Incorporating passive sub-slab venting systems into new construction will be less costly and more effective than in existing construction.
- Typical installed costs for a new construction passive venting system vary widely depending upon materials used, but typically range from around $3 per linear foot for low-profile vent materials and around $8 per linear foot for slotted PVC pipe. This range does not include cost for a barrier and the permeable layer.
- Use of collection plenums may reduce the number of horizontal pipe sections or overall pipe length.
- The type of riser pipe used on the interior of the building affects cost. PVC riser pipes are more economical; however, more expensive cast iron vent riser pipes may be required to meet local building code requirements or to prevent damage post-installation.

Special Circumstances

- High water table or an impermeable sub surface may limit venting effectiveness and prevent use.
- Isolated areas under elevated or noncontinuous slabs should be addressed by placing adequate gravel below these areas and adding additional ventilation pipe to the passive venting system.

Occupant, Community, and Stakeholder Considerations

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals and minimize the disruption of people’s lives and businesses. For more details, see the ITRC ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet***.

Resources

Related Links:

- EPA Engineering Issue: Indoor Air Vapor Intrusion Mitigation Approaches, EPA/600/R-08-115 October 2008
- Guidance Document for the Vapor Intrusion Pathway, Michigan Department of Environmental Quality, May 2013
- NAVFAC: Vapor Intrusion Mitigation in Construction of New Buildings Fact Sheet,

For more information and useful links about VI pathways and mitigation technologies, go to http://www.itrcweb.org/.

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ECOS

ITRC is affiliated with the Environmental Council of the States

VAPOR INTRUSION MITIGATION SYSTEM DESIGN AND DOCUMENTATION CHECKLISTS

This checklist provides information necessary to proceed through the design process described in the ***Design Considerations Fact Sheet***. This checklist focuses on system design and documentation for active strategies (first portion of checklist) and passive strategies (second portion of checklist). Before completing this checklist, review and complete the ***Vapor Intrusion Mitigation Conceptual Site Model (CSM) Checklist***. Not all the information presented below is necessary to document a particular design. For example, some small residential building designs may be completed with very little predesign information and systems may be installed using only a conceptual design. The user should be able to identify which considerations best represent effective design for their specific vapor intrusion mitigation system (VIMS). If a checklist item is not applicable to the design, select "NA" for not applicable and consider documenting the rationale as an attachment to this checklist. Click **here** to download a fillable digital checklist.

Active Mitigation Checklist for Existing Buildings and New Construction

Details and types of active mitigation can be reviewed in the ***Active Mitigation Fact Sheet***. The primary active technologies that are the focus of this design checklist are sub-slab depressurization, sub-slab venting, sub-membrane depressurization, and crawlspace venting, and these technologies are detailed in their respective technical information sheets. This section focuses on design checklist considerations for existing buildings where the design needs to accommodate an existing building slab. Some of the considerations in the checklist below may also apply to new construction if an active system such as a sub-slab depressurization (SSD) system is being installed. This is different than mitigation of new construction that consists of a passive barrier or aerated floor. For the passive mitigation systems, see the passive mitigation checklist below.

1. ACTIVE MITIGATION SYSTEM DESIGN AND DOCUMENTATION

- Have all the building slab areas been fully characterized for contaminants? ☐ Yes ☐ No ☐ NA
- Has pressure field extension (PFE) testing been completed? ☐ Yes ☐ No ☐ NA

1.1. Selection of system materials and methods

- Were total building footprint, foundation type, and under-slab compartments (created by haunches, thickened slab, or elevation changes) considered in the design process? ☐ Yes ☐ No ☐ NA

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- Have monitoring points (i.e., sub-slab differential pressure monitoring points/embedded probes, riser vacuum, and flow monitoring points) been included in design? ☐ Yes ☐ No ☐ NA
- Has depth to groundwater been considered (along with management methods as warranted, such as dewatering)? ☐ Yes ☐ No ☐ NA
- Have system components and locations been included in the system design drawing set? System components may include, for example: ☐ Yes ☐ No ☐ NA
  - vent piping diagrams provided by the design firm/engineer
  - vent stack piping
  - pipe diameters based on airflow and velocity-induced drag
  - pipe joints and connections sealed using material manufacturers' approved methods
  - exhaust pipes supported and secured in a permanent manner
  - horizontal piping runs sloped downward or designed to drain condensation into the ground beneath the slab
  - vertical piping runs that drain naturally or can be documented to be able to drain water/moisture.
- Have critical motor criteria been considered when selecting a fan or blower? ☐ Yes ☐ No ☐ NA
  For example:
  - calculations from the pressure field extension processes and pressure drop in the conveyance piping
  - sufficient power (voltage and amperage) in building to support electrical requirements in motor
  - sufficient power to accommodate extra system components if they are needed (e.g., emission controls, filters, knockout tanks)
  - sufficient roof support for the blower
  - wind loading and ballast requirements
- Have all monitoring components and locations been included in the system design drawing set? ☐ Yes ☐ No ☐ NA
  For example:
  - manometers
  - mechanical differential pressure gauges
  - light and/or audio alarms
  - electronic monitoring/telemetry
  - electromechanically activated control switches
  - electronic sensors with data recording
  - automated electronic fault notification
- Have piping specifications been completed, including exhaust piping? ☐ Yes ☐ No ☐ NA
- Have exhaust concentrations and primary wind flow direction been considered when selecting exhaust locations, if warranted? ☐ Yes ☐ No ☐ NA

- Has a screened cap (for bird and rodent protection) been included on the vent stack? ☐ Yes ☐ No ☐ NA
- To reduce the risk of vent stack blockage, has the point of discharge from vent stack pipes been designed per applicable guidance/regulation: ☐ Yes ☐ No ☐ NA
  - a vertical discharge pipe or not more than 45˚ from vertical
  - outside the structure
  - an appropriate distance above the edge of the roof
  - an appropriate distance away from any air intake location, opening (door, window, vent, etc.), or occupied spaces (including adjacent structures)
  - for horizontal or vertical vent stack pipes attached to or penetrating the sides of buildings, the point of discharge is vertical, an appropriate distance above the edge of the roof, and is located and/or designed to prevent precipitation or other materials from entering vent stack pipes
- Have language(s) and location(s) (including prominent locations, such as exterior venting locations) of system labeling been planned? ☐ Yes ☐ No ☐ NA
- Has notification to occupants been planned? ☐ Yes ☐ No ☐ NA
- Does signage contain language indicating the mitigation vent may contain volatile organic compounds (if warranted)? ☐ Yes ☐ No ☐ NA

1.2. Buildings slab evaluation

- Has sealing of cracks, floor openings, or expansion joints been included in the design to address potential preferential pathways or potential system short circuiting? ☐ Yes ☐ No ☐ NA
- Was a floor sealer for the slab considered based on slab integrity and contaminant concentrations? ☐ Yes ☐ No ☐ NA
- Have drains, plumbing sleeves, and conduits penetrating the slab been identified and included in the sealing plan? ☐ Yes ☐ No ☐ NA

1.3. Regulatory confirmation prior to installation and commissioning

- Have applicable codes and permits (e.g., building codes, and environmental permits) been addressed in the design? ☐ Yes ☐ No ☐ NA
- Is regulatory body (federal/state/local) approval required or recommended for the mitigation design prior to construction? ☐ Yes ☐ No ☐ NA
- Does your state, municipality, and/or governing regulatory body require or recommend approval of an operation, maintenance, and monitoring (OM&M) plan prior to construction? ☐ Yes ☐ No ☐ NA
- Have stakeholders been notified of the planned system and necessary OM&M plan? ☐ Yes ☐ No ☐ NA

1.4. System installation and commissioning

- Does the design provide a schedule for design standards to be inspected by a competent/experienced person during construction? ☐ Yes ☐ No ☐ NA
- Does the design summarize the design objectives and how the design objectives can be documented as being met during system commissioning (i.e., performance metrics such as sub-slab pressure field extension testing, riser vacuum, and flow measurements, sampling)? ☐ Yes ☐ No ☐ NA
- Does the design include a method for how changes to the design, if needed, will be communicated to stakeholders during installation? ☐ Yes ☐ No ☐ NA
- Does the design plan document if as-built drawings will be warranted at the completion of system installation (note, as-built drawings are typically needed/required)? ☐ Yes ☐ No ☐ NA
- Has continued monitoring been included in accordance with the OM&M plan? ☐ Yes ☐ No ☐ NA

1.5. Regulatory confirmation post-installation and commissioning

- Does the design plan include details on how system installation will be documented, reported, and approved as needed by the client and/or regulatory body? ☐ Yes ☐ No ☐ NA
- Does the design taken into account the need for a deed amendment of land use restriction following installation, if applicable? ☐ Yes ☐ No ☐ NA

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Passive Mitigation Checklist for New Construction and Existing Buildings

Details and types of passive mitigation can be reviewed in the ***Passive Mitigation Fact Sheet***. The primary passive technologies that are the focus of this design checklist are aerated floors, epoxy floor coatings, passive barrier systems, and passive sub-slab venting systems. These technologies are detailed in their respective technical information sheets. This section focuses mainly on design checklist considerations for new construction. Passive mitigation systems are most commonly used within new building construction. Passive mitigation systems can also be implemented within existing buildings. For existing buildings, removal of the floor slab may be necessary to allow installation of some passive mitigation systems. Alternatively, some passive mitigation systems can be installed above existing floor slabs, such as an aerated floor, EFC, or vapor barrier membrane.

2. PASSIVE MITIGATION SYSTEM DESIGN AND DOCUMENTATION

- Will the building of interest have an effective venting layer to install perforated piping within, or equivalent sub-slab ventilation plenum system? ☐ Yes ☐ No ☐ NA
- Does the system design incorporate an open aerated floor ventilation plenum? ☐ Yes ☐ No ☐ NA
- Has the aerated floor structure been approved by a structural engineer? ☐ Yes ☐ No ☐ NA

2.1. Selection of system materials and methods

- Were total building footprint, foundation type, and under-slab compartments (created by haunches, thickened slab, or elevation changes) considered when selecting under slab ventilation and aeration materials and methods? ☐ Yes ☐ No ☐ NA
- Have monitoring points (i.e., embedded probes and flow monitoring points) been included in design? ☐ Yes ☐ No ☐ NA
- Has depth to groundwater been considered (along with management methods as warranted, such as dewatering)? ☐ Yes ☐ No ☐ NA
- If waterproofing is required, is the selected waterproofing product also designed to mitigate VOCs and is it included in the design? ☐ Yes ☐ No ☐ NA
- Have system and monitoring components and locations been included in the system design drawing set? ☐ Yes ☐ No ☐ NA
  For example:
  - vent piping diagrams
  - vent stack piping

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  - exhaust pipes supported and secured in a permanent manner
  - horizontal piping runs are sloped downward or designed to drain condensation into the ground beneath the slab
  - Quality assurance/quality control checks required by manufacturer or recommended for passive barriers (Note: A smoke test, pressure test, or other test may be recommended).

- Have manufacturer-approved methods been considered for pipe joints and connections? ☐ Yes ☐ No ☐ NA
- Do vertical piping runs terminate in a location that can drain naturally or can be documented to be able to drain water/moisture? ☐ Yes ☐ No ☐ NA
- Have piping specifications been included for exhaust piping? ☐ Yes ☐ No ☐ NA
- Have exhaust concentrations and primary wind flow direction been considered when selecting exhaust locations? ☐ Yes ☐ No ☐ NA
- To reduce the risk of vent stack blockage, has the point of discharge from vent stack pipes been designed per applicable guidance/regulation: ☐ Yes ☐ No ☐ NA
  - a vertical discharge pipe or not more than 45˚ from vertical
  - outside the structure
  - an appropriate distance above the edge of the roof
  - an appropriate distance away from any air intake location, opening (door, window, vent, etc.), or occupied spaces (including adjacent structures)
  - for horizontal or vertical vent stack pipes attached to or penetrating the sides of buildings, the point of discharge is vertical, an appropriate distance above the edge of the roof, and is located and/or designed to prevent precipitation or other materials from entering vent stack pipes
- Have language(s) and location(s) (including prominent locations, such as exterior venting locations) of system labeling been planned? ☐ Yes ☐ No ☐ NA
- Has notification to occupants been planned? ☐ Yes ☐ No ☐ NA
- Does signage contain language indicating the mitigation vent may contain volatile organic compounds, if warranted? ☐ Yes ☐ No ☐ NA
- Has notice been provided to all tenants that will be occupying the structure? ☐ Yes ☐ No ☐ NA
- Have construction quality assurance/quality control and third-party oversite protocols been put in place for the installation of the passive barrier and ventilation system? ☐ Yes ☐ No ☐ NA

2.2. Selection of a passive barrier

- Was an evaluation conducted to determine if this mitigation system is a pre-emptive or precautionary measure (i.e., investigation through multiple lines of evidence did not suggest that a current vapor intrusion pathway is complete)? ☐ Yes ☐ No ☐ NA
- When selecting a passive barrier were membrane thickness, chemical resistance, adhesion to concrete, transmission rates and/or diffusion coefficients for contaminants of potential concern, puncture resistance, tensile strength, and elongation considered? ☐ Yes ☐ No ☐ NA
  Note: These parameters should be documented in design specifications and plan.
- Has a warranty from the passive barrier manufacturer been included in the design? ☐ Yes ☐ No ☐ NA

2.3. Regulatory confirmation prior to installation and commissioning

- Have all applicable codes and permits been identified and included in design? ☐ Yes ☐ No ☐ NA
- Is regulatory body (federal/state/local) approval required for the mitigation design prior to construction? ☐ Yes ☐ No ☐ NA
- Does your state, municipality, and/or governing regulatory body require approval of an OM&M plan prior to construction? ☐ Yes ☐ No ☐ NA
- If the goal of the passive mitigation system design is to allow for conversion to an active system, are mechanical and electrical provisions included in the design to activate the system, if needed? ☐ Yes ☐ No ☐ NA
- Have all stakeholders been notified of the planned system and necessary OM&M plan? ☐ Yes ☐ No ☐ NA

2.4. System installation and commissioning

- Is there a schedule for system installation to be inspected by a competent/experienced person during construction? ☐ Yes ☐ No ☐ NA
- After completion of installation, are there procedures planned to verify components are operating in accordance with design criteria? ☐ Yes ☐ No ☐ NA
- Have post-system installation verification performance metrics (e.g., sampling) been considered and included in the design plan, if needed? ☐ Yes ☐ No ☐ NA
- Has continued monitoring been considered during the design phase either in the work plan or as part of an OM&M plan? ☐ Yes ☐ No ☐ NA

2.5. Regulatory confirmation post-installation and commissioning

- Have system installation and commissioning specifications been included in the design plan? ☐ Yes ☐ No ☐ NA

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• Have stakeholders been notified of the system to be installed and the OM&M plan requirements?	☐ Yes ☐ No ☐ NA
• Does the system require a deed amendment or land use restriction?	☐ Yes ☐ No ☐ NA

VAPOR INTRUSION MITIGATION SYSTEM POST-INSTALLATION VERIFICATION CHECKLIST

The purpose of this checklist is to provide the user with a selection of tools to verify that the appropriate system components for the vapor intrusion mitigation system (VIMS) were installed and the system is operating as designed. This information applies to the four most common active mitigation systems (SSD, SSV, SMD, and CSV) and passive systems that are described in the associated Fact Sheets and Technology Information Sheets. The user of this checklist should review the VIMS design or as-built documentation prior to completing this checklist.

This document was prepared in consideration of multiple types of VIMS. Not all the information presented below is necessary to document system operation for all types of systems on all types of buildings. The user should be able to identify which criteria below best represent effective operation for their specific mitigation system and which criteria will validate the conceptual site model for the VIMS that was implemented. Timing on when to collect post-installation verification data may vary and more than one event may be reasonable. See the ***Post-Installation Verification Fact Sheet*** for additional information on timing a post-installation verification site visit. Click **here** to download a fillable digital checklist.

Instructions for Use: Major system components are grouped below for this checklist, and one or more of these groups may not apply to a particular VIMS design. Those groups can be marked as Not Applicable by selecting the 'X' box to the right of the group.

Design elements within these groups that **will** apply should be selected by checking the appropriate box included for this checklist:

Yes—the design element was considered and documented

No—this item was not considered and may be relevant to the overall system performance, applicable guidance, and/or best practices

NA—not applicable to the system design or operation

This checklist is intended to serve as a guide for design considerations and as documentation for VIMS installation. This list can be modified for a specific project or program if needed or can be used as shown. The list should be submitted along with the final project as-builts and/or installation oversight verification documentation and reporting.

1. SITE INFORMATION

Address inspected: ____________________

____

Date of inspection: ____________________

Inspector(s): ________________________

____

Inspector's company name:

____

Building contact:

____

Building contact phone number:

____

Note: As-built drawings & performance criteria are needed when conducting inspections of vapor intrusion mitigation systems.

2. BUILDING TYPE

☐ Existing building

☐ New construction

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3. TYPE OF SYSTEM

Active

☐ Sub-slab depressurization (SSD)
☐ Sub-slab venting (SSV)
☐ Sub-membrane depressurization (SMD)
☐ Crawlspace ventilation (CSV)

Passive (Check all that apply)

☐ Epoxy floor coating (EFCs)
☐ Passive barrier system
☐ Passive sub-slab venting (PSSV)
☐ Aerated floors

4. SYSTEM DESIGN COMPONENTS AND INSTALLATION DOCUMENTATION

4.1. Site Conditions/Conceptual Site Model

- Contaminant concentrations at the site have been reviewed and compared to generic or building-specific screening levels. The level of applied effort (flow and vacuums) should be proportional to the magnitude of the concentrations. In large buildings, the VIMS target treatment area may not include the entire footprint, but should allow for adequate capture of vapors to mitigate the potential for unacceptable risk to the occupants of the building. ☐ Yes ☐ No ☐ NA
- Slab conditions should be verified/inspected for cracks/voids/utility penetrations/potential preferential pathways (if known/observed) and identified on a diagram, sealed to the extent practical, and visually inspected during post-installation verification event. ☐ Yes ☐ No ☐ NA

4.2. Extraction Point(s)

☐ Not applicable

- Suction point location, diameter, and sealing are documented. ☐ Yes ☐ No ☐ NA
- Pipe and manifold location, materials, diameter, slope, and sealing are documented. ☐ Yes ☐ No ☐ NA
- Sample port, shutoff valve, and access have been identified.
- U-tube manometer (or similar vacuum gauge) is installed and target vacuum level is clearly marked ☐ Yes ☐ No ☐ NA

4.3. Collection Piping

☐ Not applicable

- As-built collection piping diagrams have been provided. ☐ Yes ☐ No ☐ NA
- Riser pipe is located in an interior wall where possible and does not penetrate firewalls or shear walls. ☐ Yes ☐ No ☐ NA
- Fire collars are installed on pipes where firewalls are penetrated. ☐ Yes ☐ No ☐ NA
- Vent piping system was designed by a qualified individual with VIMS design experience. ☐ Yes ☐ No ☐ NA
- All vent stack piping is identified as solid, rigid pipe. ☐ Yes ☐ No ☐ NA
- All pipe joints and connections are permanently sealed. ☐ Yes ☐ No ☐ NA
- Foundation penetration sleeves are installed as approved by the structural engineer. ☐ Yes ☐ No ☐ NA
- All exhaust pipes are supported and secured in a permanent manner consistent with building codes. ☐ Yes ☐ No ☐ NA

- Horizontal piping runs are sloped to ensure that condensation drains into the ground beneath the slab. ☐ Yes ☐ No ☐ NA
- Vertical piping runs drain naturally or can be verified to be free of water or moisture. ☐ Yes ☐ No ☐ NA

4.4. Piping Completion Specifications ☐ **Not applicable**

(Review the primary wind flow direction from nearby weather stations.)

- As-built collection piping diagrams have been provided. ☐ Yes ☐ No ☐ NA
- Pipes are completed with an exhaust stack and are an appropriate height above the roof. ☐ Yes ☐ No ☐ NA
- Point(s) of discharge are an appropriate distance away from any air intake location, opening (door, chimney flue, window, vent, etc.), or occupied spaces, including adjacent structures. ☐ Yes ☐ No ☐ NA
- To reduce the risk of vent stack blockage, confirm that the point of discharge from vent stack pipes is vertical and upward, outside the structure. Consider wire mesh to deter birds and small animals ☐ Yes ☐ No ☐ NA

4.5. Blower/Fan ☐ **Not applicable**

- Blower/fan number, location, size, model number, and performance specifications are documented. ☐ Yes ☐ No ☐ NA
- Blower/fan is securely mounted with discharge locations far from building intake locations. ☐ Yes ☐ No ☐ NA
- Electrical components and wiring were installed by a licensed electrician in accordance with applicable building codes. ☐ Yes ☐ No ☐ NA
- Intrinsically safe or explosion-proof components installed where specified in the project plans. ☐ Yes ☐ No ☐ NA
- Diagnostic testing and results are documented and summarized to meet design criteria. ☐ Yes ☐ No ☐ NA
- Audible and/or visual low vacuum alarm is installed, tested, and separately powered (e.g., battery). ☐ Yes ☐ No ☐ NA
- Controller system (where present): model number, location, OM&M manual are documented. ☐ Yes ☐ No ☐ NA
- Telemetry system (where present): model number, location, OM&M manual are documented. ☐ Yes ☐ No ☐ NA

4.6. Monitoring Probes ☐ **Not applicable**

- Sub-slab vapor probes, if needed, are installed in accordance with design (appropriate number and location(s)). ☐ Yes ☐ No ☐ NA
- Surface completion provides a seal to the subsurface and a leak check test was passed. ☐ Yes ☐ No ☐ NA
- Probes and surface completions are level to grade to minimize trip hazard. ☐ Yes ☐ No ☐ NA

4.7. Post-Installation Diagnostic Testing ☐ **Not applicable**

- System flow and vacuum are documented in vent pipe(s) and data meet design criteria. ☐ Yes ☐ No ☐ NA

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- Pressure field extension (PFE) testing is documented to meet design criteria across targeted areas. ☐ Yes ☐ No ☐ NA
- Additional diagnostics were performed as appropriate where data do not meet expectations. ☐ Yes ☐ No ☐ NA
- Effluent concentrations were measured and calculated discharge meets design criteria/permit limits, if needed. ☐ Yes ☐ No ☐ NA
- Nonsealed combustion appliances were checked for back drafting/CO_2 levels. ☐ Yes ☐ No ☐ NA

4.8. System Monitors and Labeling ☐ **Not applicable**

- System labels are placed on the mitigation system, riser piping, electrical panel breaker and junction box, and other prominent locations, including the exterior venting locations. ☐ Yes ☐ No ☐ NA
- Description of signage and locations is provided. ☐ Yes ☐ No ☐ NA
    - signage contains language indicating that the mitigation vent may contain volatile organic compounds ☐ Yes ☐ No ☐ NA
    - figure provided, if needed, identifying locations of signs ☐ Yes ☐ No ☐ NA
    - name and contact information for operator clearly visible with instructions to notify operator in the event of alarm conditions, damage to any system component, power failure, etc. ☐ Yes ☐ No ☐ NA
- Documentation states that a notice has or will be provided to tenants that will be occupying the structure. ☐ Yes ☐ No ☐ NA

4.9. System Design and Specification ☐ **Not applicable**

- Mitigation system design has been reviewed by a vapor intrusion mitigation specialist, professional engineer, or professional with demonstrated mitigation design experience. ☐ Yes ☐ No ☐ NA
- As-built project plans and specifications have been prepared and reviewed by the designer. ☐ Yes ☐ No ☐ NA
- Electrical one-line diagrams have been prepared and reviewed by a licensed electrician. ☐ Yes ☐ No ☐ NA
- Dewatering has been considered and, if necessary, incorporated into the design. ☐ Yes ☐ No ☐ NA
- Engineer or design firm is identified. ☐ Yes ☐ No ☐ NA
- Building/fire codes: Document states that mitigation systems is designed and installed to conform to applicable building and fire codes and to maintain the function and operation of existing equipment and building features, including doors, windows, access panels, etc. ☐ Yes ☐ No ☐ NA
- Permits: Documentation is provided that the system passed required permit inspections. ☐ Yes ☐ No ☐ NA

4.10. Sumps ☐ **Not applicable**

- Floor drains are designed to allow water to flow into sumps while sealing out soil gases from entering the indoor air space from the sub-floor area (e.g., Drainjer-style drain). ☐ Yes ☐ No ☐ NA

5. NEW CONSTRUCTION ☐ Not applicable

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5.1. Aggregate Layer ☐ **Not applicable**

- Delivered sub-slab aggregate grain size gradation matches project design specifications. ☐ Yes ☐ No ☐ NA
- Aggregate is uniformly compacted and rolled flat and is free of protrusions or debris that may be a puncture hazard. ☐ Yes ☐ No ☐ NA
- Aggregate thickness was measured and documented to meet project specifications. ☐ Yes ☐ No ☐ NA

5.2. Engineered Plenums (e.g., drainage mats) ☐ **Not applicable**

- Engineered plenums were supplied and documented to meet project specifications. ☐ Yes ☐ No ☐ NA
- Plenum was uniformly laid flat across target treatment area to meet project specifications. ☐ Yes ☐ No ☐ NA

5.3. Collection and Manifold Piping ☐ **Not applicable**

- Delivered vapor collection piping matches project design specifications. ☐ Yes ☐ No ☐ NA
- Vapor collection piping is laid and pipe joints and connections are permanently sealed. ☐ Yes ☐ No ☐ NA
- Solid piping is used in areas adjacent to utilities or trenches or where short circuiting may occur ☐ Yes ☐ No ☐ NA

5.4. Membrane Installation Documentation ☐ **Not applicable**

- Membrane manufacturer installation requirements are provided. ☐ Yes ☐ No ☐ NA
- System was installed by a certified installation vendor, if required by the manufacturer. ☐ Yes ☐ No ☐ NA
- Mitigation system as-built drawings are provided. ☐ Yes ☐ No ☐ NA
- Photographic log is provided for seals/repairs at the following locations: ☐ Yes ☐ No ☐ NA
    - along foundation edge ☐ Yes ☐ No ☐ NA
    - around foundation penetrations ☐ Yes ☐ No ☐ NA
    - along vertical exterior walls ☐ Yes ☐ No ☐ NA
    - around elevator shafts ☐ Yes ☐ No ☐ NA
    - coupon/smoke testing repairs ☐ Yes ☐ No ☐ NA
- **Trench Dams:** Utility trench dams were installed in all utility trenches leading to the building. ☐ Yes ☐ No ☐ NA
- **Conduit Seals**: Conduit seals were installed in all electrical conduits that extend below the membrane. ☐ Yes ☐ No ☐ NA

5.5. Membrane Design and Specification ☐ **Not applicable**

- Membrane selection and/or thickness was considered for potential contaminant concentrations in the subsurface (i.e., chemical compatibility). ☐ Yes ☐ No ☐ NA
- Sub-slab screening levels protective of diffusive transport across the slab have been calculated and monitoring is specified to document sub-slab concentrations after the membrane is placed. Contingencies are in place to modify the system (i.e., ☐ Yes ☐ No ☐ NA

potentially activate a passive system) if diffusive transport may become an issue.

- Documentation provides details for areas that require specialized completion, including all penetrations and terminations. ☐ Yes ☐ No ☐ NA
- Drains that perforate the barrier are designed to allow water to flow into sumps and floor drains while sealing out soil gases from entering the indoor air space from the sub-floor area (e.g., Drainjer-style drain). ☐ Yes ☐ No ☐ NA
- Membrane selection and/or thickness was considered for potential contaminant concentrations in the subsurface (i.e., chemical compatibility). ☐ Yes ☐ No ☐ NA

5.6. Quality Assurance/Quality Control Installation Plan Requirements Identified in the Design Document **☐ Not applicable**

- Products and materials installed meet the project design specifications. ☐ Yes ☐ No ☐ NA
- Material Safety Data Sheets (MSDS) for potential background contaminants (e.g., adhesives, glues, etc.) were reviewed. ☐ Yes ☐ No ☐ NA
- Installation was conducted in accordance with manufacturer's specifications (e.g., weather, curing time). ☐ Yes ☐ No ☐ NA
- Estimated quantities of the product to be used are provided. ☐ Yes ☐ No ☐ NA
- Engineer of record or barrier manufacturer identifies steps to document the effectiveness of the mitigation system. ☐ Yes ☐ No ☐ NA
    - Coupon sampling ☐ Yes ☐ No ☐ NA
        - Sample frequency is appropriate to assess integrity of entire barrier.
    - Smoke testing ☐ Yes ☐ No ☐ NA
        - Locations are appropriate to assess integrity of entire barrier. ☐ Yes ☐ No ☐ NA
        - Assessment of barrier integrity is based on visual observation of where smoke has migrated and/or where membrane repairs were made. ☐ Yes ☐ No ☐ NA
- On-site installation oversight and documentation by the design firm is noted. ☐ Yes ☐ No ☐ NA
- Documentation is present verifying that the installation and repairs have been completed per project specifications and manufacturer's installation instructions. ☐ Yes ☐ No ☐ NA
- Verification sampling was performed in accordance with the system design plan. ☐ Yes ☐ No ☐ NA
    - Field sampling procedures specified were followed. ☐ Yes ☐ No ☐ NA
    - The correct number and locations of verification samples were collected. ☐ Yes ☐ No ☐ NA
    - Verification samples were collected at the appropriate frequency. ☐ Yes ☐ No ☐ NA
    - Verification samples were analyzed using the appropriate analytical method. ☐ Yes ☐ No ☐ NA

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- Results of the verification samples indicate that the VIMS is effectively mitigating the vapor intrusion risk present at the site. ☐ Yes ☐ No ☐ NA
- Deviations in the verification sampling plan, if needed, are documented with rationale for the change. ☐ Yes ☐ No ☐ NA

VAPOR INTRUSION MITIGATION SYSTEM OPERATION, MONITORING, AND MAINTENANCE CHECKLIST

Scope of Checklist: The purpose of this checklist is to guide the user during the inspection of a vapor intrusion mitigation system (VIMS) to (1) verify that the VIMS is operating as designed and (2) determine if certain operation, maintenance, and monitoring (OM&M) activities are necessary for continued operation and effectiveness of the system. This checklist is intended to provide factors to consider when documenting that the VIMS is operating and is effectively mitigating the vapor intrusion pathway during the lifecycle of its operation. Not all the information presented below is necessary to document system operation for all types of systems on all types of buildings, and some items may not be needed during every monitoring event. The user should be able to identify which criteria below best represent effective operation and responsible maintenance of their specific VIMS and if the conceptual site model (under which the system was designed) is still valid.

Prior to completing the inspection, it is recommended that the user review previously prepared OM&M plans. As-built drawings and performance (baseline) criteria are needed when conducting inspections of a VIMS. Monitoring scope, schedule, and methods may follow applicable agency requirements, which may be amended on a case-by-case basis through regulatory negotiation and approval. Where applicable, the monitoring and inspections must also comply with standards of practice and applicable codes (electrical code, building code).

In some situations, OM&M plans may not exist or be available or were not provided to a new operator or new building owner. Thus, the original as-built drawings and possibly the original performance criteria may not be known. In these cases, the checklist below can still be used to assist in developing the appropriate ongoing OM&M parameters for that particular site, although additional effort may be appropriate depending on the complexity of the building and site conditions. Click **here** to download a fillable digital checklist.

1. SITE INSPECTION INFORMATION

Address inspected:____

Date of inspection: ______________________ Date of last inspection: ________________

Inspector(s): ______________________ Title:________________ Company:___________

Building contact:____________________________________ Phone number:__________

Frequency of inspections:
____ Annual____ Semi-annual ___ Quarterly ___ Monthly ___Other (specify) ________

Type of system being inspected: ____

2. MITIGATION SYSTEM OPERATION

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2.1. Was the mitigation system functioning as designed and operating upon arrival? ☐ Yes ☐ No ☐ NA

If "no," explain in Section 5, Observations and Corrective Actions, why the system was not operational and steps taken to correct the problem.

If "no" and the cause of the system shutdown is determined, follow the start-up procedures as detailed in the system OM&M plan and complete the remainder of the checklist.

2.2. Has the mitigation system been altered from what is shown in the as-built drawings? ☐ Yes ☐ No ☐ NA

If yes, discuss in Section 5 changes and possible impacts.

2.3. Has the mitigation system operated continuously since the last OM&M event? ☐ Yes ☐ No ☐ NA

If no, discuss in Section 5 changes and possible impacts.

2.4. Have procedures and equipment been checked for proper operation? ☐ Yes ☐ No ☐ NA

If no, discuss in Section 5 changes and possible impacts.

2.5. Are labels identifying the system components in place and legible? ☐ Yes ☐ No ☐ NA

If no, specify the date of replacement.

2.6. Conduct a visual inspection of accessible system piping and pipe seals, including membrane seals (if applicable), connections, etc. Were any cracks/gaps or any changes in the system configuration observed? ☐ Yes ☐ No ☐ NA

If yes, list the inspection results in Section 5 and document the corrections to fix these problems.

3. BUILDING CONDITIONS AND USE

3.1. Is the building's heating system or heating, ventilating, and air conditioning (HVAC) system operating? ☐ Yes ☐ No ☐ NA

If yes, provide a summary below and explain in Section 5 if the HVAC system operation could impact the effectiveness of the mitigation system.

*Hours/day of HVAC operation*___________________

Climate controlled? ☐ Yes ☐ No ☐ NA

3.1.1. Is the building's heating system or HVAC system on during this OM&M event? ☐ Yes ☐ No ☐ NA

3.1.2. Is the building's heating system or HVAC system equipped with outside dampers? ☐ Yes ☐ No ☐ NA

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If yes, how many? ________ % opened ___________

3.2. Has the building had a change in use since the system began operation? (i.e., Are the exposure assumptions still appropriate?) ☐ Yes ☐ No ☐ NA

If yes, explain in Section 5 what these changes are and how they may impact the effectiveness of the mitigation system.

3.3. Has the building undergone any physical modifications (building additions, change to interior walls, new sumps or French drains, any new permits filed, etc.)? ☐ Yes ☐ No ☐ NA

If yes, explain in Section 5 the building changes and how they may impact the effectiveness of the passive mitigation system.

3.4. Has the condition of the basement (lowest floor) walls, floors, sumps, and utility penetrations been inspected for cracks, gaps, or seal failure? ☐ Yes ☐ No ☐ NA

If yes, list the inspection results in Section 5 and document the corrections (if necessary) to fix any problems.

3.5. Has a visual inspection been conducted assessing the presence of moisture and/or efflorescence as crystalline deposits in the basement or lowest floor, including any crawlspaces? ☐ Yes ☐ No ☐ NA

If evidence of moisture or efflorescence was found, list the inspection results in Section 5 and document the corrections to fix these problems.

4. MONITORING AND DIAGNOSTIC MEASUREMENTS

4.1. Record vacuum and air flow at the suction point(s) and compare to baseline values (if applicable). Note: Field instruments such as a micromanometer can be used if in-line gauges/displays are not built-in. ☐ Yes ☐ No ☐ NA

Prepare and attach monitoring data table to summarize the results.

If consistent, note the conclusion in Section 5.
If not consistent, explain discrepancies in Section 5 and whether further corrective steps are necessary for the VIMS or actions taken.

4.2. Record fan or blower/fan air flow and vacuum and compare to baseline values (if applicable). Note: Field instruments such as a hot-wire anemometer can be used if in-line gauges/displays are not built-in. ☐ Yes ☐ No ☐ NA

Prepare and attach monitoring data table to summarize the results.
If consistent, note the conclusion in Section 5.

If not consistent, explain discrepancies in Section 5 and whether further corrective steps are necessary for the VIMS or actions taken.

4.3. Are telemetry systems indicating normal operating conditions? ☐ Yes ☐ No ☐ NA

If no, describe issues and any mitigative actions in Section 5.

Type of telemetry: ____________________________________

Location: ____

Summary of operating conditions: ______________________

____

4.4. Did any telemetry system data show irregular entries or shutdown? ☐ Yes ☐ No ☐ NA

If yes, describe issues and any mitigative actions in Section 5.

4.5. Conduct vapor concentration monitoring within system (if applicable). Field instruments need to be calibrated and meet detection levels of vapors being monitored. If no sampling ports are built into the system, conduct monitoring at the piping discharge/exhaust. Monitoring options include:

a) field screening with a photoionization detector (PID) for total ionizable VOCs or flame ionization detector (FID) for total hydrocarbons, including methane

b) b) landfill gas monitoring for oxygen, carbon dioxide, and methane to assess cross-slab leakage, and sub-slab ventilation rates

c) whole gas (Tedlar bag, Summa canister, Bottle-Vac, etc., for analysis by USEPA Method TO-15 or similar) or sorbent sample (pumped ATD tube and TO-17 analysis). Holding time requirements of VOC samples for laboratory analysis need to be followed.

Has there been a significant increase or decrease in concentrations since the previous monitoring event(s)? ☐ Yes ☐ No ☐ NA

Multiply the concentration(s) by the flow rate to calculate mass emission rates.

- If the emission rates are higher than permit discharge limits, if present, consider off-gas treatment, taller stack, permit variance, or other options.
- If there has been a building depressurization test, is the initial mass removal rate from the system greater than the mass emissions through the building during depressurization?
- If the rate of mass removal from the system is too low to pose a potential risk to indoor air quality (i.e., the product of vent pipe concentrations multiplied by vent pipe flow rate is less than the product of the indoor air screening

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level multiplied by the building volume and air exchange rate), consider whether it may be appropriate to transition to a sub-slab ventilation system, semi-passive system (wind or solar fans), passive system (no fan, but open vent-pipes) or a decommissioned system.

Record the monitoring results in Section 5 or the attached monitoring data tables.

Discuss in Section 5 the reason(s) for any significant changes observed.

4.6. Record differential pressure (between sub-slab and indoor air) at monitoring points beneath the building floor slab if appropriate. Is the minimum differential pressure recorded at all monitoring points? ☐ Yes ☐ No ☐ NA

Record the monitoring results in the attached monitoring data tables.
Discuss in Section 5 the reason(s) for any significant changes observed.
Conduct a periodic leak check of the sampling probes if collecting soil gas samples.

For locations where the minimum vacuum is not observed, consider additional data collection.

a) *Connect a digital micromanometer to the probe, set data logging to a 1-second frequency and cycle the fan on and off (e.g., one minute on and then off, or until the micromanometer readings have stabilized). Repeat this cycle at least two times. Does the trend show a characteristic saw-toothed pattern with a magnitude similar to the target vacuum level?* ☐ Yes ☐ No ☐ NA

b) *Hold a smoke pen over the probe when open. Is the smoke drawn strongly into the probe?* ☐ Yes ☐ No ☐ NA

c) *Consider collecting a soil gas sample from the probe. If the vapor concentrations are below conservative sub-slab screening levels, it may not be necessary or appropriate to modify the system to exert additional vacuum to this location.*

4.7. Were indoor air samples collected for laboratory analysis as performance metrics? ☐ Yes ☐ No ☐ NA

If yes, summarize in Section 5 the results for COCs and any mitigative actions.
Background sources (consumer products and building materials inside buildings and ambient outdoor air VOCs) are a common confounding factor and must be explicitly considered when interpreting indoor air samples.

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4.8. Has a smoke test been conducted (if necessary) to verify the continued integrity of the liner? ☐ Yes ☐ No ☐ NA

If yes, summarize in Section 5 the results and any corrective actions.

4.9. Has the appropriate frequency for system inspections been completed to date? ☐ Yes ☐ No ☐ NA

If no, explain the discrepancy in Section 5.

*Current frequency of inspections*___________________.

4.10. Were batteries replaced in any battery-powered alarms (if needed)? ☐ Yes ☐ No ☐ NA

4.11. Were additional items inspected? ☐ Yes ☐ No ☐ NA

If yes, explain in Section 5 the item(s) inspected and the findings from the inspection

4.12. Was system component maintenance completed per equipment manufacturer specifications? ☐ Yes ☐ No ☐ NA

If yes, explain in Section 5 the maintenance completed.

.

5. OBSERVATIONS AND CORRECTIVE ACTIONS

Document observations and corrective actions or modifications made or planned to be made to the VIMS, and the results obtained to verify the effectiveness of the actions or modifications. Refer to the specific item number above for each observation or corrective action. Use additional pages as necessary.

6. PHOTOGRAPHIC LOG

Photographs taken and included as attachment? ☐ Yes ☐ No ☐ NA

7. OVERALL VI MITIGATION SYSTEM ASSESSMENT

Is the mitigation system still protective? ☐ Yes ☐ No

8. INSPECTOR INFORMATION

Name: ____________________________________

Signature: ____________________________________

Date: ______________

Remediation and Institutional Controls as Vapor Intrusion Mitigation

ITRC has developed a series of fact sheets that summarizes the latest science, engineering, and technologies regarding vapor intrusion (VI) mitigation. This fact sheet describes:

- the use of remediation systems and institutional controls (ICs) as a means of VI mitigation
- differences between remediation and mitigation
- various remediation methods that can serve as VI mitigation
- benefits and disadvantages of ICs and remediation as mitigation
- additional considerations for assessing the impact of remediation on VI mitigation

1 INTRODUCTION

VI describes the migration of volatile chemicals from the subsurface into overlying buildings. When the resulting indoor air concentrations of these chemicals exceed levels of concern, vapor control strategies can include environmental remediation, building mitigation, or ICs (ITRC, 2007a).

VI mitigation includes actions that prevent or limit the exposure of the building occupants to the intruding vapors. VI mitigation has become a significant environmental issue for regulators, potentially responsible parties, and concerned citizens.

In some instances, environmental technologies designed for source remediation can also serve as VI mitigation. ICs can also provide protection and serve as an administrative assurance for mitigation of a known or potential VI concern. This guidance will help the reader evaluate the applicability of environmental remediation and ICs as means of VI mitigation.

The following ITRC technology information sheets discuss in more detail technologies presented in this fact sheet:

- ***Soil vapor extraction (SVE) Technology Information Sheet***
- ***Multiphase extraction (MPE) Technology Information Sheet***
- ***Institutional controls (ICs) Technology Information Sheet***

2 MITIGATION VS. REMEDIATION

Some VI investigations will indicate that corrective actions should be taken to reduce the indoor air concentrations to acceptable levels. “Remediation” commonly refers to an action that reduces the level of contamination in the environmental medium (e.g., groundwater) that is acting as the source of the volatile organic compounds (VOCs) in indoor air. “Mitigation,” on the other hand, is generally applied to actions that prevent or limit exposure.

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VI mitigation is aimed at eliminating or reducing human exposure to impacted indoor air due to contaminated subsurface soil vapors. VI mitigation selection typically relies on methods that eliminate or reduce the migration of vapors from the subsurface to indoor air (e.g., sub-slab depressurization, building pressurization, vapor barrier, or slab reinforcement), or that treat (e.g., indoor air purifiers, increased ventilation) vapors already inside a structure. VI mitigation is typically a building-specific measure implemented within a relatively short time frame (e.g., immediately for acute exposure risk, weeks to months for chronic exposure risk).

Environmental remediation is aimed at reducing source area concentrations to below response action levels. However, it can also serve as VI mitigation. Examples of common remediation technologies that could serve as VI mitigation include soil vapor extraction (SVE) and multiphase extraction (MPE). Remediation performance metrics and site closure are based on achieving soil or groundwater cleanup goals, and remediation of VI sources generally requires more extensive investigation, design, and regulatory activities than VI mitigation. Consequently, the implementation of remediation is typically over a longer time frame (e.g., months or years).

REMEDIATION AS VI MITIGATION

For remediation to serve dually as VI mitigation and site cleanup, it must accomplish the same objective as a dedicated VI mitigation system, which is to rapidly reduce concentrations of the constituents of concern (COCs) in indoor air below the applicable regulatory levels. Remediation technologies that potentially can serve this purpose include SVE and MPE. An overview of each of these technologies is presented below; the main features are summarized in Table 3-1. Additional information can be found in the accompanying ***Soil Vapor Extraction Technology Information Sheet*** and ***Multiphase Extraction (MPE) Technology Information Sheet***.

Table 3-1. Remediation technologies that can serve as VI mitigation.

Remediation Technology	Site Type				COC Type		
	Basement		Scale				
	Wet	Dry	Single Structure	Site-wide	Volatile Chlorinated Hydrocarbons	Volatile Petroleum Hydrocarbons	Methane
SVE		✓	✓	✓	✓	✓	✓
MPE	✓	✓	✓	✓	✓	✓	✓

3.1 SVE

SVE is a remediation technology that relies on the extraction of soil vapor to reduce or eliminate the source of VOCs in the subsurface (see Figure 3-1). The soil vapor is extracted by creating low pressure in the subsurface by means of extraction wells or trenches connected to blowers. SVE can provide VI mitigation as long as the system intercepts soil vapors before they reach the building or creates a negative pressure below the building. SVE is directly applicable as a method of VI mitigation for relatively small sites, such as a single building, where it can be installed relatively quickly. SVE can also be effective as VI mitigation at larger sites; however, the implementation is longer than the VI mitigation timeframe typically required by regulatory

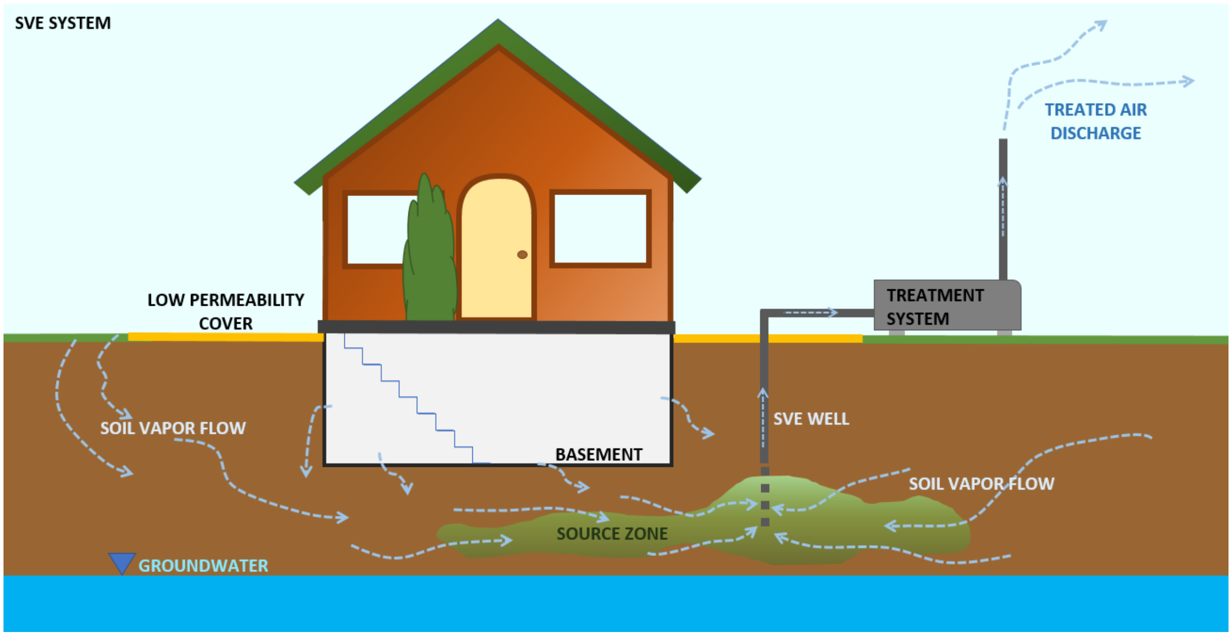

Figure 3-1. Conceptualization of a soil vapor extraction system. (Source: Laura Trozzolo, used with permission.)

3.2 MPE

MPE is a remediation technology that relies on the extraction of both liquids (groundwater and free product) and soil vapor to reduce or eliminate the source of VOCs in the subsurface (see Figure 3-2). The soil vapor is extracted by creating low pressure in the subsurface using extraction wells or trenches connected to suction. During MPE the thickness of the unsaturated zone is increased by depressing the water table through groundwater extraction to enhance the recovery of soil vapor. VOCs in the induced unsaturated zone undergo volatilization from the source material and are removed with the extracted soil vapor. VOCs in the saturated zone are recovered with the extracted liquid, which must be managed in accordance with applicable federal, state, or local laws and regulations. MPE can provide VI mitigation if the system intercepts soil vapors before they reach the building or creates a negative pressure below the building. MPE is directly applicable as a method of VI mitigation for relatively small sites. At larger sites, the implementation is longer than the VI mitigation timeframe typically required by regulatory agencies. A temporary VI mitigation system may need to be installed while a large MPE is being constructed.

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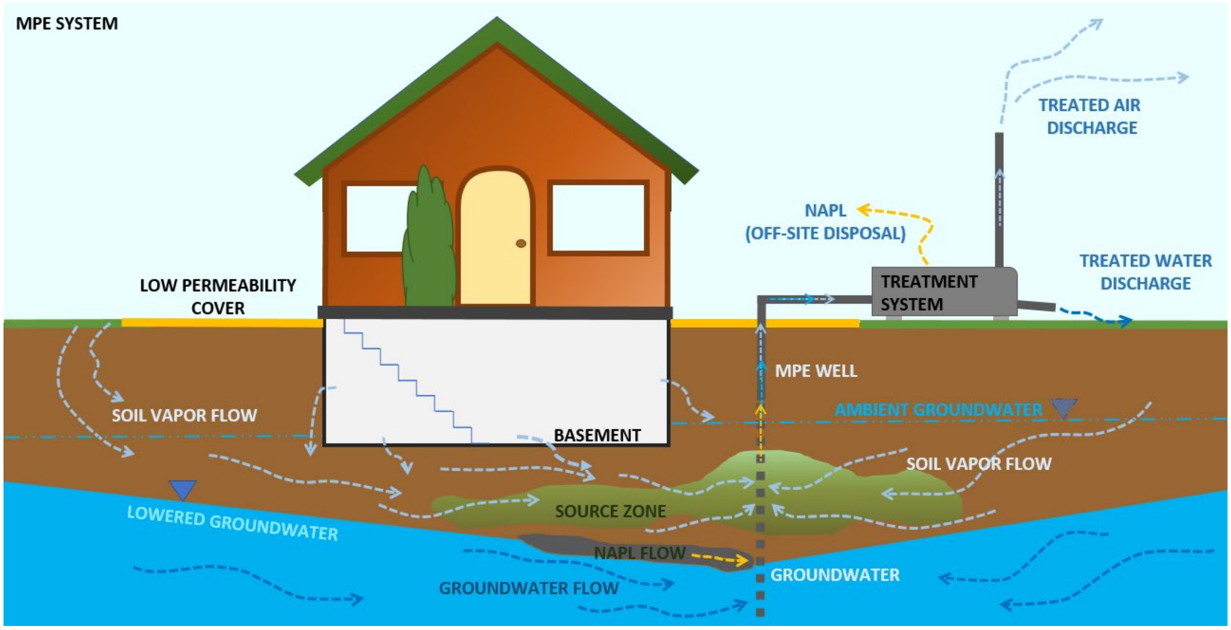


Figure 3-2. Conceptualization of a multiphase extraction system. (Source: Laura Trozzolo, used with permission.)

4 INSTITUTIONAL CONTROLS AS VI MITIGATION

ICs are a form of land use controls that provide protection from exposure to site-related contaminants. While ICs consist of administrative or legal restrictions on a site, land use controls can also use physical measures, which are called engineering controls or ECs (e.g., physical barriers). In contrast to ECs, ICs are primarily government controls, proprietary controls (e.g., deed restrictions), enforcement or permit mechanisms, and informational devices. Planning that protects human health and the environment and uses all aspects of an IC life cycle (ITRC, 2016) is essential for long-term success (e.g., a long-term stewardship plan). As it relates to the VI pathway, ICs can be applied as a stand-alone remedy (for undeveloped lands or restricted use on developed land), as part of an overall remedy selection, or as a mechanism that requires ongoing monitoring and maintenance of the mitigation system. More details are provided in the accompanying ***Institutional Controls*** Technology Information Sheet.

For further information on the various types of ICs, also refer to ITRC's Long-term Contaminant Management Using Institutional Controls (ITRC, 2016).

5 ADVANTAGES AND DISADVANTAGES OF REMEDIATION AND INSTITUTIONAL CONTROL AS VI MITIGATION

The advantages and disadvantages of environmental remediation and/or ICs as VI mitigation should be assessed on a site-specific basis. Several advantages and disadvantages of these methods are listed below:

5.1 Advantages

- Remediation may be less intrusive than mitigation and can avoid inconvenience to residents and businesses.
- Remediation can reduce the length of time required for mitigation by eliminating the source of impacts.
- Remediation can lessen or eliminate future on-site or off-site impacts and liability.
- ICs ensure that the VI exposure pathway is addressed in the future for undeveloped lands or buildings that have a change in use or zoning.
- ICs can limit or prevent human exposure when site-wide remedies are not immediately effective in eliminating VI.

5.2 Disadvantages

- Implementation time is longer for remediation; consequently, only relatively small remediation systems (prebuilt or made with off-the-shelf components) that can be implemented rapidly can serve as VI mitigation.
- Remediation requires more specialized installation and greater costs than typical VI mitigation systems.
- Remediation operation and maintenance requirements are typically more complex than mitigation systems and need to be addressed by an appropriately qualified consultant.
- An additional treatment system for extracted soil gas and/or groundwater may be necessary in a remediation system in accordance with applicable federal, state, or local laws and regulations.
- ICs may be difficult to implement and enforce over time.
- ICs may limit or prevent future development activities.

6 OTHER CONSIDERATIONS

Some types of remediation, while not directly employed with the intent to affect the soil vapor, may influence the operation of the existing or future VI mitigation systems. Some examples include:

- addressing the source of VI impacts, such as contaminated soils, nonaqueous phase liquid, or groundwater, may result in the improvement of soil vapor quality and reduction of the time frame when VI mitigation needs to be conducted (e.g., excavation, sparging, in situ treatment, hydraulic containment)
- performing remediation using technologies that result in the generation of emissions or altering of the soil vapor flow patterns may require that VI mitigation be applied to previously unaffected areas (e.g., sparging, in situ chemical treatment, thermal treatment)

Due to the potential threat/liability posed by identified, ongoing VOC sources, regulatory agencies may request that:

- interim measures be implemented before completion of typical VI mitigation systems

- remedial actions be taken at undeveloped land or unoccupied buildings, prior to implementing VI mitigation at new construction or re-occupancy of existing buildings
- remediation be performed independently of the VI mitigation

7 OCCUPANT, COMMUNITY, AND STAKEHOLDER CONSIDERATIONS

Carefully designed public outreach is an essential part of any aspect of the VI mitigation. This includes ICs, including informational devices, and remedial actions. ICs may be established to ensure the occupants, owners, and managers are informed and involved as partners in the long-term management of mitigation systems and, if necessary, monitoring of the affected building. See ITRC's ***Public Outreach during Vapor Intrusion Mitigation Fact Sheet*** for more information.

8 REFERENCES AND ACRONYMS

The ITRC VI Mitigation Training web page includes lists of acronyms, a full glossary, and combined references for the fact sheets. The user is encouraged to visit the ITRC VI Mitigation Training web page to access each fact sheet and supplementary information and the most up-to-date source of information on this topic.

ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Remediation & Institutional Controls Subgroup

Institutional Controls (ICs)

Applicability as a method of vapor intrusion mitigation

This ITRC Technology Information Sheet provides the general description of institutional controls (ICs), the various types of ICs, and the unique application of ICs to the vapor intrusion (VI) pathway. In many states, ICs may be used as the sole site remedy or in conjunction with other remedies, such as engineered controls (ECs). ICs are non-engineered instruments, such as administrative and legal controls, that help minimize the potential for human exposure to contamination and protect the integrity of the remedy.

Overview

Institutional controls (ICs) are a form of land use controls (LUCs) that provide protection from exposure to contaminants on a site. While ICs consist of administrative or legal restrictions on a site, LUCs can also use physical measures, which are called engineering controls or ECs (e.g., typical mitigation measures, physical barriers). In contrast to ECs, ICs include government controls, proprietary controls, enforcement or permit mechanisms, and informational devices. Planning that protects human health and the environment and uses all aspects of an IC life cycle (ITRC, 2016) is essential for long-term success (e.g., a long-term stewardship plan). As it relates to the vapor intrusion (VI) pathway, ICs can be applied as a stand-alone remedy (for undeveloped lands or restricted use on developed land), as part of an overall remedy selection, or as a permit that requires ongoing monitoring and maintenance of the mitigation system.

ICs often work best if "layered" with other ICs, particularly if required for a long period of time. This provides some redundancy and increased levels of oversight (more eyes on the process) and may increase long-term robustness of the overall IC program.

Types of ICs

ICs are divided into four categories:

- **Government controls**

  Governmental controls rely on the regulatory powers of federal, state, or local government and include ordinances, building and development rules, environmental restrictions, and other restrictions on land or resource use. Common examples include zoning ordinances (which limit or condition the type of land use that can occur in defined zones), groundwater use or well drilling limitations via restrictive covenants, and restrictions on reuse of contaminated soils generated from IC areas, and land development regulations (e.g., requiring all new construction to have VI mitigation). Government controls can be enforced by the jurisdiction that enacted the control.

- **Proprietary controls**

  Proprietary controls usually affect a single parcel of property and are considered proprietary or private because they are established by a private agreement between the landowner and an outside party. Proprietary controls are created under the authority of state real property law; thus, these agreements constitute a property right. These controls are attractive because they "run with the land"—meaning they endure as the affected property is sold to new owners. Proprietary controls are sometimes called "deed restrictions," which is a general term used to describe property rights that restrict the use of the property.

For example, when indoor air concentrations are acceptable for commercial/industrial use but unacceptable for residential use, deed restrictions are put in place to ensure protection of human health by limiting the current and future use of the building to non-residential activities only.

- **Enforcement or permit mechanisms**

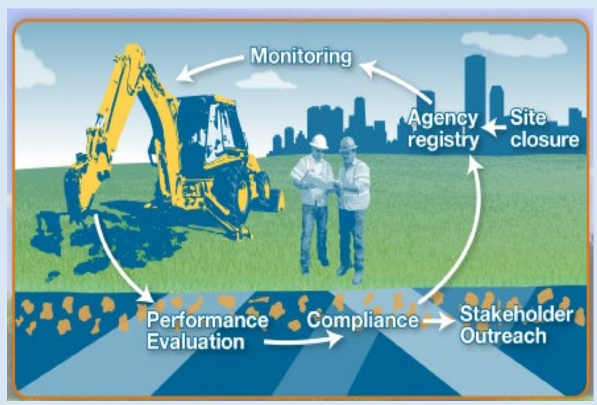
  Enforcement and permit mechanisms include government agency–issued permits, administrative orders, and enforcement agreements (such as consent decrees) that are enforceable by state or federal agencies. These tools can include requirements that restrict future land use. Rather than being a property right (as with proprietary controls), most enforcement and permit mechanisms are binding only to the signatories of the agreement (or the party named in the permit or order), and therefore, the property restrictions do not bind subsequent owners (they do not “run with the land”). Environmental agency permits often include long-term stewardship requirements for periodic monitoring and maintenance inspections of VI mitigation systems. Records of Decision and Five-Year Reviews under CERCLA are examples of these mechanisms.

- **Informational devices**

  Informational devices provide information about risks from contamination. These devices are meant to inform and are generally not legally enforceable, although some states require real estate agents to report this information (e.g., VI mitigation systems) to potential buyers. Common examples include the following:

  - **Deed notices**—documents filed in public land records with the property deed.
  - **State registries** (hazardous waste sites)—contain information about contaminated properties.
  - **Advisories—**warn the public of potential risks associated with using contaminated land, surface water, or groundwater, and are usually issued by public health agencies.
  - **On-site notifications**—signs placed at the site providing notification of the activities or actions taken to address a contaminated condition.
  - **Community participation requirements**—Community Involvement Plans (also referred to as community engagement plans) and Restoration Advisory Boards under CERCLA

For further information on the various types of ICs, refer to ITRC’s Long-term Contaminant Management Using Institutional Controls (ITRC 2016).



Advantages

There are some advantages of using ICs for VI mitigation:

- They can be used during any stage of the cleanup process to accomplish various short- and long-term cleanup-related objectives.
- ICs help ensure the protectiveness of the remedy.
- They can include vital elements of response alternatives because they simultaneously influence and supplement the physical component of the remedy.
- ICs can be a suitable alternative when there is no funding sufficient for complete remediation of contamination.

Limitations

There are also some limitations when using ICs for VI mitigation:

- ICs can be difficult to implement and enforce over time.
- Some states or parties may not have adequate statutory authority to implement ICs.
- An IC may not be immediately apparent and may be difficult to identify, especially for those that establish building type, occupancy, or even prohibited activities on all or even a portion of the property.
- ICs may limit or prevent future development activities, possibly reducing property values.

- An IC may require a financial assurance component.
- Under some circumstances, ICs may not be able to be removed, only amended, so the record will always be there.

Cost Considerations

The initial implementation/recording costs associated with ICs can range from as low as $100 to $50,000 or more, depending on the size of the site, the complexity of the requirements, the role of consultants/lawyers, and other issues. Likewise, many factors will affect the annual costs, including the type/frequency of inspections and related reporting requirements stipulated in the ICs. The Association of State and Territorial Solid Waste Management Officials (ASTSWMO) has developed an IC costing tool designed to assist state agencies with the process of estimating the full scale of long-term IC stewardship costs (see Resources below). Also included in the Resources section is a similar planning tool from the U.S. Environmental Protection Agency (USEPA) as it pertains to brownfield sites.

Occupant, Community, and Stakeholder Considerations

Carefully designed public outreach is an essential part of any aspect of the VI response. This includes ICs, informational devices, and remedial actions. ICs may be established to ensure the occupants, owners, and managers are informed and involved as partners in the long-term management of mitigation systems and, if necessary, monitoring of the affected building. See ITRC's ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet*** for more information.

Resources

- ITRC (Interstate Technology & Regulatory Council). 2016. Long-Term Contaminant Management Using Institutional Controls. IC-1. Washington, D.C.: Interstate Technology & Regulatory Council, Long-Term Contaminant Management Using Institutional Controls Team. https://institutionalcontrols.itrcweb.org/
- USEPA. 2012. Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites. OSWER 9355.0-89(EPA-540-R-09-001): 40.
- ASTSWMO.2012. "A Long-Term Stewardship State Conceptual Framework to Estimate Associated Cost" http://astswmo.org/files/policies/CERCLA_and_Brownfields/2012-05-LTS_State_Conceptual_Framework_to_Estimate_Associated_Cost.pdf
- USEPA. 2010. Local Government Planning Tool to Calculate Institutional and Engineering Control Costs for Brownfield Properties. EPA 560-F-10-230.

Related Links:

For more information and useful links about VI pathways and mitigation technologies, go to http://www.itrcweb.org/

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ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Remediation & Institutional Controls Subgroup

Multiphase Extraction (MPE)

Applicability as a method of vapor intrusion (VI) mitigation

This ITRC Technology Information Sheet provides the general description of MPE as a remedial technology that can serve as VI mitigation. Included is an overview of MPE, as well as design considerations, a list of typical MPE components, conditions for applicability as a VI mitigation method, and advantages and disadvantages of applying MPE to mitigate VI. Cost considerations and a list of additional resources are provided. This Technology Information Sheet is intended to provide basic information that will enable the user to evaluate the applicability of MPE to support VI mitigation.

Overview

MPE is a remediation technology based on the extraction of both liquids (groundwater, nonaqueous phase liquid (NAPL)) and soil vapor from the subsurface to reduce or eliminate a source of volatile organic compounds (VOCs). The soil vapor is extracted by creating negative pressure in the unsaturated zone using extraction wells or trenches connected to suction (Figure 1). This is similar in concept to sub-slab depressurization (SSD), and both technologies can provide means of mitigating VI into buildings. However, while VI mitigation is the main objective of SSD, MPE is concerned primarily with addressing the source, with the VI mitigation being a possible ancillary effect. To enhance the recovery of soil vapor during MPE, the thickness of the unsaturated zone is increased by depressing the water table through groundwater extraction. VOCs in the unsaturated zone undergo volatilization from the source material and are removed with the extracted soil vapor. VOCs in the saturated zone are recovered with the extracted liquid. Liquid and soil vapor can be extracted using the same source of suction or by separate pumps. The off-gas and the extracted liquid are typically treated before being discharged. MPE is applicable to sites impacted by VOCs where a sufficient permeability exists to enable the vapor/liquid extraction. MPE can be used for depressing the groundwater table; therefore, it does not require that an unsaturated zone be present under ambient conditions. However, drawdowns may be difficult to achieve in high-permeability soils.

In the context of VI mitigation, an MPE system can prevent the migration of VOCs into a building from sources located both below and at certain distance from the structure. In the former case, the mitigation mechanism is the development of a negative pressure zone in the subsurface below the building, resulting in an outward air flow across the building floor. In the latter case, the MPE system might intercept the VOCs before they reach the building footprint.

Design Considerations

MPE systems are designed based on the findings of field investigations and a conceptual site model representative of site-specific conditions. Pilot testing is performed to establish the number and locations of the soil gas and liquid extraction wells/trenches. The system must be capable of dewatering the area to expose the source zone as well as developing sufficient venting rates within the remediation zone to affect the VOC mass removal in a reasonable time frame (typically assumed to be between 1 and 5 years). Therefore, primary indicators evaluated are the vapor flow rate in the subsurface (rather than the pressures) and the water table drawdown. The testing also provides information on the need to install a surface cover to reduce the short-circuiting of the vapor flow through the surface near the extraction facilities, or to include air inlet wells/trenches to direct the flow and optimize venting. Furthermore, the VOC concentrations in the extracted vapor and liquid streams are measured and used to evaluate the need for the treatment and to design the treatment systems. Many MPE systems require atmospheric discharge and treated water discharge permitting in accordance with applicable federal, state, or local laws and regulations. Noise mitigation measures may also be necessary.

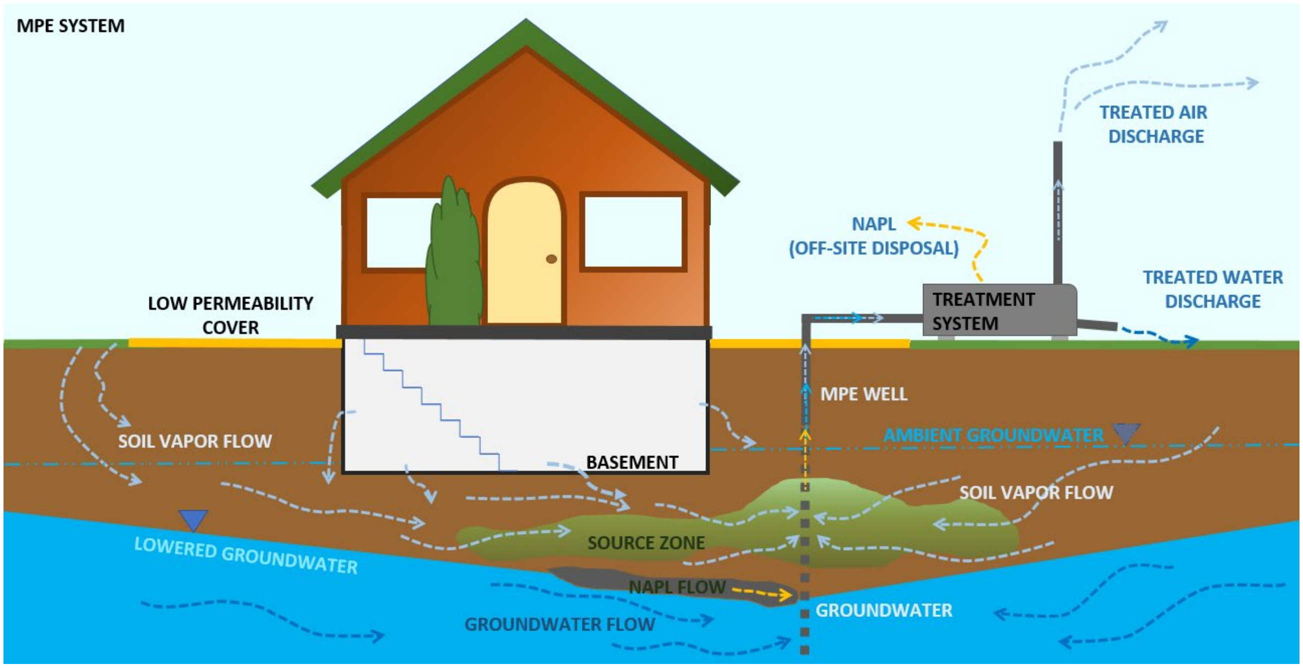

Figure 1. Conceptualization of a multiphase extraction system. (Source: L. Trozzolo, used with permission.)

In the context of VI mitigation, the investigation should include an assessment of the MPE system's effect on the indoor air quality. This may include pre- and postimplementation sampling of the indoor air for the target VOCs and monitoring of the pressure differential across the floor slab.

Components and Operation

A typical MPE system (Figure 1) consists of soil vapor and liquid extraction facilities (wells or trenches) and mechanical/treatment equipment (conveyance piping, blower, liquid pumps, liquid separator, liquid treatment, vapor treatment, instrumentation, and controls). A surface cover (e.g., building or cap) and air supply (inlet wells or trenches) may also be included. An MPE system requires regular maintenance and monitoring, which can constitute a large portion of the remediation costs. MPE system closure typically involves achieving the site-specific cleanup goals of soil and groundwater quality. If used as a means of VI mitigation, additional closure requirements related to the indoor air quality may be necessary.

Applicability of MPE for VI Mitigation

MPE is directly applicable as a method of VI mitigation for relatively small sites, such as a single building, where rented mobile systems or repurposed systems from other sites can be deployed relatively quickly. MPE can also be effective as VI mitigation at larger sites. However, the permitting, design, and implementation time for larger sites is longer than the VI mitigation time frames typically required by regulatory agencies. Temporary VI mitigation may be needed until the MPE starts operating. Refer to the ***Active Mitigation Fact Sheet, Passive Mitigation Fact Sheet***, and ***Rapid Response for Vapor Intrusion Mitigation Fact Sheet*** for information on possible temporary VI mitigation methods.

Advantages

The features of an MPE system are based on the requirement to accomplish the main objective of this technology—source remediation. Compared to the dedicated VI mitigation systems, the advantages of MPE are:

- provides both remediation and exposure mitigation
- can result in complete removal of the source of the impacts to soil vapor, limiting the total time frame of the system operation (providing site closure, limiting long-term cost)
- can reduce or eliminate potential future liability and on-site or off-site contaminant impacts

- typically more robust than sub-slab depressurization (negative pressure subsurface may be up to two orders of magnitude higher than in SSD systems)
- can be applied to sites with high groundwater table (wet basements)
- can be less intrusive to building occupants
- can be a suitable alternative when access is limited or denied

Limitations

The limitations of MPE systems include:

- typically higher short-term cost than dedicated VI mitigation systems
- permitting for off-gas discharge and treated liquid discharge
- need for treatment of the off-gas and extracted liquids, which may include NAPL, in accordance with applicable federal, state, or local laws and regulations (increased long-term operation and maintenance costs)
- need for additional sampling and reporting due to the increased volatilization from the exposed source zone and possible fluctuations of the water level in response to the outside stresses
- greater likelihood for noise complaints
- feasible only at sites with granular and relatively permeable soils

Cost Considerations

An MPE system is designed to address the source of the VOCs in the subsurface. The cost typically depends on the size and the logistics of the site, the nature of the subsurface, and the type of impacts. The added cost if MPE is used also as a means of VI mitigation is typically negligible. If comparing to the cost of a dedicated VI mitigation system, the entire life cycle costs should be included.

Occupant, Community, and Stakeholder Considerations

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. For more details see ITRC's ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet***.

Resources

Related ITRC Documents:

- ITRC. 2006. Above Ground Treatment Technologies. https://www.itrcweb.org/GuidanceDocuments/RPO-4.pdf

Related Links:

- NAVFAC (Naval Facilities Engineering Command). 2020. "Technologies Overview". https://www.navfac.navy.mil/navfac_worldwide/specialty_centers/exwc/products_and_services/ev/erb/tech/rem/mpe.html
- US Army Corps of Engineers. 1999. ENGINEERING AND DESIGN, Multi-Phase Extraction, EM 1110-1-4010. https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-1-4010.pdf?ver=2013-09-04-161049-977

For more information and useful links about VI pathways and mitigation technologies, go to http://www.itrcweb.org/

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ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Remediation & Institutional Controls Subgroup

Soil Vapor Extraction (SVE)

Applicability as a method of vapor intrusion (VI) mitigation

This ITRC Technology Information Sheet provides the general description of SVE as a remedial technology that can serve as VI mitigation. Included is an overview of SVE, as well as design considerations, a list of typical SVE components, conditions for applicability as a VI mitigation method, and advantages and disadvantages of applying SVE to mitigate VI. Cost considerations and a list of additional resources are provided. This Technology Information Sheet is intended to provide basic information that will enable the user to evaluate the applicability of SVE to support mitigating VI.

Overview

SVE is a remediation technology that is based on the extraction of soil vapor from the subsurface to reduce or eliminate a source of volatile organic compounds (VOCs) in the unsaturated zone. The soil vapor is extracted by creating negative pressure in the unsaturated zone by means of extraction wells or trenches connected to suction (Figure 1). This is similar in concept to sub-slab depressurization (SSD), and both technologies can provide means of mitigating VI into buildings. However, while VI mitigation is the main objective of SSD, SVE is concerned primarily with addressing the source, with the VI mitigation being a possible ancillary effect. During SVE, the VOCs in the unsaturated zone undergo volatilization from the source materials and are removed with the extracted soil vapor. The off-gas is typically treated before being discharged into the atmosphere in accordance with applicable federal, state, or local laws and regulations. SVE is applicable to sites impacted by VOCs where a sufficient thickness and permeability of the unsaturated zone are present to enable soil vapor extraction.

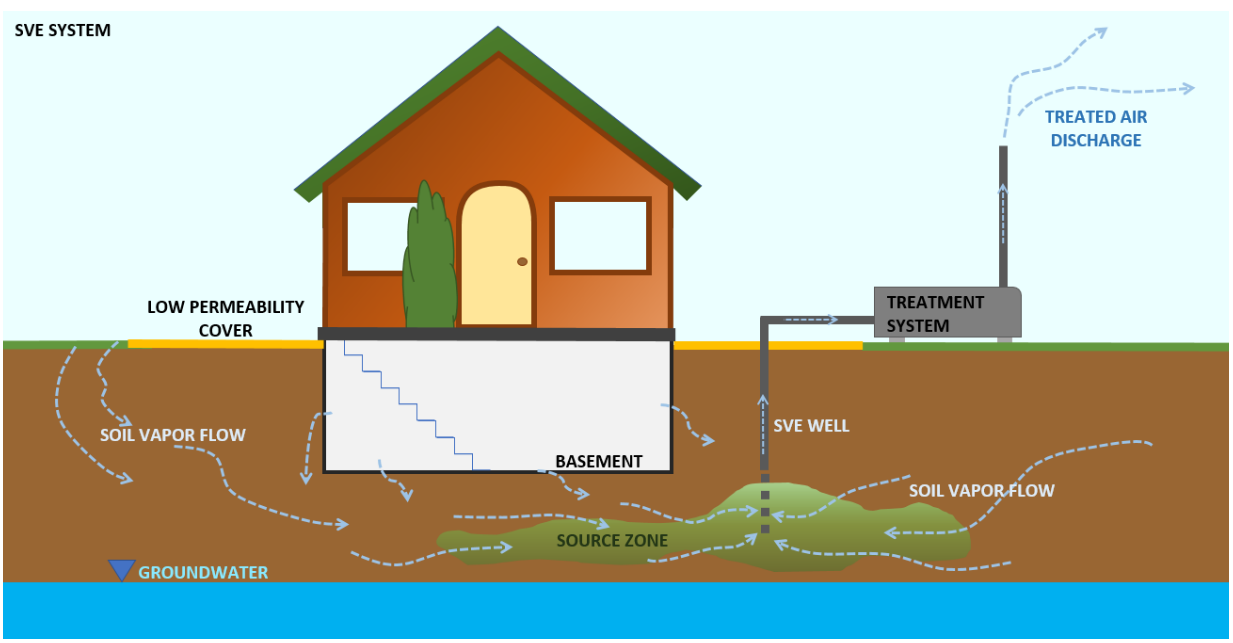

Figure 1. Conceptualization of a soil vapor extraction system. (Source: L. Trozzolo, used with permission.)

In the context of VI mitigation, an SVE system can prevent the migration of VOCs into a building from sources located both below and at certain distance from the structure. In the former case, the mitigation mechanism is the development of a negative pressure zone in the subsurface below the building, resulting in an outward air flow across the building floor. In the latter case, the SVE system might intercept the VOCs before they reach the building footprint.

Design Considerations

SVE systems are designed based on the findings of field investigations and a conceptual site model representative of site-specific conditions. Pilot testing is performed to establish the number and locations of the extraction wells/trenches and the vacuums applied. The system must be capable of developing sufficient venting rates to affect the VOC mass removal in a reasonable time frame (typically assumed to be between 1 and 5 years). Therefore, the primary indicator evaluated is the vapor flow rate in the subsurface, rather than the negative pressure. The testing also provides information on the need to install a surface cover to reduce the short-circuiting of the vapor flow through the surface, and the need to include air inlet wells/trenches to direct the flow and optimize venting. Furthermore, the VOC concentrations measured in the extracted air stream are used to evaluate the need for off-gas treatment and to design the treatment system. Many SVE systems require atmospheric discharge permitting in accordance with applicable federal, state, or local laws and regulations. Noise mitigation measures may also be necessary.

In the context of VI mitigation, the investigation should include an assessment of the SVE system's effect on the indoor air quality. This may include pre- and postimplementation sampling of the indoor air for the target VOCs and monitoring of the pressure differential across the floor slab.

Components and Operation

A typical SVE system (Figure 1) consists of extraction facilities (wells or trenches) and mechanical/treatment equipment (conveyance piping, blower, vapor/liquid separator, liquid treatment or disposal, vapor treatment, instrumentation, and controls). A surface cover (e.g., building or cap) and air supply (inlet wells or trenches) may also be included. An SVE system requires regular maintenance and monitoring, which can constitute a large portion of the remediation costs. SVE system closure typically involves achieving the site-specific cleanup goals of soil quality. If used as a means of VI mitigation, additional closure requirements related to the indoor air quality may be necessary.

Applicability of SVE for VI Mitigation

SVE is directly applicable as a method of VI mitigation for relatively small sites, such as a single building, where rented mobile systems or repurposed systems from other sites can be deployed relatively quickly. SVE can also be effective as VI mitigation at larger sites. However, the permitting, design, and implementation time for larger sites is longer than the VI mitigation time frames typically required by regulatory agencies. Temporary VI mitigation may be needed until the SVE starts operating. Refer to the ITRC documents for the active, passive, and rapid response VI mitigation for information on possible temporary VI mitigation methods.

Advantages

The features of an SVE system are based on the requirement to accomplish the main objective of this technology, —source remediation. Compared to the dedicated VI mitigation systems, the advantages of SVE are:

- provides both remediation and exposure mitigation
- can result in complete removal of the source of the impacts to soil vapor, limiting the total time frame of the system operation (providing site closure, limiting long-term cost)
- can reduce or eliminate potential future liability and on-site or off-site contaminant impacts
- typically more robust than SSD (higher negative pressures in the subsurface)
- can be less intrusive to building occupants
- can be a suitable alternative when access is limited or denied
- by intercepting soil vapor migrating horizontally, it can provide VI mitigation for offsite sources

Limitations

The limitations of SVE systems include:

- typically higher short-term cost than dedicated VI mitigation methods
- permitting for off-gas discharge
- need for treatment of the off-gas and moisture in accordance with applicable federal, state, or local laws and regulations (increased long-term operation and maintenance costs)
- need for sampling and reporting
- greater likelihood for noise complaints
- feasible only at sites with granular and relatively permeable soils

Cost Considerations

An SVE system is designed to address the source of the VOCs in the unsaturated zone. The cost typically depends on the size and the logistics of the site, the nature of the subsurface, and the type of impacts. The added cost if SVE is also used as a means of VI mitigation is typically negligible. If comparing to the cost of a dedicated VI mitigation system, the entire life cycle costs should be included.

Occupant, Community, and Stakeholder Considerations

It is essential to develop and implement a site-specific community involvement plan that addresses, among other things, how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses. For more details see ITRC's ***Public Outreach During Vapor Intrusion Mitigation*** Fact Sheet.

Resources

- US Army Corps of Engineers. 2002. Engineering and Design, Soil Vapor Extraction and Bioventing. EM 1110-1-4001. https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-1-4001.pdf
- USEPA, Office of Solid Waste & Emergency Response. 2012. A Citizen's Guide to Soil Vapor Extraction and Air Sparging.542-F-12-018. https://www.epa.gov/remedytech/citizens-guide-soil-vapor-extraction-and-air-sparging
- Stewart, L, C. Lutes, R. Truesdale, B. Schumacher, J.H. Zimmerman, and R. Connell. 2020. Field Study of Soil Vapor Extraction for Reducing Off-Site Vapor Intrusion. Groundwater Monitoring & Remediation 40(1):74-85.
- USEPA. 2018. Engineering Issue: Soil Vapor Extraction (SVE) Technology. EPA/600/R-18/053. https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=345171&Lab=NRMRL

Related Links:

For more information and useful links about VI pathways and mitigation technologies, go to http://www.itrcweb.org/

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ITRC Technology Information Sheet

Vapor Intrusion Mitigation Team | December 2020

Remediation & Institutional Controls Subgroup

Aerobic Vapor Migration Barrier (AVMB)

Applicability as a method of vapor intrusion mitigation and remediation

This ITRC Technology Information Sheet describes a novel method for in situ vapor intrusion (VI) mitigation and remediation at sites with existing buildings situated above subsurface sources of VOCs that rapidly biodegrade aerobically—namely, petroleum hydrocarbons and methane. The method involves the delivery of atmospheric (ambient) air below and around a building foundation at rates sufficient to maintain aerobic conditions in the vadose zone that act as a “biobarrier” to VI. The technology can also enhance the remediation of certain shallow subsurface vapor sources. The method represents a safer, more sustainable, and cost-effective alternative to other petroleum VI mitigation and remediation technologies (e.g., soil vapor extraction (SVE) and sub-slab depressurization (SSD)) because the technology is applied in situ and does not require expensive vapor treatment or intrinsically safe equipment. This Technology Information Sheet provides basic information to assist the practitioner in potential AVMB application and decision making.

Overview

Aerobic vapor migration barrier (AVMB) is an in situ VI mitigation and remediation technology designed to aerobically biodegrade hydrocarbons in the vadose zone before they migrate to indoor air. The technology is primarily applicable for volatile organic compounds (VOCs), such as petroleum hydrocarbons (e.g., benzene, toluene, ethylbenzene, and xylenes (BTEX)) and methane, that tend to biodegrade rapidly under aerobic conditions at rates that exceed rates of gas migration by diffusion and advection (DeVaull, 2007). The technology involves the slow delivery of atmospheric (ambient) air containing 21% oxygen (O_2) below and around existing building foundations at low rates via sub-slab vents, drain tiles, or horizontal wells (see Figure 1). The technology can also serve as a remediation technology at certain sites with shallow vapor sources. The technology represents a more cost-effective alternative to conventional petroleum VI mitigation and remediation methods because mitigation and remediation may be achieved in situ, thereby eliminating the need for expensive vapor treatment and intrinsically safe equipment. The technology is described in greater detail in (Luo et al., 2013).

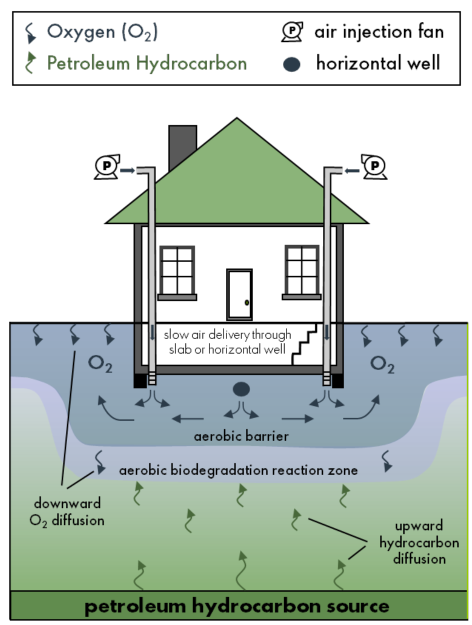

Figure 1. Conceptualization of an aerobic vapor mitigation barrier. (Source: Shell Global Solutions, Inc, used with permission.)

Design Considerations

The aim of the AVMB is to create an atmospheric oxygen boundary condition between the contaminant source and building foundation sufficient to aerobically biodegrade petroleum hydrocarbon concentrations (and methane) below risk-based screening levels for VI. The air is delivered at a slow rate (e.g., 1–10 liters per minute) that is only sufficient to develop and maintain a 3- to 5-foot-thick aerobic biodegradation zone (defined by oxygen concentrations greater than 5% by volume) between the building foundation and the source of petroleum vapors in the subsurface. The air is not injected at pressures that would enhance potential short-term VI or displace vapors around the building foundation. An equation to estimate the minimum air injection rate is provided in (Luo et al., 2013). This airflow rate is approximately 10–1,000 times lower than airflow rates typically associated with typical 90-watt fans used for SSD or sub-slab ventilation (SSV) systems. The technology relies predominantly on molecular diffusion (concentration gradient–driven transport) rather than advection (pressure gradient–driven transport) for oxygen delivery and VI mitigation. Minimizing the formation of pressure gradients avoids the displacement of hydrocarbon vapors through and around building foundations that could potentially occur during the initial few days after system start-up. Key variables affecting the air injection rate include:

- the area of the building foundation
- total petroleum hydrocarbons (TPH), methane, or hydrocarbon-specific source vapor concentrations
- the oxygen concentration and depth below the foundation for which aerobic conditions are targeted
- the vertical separation distance between the hydrocarbon vapor source and the air injection point
- the effective diffusion coefficient of the soil around the injection point, which can either be estimated from theoretical relations or measured in situ (Johnson et al., 1998)

Components of AVMB Systems

Components of an AVMB system generally include:

- an air-injection fan that can generate air-flow rates in excess of 100 liters per minute at 20 pounds per square inch gauge
- a valve and flowmeter to regulate and measure airflow, respectively
- horizontal wells, drain tiles, or sub-slab vents for air injection
- a network of multilevel soil-gas monitoring points located adjacent to and beneath the building foundation for measuring concentrations of hydrocarbon vapors (TPH, including methane and/or specific hydrocarbons, such as benzene) and certain fixed gases (e.g., oxygen, carbon dioxide, methane, and nitrogen)

Optional equipment and measurements include:

- oxygen sensors to measure concentrations in real time and allow for automated and optimized ambient air injection
- the moisture content and total porosity of the soil around the injection point for estimating the effective diffusion coefficient, if not measured in situ

The equipment and materials needed for AVMB applications are reported in greater detail in Luo et al. (2013).

Applicability of AVMB for Vapor Intrusion Mitigation

AVMB systems are mainly applicable for existing buildings with petroleum hydrocarbon sources that are susceptible to aerobic biodegradation in the subsurface and sites where individual, discrete building VI mitigation is desired.

Advantages

AVMB systems are generally safer than typical SSD systems for petroleum VI mitigation because they do not require intrinsically safe equipment to process flammable hydrocarbon vapors drawn in from shallow light non-aqueous phase liquid (LNAPL) sources by SSD implementation. AVMB systems are also relatively more sustainable and cost-effective than conventional SVE, multiphase extraction (MPE), and SSD systems that require expensive vapor treatment. These advantages result largely because vapor mitigation and remediation take place in the subsurface rather than ex situ. In general, AVMB systems:

- do not require expensive vapor treatment and permitting, intrinsically safe equipment, or mechanisms to treat entrained formation/source water
- can be operated over shorter time periods relative to SSD and SSV systems, which do not remediate the vapor source

Limitations

Primary limitations of AVMB systems include:

- novelty of the technology (i.e., no widespread implementation)
- inability to effectively
  - mitigate constituents that do not biodegrade rapidly under aerobic conditions (e.g., most chlorinated solvents) and shallow groundwater sources located within a foot of the building foundation
  - remediate hydrocarbon sources located beyond 5–10 feet below the injection point or low-permeability soils
- need for specialized drill rigs and sufficient open space from the edge of the building foundation (e.g., ~20 feet) for horizontal well installations
- potential to damage under-foundation pipework (e.g., drains and other building penetrations) during horizontal well installation

Cost Considerations

Primary factors affecting the cost of an AVMB system are the size of the building foundation and diffusive properties of the soils located near the injection point. Installation costs are assumed to range between $10 and $100,000 depending on the building footprint and number of injection points. Annual operating costs are estimated to be about $1.75 at $0.1/kwh, or about 100 times less than those associated with conventional sub-slab ventilation systems.

Occupant, Community, and Stakeholder Considerations

The development and implementation of a site-specific community involvement plan that includes how to win trust and gain access to properties, communicate risk to potentially exposed individuals, and minimize the disruption of people's lives and businesses is essential. For more details see the ITRC VI ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet***.

Related Links:

- DeVaull, G.E. 2007. Indoor vapor intrusion with oxygen-limited biodegradation for a subsurface gasoline source. Environ. Sci. & Technol. 41, 3241–3248.
- Johnson, P.C., Bruce, C, Johnson, R.L., and M.W. Kemblowski. 1998. In situ measurement of effective vapor-phase porous medium diffusion coefficients. Environ. Sci. Technol. 32, 3405−3409.
- Luo, H., Dahlen, P.R., Johnson, P.C., and T. Peargin. 2013. Proof-of-concept study of an aerobic vapor migration barrier beneath a building at a petroleum hydrocarbon-impacted site. Environ. Sci. Technol. 47, 1977-1984.

For more information and useful links about VI pathways and mitigation technologies, go to http://www.itrcweb.org/

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Design Considerations Fact Sheet

ITRC has developed a series of fact sheets that summarizes the latest science, engineering, and technologies regarding the mitigation of vapors associated with vapor intrusion (VI). This fact sheet describes the most common design considerations for active mitigation systems, passive mitigation systems, and environmental remedial technologies that need to be considered as part of any design process.

INTRODUCTION

Multiple factors affecting the suitability and efficacy of a mitigation system should be considered during the design, review, and approval process, as discussed in this fact sheet. The selected technology should be based on a good understanding of the VI conceptual site model (VI CSM) (see ITRC ***Conceptual Site Models for Vapor Intrusion Mitigation Fact Sheet***) and able to meet the remedy objectives pertaining to soil vapor conditions at the site, whether applying an active system, passive system, rapid response, and/or an environmental remediation technology.

The design process should begin with a consideration of the VI CSM elements applicable to mitigation and the remedy objectives, leading to the design basis (i.e., an explanation of how the selected approach and technologies will meet the remedy objectives at the site). In many cases, this review indicates that additional information is needed for design of a specific type of mitigation system; therefore, the need for predesign investigations and/or testing should be considered. Once sufficient information is available for design, the next consideration is the design itself—the area that requires mitigation along with the system components, installation details, and specifications. Other design considerations include installation and operating permitting requirements; stakeholder requirements and communications; and the need for construction quality control, demonstration of system effectiveness and reliability, and operation, maintenance, and monitoring (OM&M) plans, including an exit or closure strategy.

Table 1-1 identifies the design considerations that are discussed in more detail below and evaluates their typical importance and impact on the design of an active (see ITRC ***Active Mitigation Fact Sheet)*** system, passive (see ITRC ***Passive Mitigation Fact Sheet***) system, or an environmental remediation technology (see ***Remediation and Institutional Controls as Vapor Intrusion Mitigation Fact Sheet).*** Note that the importance of any factor can vary depending on site- and building-specific conditions and regulatory requirements.

Table 1-1 Summary of design considerations and impact on mitigation approach.

Design consideration	Active approaches	Passive approaches	Remediation	Rapid response
VI CSM considerations				
Vapor source and concentration				
Vapor source and concentration	●	●	●	◐
Geology and hydrogeology				
Subgrade soil type	●	◒	●	◒
Depth to groundwater/high water conditions	●	●	●	◐
Building conditions – new buildings				
New building	●	◒	◒	◒
Building conditions – existing buildings				
Foundation type(s)	●	◒	●	◒
Slab condition	◐	◒	●	●
Preferential pathways and utility penetrations	◐	●	●	●
Heating, ventilation, and cooling (HVAC) system	◐	◐	—	●
Height of building	◐	●	◒	◒
Historic building	◒	●	◐	◒
Building codes and industry standards	◐	◐	◐	◐
Design investigation and diagnostic testing				
Sub-slab diagnostic tests				
Pressure field extension (PFE) testing	●	—	●	◒
Differential pressure measurements	●	—	●	●
Barrier or liner material tests				
Diffusion coefficients	◒	●	◒	—
Building HVAC tests				
PFE testing/air flow rate testing/smoke tracer testing	◐	—	◒	●
Mitigation system design				
Design basis				
Design basis	●	●	●	◒
Design layout and components				
System layout	●	◒	●	◐

Table 1-1 Summary of design considerations and impact on mitigation approach.

Design consideration	Active approaches	Passive approaches	Remediation	Rapid response
System components	●	◐	●	●
Windows, air intake, and building exhaust	●	●	●	●
Permit requirements				
Installation permits	◐	◒	●	◒
Operational permits	◒	◐	●	◒
Stakeholder requirements				
Stakeholder engagement	●	●	●	●
Community engagement	●	●	●	●
System construction and implementation				
Construction oversight and quality control testing	◐	●	●	—
Smoke and tracer gas testing	◒	●	●	◐
System integrity testing	◒	●	◒	—
System effectiveness and reliability				
System effectiveness and reliability	●	●	●	●
Operation, maintenance, and monitoring considerations				
Operation, maintenance, and monitoring plans	◐	◐	●	●
Exit strategies				
Exit strategies	◐	◒	●	◐
Key | High impact ● | Medium impact ◐ | Low impact ◒ | Not applicable — |				

VI CSM CONSIDERATIONS

The design of a VI mitigation system should begin with a review of the existing VI CSM to ensure that the design will effectively address the VI pathway and achieve remediation objectives in an efficient manner consistent with the vapor source, site conditions, and building conditions. In many situations, this review is likely to identify data gaps that will require additional data gathering and predesign testing and revision to the VI CSM (see ***Conceptual Site Model for Vapor Intrusion Mitigation Fact Sheet***), as discussed in the next section. A summary of design considerations and their general impact on mitigation system design is provided in Table 1-1. The rationales behind these ratings are provided in the remainder of the fact sheet.

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2.1 Vapor Source and Concentration

The approach and technology selected for vapor control at a site should take into account the compounds of concern (COCs), impacted media, and concentration ranges, as well as the location and depth of the vapor source(s).

For example, it may be possible to remediate the source of petroleum compounds quickly enough to address short-term VI risks. Similarly, technologies that promote the inflow of air (oxygen) below a building may enhance aerobic biodegradation of petroleum vapors before they reach the building. On the other hand, intrinsically safe equipment and combustible-gas monitors may be necessary if COC concentrations are in or near explosive ranges (e.g., methane due to biodegradation of petroleum compounds).

COCs sourced from solvent-impacted soil immediately below slabs may result in concentrations high enough to cause diffusion mass flux through intact slabs and even certain thin liners at rates sufficient to impact indoor air quality, even if the sub-slab region is actively depressurized. Vapors due to sources located outside of a building footprint may be intercepted before they migrate under the building. These are just a few examples of how the nature, magnitude, and location of the vapor source can impact mitigation strategy and technologies.

Active Mitigation	**High Impact:** Source mass controls the duration of operation, and source concentrations influence the target area to be contained. Discharge permits or off-gas treatment may be required for highly concentrated or large volume sources. High sub-slab concentrations may require diffusion control in addition to depressurization or venting.
Passive Mitigation	**High Impact:** Evaluation of which media are impacted, the COCs that pose an unacceptable risk to the subject building, the concentration range of each COC, and the location of the vapor source relative to the subject building are critical in the successful selection and implementation of an effective passive mitigation technology.
Environmental Remediation Technology	**High Impact:** The selection of the multiphase extraction (MPE) vs. soil vapor extraction (SVE) system is typically governed by the nature of the source (e.g., saturated vs. unsaturated zone). The type of COCs present determines the method of treatment of the extracted streams.
Rapid Response	**Medium Impact:** The COCs, concentration ranges, and location of source (particularly for large buildings) are very important for planning and selecting rapid responses measures. However, since rapid response efforts are typically focused inside the building, the media impacted and depth of the source outside the building envelope are of less concern.

2.2 Geology and Hydrogeology

Site geology and hydrogeology can affect the rate of COC migration in soil vapor toward and into buildings, depending on the nature and location of the vapor source, and remediation technologies that can be employed. Subsurface conditions can affect the efficacy of mitigation technologies that rely on vapor movement and/or the extension of negative pressure fields. Data on site geology and hydrology (e.g., soil moisture and porosity) to support the interpretation of soil gas profiles, the characterization of gas permeability, and the identification of anticipated soil gas migration routes in the vadose zone or the identification and characterization of impeded migration are important considerations in the design of any mitigation strategy, as discussed below.

Subgrade Soil Type: In most cases, the properties of soils immediately adjacent to the building (e.g., below the slab or next to foundation walls and footings) have the greatest impact on active mitigation technologies that require the movement of air and/or the propagation of vacuum below the slab. Soil type plays a major consideration for active mitigation strategies and makes some remediation technologies difficult to implement. For a more detailed description of methods to test and mathematically model the sub-slab permeability and transmissivity see (McAlary et al,, 2018). See Section J.2.5 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014) for more information on the consideration of soil type in active mitigation.

Active Mitigation	**High Impact:** Permeability of the sub-slab fill material and underlying soil controls the pressure field extension (PFE) and air flow rates and, therefore, the degree to which sub-slab depressurization (SSD) and sub-slab ventilation (SSV) contribute to indoor air quality protection. This affects the spacing of suction points and fan size required to induce and maintain the negative pressure field beneath the structure.
Passive Mitigation	**Low Impact:** Passive mitigation systems typically incorporate a permeable layer beneath barriers and around vent piping in new construction. It may not be feasible to incorporate a permeable layer beneath an existing building. Therefore, passive venting systems function best in soils that are highly permeable when retrofitting an existing building.
Environmental Remediation Technology	**High Impact:** Remediation technologies require the characterization of soils beyond the subsurface to evaluate the effectiveness of the proposed technology. MPE and SVE are generally not applicable to low-permeability soils.
Rapid Response	**Low Impact:** Rapid responses typically include ventilation changes, indoor air treatment, or other efforts that are focused inside the building, therefore sub-slab conditions are not relevant.

Depth to Groundwater/High Water Conditions: Most active mitigation strategies require some type of air flow below the building slab; therefore, the presence or absence of shallow groundwater may play a key role in defining what technologies can be implemented. The presence of a sump pump may indicate that groundwater may be shallow and close to the building foundations and slab at certain times of the year. It may be possible to manage shallow

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groundwater, especially if it is either seasonally or occasionally present, by pumping the water or by gravity-feed siphon decanting. In many cases, sumps and associated sub-slab drainpipes can be incorporated into active depressurization systems, provided there is sufficient head space in the system to move air (USEPA, 1993).

Property owners may be able to provide observations of water entry or flooding that can be used to assess whether the planned mitigation system may become blocked during periods of high water; however, it is generally recommended that groundwater observations are made through a properly installed groundwater monitoring well.

Active Mitigation	**High Impact:** The presence of a sump pump in a building usually indicates the water table may be shallow at certain times of the year or during significant precipitation events. In locations where high water is present (e.g., a seasonal or temporary high-water table that intersects the slab) active mitigation systems may not be feasible without the water level being managed by pumping the water or by gravity-feed siphon decanting. Even with these management tools in place, water entrainment into the active mitigation system can cause damage to the system blower motor and impair the effectiveness of the mitigation system.
Passive Mitigation	**High Impact:** High water close to or in direct contact with the floor slab may limit the effectiveness of venting systems. For barriers to be effective they must be both waterproof and resistant to contact with chemicals.
Environmental Remediation Technology	**High Impact:** SVE is feasible only when sufficient unsaturated thickness is present. MPE can be applied at sites with or without unsaturated thickness; however, high groundwater increases the complexity and the OM&M requirements of the system.
Rapid Response	**Medium Impact:** Rapid responses typically include efforts that are focused inside the building, therefore sub-slab conditions are not relevant. However, sealing a sump or land drain system that is present to address high groundwater could be an effective rapid response measure.

See Section J.2.6 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014) for additional discussion of considerations to be made where high water conditions may be present.

2.3 Building Conditions

The most important building factor affecting mitigation system design is whether it’s a new or existing building. A new building can largely be designed to incorporate the features required for efficient mitigation system operation, whereas mitigation system designers must generally work with (or around) existing building conditions. New building considerations are discussed first in this section, followed by a discussion of existing building considerations.

2.3.1 New Buildings

Mitigation systems can typically be incorporated into the design of new buildings, whether active, passive, or based on HVAC controls. With respect to active or passive systems requiring a sub-slab venting system, new construction should comply with current building codes and incorporate a “capillary break” below concrete floor slabs; i.e., 4 inches or more of coarse-textured granular fill to act as a drainage barrier to minimize water vapor diffusion through the concrete and avoid mold and damp rot issues. This may be adequately permeable for an SSD or SSV system; however, the mitigation system designer should specify a sufficiently permeable material to ensure adequate SSD/SSV performance over the long term.

While most new construction will include a moisture vapor barrier below the slab, typical membranes for this purpose may not be adequate for active mitigation systems and will generally not be adequate for mitigation systems relying on passive barriers. Therefore, the mitigation designer should specify a vapor barrier that meets the requirements of the mitigation system. The mitigation design should specify installation procedures that are consistent with intended construction procedures and reduce the potential for membrane damage during construction. For example, specify that concrete pours occur soon after membrane placement, prohibit vehicle traffic on the membrane, and specify that sharp objects be kept off the membrane. Additionally, if laser screed equipment is used during concrete pours, an adequate cushion layer (nonwoven geotextile, for example) may be required above the membrane to protect the membrane from the weight of the laser screed. The design should also specify that the contractor only turn the wheels on the laser screed when the unit is in motion to avoid unnecessary sheer strain on the membrane.

Designers of active or passive mitigation systems requiring vent riser pipes will typically need to work with the architect to ensure that suction pit, riser pipe, fan, and exhaust stack locations, dimensions, and materials are consistent with building use, aesthetics, and applicable building and fire codes. These and other design considerations for new buildings are provided in several industry standards, including ASTM and ANSI/AASRT (AARST, 2018a).

Designers should also consider whether passive systems could potentially require conversion to active systems based on performance monitoring (see ***OM&M/Exit Strategies Fact Sheet***) and, if so, how the design of the passive system can facilitate this conversion. Designs should consider more than just adding a fan to the vent stack(s). Designs may need to incorporate, among other things, size of building, air flow within the existing passive system, and the potential for short circuiting.

Active Mitigation	**High Impact:** Keys to success are a good quality floor and high permeability material below the floor, both of which can be accommodated in the building design and construction. The routing of passive ventilation stacks must be through the interior of the building and must be as straight as possible (i.e., no bends).
Passive Mitigation	**Low Impact:** Design of a passive vapor intrusion mitigation system (VIMS) in new construction allows for a high degree of control over

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	variables that impact system performance, such as the building construction sequence and access during installation of the VIMS.
Environmental Remediation Technology	**Low Impact:** The SVE and MPE systems can typically be engineered to be compatible with the building features.
Rapid Response	**Low Impact:** Although rapid responses may initially not be applicable to new construction, installing an HVAC system with adequate outside air supply may be a useful supplement to another mitigation technique following start-up of the system.

2.3.2 Existing Buildings

Designs of mitigation systems for existing buildings are generally constrained by the construction materials used within and below the structure. The larger and more complicated a building, the more predesign work is likely to be necessary to characterize building and sub-slab conditions and create an effective system design. A building survey is typically conducted prior to the design of any mitigation strategy. A building survey will help select a mitigation technology that is appropriate for the building conditions and the CSM (see ***Conceptual Site Model for Vapor Intrusion Mitigation Fact Sheet***). Photographic documentation, a building sketch, and detailed notes should be included as part of the building survey. Attention must also be given to aesthetic restrictions established by building owners, zoning boards, and/or historic preservation entities that may limit exterior system components. A sample building survey form can be found in Appendix G of the ITRC VI guidance (2007): Vapor Intrusion Pathway: A Practical Guideline (ITRC, 2007a).

The following is a summary of items typically reviewed during a building survey and building information that needs to be considered to design an effective mitigation system.

Foundation Type: Basic foundation type has a direct impact on active and passive system designs. For example, SSD/SSV systems are applicable to basement and slab-on-grade construction, whereas sub-membrane depressurization (SMD) and/or other venting approaches are required for crawl space construction. Basements may require foundation wall mitigation in some cases, particularly if the source of vapors is beside the building. Many buildings (particularly larger commercial/industrial buildings) have multiple foundation types and locations due to building additions over time; slab and sub-slab conditions often vary between building areas, and foundation walls or changes in floor elevation may prevent airflow or PFE from one slab area to another. Other foundation features such as elevators, pits, sumps, utility tunnels, and other structures located below the slab or floor level may complicate mitigation designs. Regional construction standards, particularly in warmer climates and areas where large aggregate materials are expensive to source, may limit the viability of sub-slab mitigation systems.

Active Mitigation	**High Impact:** The construction and condition of building foundations have a significant influence on the effectiveness and viability of active mitigation.

Passive Mitigation	**Low Impact:** Passive mitigation systems can be tailored to different types of foundations.
Environmental Remediation Technology	**High Impact:** Deep foundations may affect soil vapor flow during SVE or MPE and necessitate that these systems be expanded.
Rapid Response	**Low Impact:** Rapid responses typically include efforts that are focused inside the building; therefore, foundation type is not relevant.

See Section J.2.4 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014) for additional discussion of design considerations related to foundation types.

Slab Condition: Active mitigation systems typically rely on reasonable slab integrity to limit the flow of indoor air through the slab. Any downward airflow due to deteriorated or damaged slabs will reduce PFE and increase system airflow and, therefore, pipe and fan size requirements and energy costs (for fan operation as well as conditioning of replacement building air). In some cases, poor slab integrity can be addressed by replacing the slab or by placing a barrier or aerated floor over the slab. Even with reasonably intact slabs, some sealing of cracks and joints is typically required to optimize VIMS performance. The existing slab conditions should be noted in all areas of the building to be mitigated as well as the condition and the presence of cracks.

Active Mitigation	**Medium Impact:** Air leakage through breaks and cracks in the slab reduces the radius of influence (ROI) of an active mitigation system, and is an important parameter for selecting the number of suction points needed.
Passive Mitigation	**Low Impact:** This factor primarily applies to epoxy floor coatings with minimal impact on the effectiveness of barriers and venting systems.
Environmental Remediation Technology	**High Impact:** Highly fractured slabs may affect soil vapor flow during SVE or MPE and necessitate that these systems be expanded.
Rapid Response	**High Impact:** Floor slab crack, gap, or joint sealing can be an effective rapid response measure.

See Section J.2.4 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014) for a summary of slab conditions or foundation conditions as they relate to mitigation design.

Preferential Pathways and Utility Penetrations: Preferential advective flow pathways through the building slab and foundation walls, if applicable, should be identified and plans to seal the pathways should be considered as part of the mitigation system design. Such openings may include utility penetrations, sumps, and/or the slab-foundation perimeter joint. Elevator shafts will need to be considered separately as they cannot be sealed (building codes require there to be a drain at the bottom of an elevator shaft, and this must not be sealed).

It should be noted that penetration sealing may have already been completed as part of rapid response actions at the site (see ITRC ***Rapid Response and Ventilation for Vapor Intrusion Mitigation Fact Sheet)*** or if a passive membrane is installed prior to active mitigation.

Active Mitigation	**Medium Impact:** Sealing potential preferential pathways will improve the efficiency and effectiveness of an active mitigation system by eliminating open vapor conduits into the structure, increasing the PFE, and reducing the amount of building air that is extracted and vented by the system.
Passive Mitigation	**High Impact:** Sealing around penetrations within the floor slab is critical to the effectiveness of passive mitigation systems.
Environmental Remediation Technology	**High Impact:** Sealing around penetrations within the floor slab may be critical to the effectiveness of SVE and MPE.
Rapid Response	**High Impact:** Sealing of preferential pathways and utility penetrations can be an effective rapid response measure.

See Section J.2.4 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014) and Section 8 of AARST SGM-SF 2017 (AARST, 2017).

HVAC System: Evaluating the components, configuration, and operation of the HVAC system is an important step in the VI mitigation design process. Engineered HVAC adjustments can be considered as a component of VI mitigation by either (1) controlling cross-slab pressures by pressurizing the building, or (2) increasing air exchange rates (AERs). The size, age, and complexity of HVAC systems vary widely, from single family homes to large commercial/industrial buildings. Key aspects and components that should be assessed include number of units, airflow capacity, operating schedule/duty cycle (daily, weekly, seasonally), and other exhaust components that are not part of the HVAC system (e.g., exhaust fans in bathrooms, fume hoods in laboratories or kitchens, utility stacks). For more information refer to the ***Heating, Ventilation, and Air Conditioning (HVAC) Modification Technology Information Sheet***.

Active Mitigation	**Medium Impact:** An HVAC system may either enhance (i.e., create positive pressure and/or increase air exchange within the building) or impair (i.e., increase negative pressure within the building) active mitigation system performance.
Passive Mitigation	**Medium Impact:** An HVAC system may either enhance (i.e., create positive pressure and/or increase air exchange within the building) or impair (i.e., increase negative pressure within the building) passive mitigation system performance.
Environmental Remediation Technology	**No Impact:** HVAC modifications do not address/remediate the VOC source.
Rapid Response	**High Impact:** HVAC modifications can be an effective rapid response measure.

Building Height: The height of a building, as well as its height in relation to other surrounding buildings, plays a key condition in vent stack design and placement.

Active Mitigation	**Medium Impact:** Proximity of the exhaust point to occupiable areas, operable windows, or air intakes of surrounding buildings is an important consideration, especially where the emissions from

	the stack are high enough to sustain indoor air quality concerns considering the volume and air exchange rate of nearby buildings.
Passive Mitigation	**High Impact:** It is critical to consider vent stack placement in relation to entry points of surrounding buildings to ensure that effluent vapors do not enter adjacent buildings and that the system is able to vent.
Environmental Remediation Technology	**Low Impact:** Institutional controls (ICs) and SVE/MPE systems are typically not affected by the building height.
Rapid Response	**Low Impact:** Rapid responses typically include efforts that are focused inside the building; therefore, building height is not relevant.

Historic Buildings: Special considerations may be needed for mitigation system installation performed on historic buildings. In particular, the aesthetics of historic buildings may not only be important to the building owner or tenant but may also be guided by a historic preservation society. Installation may involve hiding system components behind false walls/cupboards and ensuring vent stacks do not break certain building sightlines.

Active Mitigation	**Low Impact:** Design of the overall system and specifically of exterior system components (blowers, pipes, and exhaust points) must consider aesthetics and historic building codes. Note that these restrictions do not alter the functional standards of the mitigation system.
Passive Mitigation	**High Impact:** Retrofitting passive mitigation systems in existing buildings may pose unique challenges to system design.
Environmental Remediation Technology	**Medium Impact:** SVE/MPE systems are generally temporary; however, they may need to be designed to be compatible with historic buildings.
Rapid Response	**Low Impact:** Rapid response measures can typically be implemented in historic buildings as they are in modern buildings.

Building Codes and Industry Standards:

The design of mitigation systems must consider the building codes, regulations, and standards that might apply. There are no overarching building codes for system construction that apply to every building in every state; however, municipalities may have requirements in their local building codes regarding system construction (material types, component locations, etc.). These codes should be reviewed and followed as applicable.

The radon mitigation industry has standards, which may provide useful information for design of VI mitigation systems, including recommendations on gravel size for venting media; gas conveyance pipe sizing, materials, and installation practices; vapor barrier materials and installation; exhaust vent configuration; vapor probe and other monitoring systems; and other criteria. The designer should exercise judgment in the application of radon standards, however, considering some of the differences in radon gas and chemical VI behavior and the degree of concentration reduction that may be required. In addition, new mitigation materials and technologies are being developed all the time, which may not be captured by existing radon or even VI guidance and standards.

Commonly used radon and soil gas standards include:

- ASTM E2121-13 - Standard Practice for Installing Radon Mitigation Systems in Existing Low-Rise Residential Buildings
- AARST has standards for single-family, multifamily, schools/large buildings, and new construction. (ANSI/AARST: SGM-SF-2017 [AARST, 2017]; CC-1000-2018[AARST, 2018a]; RMS-MF-2018 [AARST, 2018b]; RMS-LB-2018[AARST, 2018c]). AARST is continually working to maintain and update these standards.

Active Mitigation	**Medium Impact:** Building codes and regulatory requirements must always be met, and at times will directly affect the mitigation approach. Radon standards have been established and updated for several decades and are an important tool in the mitigation design process. It is important to note that the radon standards are designed around mitigation of 100% of the occupied areas of the structure, which may not be necessary for point-source volatile organic compound (VOC) mitigation projects.
Passive Mitigation	**Medium Impact:** The degree to which local building codes affect passive mitigation system design varies from location to location and should be followed. However, local building codes do not exist in many locations.
Environmental Remediation Technology	**Medium Impact:** Building codes may impose certain restrictions on the construction of the SVE and MPE systems.
Rapid Response	**Medium Impact:** Some states may have rules or regulations on who can evaluate/modify HVAC systems to ensure they comply with building and energy code requirements.

3 DESIGN INVESTIGATION AND DIAGNOSTIC TESTING

Review of existing information and the VI CSM will often indicate the need for additional data gathering and/or design testing to develop the system design, including system location or layout, system components, and material specifications. Predesign tests commonly required for active, passive, and HVAC mitigation systems are discussed below.

3.1 Sub-Slab Diagnostic Tests

The most common sub-slab diagnostic tests conducted in existing buildings are pressure field extension (PFE) testing and measurement of differential pressures across the slab. These tests may also be conducted to evaluate the performance of mitigation systems installed in new construction.

PFE testing: PFE testing, also called ROI testing or communication testing, is conducted to understand the potential distance that differential pressure can be measured from a point of applied vacuum (a suction point), which is used to design the number of suction points and fan/blower size needed to achieve the desired system coverage. The PFE distance varies based on numerous factors—primarily the contrast in permeability between the floor slab and the material beneath the floor, as well as the underlying soils, but also including the location of building footers, floor drains, trenches, and utilities. Floor leakage may also be indicated by PFE assessments (i.e., areas of less than expected sub-slab vacuum could be near areas of air recharge across the floor slab). Active system design should consider the potential for PFE to vary due to soil drying and other factors that could change soil and building shell transmissivity over time.

Where PFE is not adequate to extend to all areas of potential concern, it may be appropriate to seal floor cracks, expansion joints, conduit openings, and joints around manhole covers to prevent short circuiting and improve efficiency of the active mitigation system. Where these pathways are inaccessible (under floor coverings, behind walls, etc.), additional suction points may be required. These pathways may have already been sealed during previous building mitigation activities (either previous rapid response activities or passive mitigation activities), but sealants are not always applied correctly, and vary in terms of their longevity, so it may be appropriate to reseal openings (see ***Passive Mitigation Fact Sheet*** or ***Rapid Response and Ventilation for Vapor Intrusion Mitigation Fact Sheet)***.

PFE testing is used in most commercial/industrial buildings to inform design of an SSD or SSV system (i.e., select the number and locations of suction points, fan sizes, etc.). Residential properties may not need a PFE test, if sufficient information is available to be reasonably confident in the mitigation system design (i.e., the slab is visible and in good condition and granular fill material is present below the slab). PFE testing on new construction may be performed during predesign activities to understand fan sizing but likely not to understand subsurface conditions as the engineered components are known and controlled during building construction. PFE testing is also not implemented for crawl space venting.

Active Mitigation	**High Impact:** PFE measurements have been the primary design metric for decades and are an integral part of the system design process. Additional testing options are also available (McAlary et al., 2018).
Passive Mitigation	**Not Applicable:** PFE testing is typically not considered in passive mitigation system design.
Environmental Remediation Technology	**High Impact**: PFE testing is crucial in confirming the effectiveness of the SVE and MPE systems in providing VI mitigation.
Rapid Response	**Low Impact:** Sub-slab depressurization is typically not a rapid response, therefore PFE is not relevant.

More information on PFE testing is included in AARST SGM-SF 2017 Section 6.2 (AARST, 2017) and more information on characterizing the transmissivity below the floor and the leakance of the floor is provided by ESTCP (McAlary et al., 2018).

Differential pressure measurements: The difference in pressures above and below the slab in existing buildings (the cross-slab pressure differential) is an indicator of the potential driving force behind the migration of soil vapors into buildings through joints, cracks, and other openings in the slab or foundation walls. To the extent the pressure is lower in the building relative to the sub-slab, this negative building pressure must be overcome by active systems based on sub-slab depressurization. It is important to note that in most buildings, the magnitude and direction of the pressure differential will vary over time due to changes in meteorological and building ventilation conditions, in both naturally ventilated buildings (most single-family homes) and in buildings with HVAC systems (many larger residential and commercial and industrial buildings).

Readings can be made with a digital micromanometer accurate to 0.25 Pa (0.001 inches H_20). Existing sub-slab sampling locations, or newly installed permanent test points, can be used to determine the vacuum across the slab. Enough locations should be installed and measured to be able to evaluate system effectiveness. PFE measurements should be collected at multiple radial distances from the suction points or sub-slab system piping to facilitate assessment of the trend of vacuum vs. distance. Variability in this trend should be evaluated prior to determining whether the system is affecting the area designated for mitigation. Where such locations are inaccessible, it may be valuable to use a combination of measurements from other areas and mathematical modeling to extrapolate system effectiveness (see McAlary et al., 2018 for examples). For SMD systems, the measurement of PFE may be taken only at location(s) farthest from the suction point, as long as the PFE is clearly measurable at that location.

Targeted differential pressure levels for design should provide a general factor of safety range to ensure depressurization is maintained under reasonably anticipated building conditions. A digital micromanometer can be used with data-logging capabilities to monitor cross-slab differential pressure to inform decisions on appropriate, building-specific target vacuum levels. Some states provide a guideline of generic values that generally range between a minimum of 1–6 Pa (example guidance documents with specified targeted differential pressures include New Jersey [NJDEP, 2018], Minnesota [MPCA, 2015], Massachusetts [MADEP, 2016], Pennsylvania [PADEP, 2019], and California [CalEPA, 2011]). For SSD, SSV, and SMD systems, levels of 1 Pa have been shown to be effective as long as it is maintained over time under normal building operating conditions (Lutes et al., 2011; Moorman, 2009). When soils under the slab are highly permeable, lower vacuums may be generated under high flow rate conditions, resulting in successful mitigation at differential pressure levels lower than 1 Pa (under normal building operating conditions). In these instances, the primary mechanism for system operation is likely SSV versus SSD. If lower vacuums are being observed under the slab in all or a portion of the designated mitigation area then other lines of evidence may be available to provide system verification (e.g., tracer testing, mathematical modeling, mass loading measurements, smoke pen, manual bubble flow meter, indoor air sampling) [McAlary et al., 2018]. More recent research also includes calculating PFE based on flux as another method to determine system effectiveness over the mitigated area (McAlary et al., 2020), though it may not be widely accepted by regulatory agencies.

There are often ambient fluctuations in the differential pressure across the floor slab caused by wind, mechanical fans, thermal gradients, etc., which create “noise” in baseline cross-slab vacuum measurements. It can be difficult to measure low levels of applied vacuum if there is substantial noise in the signal. A digital micromanometer with a datalogger can be used to make high frequency measurements of the baseline and characterize these fluctuations. Cyclic operation of the mitigation fan (on and off a few times) can create a characteristic saw-tooth pattern of drawdown and recovery that can be discerned from the noise in the baseline.

Some telemetry systems may also be able to measure and remotely monitor differential pressures. Telemetry systems, discussed in the operation, maintenance, and monitoring (OM&M) fact sheet, can be used to provide confidence in operating systems that are achieving lower levels of vacuum influence relative to baseline fluctuations or seasonal drift even if these values are lower than the applicable state's generic guidelines.

Active Mitigation	**High Impact:** The pressure differential is often the key parameter affecting the design, operation, and performance of an active system.
Passive Mitigation	**No Impact:** Differential pressure measurements are typically not considered in passive mitigation system design.
Environmental Remediation Technology	**High Impact:** Differential pressure testing confirms the effectiveness of the SVE and MPE systems in providing VI mitigation.
Rapid Response	**High Impact:** Differential pressure is the primary performance metric for rapid response measures that include modifying HVAC systems to pressurize a building.

3.2 Barrier or Liner Material Tests

VI barrier materials, such as membrane or spray-on liners, are often a key component of both passive and active systems. The required barrier properties depend on the barrier function, and other factors discussed in the following section. When the barrier is required to control diffusion of VOCs, it may be necessary to perform tests to determine the diffusion coefficient of the barrier, if not available from the barrier manufacturer.

Diffusion Coefficients: Standard ASTM methods used to calculate water vapor permeation (ASTM E96) can be rudimentary when water is replaced with COCs. Water vapor tests are not appropriate due to their inability to monitor challenge concentrations (the side of the testing chamber containing COCs). However, more nuanced testing methodologies have been developed to more accurately calculate diffusion coefficients for passive barriers. While there is not a universal testing standard, best practices for testing method reporting should include a mass flux rate (m^2/sec), barrier sample thickness, test duration, and challenge concentration. Manufacturers of VI barrier products should publish diffusion test results and these testing results should be evaluated on their own merits. While testing methodologies can vary between manufacturers, there are independent laboratories and universities using standard protocols to determine chemical diffusion rates for various commercially available passive barriers. When selecting a passive barrier system, diffusion coefficients established for specific barrier products should be assessed to determine if they are capable of providing an adequate level of protection against COC concentrations present within the vapor source.

Active Mitigation	**Low Impact:** This is primarily a concern where sub-slab concentrations are very high or a vapor membrane is installed in conjunction with the active system.
Passive Mitigation	**High Impact:** Diffusion coefficients can be a good indicator of a product's ability to be protective against COCs.
Environmental Remediation Technology	**Low Impact:** SVE/MPE systems typically generate high flow rates, with advective effects dominating.
Rapid Response	**Not Applicable:** Backdraft testing is not typically relevant to rapid response.

3.3 Building HVAC Tests

Differential Pressure Measurements: PFE testing can be used to assess the impact an HVAC system has on the cross-slab pressure gradients, as also discussed in Section 3.1. Depending on the operation of the HVAC system, the building space may be pressurized or under vacuum in comparison to sub-slab conditions. To test the cross-slab pressure gradients, differential pressure readings can be recorded using digital micromanometers connected to sub-slab monitoring ports while the HVAC system operates at different conditions.

Air Flow Rate Testing: Air flow rates can be recorded at HVAC intakes and exhausts to quantify AER within a building. These readings are typically collected using a digital anemometer placed at the intake and exhaust points of an HVAC system. This information can help determine if supply or return air flow rates need to be adjusted to accomplish the desired AER or pressure within a building.

Smoke Tracer Testing: Smoke tracer testing involves the use of smoke to evaluate the air flow paths within a building due to HVAC operations. This can be helpful in evaluating how the impacts of VI in one area of a building may affect other areas. Smoke tracer testing can be completed by releasing a small amount of smoke or other visible vapor or powder into the indoor air and observing its flow path visually. This process can be completed at various HVAC operating conditions to compare its impact on the flow of indoor air.

Active Mitigation	**Medium Impact:** PFE testing is of high importance to the design of SSD systems, as described in Section 3.1, but other building tests may also have a significant impact on active system design.
Passive Mitigation	HVAC typically has **little to no impact** on design of passive mitigation systems.
Environmental Remediation Technology	**Low Impact:** SVE/MPE systems typically rely on relatively high vacuum and soil vapor flow rates; therefore, operation of the building HVAC system has limited impact on their effectiveness.
Rapid Response	**High Impact:** HVAC modification is one of the primary rapid response approaches that can be implemented. Therefore, conducting building HVAC tests to fully understand system characteristics, capacities, etc., is critically important.

4 MITIGATION SYSTEM DESIGN

Key considerations related to mitigation system design include the design basis, the system layout and components, permit requirements, and stakeholder requirements, as discussed below.

4.1 Design Basis

The mitigation system design should include a design basis document that explains how VI is occurring (or could occur in new buildings) based on the VI CSM (see ITRC ***Conceptual Site Models for Vapor Intrusion Mitigation Fact Sheet)*** and how the mitigation approach and technologies selected will control VI sufficiently to meet the remedy objectives. For example, if VOCs are entering the building by advective flow of soil vapor through cracks and other openings in the slab, the design basis should show how these entry points will be controlled, e.g., through passive barriers (see ITRC ***Passive Barriers Technology Information Sheet)*** and/or active depressurization (see ITRC ***Sub-slab Depressurization Technology Information Sheet***). The design basis should indicate whether VOC concentrations below the slab are high enough to cause VI by diffusion through the slab and, if so, how the diffusion pathway will be controlled. Similarly, the design basis should indicate how any preferential pathways will be controlled. If HVAC and/or indoor air treatment technologies are selected, the design basis should demonstrate that indoor air concentrations can be reduced sufficiently to meet remedy objectives (unless used solely as a rapid response, in which case, partial reduction of indoor air concentrations may be an acceptable short-term objective).

The design of a mitigation system or an environmental remedy intended to control VI will depend in part on the remedy objectives, typically related to applicable regulatory requirements. The technology selected must be capable of reducing indoor air concentrations, for example, below target levels, within an acceptable time frame, for as long as required.

The design basis document should also identify additional information needed to complete the design, such as predesign inspections, surveys, and testing, and how the performance of the system will be measured to demonstrate that remedy objectives are met initially and over the long term. The design considerations pertinent to predesign testing, the layout and components of the design, construction quality control, system OM&M, and ultimate system closure are discussed in the following sections.

Active Mitigation	**High Impact:** The design basis is critical to all long-term mitigation system designs.
Passive Mitigation	**High Impact:** The design basis is critical to all long-term mitigation system designs.
Environmental Remediation Technology	**High Impact:** The design basis is critical to all long-term mitigation system designs.
Rapid Response	**Low Impact:** The design basis is less important for rapid response, as these actions are generally based on presumptive actions that will typically lessen the impacts of VI but are not necessarily expected to meet long-term remedy objectives.

4.2 Design Layout and Components

Mitigation system designs will commonly include one or more layout sheets, showing where the various components of the system will be placed in, below, or around the building; detail drawings showing how system components will be configured in specific areas; and the components' dimensions, materials, and other specifications. A number of things should be considered associated with the system layout and component specifications.

System Layout: Whether a new or existing building, the system should be placed where needed to prevent VI from occurring. This relates to the VI CSM and the location of vapor sources and vapor entry points (particularly for existing buildings), as well as the design basis for controlling vapor entry. For active systems, the points where pressure differentials are applied and the ROI determine the system coverage. For passive systems, the barrier must cover the area of potential vapor or VOC (i.e., by diffusion through slabs or foundation walls) entry. For HVAC systems, positive pressure and/or ventilation must occur in rooms that will be affected by VI, which can include areas well beyond the vapor entry points.

Active Mitigation	**High Impact:** The selection of the mitigation blower(s) and the number and locations of suction points are key design parameters. The selected mitigation fan can directly impact the diameter and amount of system piping. Discharge stacks must be located to avoid re-entrainment and fans located to maintain negative pressure on components inside the building.
Passive Mitigation	**Low Impact:** System design is generally consistent underneath the entire building foundation.
Environmental Remediation Technology	**High Impact:** Proper SVE/MPE system layout is essential to ensure that these systems can serve as means of VI mitigation.
Rapid Response	**Medium Impact:** Although the design phase of a rapid response is typically very abbreviated, consideration should be given to the location where rapid response measures are implemented. For example, the layout of the existing HVAC system, locations of doors and windows, and the location of preferential pathway sealing and placement of indoor air treatment units are critical.

System Components: The system components include materials such as permeable sub-slab gravel layers; gas conveyance and riser pipes; liners for both active and passive systems; and fans and monitoring equipment for active systems (although both may include many additional components). The design should include the standard components recommended by applicable standards and guidance documents; therefore, reference to such documents is something a reviewer should look for. Similarly, the type, material, size, dimensions, and spacing of system components should be based on standard practice and/or design calculations, showing the components will provide sufficient performance to meet design objectives. Further, the design drawings and/or specifications should indicate how materials should be installed, the codes that should be met, and the quality control testing required to confirm proper materials and installation.

Active Mitigation	**High Impact:** System performance depends on selection of adequate components. Fan selection depends primarily on the permeability of the material below the floor, suction point spacing, pipe friction losses, and the required negative pressure. Alarms, placards, telemetry, and performance monitoring infrastructure are important to ensure system reliability. Barriers are generally required to reduce downward air flow through the floor and reduction in system efficiency, although they also may serve to minimize upward soil vapor flow for short time periods if systems shut down.
Passive Mitigation	**Medium Impact:** System components should be identified and located on mitigation system design sheets. System components such as vent riser pipe should be spaced and placed uniformly underneath the entire building foundation to ensure adequate coverage.
Environmental Remediation Technology	**High Impact:** Specifying proper components of SVE/MPE system layout is essential to ensure that these systems can serve as means of VI mitigation.
Rapid Response	**High Impact:** Selecting the property equipment and materials for a rapid response is critical. Examples include selecting appropriate sealants for cracks and preferential pathways and properly sized indoor air treatment equipment.

Windows, Air Intake, and Building Exhaust: The location and configuration of active (and to a lesser degree, passive system) vent stacks is critical to prevent inadvertent re-entrainment of exhausted vapors back into the building. The radon industry has developed recommended distances between exhaust points and building entryways (doors, windows), as described in existing industry guidance (e.g., AARST, 2018a), as well as in some state VI guidance. Typically, vent stack locations are not less than 2 feet above or not less than 10 feet horizontal distance away from openings (windows, doors, etc.) and not less than 30 feet away from mechanical equipment air intakes, although building- and site-specific conditions, as well as local codes and regulations, may result in different requirements. For many VOCs, the indoor air screening levels are very low, and it may be necessary to have taller stacks or larger separation distances to avoid re-entrainment of VOC vapors from the effluent to indoor air. In some cases, air dispersion modeling may be useful to help appropriately place a vent stack for a system.

The top of the vent stack discharge pipe should typically be vertical or as close to vertical as possible (not more 45 degrees from vertical) (AARST, 2018a). Rain caps are often not necessary or recommended, but if rain caps are used, they should not impinge on the vertical discharge of vapors from the stack. See Section J.3.3 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014) and ANSI/AARST: SGM-SF-2017 (AARST, 2017); CC-1000-2018 (AARST, 2018a); RMS-MF-2018 (AARST, 2018b); RMS-LB-2018 (AARST, 2018c).

Active Mitigation	**High Impact:** Impact depends on the mass loading: if the emission rate is small, the risk of significant re-entrainment is also small. Where the emission rate is high, a taller stack, greater distance from re-entrainment points, or off-gas treatment may be needed.

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Passive Mitigation	**High Impact:** Vent stack placement is critical to ensuring effluent vapors do not enter adjacent buildings.
Environmental Remediation Technology	**High Impact:** Placement of the SVE/MPE system discharge is critical to ensuring that system exhaust does not enter buildings.
Rapid Response	**High Impact:** Rapid response measures typically do not include vent stacks; however, the location of windows, fresh air intakes, and other building exhausts are important considerations for rapid response measures such as ad hoc ventilation and HVAC modification.

4.3 Permit Requirements

Mitigation system designs must consider building codes, including radon requirements if applicable, and other permits that need to be addressed, depending on the type of system and design, including installation permits and operating permits.

Below is a description and more information on permits that may need to be considered prior to, during, or immediately before system construction.

Installation Permits: Some municipalities may require a building permit or electrical permit for system installation. A person should check with the local municipality prior to installation for requirements. In some states, subsurface mitigation systems may be exempt from or do not require installation permits. More detail is provided in Section J.3.2 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014).

Active Mitigation	**Medium Impact:** State, local, and federal permitting requirements need to be reviewed during the design phase, and any relevant requirements should be incorporated into the design. Typically, there are few installation permit requirements that will significantly affect an active mitigation design, especially on a typical residential property.
Passive Mitigation	**Low Impact:** Permits are typically not required for the installation of passive mitigation systems. Confirm installation permit requirements with your state and local regulatory agencies and the building department of your local unit of government.
Environmental Remediation Technology	**High Impact:** Most SVE/MPE systems include treatment and discharge, as well as electrical and plumbing work, and therefore require that relevant permits be secured.
Rapid Response	**Low Impact:** Due the expedited nature, permitting is typically not relevant for a rapid response, although close regulatory stakeholder engagement is recommended.

Operational Permits: As detailed in Section J.3.2 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014), air permits and emission controls on active mitigation systems must be considered for each project based on the system design, the conceptual site model, and the applicable state, federal, or local regulations. The regulations are generally associated with the Clean Air Act or local ordinances that have been set by statute. In some states, subsurface mitigation systems may be exempt from or do not require permits. More detail is provided in Section J.3.2 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014).

Active Mitigation	**Low Impact:** Emissions from individual active systems are often below minimum thresholds for air discharge permits. For larger sites with multiple active systems, the mass removal rate should be determined. The required permits for the system should be obtained if discharge volumes and concentrations indicate the need.
Passive Mitigation	**Medium Impact:** Permits are typically not required for the installation of passive mitigation systems. However, consideration should be given to applicable emission permits required by your state and local regulatory agencies.
Environmental Remediation Technology	**High Impact:** Discharge permits are typically required to operate the SVE and MPE systems.
Rapid Response	**Low Impact:** Due to the expedited nature, permitting is typically not relevant for a rapid response, although close regulatory stakeholder engagement is recommended.

4.4 Stakeholder Requirements

Owners, tenants, and other parties (including contractors and architects for new buildings) often have strong opinions about the aesthetic effects and inconvenience experienced with the location of mitigation system components, including fans, pipe runs, and vent stacks. Stakeholders should be engaged, and their considerations incorporated into the system design as early as practical.

Stakeholder Engagement: To ensure that stakeholder concerns and requirements are addressed early in the design process, the building owner, tenant, and other parties in the building should be provided with information regarding the mitigation system installation activities. Common items may include:

- basic description of mitigation system (components, operation, etc.) to be installed
- photos of typical system components to be expected
- length of time for system installation and start-up
- any restrictions to access or use to portions of their property during system installation
- potential noise level from construction activities that may be expected with system installation (if anticipated to be disruptive to the building occupants)
- other building activities that may need to be completed for system installation to be possible (e.g., a furnace needs to be raised to access the basement floor or a staircase needs to be fixed so that the basement can be accessed safely by the workers). These activities may be part of the installation activities completed by the responsible party.
- contact information if issues or questions arise during the mitigation system installation.

The ITRC ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet*** provides additional information for plan communications with property owners and building occupants.

Communication with the property owner on their expectation of the design, if any, early in the design process will help to avoid problems during installation and operation. Homeowners should be made aware of the need for and importance of ensuring proper function of the mitigation system. Items such as possible piping locations, blower locations, power use, how modification to the building may affect the performance of the mitigation system, and future system OM&M (incorporation of certain types of telemetry in the design may limit or reduce the need for frequent property visits) should be discussed in the design phase. Considerations should also be made to address the potential for noise issues for the building occupants, depending on the type and locations of blowers planned for the design.

Active Mitigation	**High Impact:** Owner, tenant, and stakeholder engagement is a critical part of any active mitigation response.
Passive Mitigation	**High Impact:** Owner engagement is a critical part of the implementation of a passive mitigation system. Contact your state and local regulatory agencies to confirm your regulatory obligations with respect to notification requirements.
Environmental Remediation Technology	**High Impact:** Implementation of the SVE/MPE typically involves an extensive interaction with the property owners, including access agreements.
Rapid Response	**High Impact:** Owner, tenant, and stakeholder engagement is a critical part of any rapid response.

Community Engagement: In many cases where multiple buildings are involved, the larger community and other stakeholders should be engaged as early and often as possible. Contact your state and local regulatory agencies to confirm your regulatory obligations with respect to notification requirements. See the ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet*** for more information.

Active Mitigation	**High Impact:** Community engagement is a critical part of any active mitigation response that may impact multiple parties beyond the owner/occupant of the property.
Passive Mitigation	**High Impact:** Community engagement is a critical part of the implementation of a passive mitigation system, especially if the rapid response is large scale or highly visible.
Environmental Remediation Technology	**High Impact:** Implementation of SVE/MPE typically involves an extensive interaction with the stakeholders, including discussions about such issues as the effect of the system noise and treated air stream discharge.
Rapid Response	**High Impact:** Community engagement is a critical part of any rapid response, especially if the rapid response is large scale or highly visible.

SYSTEM CONSTRUCTION AND IMPLEMENTATION

The mitigation design should include requirements for construction quality control, including observation and inspection and quality control testing requirements.

5.1 Construction Oversight and Quality Control Testing

Quality control and assurance procedures should be selected during the design phase of a mitigation system in order to ensure these procedures will be incorporated during the construction process. The manufacturer's requirements, regulatory requirements, and site-specific needs should be considered when selecting which system integrity testing methods to use.

After the VIMS design has been developed and documented, the engineer of record or equivalent should confirm that a preconstruction meeting is planned with all persons involved with the installation of the VIMS, as well an any subcontractors whose work may affect the performance of the VIMS during and/or following the installation process. This may include, but is not limited to the architect, engineer of record, environmental consultant, general contractor, mitigation system installation contractor, and concrete contractor, including the rebar installer, electrician, and plumber. The purpose of this meeting is to inform all contractors involved of the purpose and importance of the VIMS. During this meeting, all parties in attendance should review the VIMS installation drawing set to confirm that the details shown in the drawings match the project conditions. This allows all contractors to review and confirm substrate specifications, vent layout, and locations of vent risers and utility penetrations, and allows the general contractor to clarify the construction/installation sequence with all trades. Once all site conditions are confirmed, action items should be created that address any conditions not reflected in the project drawings.

Installation oversight will vary depending on local building code and regulatory requirements. Frequency and duration should be specified in the VMS plan, but providing oversight prior to installation and during installation will increase the likelihood that the system is installed per plans and specifications. Oversight documentation will provide a record for future building occupants and operators.

For installation of any type of active mitigation system, it is important that properly trained and licensed, if necessary, technicians provide construction quality assurance (CQA) during installation of mitigation system components. The mitigation system design should provide for typical CQA tasks, such as the following for active and/or passive systems:

- review and approval of applicable submittals, including gravel specification; membrane (and membrane adhesives, mastics, etc.); aerated slab forms; pipe and fittings; system monitors and alarms; and fan(s)
- inspection of system components, including gravel placement, piping/vent strips, membrane, and aerated floor; membrane penetrations and boots; slab placement; riser and conveyance pipes; fans; and system monitors and alarms
- Although CQA is always important for any project, the level and formality of CQA completed will depend on the size and complexity of the building and associated system to be constructed.

Active Mitigation	**Medium Impact:** Impact of the need and details of construction quality controls will depend of the size and complexity of the

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	system. Typical designs on residential properties will need few construction quality control considerations, but large building designs may require several discussions and meetings to finalize the design. The performance of active systems can often be enhanced after initial installation, if necessary, by increasing fan capacity or adding suction points.
Passive Mitigation	**High Impact:** It is usually difficult to modify passive systems after installation. It is critical to ensure a preconstruction meeting is planned with all persons involved with the installation of the VMS, as well an any subcontractors whose work may affect the performance of the VMS during and/or following the installation process.
Environmental Remediation Technology	**High Impact:** Construction QA/QC is a key element of the installation process of the SVE/MPE systems.
Rapid Response	**Not applicable**

Smoke and Tracer Gas Testing: Smoke and tracer gas testing is an option to test system air flow patterns. For example, if smoke is drawn below the floor strongly through an open sub-slab port during SSD/SSV operation, this indicates the system is effective (in cases where the material below the floor is highly permeable, this can occur where the applied vacuum is too low to measure even with a digital micromanometer). A smoke pen can also be used at known or suspected cracks and preferential pathways across the floor or building envelope or to verify a membrane is adequately sealed to the building walls (SMD). Radon may also be used as a tracer gas in some situations where it is naturally present at sufficient levels to measure in both indoor air and sub-slab soil gas, as a semi-quantitative indicator of system attenuation (radon and COC source and transport conditions may be different).

Helium can be used in at least two ways as a sub-slab gas flow tracer. An interwell test consists of adding a few liters of helium to a probe at some distance (e.g., 5–15 ft) from a suction point and monitoring the concentration of helium in the extracted gas at the suction point. A helium flood consists of reversing the mitigation system flow direction and blowing air with about 1% helium added into the subsurface and monitoring the arrival of helium at various sub-slab probe locations. More information can be found in Section J.4.3 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014) and ESTCP (McAlary et al., 2018).

Smoke testing for passive barriers is the process of injecting nontoxic smoke underneath the barrier, checking for any smoke penetrating the barrier, and then patching the barrier to ensure no more smoke penetrates the barrier. Smoke testing can be applied to any type of passive barrier system by injecting through a passive vent riser or by cutting a hole within the passive barrier system to inject the smoke. Smoke testing should be performed on predetermined intervals until the entire system is tested.

Active Mitigation	**Low Impact:** Smoke and/or tracer gas testing can confirm the effectiveness of active mitigation systems but should not be the sole verification method of system effectiveness or function.

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Passive Mitigation	**High Impact:** Smoke and/or tracer gas testing is a highly effective way to confirm the integrity of a passive mitigation system without the need to add penetrations to mitigation systems.
Environmental Remediation Technology	**High Impact:** Smoke and/or tracer gas testing is a highly effective way to confirm the effectiveness of SVE/MPE as VI mitigation measures.
Rapid Response	**Medium Impact:** Smoke testing can be used to demonstrate building pressurization at windows and doorways.

System Integrity Testing: Passive barriers are constructed in the field and applied prior to placing a concrete slab. Each barrier system should have installation specifications along with quality control procedures to test the integrity of seams, seals around penetrations, system termination points, and overall field membrane integrity. Quality control procedures can vary based on the passive barriers selected, but common procedures include smoke testing, coupon sampling, air lancing, and seam probing. For more information refer to the ***Passive Barrier Technology Information Sheet***.

Active Mitigation	**Low Impact:** Integrity testing would apply to active mitigation systems if a vapor membrane is installed in conjunction with the active system, although membranes primarily affect system efficiency rather than performance, if pressure differential requirements are met.
Passive Mitigation	**High Impact:** Thickness verification is important to confirm proper installation of passive mitigation systems. It is recommended to follow the product manufacturer's guidance on frequency of coupon sample collection.
Environmental Remediation Technology	**Low Impact:** SVE and MPE used for VI mitigation generally do not include barriers under existing buildings.
Rapid Response	**Not Applicable**

5.2 System Effectiveness and Reliability

Once a system is installed, inspections and testing are typically required to "commission" the system—that is, to confirm that the system is meeting performance criteria and remediation objectives. Consideration as part of the design process should evaluate the potential that the system will be effective and that it can be reliably maintained both in the short and long term. The design should consider and specify common testing to be conducted after installation to demonstrate system effectiveness and reliability, depending on the type of system installed. Active mitigation systems will typically require measurement of system vacuum and air flow, cross-slab pressure differentials, and potentially COC concentrations in exhaust gases (e.g., for air quality permitting purposes). Active and passive systems may require sub-slab, indoor air, and outdoor (ambient) air testing to demonstrate performance, particularly when the system is first commissioned. More information on testing to verify system effectiveness and reliability is provided in the ***Post-Installation System Verification Fact Sheet***.

Active Mitigation	**High Impact:** Demonstrating the effectiveness and reliability of active systems after installation is critical.

Passive Mitigation	**High Impact:** Demonstrating the effectiveness and reliability of passive systems after installation is critical.
Environmental Remediation Technology	**High Impact:** Demonstrating the effectiveness and reliability of environmental remediation to also mitigate VI is critical.
Rapid Response	**High Impact:** Demonstrating the effectiveness and reliability of HVAC controls is critical. The need to demonstrate the effectiveness and reliability of rapid response actions depends on the situation.

5.3 Operation, Maintenance, and Monitoring Considerations

The mitigation system design should consider and include post-installation OM&M requirements, commonly provided in an OM&M plan, which provides instructions for system operation and upkeep. An OM&M plan should be prepared for each installed mitigation system. Consideration of the OM&M must occur during the design phase. As part of the design, the ease of performing the OM&M activities must be considered. For example, if a monitoring system consistently requires a homeowner to access a location that is not easily accessible (e.g., their attic to monitor if a fan is running), there is a greater chance that the system will not be maintained or monitored.

Details of a typical OM&M plan can be found in Section 6.3 and Section J.3.2 in the ***2014 ITRC PVI document*** (ITRC, 2014) and are further provided in the ***OM&M/Exit Strategy Fact Sheet***.

Active Mitigation	**Medium Impact:** Most fans designed for radon-style mitigation have a long service life. An automated alarm can be used to identify the need for fan service or replacement. Monitoring needs vary, depending on the source strength, building occupancy, and local regulatory requirements. Consider also periodic collection of data that may be needed to support closure in the future.
Passive Mitigation	**Medium Impact:** During the design phase, consideration should be given to state regulatory requirements regarding ongoing operation and maintenance of a passive mitigation system. Contact the applicable state regulatory agencies to confirm your regulatory requirements.
Environmental Remediation Technology	**High Impact:** MPE and SVE systems require that OM&M be performed on a regular basis to ensure effectiveness, conduct repairs, and ensure that the treatment of the extracted media remains in compliance with the permit requirements.
Rapid Response	**High Impact:** Although rapid response measures by their nature are limited in duration, operation and maintenance are critical during deployment.

5.4 Exit Strategies

The mitigation system design should consider what information and criteria are needed to allow orderly and safe shutdown of the system at the appropriate time. The criteria for shutdown should be based on the VI CSM and design basis, and the OM&M plan should result in the collection of data necessary to determine when shutdown can occur. More information on exit strategies can be found in the ***OM&M/Exit Strategies Fact Sheet***.

Active Mitigation	**Medium Impact:** During the design process step in an active mitigation approach, it is important to understand the potential time frame over which the system may operate and what a potential exit strategy may look like.
Passive Mitigation	**Low Impact:** Passive mitigation systems will continue to function regardless of whether a vapor source has biodegraded or has been remediated and no longer poses an unacceptable risk.
Environmental Remediation Technology	**High Impact:** SVE/MPE systems are typically operated for a limited time; therefore, a clear exit strategy must be developed.
Rapid Response	**Medium Impact:** Rapid response measures are limited in duration and are implemented ahead of a long-term mitigation approach. It is important to clearly define and communicate the transition process from rapid response measures to long-term response actions.

6 SUMMARY

The design of a VI mitigation system should consider a variety of factors to ensure that the design is consistent with and will adequately address the VI pathway, including a review of the VI CSM and source, site, and building conditions that could impact mitigation strategy and design; the potential need for additional design investigations and mitigation diagnostic testing; and the appropriate locations and components of the mitigation infrastructure (i.e., the system layout and specifications). The design should also include various plans to ensure the proper construction, installation, and operation of the system, including a CQA and control plan; procedures to confirm that the system is meeting performance objectives and criteria when first installed; an OM&M plan; and potentially other plans, depending on the nature of the system and regulatory requirements.

Building structures vary widely in their size, function, and use; therefore, the implementation of mitigation technologies will vary widely, depending on the type of building for which the active system is needed and the intended design objectives of the system. This fact sheet summarizes the many considerations that go into the design, installation, verification, and operation of each of the most common mitigation technologies as they relate to some of the more common building types and uses.

7 REFERENCES AND ACRONYMS

The ITRC VI Mitigation Training web page includes lists of acronyms, a full glossary, and combined references for the fact sheets. The user is encouraged to visit the ITRC VI Mitigation Training web page to access each fact sheet and supplementary information and the most up-to-date source of information on this topic.

Post Installation Fact Sheet

ITRC has developed a series of fact sheets that summarizes the latest science, engineering, and technologies regarding the mitigation of vapors associated with vapor intrusion (VI). This fact sheet describes the most common post-installation considerations for active mitigation systems, passive mitigation systems, and environmental remediation technologies that need to be considered as part of any mitigation system verification testing process.

1 INTRODUCTION

After the implementation of a mitigation strategy, post-installation verification and testing to confirm achievement of the design and operating parameters is required. It is during this time that the conceptual site model (CSM) is validated and the mitigation system is confirmed to be operating and meeting performance specifications, typically using multiple approaches or criteria.

Below are common considerations that professionals should consider or tests they may complete after implementation of a mitigation strategy for confirmation and prior to operation, maintenance, and monitoring (OM&M). Emerging technologies, such as aerobic vapor mitigation barriers (AVMB), are not addressed within this fact sheet. Please see the ***Aerobic Vapor Mitigation Barrier Technology Information Sheet*** for more information.

2 PRECONSTRUCTION AND DURING CONSTRUCTION

Planning, preparation, and oversight conducted during installation are as important as post-installation system confirmation. Attention to these items will greatly improve the post-installation evaluation and provide for a more successful implementation. The formality of planning and construction quality assurance (CQA) during installation will depend on the size and complexity of the building and the mitigation system to be constructed.

Prior to construction, plan the post-installation evaluations and documentation requirements, and communicate them to the installer and CQA representative(s). Obtain necessary permits for installation and operation, and plan how to meet the permit requirements, including those for closure of the permit.

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During construction, pay attention to ensuring quality construction. Certain post-installation testing should occur during construction (while the installer is still present) to allow for rapid system adjustments. Other post-installation testing will likely occur days or weeks after the system is installed and operating. For purposes of this fact sheet, we will consider all of these items to be "post-installation" considerations.

POST-INSTALLATION CONSIDERATIONS

This fact sheet focuses on the most common post-installation considerations. Table 3-1, below, summarizes the considerations and identifies their impact in an active (see ITRC ***Active Mitigation Fact Sheet)*** approach, a passive (see ITRC ***Passive Mitigation Fact Sheet***)] approach, remediation (see ITRC ***Remediation & Institutional Controls as Vapor Intrusion Mitigation Fact Sheet***), or rapid response technology (see ITRC ***Rapid Response and Ventilation for Vapor Intrusion Mitigation Fact Sheet***). Detailed discussion and supporting information are presented later in this section.

Table 3-1. Summary of post-installation considerations and impact on mitigation approach

Post-installation Consideration	**Active approaches**	**Passive approaches**	**Remediation**	**Rapid response**
Groundwater elevation				
Depth to groundwater/high water conditions	●	◐	●	◒
Building information and survey				
Foundation and slab condition	●	◒	●	◐
Preferential pathways and utility penetrations	●	●	●	●
Heating, ventilation and cooling (HVAC) system	◐	◒	◒	●
Windows, air intake, and building exhaust	●	●	●	●
Building codes and industry standards	◐	◐	◐	◐
Confirmation testing				
Pressure field extension (PFE) confirmation	●	—	●	◒
System vacuum, air flow, and velocity	●	◐	●	◒
Sub-slab, indoor air, outdoor ambient air sampling	●	●	●	●
Mass removal rate	●	◒	◐	◒
Smoke and tracer gas testing	●	●	●	●
Backdraft testing	◐	—	◒	—
Coupon testing	—	●	◒	—

Table 3-1. Summary of post-installation considerations and impact on mitigation approach

Post-installation Consideration	Active approaches	Passive approaches	Remediation	Rapid response
Telemetry	◐	◒	◐	◒
Permitting				
Installation permits	◐	◐	●	◒
Operational permits	◐	◒	●	◒
Communications				
Property owner, tenant, and others	●	●	●	●
Operation, maintenance, and monitoring planning				
OM&M plans	●	◐	●	●
Key High impact ● Medium impact ◐ Low impact ◒ Not applicable —				

The remainder of this document provides a discussion of the impacts for each consideration above.

3.1 Groundwater Elevation

As the system moves past installation, a key consideration moving forward is confirmation of the control of shallow groundwater conditions. Certain mitigation strategies require air flow below the subsurface; therefore, the presence or absence of shallow groundwater may play a key role in defining the success of certain technologies. In instances where groundwater is being controlled, post-installation monitoring should confirm that the measures implemented are successful.

Active Approaches	**High Impact**. Groundwater elevation can potentially impact subsurface active mitigation systems since the presence of moisture or water can lower the air flow and pressure field extension (PFE) of an area targeted for mitigation. Specifically, sub-slab depressurization (SSD), sub-slab ventilation (SSV), sub-membrane depressurization (SMD), and drain tile depressurization can be highly impacted by groundwater near a building slab or membrane. Groundwater elevation has low impact to indoor air filtration and building pressurization.
Passive Approaches	**Medium Impact**. High water near or in direct contact with the floor slab may limit the effectiveness of venting systems. For barriers to be effective, they must be both waterproof and resistant to contact with site-specific chemicals.

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Remediation	**High Impact**. Soil vapor extraction (SVE) is feasible only when sufficient unsaturated thickness is present. Multiphase extraction (MPE) can be applied at sites with or without unsaturated thickness; however, high groundwater increases the complexity and the OM&M requirements of the system.
Rapid Response	**Low Impact.** Groundwater elevation does not impact most rapid response measures. If groundwater is in contact with preferential pathway sealants, then the effectiveness of those sealants may be compromised, depending on the constituents and concentrations thereof in groundwater. Ad hoc heating, ventilation, and cooling (HVAC) modification and indoor air treatment are not impacted by groundwater elevation.

See Section J.2.6 of ***Appendix J in the 2014 ITRC Petroleum Vapor Intrusion (PVI) document*** (ITRC, 2014) for a summary of considerations to be made where high water conditions may be present.

3.2 Building Information and Survey

An existing building survey can support the conclusion that mitigation measures are successful. An existing building survey is conducted prior to the design of any mitigation strategy to collect information critical to selecting a mitigation technology appropriate for the building conditions and the CSM (see ITRC ***Conceptual Site Models for Vapor Intrusion Mitigation Fact Sheet)***. The survey additionally provides a baseline for comparison to post-construction conditions. Photographic documentation, the building sketch, and detailed notes should be examined and compared to the baseline condition. A sample existing building survey form can be found in Appendix G of the ***2007 ITRC Vapor Intrusion Pathway: A Practical Guideline (VI-1)*** (ITRC, 2007a).

The following is a summary of items typically reviewed after implementation of a mitigation strategy.

Foundation and Slab Condition:

Depending on how the mitigation strategy was implemented and any modifications to the structure that were installed as part of the mitigation system installation, a survey should be conducted that confirms that modifications to the structure, if any, do not have an adverse impact on the functionality of building structural components.

Active Approaches	**High Impact**. The foundation and floor slab are key elements of most action mitigation systems, and their collective integrity have a significant effect on system performance.
Passive Approaches	**Low Impact**. Most passive mitigation systems are installed in new construction, which makes this a lesser consideration. However, this factor may impact and apply to epoxy floor coatings (EFC).
Remediation	**High Impact**. Certain features of buildings, such as deep foundations or highly fractured slabs, may affect soil vapor flow during SVE or MPE and necessitate that these features be evaluated.
Rapid Response	**Medium Impact**. The condition of the building foundation and slab may impact the effectiveness of preferential pathway sealants.

See Section J.2.4 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014) for a summary of considerations related to foundation types.

Preferential Pathways and Utility Penetrations:

Preferential advective flow pathways through openings in the building slab and into the building should have been identified and considered as part of the design. Such openings include utility penetrations, sumps, cracks, joints, perimeter drains, sewer pipes and related interior connections, and the slab-foundation perimeter joint. Elevator shafts may need to be considered separately as they may not be able to be sealed (certain building codes require there to be a soak-away at the bottom of an elevator shaft and this must not be sealed). Preferential pathways should be inspected and confirmed to be addressed through appropriate measures.

Active Approaches	**High Impact**. Sealing around preferential pathways and penetrations within the floor slab is critical to the effectiveness of active mitigation systems. Ensure abandoned or inactive utilities are appropriately sealed.

Passive Approaches	**High Impact**. Sealing around penetrations within the floor slab is critical to the effectiveness of passive mitigation systems.
Remediation	**High Impact**. Sealing around penetrations within the floor slab is critical to the effectiveness of SVE and MPE as mitigation measures.
Rapid Response	**High Impact**. Sealing major preferential pathways and utility penetrations is critical to the effectiveness of any rapid response action.

See Section J.2.4 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014) and Section 8 of ANSI/AARST SGM-SF-2017 (AARST, 2017) for additional information.

Heating, Ventilation and Cooling (HVAC) System:

It is important to evaluate the air exchange rate(s) and operational changes over which the HVAC system operates after the installation is complete to confirm that it is still operating in a manner consistent with pre-installation conditions. VI mitigation implementation should not impact HVAC operation, unless HVAC adjustments were intended as part of the design.

Some mitigation systems, almost exclusively in commercial buildings, function by adjusting the HVAC to pressurize the indoor space relative to sub-slab, or by increasing the air exchange rates to reduce concentration of indoor contaminants (see ITRC ***Heating, Ventilation & Air Conditioning (HVAC) Modification Technology Information Sheet***)]. It is also critical to assess if the mitigation strategy, now that it is no longer conceptual in nature, will remain effective for reasonably anticipated operating conditions and heating and cooling seasons.

Active Approaches	**Medium Impact**. If depressurization below the building is the goal, such as with SMD and SSD, then decreased pressure within the building interior can reduce the differential vacuum with the subsurface below acceptable levels. Conversely, if the pressure within the building interior is increased, the effectiveness of a depressurization system is enhanced.

Passive Approaches	**Low Impact**. This factor primarily applies to building design with minimal impact on the effectiveness of barriers and venting systems.
Remediation	**Low Impact**. Remediation technologies are typically not impacted by the HVAC operation.
Rapid Response	**High Impact**. Modifications to HVAC systems can greatly impact indoor air quality during a rapid response. HVAC operation is best modified through adjustment of supply/return air and exhaust fan flow rates.

Windows, Air Intake, and Building Exhaust:

Vent stack location standards, including prescribed distances from building entryways (doors, windows) and building vents, are detailed in existing industry guidance for radon mitigation systems, as well as in states' VI guidance. Typically, vent stack locations are not less than 2 feet above the eve of the roof (including any walls/parapets) and not less than 10 horizontal feet away from openings (windows, doors, etc.) and mechanical equipment air intakes. Increased distancing is required for larger exhaust pipes or for angled discharge, and increased distancing may be required near certain fan-powered air intakes. Additional specifications, created for all soil gas control systems, were developed by ANSI/AASRT (AARST, 2018c) and provide a useful set of initial considerations for volatile organic compound (VOC) mitigation system vent stack design. For VOC VI mitigation systems, the vent stack height and distance from openings and air intakes will depend on the concentrations of VOCs being emitted, and air velocity. For many VOCs, the indoor air screening levels are very low, which may necessitate taller vent stacks or larger separation distances to avoid introduction of VOC vapors from the mitigation system effluent to indoor air. In some cases, air dispersion modeling may be useful to help appropriately place a vent stack for a mitigation system.

The top of the vent stack discharge pipe should also be vertical, or as close to vertical as possible (not more 45 degrees from vertical) (AARST, 2018c). Generally, rain caps are not necessary. However, if rain caps are used, they should not impinge on the vertical discharge of vapors from the stack. For more information, see Section J.3.3 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014) and ANSI/AARST: SGM-SF-2017 (AARST, 2017); CC-1000-2018 (AARST, 2018c); RMS-MF-2018 (AARST, 2018a); and RMS-LB-2018 (AARST, 2018b).

During the post-installation review, vent stack distances are evaluated to confirm the design specifications have been met. Note that during construction, the vent stack may be been relocated based on input from owners, tenants, architects, or other engineers (for aesthetics, convenience, or other reasons). It is important to revisit vent stack placement requirements during relocation discussions.

Active Approaches	**High Impact**. Vent stack placement is critical to ensuring effluent vapors do not enter the building.
Passive Approaches	**High Impact**. Vent stack placement is critical to ensuring effluent vapors do not enter the building.
Remediation	**High Impact**. Placement of the SVE/MPE system discharges is critical to ensuring that system exhaust does not enter buildings.
Rapid Response	**High Impact**. The location of the outside air intake and the quality of the outside air will greatly impact indoor air quality. Any form of building exhaust should be away from HVAC air intakes.

Building Codes and Industry Standards:

There are no overarching building codes for system construction that apply to every building in every state. However, states or municipalities may have requirements in their building codes regarding system construction (material types, component locations, etc.). These codes should have been reviewed and incorporated into the design.

Post-installation activities confirm that the all building codes and industry standards have been followed. While building codes may or may not have a significant impact on VIMS, applicable building codes must be followed and must be evaluated when they impact the installed system.

Active Approaches	**Medium Impact**. The degree to which building codes affect active mitigation system installation varies from location to location and should be followed.

Passive Approaches	**Medium Impact**. The degree to which building codes affect passive mitigation system design varies from location to location and should be followed.
Remediation	**Medium Impact**. Building codes may impose certain restrictions on the construction of SVE and MPE systems.
Rapid Response	**Medium Impact**. Some states may have rules or regulations on who can evaluate/modify HVAC systems to ensure they comply with building and energy code requirements.

3.3 Confirmation Testing

Confirmation testing is performed subsequent to completion of installation and start-up of the mitigation system. Confirmation testing confirms that the mitigation system is meeting the design and performance objectives. The approach to confirmation testing will be dependent on the mitigation approach and applicable regulations/guidance.

For active mitigation and remediation systems, this process is frequently referred to as commissioning, which is an important step to verify that the system is functioning consistent with the design and specifications. Commissioning additionally provides a performance baseline for comparison to measurements collected during OM&M.

During commissioning, keep in mind exit strategies, discussed in detail in the ITRC ***Operation, Maintenance & Monitoring/Exit Strategy Fact Sheet***. Data can be collected during post-installation confirmation testing to support an exit strategy. In certain instances, it is important to demonstrate data trends early in the mitigation process.

Pressure Field Extension (PFE) Confirmation:

PFE confirmation, also called radius of influence (ROI) testing or communication testing, should be completed to understand and confirm proper SSD, SVE, or MPE operation. PFE testing consists of measuring the distance that differential pressure can be measured from a point of applied vacuum (a suction point). It is used to confirm the number and placement of suction points, and that the fan/blower sizes are appropriate to meet performance objectives, especially at the remote extents of the system. Target differential pressure levels should provide a general factor of safety range to confirm depressurization is maintained under reasonably anticipated building conditions. Certain states provide a differential pressure minimum guideline, which is generally 1–6 Pa, depending upon the state. For SSD, SSV, and SMD systems, a differential pressure as low as 1 Pa has been shown to be effective as long as it is maintained over time under normal operating building conditions (Lutes et al., 2011; Moorman, 2009). More information on differential pressure measurement collection and target ranges is in the ***Design Considerations Fact Sheet***.

The PFE distance varies based on numerous factors—primarily the contrast in permeability between the floor slab and the material beneath the floor, but also including the location of building footers, floor drains, trenches, and utilities. Floor leakage may also be indicated by PFE assessments (i.e., areas of less sub-slab vacuum than expected could be near areas of air recharge across the floor slab). Use of mathematical models for flow and vacuum can be helpful for interpolation or extrapolation of known data to demonstrate PFE coverage or excessive leakage.

Where PFE is not adequate to extend to all areas of potential concern, it may be appropriate to seal floor cracks, expansion joints, conduit openings, and joints around manhole covers to prevent short circuiting and improve efficiency of an active mitigation system. Where these pathways are inaccessible (under floor coverings, behind walls, etc.), additional suction points may be required. These pathways may have already been sealed during previous building mitigation activities (by previous rapid response activities and/or passive mitigation activities) but have failed through improper application or natural deterioration; therefore, re-application of sealants should be considered.

Active Approaches	**High Impact**. This is a critical step to demonstrate that the VI pathways are being effectively interrupted for SSD systems, but may not be practical for certain active systems, such as SMDs or block wall mitigation systems.
Passive Approaches	**Not Applicable.** PFE testing is not considered for passive approaches.
Remediation	**High Impact**. PFE testing is crucial in confirming the effectiveness of SVE and MPE systems in providing VI mitigation.
Rapid Response	**Low Impact**. PFE is not typically associated with rapid response approaches. However, during building pressurization with HVAC modification, sub-slab to indoor air differential pressure may be collected to confirm adequate pressurization.

More information on PFE testing is included in ANSI/AARST SGM-SF 2017 Section 6.2 (AARST, 2017) and more information on characterizing the transmissivity below the floor and the leakance of the floor is provided by ESTCP (McAlary et al., 2018).

System Vacuum, Air Flow, and Velocity:

System vacuum and air flow readings collected after start-up are used to verify that system operation is meeting the design specifications. Flow velocity is usually measured using a critical orifice, thermal anemometer (i.e., hot-wire anemometer), vane anemometer, pitot tube, or similar device. Vacuum is usually measured with a U-tube manometer, dial gauge, or digital manometer. Vacuum and flow readings should be collected concurrently with PFE readings so that the approximate vacuum and flow rate that generated the PFE range are known. High flow at the blower with low vacuum (e.g., 100 standard cubic feet per minute [scfm] or more of flow at a vacuum of 1 inch of water column [in-H_2O] or less) indicates highly permeable materials below the floor and is conducive to the system having a significant component of SSV. Low flow with high vacuum (e.g., 10 scfm or less flow at a vacuum of 10 or more in-H_2O) indicates low-permeability material below the floor. The ratio of flow/vacuum is the specific capacity of the venting system and is a parameter that can be affordably and easily monitored over time to evaluate whether the permeability of the material below the floor is changing.

For SSV and crawl space ventilation (CSV) systems, flow velocity is a useful performance criterion as it indicates that vapors are moving within the subsurface or crawl space, allowing for dilution and reduction of contaminant concentrations. Sub-slab tracer testing and mathematical modeling to evaluate adequate sub-slab flow velocity are detailed by ESTCP (McAlary et al., 2018). Following the initial assessment, air flow rate in the vent pipes can then be monitored over time to confirm proper system operations are maintained.

Active Approaches	**High Impact**. Active system vacuum, air flow, and velocity readings confirm the system is operating according to design criteria and are useful in evaluating effectiveness of the active system. Measurements may also be used for calculating discharge criteria or permit limits.
Passive Approaches	**Medium Impact**. Passive approaches do not use mechanical means in their design; therefore, system vacuum does not apply to passive approaches. However, confirmation of flow, even if intermittent, within passive venting systems can be used to ensure proper design and installation of passive mitigation systems.
Remediation	**High Impact**. Flow characteristics are key design elements of SVE and MPE systems.

Rapid Response	**Low Impact**. Rapid response approaches do not typically include monitoring of vacuums and flows related to blowers or fans. However, air flow rates should be evaluated during HVAC modifications. Refer to Section 3.2.3 above for information on HVAC systems.

Sub-Slab, Indoor Air, Outdoor Ambient Air Sampling

Collection of soil vapor or indoor/outdoor air samples following start-up of a mitigation system is another approach to document system effectiveness. Sampling procedures should generally match those conducted during the remedial investigation (i.e., pre-installation). However, for SSD and SSV systems, soil gas samples may be collected after system start-up from a sampling port in the vent pipe or from a monitoring point within the floor.

It may be necessary to verify that indoor air concentrations are below a building-specific cleanup level or show that continued/remaining indoor air concentrations are due to background indoor air sources, and not due to VI (either via subsurface or outdoor air [due to poor vent pipe placement or inadequate treatment, if required, of extracted soil vapor]).

Active Approaches	**High Impact**. Regulatory agencies likely will require air sampling for system verification and effectiveness confirmation.
Passive Approaches	**High Impact**. State regulatory agencies likely will require paired sampling (i.e., sub-slab soil gas and indoor air sampling) for system verification purposes.
Remediation	**High Impact**. Air quality sampling is essential to confirming the effectiveness of SVE and MPE when acting as VI mitigation measures.
Rapid Response	**High Impact**. Indoor air sampling is critical to confirm the effectiveness of a rapid response. Samples should be collected throughout the building, including within each HVAC zone, if applicable. Outdoor air samples should also be collected near air intakes to assess the quality of the air supply.

Mass Removal Rate:

Although mass removal may not be the primary function of a mitigation system, it can be useful for assessing whether an SSD/SSV is capturing appropriate sub-slab chemical mass, and whether permit conditions are met. The rate of mass removal from the mitigation system can be calculated from system airflow measurements and contaminant concentrations measured in the vent system piping. The mass removed by the system can be compared to the rate of mass removal from the building if building depressurization testing (i.e., blower door testing) was performed during the VI assessments prior to system installation (Dawson, 2016). This comparison can be used to assess whether the SSD/SSV is capturing all of the mass that might have otherwise entered the building and can inform the potential need for additional suction points or larger fans to increase the rate of mass capture.

Mass removal rate data are also useful for verifying compliance with applicable air discharge permit requirements or regulatory effluent limits, and for assessing whether emission controls would be required during system start-up. The mass removal rate can also be tracked over time, as part of an exit strategy that assesses whether the concentration of contaminants diminishes to levels that no longer require mitigation, as described in the OM&M Section (see Section 3.6 below). However, the use of mass removal rates is rarely a demonstration that does not require other forms of performance verification, such as sub-slab and indoor air sampling.

Active Approaches	**High Impact**. Mass removal can be used to assess system performance and for compliance with air discharge permit requirements.
Passive Approaches	**Low Impact**. Mass loading rates are typically not considered in passive mitigation system design.
Remediation	**Medium Impact**. Proper design is required to manage mass loadings from SVE and MPE systems (e.g., treatment). In addition, mass loading records are used to propose exit strategies.
Rapid Response	**Low Impact**. Mass loading rates are typically not considered for rapid responses.

Smoke and Tracer Gas Testing:

Smoke and tracer gas testing are options to test air flow patterns. For example, if smoke is drawn rapidly below the floor through an open sub-slab port during SSD/SSV operation, this indicates the system is effective at the location tested. In cases where the material below the floor is highly permeable, this can occur where the applied vacuum is too low to measure with the most sensitive devices, such as a digital micromanometer.

Smoke tests (implemented using a smoke pen or other suitable methods) can also be used to evaluate system effectiveness. Smoke tests can be conducted at known or suspected preferential pathways across the floor or building envelope. They can additionally be used to verify that a membrane is adequately sealed to building walls, as in an SMD system.

Helium can be used in at least two ways as a sub-slab gas flow tracer. The first is an interwell test, which consists of adding a few liters of helium to a probe at some distance (e.g., 5–15 ft) from a suction point and monitoring the concentration of helium in the extracted gas at the suction point. The second is a helium flood, which consists of reversing the mitigation system flow direction and blowing air with about 1% helium into the subsurface while monitoring the arrival time of helium at various sub-slab probe locations. The data from either test can be input into a mathematical model to evaluate the effectiveness of the system. More information can be found in Section J.4.3 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014) and ESTCP (McAlary et al., 2018).

Active Approaches	**High Impact**. Smoke or tracer gas testing is an effective way to evaluate the efficacy of an active mitigation system.
Passive Approaches	**High Impact**. Smoke or tracer gas testing is an effective way to evaluate the integrity of a passive mitigation system without the need to add penetrations.
Remediation	**High Impact**. Smoke or tracer testing is crucial for confirming the effectiveness of the SVE and MPE systems when used for VI mitigation.
Rapid Response	**High Impact**. Smoke testing can be a highly effective method in evaluating the efficacy of preferential pathway seals. Smoke testing can also be used to assess the airflow paths throughout a building due to HVAC operations.

Backdraft Testing:

As stated in Section J.3.9 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014), a backdraft condition occurs if a building's ventilation equipment is not properly balanced against the building's combustion devices (e.g., furnaces, clothes dryers, water heaters, fire places, wood stoves, etc.), resulting in exhaust gases (e.g., carbon monoxide) collecting inside the building. Most residential mitigation activities (SSD, SMD, SSV) add little to the potential for overall building depressurization due to the blower's low flow rates and minimal pressure differentials across the slab. However, the installer should understand the building's air supply (i.e., is it "natural draft" or does it have cold air supply vents) and conduct backdraft testing, as applicable or as recommended by state guidance. The U.S. Environmental Protection Agency provides recommended procedures for backdraft testing that can be completed before and after mitigation system installation and start-up (USEPA, 1993). Backdraft conditions should be corrected before the depressurization system is placed in continued operation. Carbon monoxide detectors are recommended within buildings, including the basement.

Active Approaches	**Medium Impact**. Active mitigation systems typically do not affect backdraft; however, it is critically important to confirm the absence of backdraft after installation of an active system.
Passive Approaches	**Not Applicable**. Backdraft testing is not employed.
Remediation	**Low Impact**. Remediation technologies generally do not affect backdraft.
Rapid Response	**Not Applicable**. Backdraft testing is not employed for rapid responses.

Coupon Testing:

Confirmation of spray-applied liner thickness can be accomplished by removing a small section of the liner (a "coupon") and measuring its thickness with calipers or another measurement device. After the spray-applied liner has cured, one or more coupons are removed. The thickness of the coupons is measured and, if a coupon is too thin, additional barrier is applied in the area of the deficient coupon. The liner is repaired where the coupons were removed. This process is typically conducted in accordance with manufacturer's guidance for the number of coupons and acceptable thickness.

Active Approaches	**Not Applicable.** Active mitigation approaches do not use coupon testing.

Passive Approaches	**High Impact**. Thickness verification is important to confirm proper installation of passive mitigation systems. It is recommended to follow the product manufacturer's guidance on frequency of coupon sample collection.
Remediation	**Low Impact**. Most SVE and MPE systems do not require the use of barriers that would require coupon testing.
Rapid Response	**Not Applicable**. Coupon testing is not considered for rapid responses.

Telemetry:

If telemetry is incorporated into the system design, then communication of the telemetry system to designated users must be tested. Telemetry could be as simple as a communication if the system shuts down, or as complex as continuous broadcast of system parameters. More information about telemetry is detailed in the ***Operation, Maintenance & Monitoring Process/Exit Strategy Fact Sheet***.

Active Approaches	**Medium Impact**. Active systems may be installed with telemetry to monitor and provide data to optimize the operation of the system.
Passive Approaches	**Low Impact**. Telemetry is not typically incorporated into passive mitigation systems.
Remediation	**Medium Impact**. SVE and MPE systems may be installed with capabilities for telemetry.
Rapid Response	**Low Impact**. Telemetry is not typically incorporated into rapid responses.

3.4 Permitting

Permits typically consist of the following two types:

- Installation permits: Some states or municipalities may require a building permit or electrical permit for system installation.
- Operational permits: Discharge permits may be required by local, county, or state government prior to start-up. Some agencies may require a permit application to be submitted with available analytical data and system flow rates to determine if a discharge permit or exhaust treatment is needed. See Section J.3.2 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014).

Installation Permits:

After the installation of a mitigation system, it is important to confirm that installation permit conditions have been met. These permits will need to be appropriately closed with the regulatory agencies or building departments. The following are typical CQA or post-installation tasks that are performed related to installation permits:

- review and approval of applicable submittals, including gravel specification; membrane (and membrane adhesives, mastics, etc.); aerated slab forms; pipe and fittings; system monitors and alarms; and fans
- inspection of system components, including gravel placement; piping/vent strips; membrane; aerated floor; membrane penetrations and boots; slab placement; riser and conveyance pipes; fans; system monitors; and alarms

Active Approaches	**Medium Impact**. Installation permits may be required for active mitigation systems. Confirm installation permit requirements with your state and local regulatory agencies, and with the municipal building department.
Passive Approaches	**Medium Impact**. Permits may or may not be required for the installation of passive mitigation systems. Confirm installation permit requirements with your state and local regulatory agencies and the building department of your local unit of government.
Remediation	**High Impact**. SVE and MPE systems typically require permits related to the treatment and discharge of the impacted vapor.

Rapid Response	**Low Impact**. Permits are not typically required for rapid responses. However, if HVAC systems are modified, building permits may be required.

While permits may or may not have a significant impact on mitigation systems, applicable permits must be obtained and followed.

Operational Permits:

The two main types of operational permits that need to be considered can be classified as emission permitting and control permitting.

As detailed in Section J.3.2 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014), air permits and emission controls on active mitigation or remediation systems must be considered for each project based on the system design, the conceptual site model, and the applicable state, federal, or local regulations. The regulations are generally associated with the Clean Air Act or local ordinances that have been set by statute. In some states, subsurface mitigation systems may be exempt from permitting. More detail is provided in Section J.3.2 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014).

Active Approaches	**Medium Impact**. Emission or control permits may be required to operate an active mitigation system. Contact your state and local regulatory agencies to ensure compliance with applicable emission permit requirements.
Passive Approaches	**Low Impact**. While typically not required for passive mitigation systems, emission permits may be required by your state or local regulatory agencies. Contact your state and local regulatory agencies to ensure compliance with applicable emission permit requirements.
Remediation	**High Impact**. Discharge permits are typically required to operate SVE and MPE systems.
Rapid Response	**Low Impact**. Operational permits are typically not considered for rapid responses.

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While permits may or may not have a significant impact on mitigation systems, applicable permits must be obtained and followed.

3.5 Communications

The building owner, tenant, and other parties involved with the building are typically provided with information regarding the mitigation system. Common items may include:

- basic description of mitigation system (components, operation, etc.) installed
- photos of typical system components
- restrictions, if any, to access, perform construction on, or use portions of the property due to the mitigation system
- information relating to the mitigation system alarm/monitors, and instructions for whom to contact in the event of an alarm condition or unusual noise related to the mitigation system
- contact information if other issues or questions arise related to the mitigation system

Active Approaches	**High Impact**. Communication with the building owner or tenant regarding the operation of the active mitigation system is critical.
Passive Approaches	**High Impact**. Community engagement is a critical part of the implementation of a passive approach, especially if the approach is large scale or highly visible. Contact your state and local regulatory agencies to confirm your regulatory obligations with respect to notification requirements.
Remediation	**High Impact.** Implementation of SVE or MPE typically involves an extensive interaction with the stakeholders, including access agreements.
Rapid Response	**High Impact**. Adjustments to HVAC systems or implementation of indoor air treatment units must be clearly communicated, as the operation of these responses may fall on the owner or tenant.

The ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet*** provides additional information to plan communications with property owners and building occupants.

3.6 Operation, Maintenance, and Monitoring Planning

An OM&M plan provides instructions for system operation and upkeep and should be prepared for each installed mitigation system. Consideration of the OM&M should have begun during the design phase, and modifications to the plan will occur based on the post-installation evaluation and testing. Certain states may have standardized templates or minimum content requirements when OM&M plans are prepared.

Details of a typical OM&M plan can be found in Section 6.3 and Section J.5 of in the ***2014 ITRC PVI document*** (ITRC, 2014) and are further discussed in the ***Operation, Maintenance & Monitoring Process/Exit Strategy Fact Sheet***.

Active Approaches	**High Impact**. Since active systems are generally a part of long-term stewardship plans, the OM&M plan is critical to prepare and follow to ensure continued proper operation of the system.
Passive Approaches	**Medium Impact.** OM&M of a passive approach primarily consists of an inspection to evaluate the integrity and function of the installed system. Contact your applicable state regulatory agencies to inquire about regulatory requirements for submission of OM&M documentation.
Remediation	**High Impact**. MPE and SVE systems require that OM&M be performed on a regular basis to ensure their effectiveness, operation, and compliance with permit requirements.
Rapid Response	**High Impact**. OM&M is critical to keep the rapid responses operating properly. HVAC systems must be maintained to ensure the proper supply/return airflow rates. Indoor air treatment units, specifically their filters, must be maintained and changed out periodically.

4 SUMMARY

Any mitigation strategy implementation should be carefully evaluated during and after installation to confirm that the design and permitting requirements, if any, were followed. It is important to conduct confirmation testing of mitigation measures to provide multiple verification criteria that the system is operating properly and is protective of human health and the environment.

REFERENCES AND ACRONYMS

The ITRC VI Mitigation Training web page includes lists of acronyms, a full glossary, and combined references for the fact sheets. The user is encouraged to visit the ITRC VI Mitigation Training web page to access each fact sheet and supplementary information and the most up-to-date source of information on this topic.

Operation, Maintenance and Monitoring/Exit Strategy Fact Sheet

ITRC has developed a series of fact sheets that summarizes the latest science, engineering, and technologies regarding the mitigation of vapors associated with vapor intrusion (VI). This process fact sheet describes the most common Operation, Maintenance, and Monitoring considerations for active mitigation systems, passive mitigation systems, rapid response, and environmental remedial technologies that need to be considered as part of any design process. In addition, a termination or exit strategy is discussed in this process fact sheet.

1 INTRODUCTION

After the mitigation strategy has been selected, designed, and commissioned, the operation, maintenance, and monitoring (OM&M) plan plays a key role in demonstrating the ongoing effectiveness of the vapor intrusion mitigation system (VIMS). This fact sheet describes the key considerations of OM&M. Complex mitigation strategies will typically require more complex OM&M procedures. The key to OM&M is to gather data to support maintaining the VIMS to operate as designed, with the goal that it remains effective in the short and long term until it is appropriate to implement an exit strategy.

Emerging technologies, such as aerobic vapor mitigation barriers (AVMB), are not addressed within this OM&M Process fact sheet. Please see the ***Aerobic Vapor Mitigation Barriers Technology Information Sheet*** for more information.

2 OPERATION, MAINTENANCE, AND MONITORING PLAN

An OM&M plan provides instructions for VIMS operation and upkeep and should be prepared for each installed VIMS. Details of a typical OM&M plan can be found in Section 6.3 and Section J.5 of in the ***2014 ITRC Petroleum Vapor Intrusion (PVI) document*** (ITRC, 2014). Information in these sections provides details for OM&M plan content that applies to the installed VIMS in general and is not specific to just PVI. The goals of OM&M are to verify performance of the VIMS during operation as compared to performance during system commissioning, and to inspect and repair any system malfunction (i.e., VIMS not operating to meet performance objectives or due to system equipment life expectancy). "In cases where testing shows the VIMS is not working and no defects in the system components have been identified, ITRC recommends re-evaluating the CSM to determine the presence or contribution of additional VOC sources." For example, volatile organic compound (VOC) transport via sewers or other preferential pathways may require further evaluation if this pathway had not been addressed previously.

The ***Operation, Monitoring, and Maintenance Checklist*** includes a list of considerations that may be reviewed, inspected, and/or measured during an OM&M site visit. A series of summary tables are included with the ***Operation, Monitoring, and Maintenance Checklist*** to record VIMS monitoring data (logs). Considerations during OM&M inspections may range from OM&M of both active and passive components to environmental remedial technologies that act as VI mitigation activities.

Table 2-1 identifies key OM&M considerations (discussed below in greater detail) and identifies their typical importance for OM&M for different approaches to address VI, including active systems (see ***Active Mitigation Fact Sheet***), passive systems (see ***Passive Mitigation Fact Sheet***), and environmental remediation technology (see

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Remediation and Institutional Controls as Vapor Intrusion Mitigation Fact Sheet). Depending on the situation, rapid response actions may or may not have an OM&M component. A rapid response action is typically temporary in nature and may be promptly replaced by a permanent VIMS.

Table 2-1 Summary of OM&M/exit strategy considerations and impact on mitigation approach.

OM&M consideration	Active approaches	Passive approaches	Remediation	Rapid response
Mitigation system operation				
Purpose of installation of VIMS	●	●	●	●
Brief description of VIMS	◐	◐	●	◐
Monitoring frequency & maintenance schedule	◐	◐	●	◐
VIMS start-up and shutdown				
Start-up procedure	●	◒	●	◐
Shutdown procedure	◐	◒	◐	◒
Building condition and use				
Heating ventilation and air conditioning (HVAC) system	◒	◐	◒	●
Windows, air intake, and building exhaust	●	◐	●	◒
Change in use	●	●	◒	◒
Physical modifications to building	●	●	◐	◒
Inspection of building's lowest floor	◒	◐	◒	◐
System inspection and performance metrics				
Visual inspection of system components	◐	◐	◐	◐
Identification and collection of performance measurements	●	◐	●	◐
Telemetry	◐	◒	◐	◒
Assessment of performance metrics	●	●	●	◐
Verification of compliance with permits	◒	◒	●	◒
Audible and visible alarms and labeling	◐	◒	◐	◒
System details and expected system operational life	◒	◒	◒	◐
Communication & reporting				
Building owner/tenant engagement	◐	●	●	●

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Community engagement	◒	◒	●	●
Regulatory reporting	◒	●	●	◐
Exit strategy				
Exit strategy	◐	●	●	◒
Key | High impact ● | Medium impact ◐ | Low impact ◒ |				

2.1 Mitigation System Operation

The considerations under the heading of Mitigation System Operations are elements of an OM&M plan and are included here to be consistent with the ***Operation, Maintenance, and Monitoring Checklist***. The OM&M plan is normally developed as part of the design phase.
Purpose of Installation of VIMS: A mitigation strategy is developed from an understanding of the conceptual site model (CSM). The strategy should be focused on interrupting the VI pathway(s) to mitigate VOC vapor migration from subsurface sources to receptors. Please see Figure 2-1 (Flow Chart) in the ***Conceptual Site Models for Vapor Intrusion Mitigation Fact Sheet***.

A mitigation strategy may include:

- Rapid response
- Active systems
- Passive systems and/or
- Environmental remedial technologies

An approach may include one of the above strategies or a combination of multiple strategies. The purpose of the VIMS should be clearly understood and summarized as part of the OM&M plan so that it is documented for future reference. Because of the potential long-term nature of VIMS operation, this summary will help stakeholders continue to understand the context of the VIMS and facilitate review of system performance over time.

Active Mitigation	**High Impact:** It is important to understand and continue to evaluate the purpose and objectives of an operating active VIMS, especially in terms of the occupation and use of the building in which it is installed. Understanding and periodically re-evaluating this purpose will facilitate the management of the VIMS and the decision points needed to progress to an exit strategy if appropriate.
Passive Mitigation	**High Impact:** The purpose and objectives of the VIMS and its role in protecting human life are essential to understanding the OM&M process, especially for passive mitigation where there are no mechanical components.
Environmental Remedial Technology	**High Impact:** Soil vapor extraction (SVE)/multiphase extraction (MPE) systems generally are implemented to remediate the site, with VI mitigation being an additional benefit. Therefore, the purpose of the system and its relationship to the VI mitigation need to be clearly established.
Rapid Response	**High Impact:** A rapid response approach is an interim VI mitigation approach (on a timescale of days to weeks) that may be appropriate prior to implementing a long-term mitigation strategy. Approaches include administrative or engineering controls. Engineering controls may warrant an OM&M component.

Description of VIMS: OM&M plans should include a brief description of the type of VIMS that has been installed (e.g., sub-slab depressurization, passive barrier, etc.), as well as a summary of key components, plans, and as-built drawings. Operational and inspection details will vary depending on the type of VIMS installed. However, the OM&M plan should provide enough detail to answer these questions:

- What should the VIMS look like when it's working?
- How can I tell if it may not be working properly?

Active Mitigation	**Medium Impact:** The description of the VIMS in the OM&M plan is a starting point for the other OM&M activities detailed in the plan and is useful to set the context of the operating system. This information should also be captured in a postconstruction completion report or as-built report that may also be referenced in the OM&M plan.
Passive Mitigation	**Medium Impact:** Understanding the components and purpose of the VIMS is part of the OM&M plan and is essential to a proper inspection.
Environmental Remedial Technology	**High Impact:** Providing the documentation of the design and completion of an SVE/MPE system is an important element in conducting the system OM&M. This documentation should also be referenced in the OM&M plan.
Rapid Response	**Medium Impact:** Certain rapid response approaches that include engineering controls, such as HVAC modification or indoor air treatment, warrant an OM&M component to verify that the response meets or continues to meet the interim VI mitigation objectives. OM&M documentation should address mitigation components that need inspection or change-out (e.g., carbon media for air purifying units [APUs]) and, as needed, how performance monitoring will be conducted.

Monitoring Frequency and Maintenance Schedule: Following successful system start-up, a routine inspection and maintenance schedule is typically followed. Inspection frequency may be recommended in state guidance. Typically, system inspections are more frequent during the first year of operation (e.g., quarterly) and then are reduced for subsequent years (e.g., semi-annual for second year of operation and then annually thereafter). It may be useful to consider the average lifetime of the system components when determining monitoring frequency (more frequent monitoring based on the age and potential failure of the components). If an alarm or telemetry system is installed, this may reduce and/or replace the number of in-person inspections necessary, depending on the type of telemetry and controls that are installed. A system monitoring schedule is usually detailed in the OM&M plan and may include provisions to update (e.g., reduce) the monitoring frequency based on data collected over time and provisions to complete unscheduled inspections if outside factors influence system operation (e.g., floods, earthquakes, building modification) (ASTM E1745). Should such an event result in detrimental impacts to the VIMS, shutdown of the VIMS to make repairs followed by restarting the VIMS and resumption of the initial monitoring program may be necessary.

Active Mitigation	**Medium Impact:** Monitoring frequencies are important to establish in the OM&M plan so that stakeholders (e.g., regulators, responsible parties, property owners) can agree on timing and access. It should be noted though that because VIMS may operate for a long time, the monitoring frequency may change and be reduced from the schedule set in the original OM&M plan. This should be documented in OM&M plan updates or addendums as appropriate. Maintenance schedules for active VIMS are primarily

	driven by system components that have manufacturer maintenance requirements and should be documented in the OM&M plan.
Passive Mitigation	**Medium Impact:** Monitoring frequency and maintenance schedule are parameters that are normally contained in the OM&M plan and developed during the design phase. Maintenance is less important to passive VIMS than active or environmental remediation technologies that typically involve mechanical devices that need occasional repairs.
Environmental Remedial Technology	**High Impact:** SVE/MPE systems typically include treatment and discharge of the extracted streams. They require that OM&M be performed on a regular basis both to ensure effectiveness and to satisfy the discharge permit requirements.
Rapid Response	**Medium Impact:** Monitoring frequency is dependent on the nature and time frame of the interim mitigation and specific requirements of the mitigation components (e.g., HVAC inspection, APU carbon change-out, routine inspection if floor cracks or other pathways were sealed, etc.).

2.2 VIMS Start-up and Shutdown

Routine maintenance or unscheduled maintenance, such as a malfunction or other problem with the VIMS, may require that a VIMS be temporarily shut down to make repairs and then restarted. This discussion does not involve the normal start-up during the initial commissioning of the VIMS.

Start-up Procedure: Prior to start-up of the VIMS, it is important to inspect building conditions, the baseline condition of the VIMS, applicable permits, and some of the key baseline data. Understanding these elements will help the VIMS to meet its design objectives.

Building conditions, such as electrical connections, cracks and holes in the building floor, integrity of the exhaust stack, and the presence/absence of water seepage on the lowest floor of the building, should be visually inspected and recorded. The integrity of the VIMS components (e.g., piping, valves, blowers, etc.) should be visually inspected and documented. If system malfunction was the reason for the shutdown, the identified malfunction and the replacement and/or repair should be recorded. If sub-slab depressurization (SSD) technology is proposed, some of the key baseline data such as vacuum/pressure differential; airflow rate; and sub-slab indoor air and outdoor ambient air parameters might need to be collected and recorded following system restart. An inspection log that lists key inspection items may include inspector, start-up date, items inspected, state of installed VIMS before operation, parts replaced, parts repaired, expected lifetime of VIMS, and manufacturer's specifications. Building occupants and other stakeholders should be notified of a system shutdown (discussed below), the subsequent start-up, and confirmation that applicable performance criteria are being met.

Active Mitigation	**High Impact:** Following system maintenance or malfunction, an active VIMS will need to be restarted and parameters collected to document that the VIMS is still meeting its design objectives. Depending on the complexity of the VIMS, this may range from returning power to the VIMS and documenting airflow rate and vacuum to more involved start-up procedures that involve multiple system documentation parameters. The OM&M plan should document the start-up process specific to the installed VIMS. The start-up procedure may also need to consider the timing of a system restart, depending on the potential risk to receptors (i.e., faster response and restart if potential for immediate impact).

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Passive Mitigation	**Low Impact:** Discussions of system start-up and shutdown are normally associated with mechanical devices (of which passive VIMS have none).
Environmental Remedial Technology	**High Impact:** SVE/MPE systems are relatively complex, as they include both the mechanical elements and treatment of the extracted streams. Therefore, the system start-up should be used to verify the effectiveness and compliance with the discharge permits, as well as to make the necessary adjustments.
Rapid Response	**Medium Impact:** Start-up procedures are dependent on the type of interim mitigation that is implemented. For instance, if HVAC adjustments are implemented, there should be some initial period to verify that these adjustments are effective and did not have unintended side effects (see also discussion in Section 2.3).

Shutdown Procedure: The shutdown procedure described here is related to shutdown of a VIMS during otherwise continued operation of the VIMS. For permanent shutdown of a VIMS please review the Exit Strategy section below. Shutdown of a VIMS during the normal course of system operation would typically occur on a schedule due to needed maintenance or due to property owner needs for maintenance on other parts of the building. Building occupants and other stakeholders should be notified of the planned VIMS shutdown as appropriate. Prior to a scheduled system shutdown, it may be appropriate to collect and record system parameters to understand and evaluate pre-shutdown conditions to compare to measurements collected following system restart. Shutdown of a VIMS may involve turning off the power to the VIMS and lock out/tag out of the power source, if appropriate. It may also be appropriate to close off suction points or vents to the subsurface, depending on the system design and the length of time the VIMS will be off. If the VIMS shuts down on its own due to a system malfunction or power failure, it may still be appropriate to complete portions of the shutdown procedure if the VIMS will need to remain off for a period of time.

Documentation of the reason for system shutdown, the parameters collected, and the activities completed as part of the shutdown procedure should be documented in an inspection or OM&M log.

Active Mitigation	**Medium Impact:** Shutdown procedures should be followed to document that an active VIMS is shut off safely. Formal procedures may not be necessary if a VIMS is turned off for a short period of time. The nature and complexity of the VIMS as well as the original purpose of the VIMS will determine the details of shutdown procedures and the duration of a shutdown that would warrant execution of the procedures.
Passive Mitigation	**Low Impact:** Discussions of system start-up and shutdown are normally associated with mechanical devises (of which passive VIMS have none).
Environmental Remedial Technology	**Medium Impact:** Shutdown procedures should be specified in the OM&M plan and should be followed to document that an SVE/MPE system is shut off safely.
Rapid Response	**Low Impact:** Shutdown procedures and the associated level of detail are dependent on the type of interim mitigation that is implemented. For instance, an APU may be temporarily turned off for cleaning or carbon change-out; however, the APU operator manual may be sufficient documentation for this effort.

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2.3 Building Condition and Use

VIMS design should be based on the building conditions and performance goals for the current or anticipated use of the building. Changes in the building conditions may compromise the effectiveness of the VIMS. A change in building use may be incompatible with the performance goals of the VIMS. Thus, the OM&M plan should include evaluation of changes in building conditions and use specific to the VIMS design**.**

HVAC System: Modifications to the building HVAC system should be evaluated to document that the modifications have not had a negative impact on VIMS effectiveness. One type of mitigation strategy used in commercial buildings functions by adjusting the HVAC to pressurize the indoor space relative to sub-slab, or by increasing the air exchange rates to reduce concentration of indoor contaminants, as indicated in the ***HVAC Modification Technology Information Sheet***. Such VIMS require regular air balancing and maintenance to ensure continued effectiveness throughout the building as well as over time. For VIMS where HVAC is used as the mitigation strategy, modifications to HVAC systems without consideration of its dual purpose as a VIMS may reduce the effectiveness of the VIMS. Institutional controls (ICs) may be in place to govern changes in the building's HVAC system, depending on how integral operation of the system is to VIMS effectiveness.

Active Mitigation	**Low Impact:** Operation of the HVAC system should be taken into account during active system design such that the VIMS will meet design objectives under the normal operating range of the HVAC system. Major updates or changes in the HVAC system (e.g., adding a restaurant with a large kitchen hood to a building) will need to be evaluated as they may have an effect on VIMS operation, but most minor seasonal adjustments in HVAC or buildings with little to no formal HVAC (i.e., residential homes) will not affect VIMS operation.
Passive Mitigation	**Medium Impact:** Depending on the role of the HVAC system for the passive mitigation operation, changes to the HVAC may have low to high impact on the effectiveness of the passive VIMS. See the ***Building Design for Passive Vapor Intrusion Mitigation Technology Information Sheet***.
Environmental Remedial Technology	**Low Impact:** SVE/MPE systems are typically little affected by the operation of the building HVAC system. However, for industrial/commercial facilities, an assessment of the influence of the HVAC operation may need to be conducted.
Rapid Response	**High Impact:** See above for specific considerations related to HVAC adjustments. Potential interaction between other interim mitigation approaches (e.g., APUs, ad hoc ventilation) and the HVAC system should also be considered.

Building Ventilation: Buildings should be evaluated for any modifications that change the separation distance between VIMS vent stacks and building entryways (doors, windows). Appropriate separation distances should be maintained to avoid re-entrainment of VOC vapors from the effluent to indoor air. See Section J.3.3 of ***Appendix J in the 2014 ITRC PVI document*** and ANSI/AARST: SGM-SF-2017 (AARST, 2017); RMS-MF-2018 (AARST, 2018a); RMS-LB-2018 (AARST, 2018b); CC-1000-2018 (AARST, 2018c). ICs may be in place to govern changes in the building and the necessity to maintain certain distances from existing VIMS equipment.

Active Mitigation	**High Impact:** Re-entrainment of vented soil gas is an important consideration to check if building modifications are planned or observed during a site visit. The appropriate location of an active system's vent stack compared to existing windows, air intakes, and building exhausts will be verified during system design and installation. Although it may be infrequent that a building will go through a major renovation that would add these components to the building structure, it is important that these items are inspected if building modifications are noted.
Passive Mitigation	**Medium Impact:** Re-entrainment of vented soil gas is an important consideration to check if building modifications are planned or observed during a site inspection.
Environmental Remedial Technology	**High Impact:** Location of an SVE/MPE system's vent stack should be selected away from the windows, doors, and other openings that may cause entrainment of the exhaust into buildings, in accordance with applicable regulations. The OM&M of the system should include periodic assessments of the compliance with this requirement, especially if the building has undergone modifications.
Rapid Response	**Low Impact:** Generally not applicable. However, any modification to an HVAC system should be designed such that HVAC air intakes are not located near an exhaust vent or stack.

Change in Use: A change in the building use that results in greater exposures may result in the VIMS being no longer sufficiently protective for the new use. For example, a VIMS designed to be protective for a commercial use may not provide acceptable VI mitigation for a change to a residential use or to a school or day-care center. Similarly, a change in the type of commercial use—for example, where a dry-cleaning operation has been replaced by another type of commercial use—may warrant re-evaluation of the effectiveness of the VIMS. ICs may be in place to govern such changes in use and should be consulted as a source of information on whether a change in the building use is acceptable. Whenever a change in use is observed, the VIMS design and mitigation goals along with air monitoring results should be reviewed to evaluate whether the change in use is acceptable.

Active Mitigation	**High Impact:** In addition to the details noted above an active VIMS may be designed to operate under only a portion of a building based on current use in specific areas of a building (e.g., no VIMS in parts of the building that are unoccupied or used only for storage). Building use changes will be important, as the VIMS may need to be expanded to cover new areas of the building previously not mitigated.
Passive Mitigation	**High Impact:** Any change in use at a building can be a significant factor that impacts the design objectives of the passive VIMS (e.g., changing a building use from a dry cleaner to a day care).

Environmental Remedial Technology	**Low Impact:** The SVE/MPE systems are typically operated for relatively short time frames; therefore, major changes in building use during system operation are not common. However, should they occur, system modifications may be required.
Rapid Response	**Low Impact:** Building use would generally not be expected to change within the relatively short-term time frame of interim VI mitigation. Otherwise, the response would need re-evaluation.

Physical Modifications to Building: Some modifications in the building structure may affect the VIMS, including physical modifications to the building or to the surrounding property.

- Building additions, partial demolition, or significant building renovations may affect VIMS effectiveness. Typically, any building additions should be subject to the same requirements for VI evaluation and possible mitigation as the original building.
- Significant interior renovations, including division of spaces that had been open, may also affect the VIMS. A VIMS designed based on building pressurization or air exchange rates may be especially vulnerable to reconfiguration of the interior of the building.
- A rise in the water table such that the water table encroaches on the building slab will reduce the effectiveness of some passive VIMS, as well as SSD and sub-slab ventilation (SSV) systems. Indications of water level concerns with the VIMS include moisture on the lowest floor of a building. For sites with a dewatering system, failure of the dewatering system may be the source of the problem.
- Structural or foundation problems in the building should trigger an evaluation of impacts to a passive barrier that may have been installed above or beneath the building slab.
- Changes in surrounding property conditions may affect concentration and migration of contaminants in soil gas beneath the building and the effectiveness of the VIMS. Such changes may include new construction or paved areas in close vicinity to the building, storm water management changes, and excavation or filling activities.
- Major improvements in building insulation may reduce air exchange and result in greater accumulation of indoor air contaminants than anticipated in the original VIMS design.
- Remodeling to add new carpet, cabinetry, or other furnishings inside the building may introduce indoor sources of contaminants that could affect indoor air monitoring results. This does not affect the operation of the VIMS but may confound the analysis of data collected to evaluate VIMS effectiveness. This can be a critical point for passive VIMS where indoor air sampling is a primary performance measurement. Documentation of potential background sources of VOCs related to remodeling or other changes should be recorded in a log for later evaluation of indoor air results.

Active Mitigation	**High Impact:** Modifications to the building will have a significant effect on VIMS operation, depending on the type and level of the building modification and the specific design of the VIMS installed. Generally, physical building modifications in commercial or industrial buildings where the VIMS may have been designed to affect a portion of the building will be of greater impact than physical modifications at a residential property.
Passive Mitigation	**High Impact:** Modifications to the building or inclusion of new furnishings (carpeting, furniture, window treatments) can significantly impact the effectiveness of a passive VIMS or the performance measurements (e.g., indoor air sampling).

Environmental Remedial Technology	**Medium Impact:** The SVE/MPE systems are typically operated for relatively short time frames; therefore, major building modifications during system operation are not common. However, should they occur, system modifications may be required.
Rapid Response	**Low Impact:** Physical modifications to the building would generally not be expected to occur within the relatively short-term time frame of interim VI mitigation. Otherwise, the response would need re-evaluation.

Inspection of Building's Lowest Floor: Inspection of the lowest floor of a building is often an important component of OM&M, especially where a passive barrier has been installed either above the slab (epoxy coating) or below the slab (asphaltic membrane, etc.) (see ***Passive Mitigation Fact Sheet***). Close inspection of the bottom floor of a building can provide information on the condition of the passive barrier and any preferential pathways for VI. Floors with epoxy coatings should be examined for cracks or peeling. All utility penetrations should be inspected for cracks, gaps, or seal failures. Additionally, installation of any new utilities or other floor penetrations should be noted and inspected for proper sealing.

The presence of moisture and/or effervescence on the lowest floor of a building may be an indication of a problem with a passive barrier or groundwater near the building slab. Some VIMS require airflow below the building (for both passive and active VIMS), so the presence of shallow groundwater may require a dewatering system or other measures to control groundwater table elevation. OM&M should include evaluation to confirm that the control measures being implemented are working properly.

Active Mitigation	**Low Impact:** As noted above, inspection of the lowest building level for water should be considered during site visits. These conditions will usually be understood and accounted for during the design and installation processes and are therefore of lower impact as compared to the other considerations described in this fact sheet.
Passive Mitigation	**Medium Impact:** The presence of water or new cracks in the floor/wall can negatively impact sub-slab airflow in passive mitigation.
Environmental Remedial Technology	**Low Impact:** Condition of the floor slab as well as the groundwater table elevation are typically accounted for during the selection and design of the SVE or MPE system. Therefore, their impact on the system OM&M should be low.
Rapid Response	**Medium Impact:** Inspection of a building lower floor slab is dependent on the nature and time frame of the interim mitigation. For instance, if preferential pathway sealing was conducted on the lower floor as part of the rapid response approach, then follow-up routine inspections may be needed to verify that there is no evidence of damage to the seals or repairs.

2.4 System Inspection and Performance Metrics

Inspection and performance metrics to be detailed in an OM&M plan and reviewed during site visits may include the following:

Visual Inspection of System Components: Conduct a visual inspection of accessible system piping and pipe seals, including membrane seals (if applicable), connections, etc. Identify significant cracks/gaps or changes in the system configuration.

Active Mitigation	**Medium Impact:** This consideration is a typical component of active VIMS site inspection visits. Visual inspection of system components, specifically vent piping, is particularly important in commercial and industrial buildings where building use (e.g., forklift use) may cause the components to be bumped or hit on a continual basis.
Passive Mitigation	**Medium Impact:** A visual inspection of the system components is a standard inspection step irrespective of the type of VIMS. Without mechanical devices or externally mounted vertical piping, passive VIMS tend to have fewer visual components compared to other VIMS.
Environmental Remedial Technology	**Medium Impact:** Visual inspection of the system components for typical wear and tear or damage caused by the use of the building should be part of the system OM&M.
Rapid Response	**Medium Impact:** Depending on time frame of interim mitigation, routine visual inspection is needed to verify that rapid response engineering controls continue to operate as intended.

Identification and Collection of Performance Measurements: OM&M performance measurements should be selected during the design phase based on the specific mitigation strategy used and what information is needed to determine whether the strategy is operating as intended or the VIMS is operating as designed. For passive VIMS that consist of physical barriers, there may be limited performance metrics to be collected and monitored during OM&M site visits other than visual inspections already discussed or the collection of air samples. However, passive technologies that include VIMS that provide for some sub-slab air movement (e.g., aerated floors in new construction or passive venting) may consider some of the criteria detailed below as appropriate. For environmental remedial technologies, the performance measurements will be focused on the OM&M parameters appropriate for the chosen remedial technology. For rapid response technologies, performance measurements may include air sampling (detailed below) and manufacturer recommended parameters detailed by the equipment used during the rapid response action. For active VIMS, there are multiple different performance criteria, the most common of which are detailed below. These parameters are typically collected after initial start-up and commissioning during post-installation verification to determine if a VIMS meets its design basis and to establish baseline values. See the ***Post-Installation Fact Sheet*** for a more detailed discussion of the various performance measurements.

- System vacuum and airflow—System vacuum and airflow readings collected over time can be used to verify that system operation is meeting the design specifications. Flow velocity measurements are usually taken using a critical orifice, thermal anemometer (i.e., hot wire anemometer), vane anemometer, pitot tube, or similar devices. Vacuum can be measured with a U-tube manometer, differential pressure gauge, or digital manometer.

- Differential pressure measurements/pressure field extension (PFE)—Some active VIMS (such as SSD systems, SMD systems, and to some extent SSV systems) work by creating a negative pressure differential between the indoor air and the air beneath the building slab. Differential pressure measurements are used to confirm PFE across the mitigated area. Some telemetry systems may also be used to measure and remotely monitor differential pressures. Telemetry systems, discussed below, can be used to provide confidence in operating systems that are achieving lower levels of vacuum influence relative to baseline fluctuations or seasonal drift even if these values are lower than the applicable state's generic guidelines.

- Sub-slab flow velocity—For SSV and crawlspace ventilation (CSV) systems, flow velocity is a useful performance criterion. Flow velocity indicates that vapors are moving within the subsurface or within the crawlspace and allowing for the dilution and reductions in concentrations to be protective of indoor air.

- Sub-slab, indoor air, outdoor ambient air sampling—Collection of soil vapor and/or indoor/outdoor air samples during OM&M site visits may be another line of evidence to document continued VIMS success. With passive VIMS, analytical sampling will likely be more common to assess the effectiveness of the VIMS (compared to active VIMS).

- Photoionization detector (PID) readings—For SSV, and for some SSD, SMD, and passive VIMS, it may be useful to demonstrate that the subsurface ventilation provided by the VIMS is reducing soil gas concentrations to be protective of indoor air cleanup levels. PID measurements may be collected at sampling points in the slab or from the vent system piping. Although PIDs provide readings of total VOCs and not compound-specific concentrations, measurements of total VOC concentrations over time may be a useful indicator of the consistency of system operations over time and whether/when to collect samples for more detailed analysis.

- Mass loading rate—Mass loading rates (calculated using system flow rate readings and VOC concentrations measured in the system's vent stack) can be calculated at some frequency through the life span of the VIMS even if not completed during each routine OM&M site visit.

- Smoke and tracer gas testing—Smoke and tracer gas testing is an option to be used to test airflow patterns.

- Other parameters—VIMS designed for mitigation of PVI may also be monitored for oxygen, carbon dioxide, and methane. The consideration for monitoring of methane or for other explosive gases is important if the VIMS was not designed to address the presence of explosive gases. Additional monitoring parameters may also be specified by the system component manufacturer. For active VIMS, it may also be useful to monitor energy usage to document increased power consumption (and increased energy bills) due to an operating active VIMS.

Active Mitigation	**High Impact:** The parameters detailed in this section are important to document that an active VIMS continues to meet its design objectives. Depending on the building type and the specific active mitigation strategy chosen, one or more of the performance measurements listed above should be considered for collection.
Passive Mitigation	**Medium Impact:** While the importance of collecting performance measurements is significant to the evaluation of the system performance, most of the measurement options are limited for passive VIMS.
Environmental Remedial Technology	**High Impact:** Performance metrics are key in assessing the effectiveness of the SVE/MPE system in providing effective VI mitigation and in evaluating the progress of the remediation.

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Rapid Response	**Medium Impact:** The collection of performance measurements should be considered to verify that a rapid response engineering control is performing as intended; the need for and type of measurements will depend on the type of interim mitigation approach, severity of conditions (e.g., elevated contaminant concentrations), and sensitivity of the building of interest (e.g., school, day care).

Telemetry: Telemetry is the remote source transmission of data from a measuring instrument to a recording device typically via telephone lines or other wireless equipment. Telemetry may be useful for passive mitigation for those strategies that include air movement (e.g., aerated floors or passive venting), for rapid response technologies (such as air filtration units or HVAC modifications), and for environmental remedial technologies and active mitigation. Telemetric monitoring can include basic systems that send alerts related to overall operation status (i.e., "on" or "off") to more involved systems that allow for controlling the system operation remotely. For active mitigation, telemetry can be advantageous because VIMS performance metrics are variable and subject to weather and building pressure events that may affect the data collected at the time of the OM&M visit. If telemetry is used to monitor more detailed parameters (e.g., active mitigation parameters such as differential pressure and/or system flow and vacuum), then frequency of on-site visits may be able to be reduced or they may be unnecessary unless manual system modifications or repairs are needed. This is particularly advantageous from VIMS that may be located in remote areas or where access is challenging.

There are three distinct categories of telemetry for VIMS. They are direct fault monitoring, continuous performance monitoring, and continuous monitoring with active system management. All three technologies are designed to notify managing parties of a fault in system operation. The types of telemetry and their advantages and limitations are summarized in Table 2-2.

Table 2-2. Advantages and limitations of various categories of telemetry.

Telemetry type	Description	Advantages	Limitations
Direct fault monitoring	Direct fault monitoring most commonly monitors the vacuum generated by the blower by using a mechanical vacuum switch or other means of closing a circuit. Once closed, the circuit actuates a callout fault notification to the managing party. The calls can be placed using the building's landline phone system or an independent cellular network.	• Rapid fault notification • Lower hardware and installation cost • Good for sites with a limited number of blowers • Messaging can be preprogramed by circuit to indicate the type of fault • Can use the building owner's landline phone system or prepaid wireless phone • Battery backup can notify a manager of a power failure • A visual light and/or audio alarm indicator may be integrated	• Single direction notification • Contact messaging is generally limited to a phone call • No system performance data recording, transmission, storage, or analysis • May rely on building occupants' landline phone service or upkeep of annual cellular fees • Equipment may require technology upgrades

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Continuous performance monitoring	Continuously monitors selected system metrics; can monitor open loop or closed loop circuitry and provide electronic notification when the system has failed or if selected metrics are performing outside of a predetermined range. The functions can vary from providing electronic notification of loss of vacuum as indicated by actuating a mechanical switch to sending a message or continuous monitoring and transmitting performance data, which may be retrieved from a stored data set.	• Rapid fault notification • Lower hardware and installation cost than continuous monitoring with active system management • Good for sites with a limited number of blowers • Event messaging can be email or text • Event notification can include multiple parties • Multiple alarm thresholds can be programed for a single sensor event • Can use the building owner's Wi-Fi or independent wireless network • Site data can be time paired with local weather data • Issuance of automated monthly or as needed reports • Offsite encrypted cloud-based data storage • Battery backup can notify a manager of a power failure • A visual light and/or audio alarm indicator may be integrated	• The hardware and sensor equipment cost more than for direct fault monitoring • May rely on building occupants' Wi-Fi service or may require a third party to provide internet service to the site to operate the equipment • May require an annual data transmission and storage contract • Cellular modems will require sufficient signal strength and bandwidth • Installation generally requires a trained technician • An annual on-site inspection will be required to verify sensor and transmission equipment performance • Equipment may require technology upgrades
Continuous monitoring with active system management	Continuously monitors multiple system metrics through closed loop circuitry; provides electronic notification when the system has failed or if selected metrics are performing outside of a predetermined range. The consultant can remotely access response-driven controls and change performance metrics such as applied vacuum, airflow, and pressure differential set points to achieve new thresholds of	• Rapid fault notification • Good for sites with multiple blowers • Event messaging can be email or text • Event notification can include multiple parties • Multiple alarm thresholds can be programed for a single sensor event • Can be operated using owner's Wi-Fi or independent wireless network • Some on-site control panels are equipped with touch screens to display performance metrics in real time • Site data can be time paired with local weather data • Issuance of automated monthly or as needed reports	• The hardware and sensor equipment cost more than direct fault monitoring and continuous performance monitoring • May rely on building occupants' Wi-Fi service or may require a third party to provide internet service to the site to operate the equipment • May require an annual data transmission and storage contract • Cellular modems will require sufficient signal strength and bandwidth • Installation will require a trained technician (may need licensing by the equipment manufacturer) • An annual on-site inspection may be required to verify sensor

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	performance. Performance data may be accessed live or retrieved from stored data sets for analysis.	• Automated response driven system performance metrics can be viewed in real time through a web portal • Performance set points such as sub-slab pressure differentials, applied vacuum, and airflow as well as gate valve positions can be preprogrammed and changed remotely through a web portal • May be possible to use energy savings calculators to track the benefits of response-driven controls • Data storage and access to historical data • Remotely operated controls limit technician foot traffic though secure or hard-to-access areas • Battery backup can notify a manager of a power failure • A visual light and/or audio alarm indicator may be integrated	and transmission equipment performance • Equipment may require technology upgrades

Active Mitigation	**Medium Impact:** A telemetry system is not needed or warranted in every active VIMS, but even simple telemetry in a single residential house can provide real-time access to understand if a VIMS is on or off. Depending on the telemetry used, it can provide value-added system effectiveness by allowing for remote monitoring and in some cases remote control over system operations. In buildings where the VIMS is difficult to access or for systems located a significant distance from the responsible party, telemetry has an important role in VIMS operation and performance.
Passive Mitigation	**Low Impact:** Telemetry has limited application to passive VIMS compared to active mitigation.
Environmental Remedial Technology	**Medium Impact:** A telemetry system is useful in providing real-time data on the system operation and in identifying the need to perform OM&M activities. However, the relative complexity of the SVE/MPE system, including the need for sampling, requires that in-person OM&M also be performed.
Rapid Response	**Low Impact:** Generally not applicable (except for sophisticated HVAC systems).

Assessment of Performance Metrics: As part of OM&M, performance measurements are collected during periodic inspections to assist with the assessment of VIMS performance. Is the VI mitigation strategy operating as intended and designed? The selection of the appropriate performance measurement is typically determined during design, as indicated in the ***Design Considerations Fact Sheet***. The performance measurements are determined in part based on the type of VIMS that is implemented—active mitigation, passive mitigation, or environmental remedial technology. Performance measurements have limited application to rapid response due to the nature of the short-term action (usually replaced or augmented by a more permanent VIMS). Baseline values for these performance measurements are established during system commissioning when the VIMS is initiated. See ***Post-Installation Fact Sheet***.

Evaluation of periodic results from performance measurements is needed to ascertain if the data are consistent with the baseline values over time. It is reasonable to assume that variations in the baseline values or data trends may occur. Some state agencies may establish what variation is acceptable prior to conducting a re-evaluation of the VIMS. For the New Jersey Department of Environmental Protection (NJDEP, 2018), anything above a 20% variation triggers supplemental actions to assess the effectiveness of the VIMS at meeting the original design goals.

Active Mitigation	**High Impact:** Comparison of the performance measurements to the baseline values is a key line of evidence to document that the active VIMS is effective at meeting its design objectives. As subsurface conditions may vary over time, deviations of performance measurement from baseline values may occur. Depending on the amount of deviation, additional measurements may be needed to document that the VIMS is still effective. Updates to the baseline values or the range of acceptable performance metrics may be needed and documented in a revised OM&M plan or OM&M plan addendum.
Passive Mitigation	**High Impact:** Comparison of the performance measurements to the baseline values is the primary method to assess the effectiveness of the passive VIMS to meet its design objectives.
Environmental Remedial Technology	**High Impact:** Analysis of the performance measurements is a key line of evidence to document that the SVE/MPE system is effective at meeting its design objectives. As subsurface conditions may vary over time, deviations of performance measurement from baseline values may occur. Depending on the amount of deviation, additional measurements may be needed to document that the system is still effective. Updates to the baseline values or the range of acceptable performance metrics may be needed and documented in a revised OM&M plan or OM&M plan addendum.
Rapid Response	**Medium Impact:** Performance metrics evaluation efforts in a rapid response setting depend on the type of interim mitigation approach, severity of conditions (e.g., elevated contaminant concentrations), and sensitivity of the building of interest (e.g., school, day care).

Verification of Compliance with Permits: There are two main types of operational permits for which compliance needs to be verified:

- emission permitting
- control permitting

As detailed in Section J.3.2 of ***Appendix J in the 2014 ITRC PVI document*** (ITRC, 2014), air permits and emission controls on active VIMS must be considered for each project based on the system design, the CSM, and the applicable state, federal, or local regulations. The regulations are generally associated with the Clean Air Act or local ordinances that have been set by statute. In some states, subsurface VIMS may be exempt from or do not require permits. More detail is provided in Appendix J.3.2.

Active Mitigation	**Low Impact:** Compliance with permits is typically set during or shortly after active system commissioning. Unless major modifications to the VIMS are planned, this consideration will have a lower impact on OM&M than other considerations detailed in this fact sheet.
Passive Mitigation	**Low Impact:** The likelihood of emission permits being an issue with passive VIMS is low.
Environmental Remedial Technology	**High Impact:** SVE/MPE systems typically include permits for discharge of the extracted streams after treatment. System OM&M should include frequent assessment of the compliance with the applicable discharge permits. The treatment system may need to be modified if the permit requirements are not met.
Rapid Response	**Low Impact:** Generally not applicable.

Audible/Visual Alarms and Labeling: Verify batteries are replaced in alarms (or power remains present to plugged-in alarms), U-tube manometers are visible, properly connected, and marked with operating set points, etc. Verify placards with information for contact person in the event of an alarm condition are visible, properly secured, and legible.

Active Mitigation	**Medium Impact:** These considerations are typical components of a site inspection visit for an active VIMS. Alarm verification is important to document, as this will likely be the way the responsible party is notified in the event that a VIMS stops working.
Passive Mitigation	**Low Impact:** Audible or visual alarms are not typically associated with passive VIMS. However, labels can be required, but are unlikely to represent a problem during OM&M inspections.
Environmental Remedial Technology	**Medium Impact:** These considerations are typical components of a site inspection visit for SVE/MPE systems. Alarm verification is important to document as this will likely be the way the responsible party is notified in the event that a system stops working.
Rapid Response	**Low Impact:** Generally not applicable (except for sophisticated HVAC systems). Consider labeling APU with contact information for repair and other operational issues.

System Details and Expected System Operational Life: An OM&M plan should include specifications for equipment used within the VIMS, system or equipment warranties, and system maintenance schedules, as well as installer contact information for future questions or maintenance. If the VIMS will be maintained by another entity following installation, then contact information for the person or company responsible for the VIMS should be recorded and updated in the OM&M plan as needed.

The OM&M plan should take into consideration the expected lifetime of that VIMS. If a site is undergoing other remedial activities to address the vapor source(s), the operational life necessary for the VIMS may be limited. This may exclude the need to consider the operational life of system components. In addition, the OM&M of a VIMS may also consider the exit strategy (see Exit Strategy below) for the VIMS and when system shutdown can be recommended or the VIMS turned over to other uses. In some cases, a pre-emptive VIMS may be installed out of an abundance of caution when it may not be known whether it is needed. If initial monitoring of this type of VIMS indicates that the mass removal rate is trivial even though the pressure field extension is adequate, then the operational life of the VIMS may be as short as a pilot-scale test.

Active Mitigation	**Low Impact:** It is important to consider the operational life of system components to help plan for repairs and replacements. However, system OM&M may be dictated by other considerations such as access restrictions, stakeholder engagement, or other remedial activities at the site. Thus this consideration may have a lower impact than others in this fact sheet.
Passive Mitigation	**Low Impact:** With passive VIMS, there are no mechanical devices that are the source of most discussions about system operational life.
Environmental Remedial Technology	**Low Impact:** SVE/MPE systems are typically operated for a limited time. Therefore, in most cases the major system elements do not require replacement and general system OM&M is sufficient.
Rapid Response	**Medium Impact:** The type of information to consider (e.g., equipment lifetime and need for replacement) is dependent on the type of interim mitigation and expected time frame. For instance, an APU may require carbon change-out to remain effective; however, change-out may not be needed if interim mitigation will cease before the carbon media is exhausted.

2.5 Communication and Reporting

Like discussions with property owners or tenants during the design and installation phase, OM&M of a VIMS typically requires continued contact with property owners or tenants. OM&M of a passive VIMS may require significantly less contact, but contact nonetheless. In some cases, long-term OM&M of a VIMS and required reporting may eventually transition from the responsible party to the property owner, tenants, or property manager. The OM&M plan (or plans) needs to be written for potentially multiple different audiences to allow for understanding by people with varying backgrounds, including the community as a whole.

Communication with the regulatory oversight agency during the OM&M phase is typically limited to required reporting. Reporting requirements, including frequency, will vary depending on the state and agency jurisdiction and should be detailed in the OM&M plan.

Building Owner/Tenant Engagement: Site visits for OM&M will require access to the property and likely access inside the building. Routine OM&M may include actions such as recording manometer readings; inspecting system components; or inspecting the building for new cracks, changes in use, construction, or HVAC modifications. Occasional follow-up actions may also eventually be necessary to repair, replace, or recommission a VIMS or individual system components. It may be appropriate to provide the building owner/tenant with a copy of the results from an OM&M inspection.

Contact information for the property owner and for property access should be included in the OM&M plan and be updated as appropriate (e.g., after a property transfer). Timing and frequency of visits should be discussed with the property owner prior to documentation in the OM&M plan. A copy of the OM&M plan as well as other relevant documents, such as component manuals, may be provided to the property owner even if they are not responsible for system operation. Depending on the property owner/tenant, electronic copies of the documents may be an alternative to hard copies.

Communication with the property owner on their expectation of the design, if any, early in the design process will help to avoid problems during installation and, most importantly, during the long-term OM&M. Incorporation of certain types of telemetry in the design may limit or reduce the need for frequent property visits.

If the intent is to eventually transition OM&M of a VIMS to the property owner, which may change over time, it is *critical* that adequate instruction (both visual and written) be prepared for the intended audience. For example, an active VIMS in a single-family residence may be designed, installed, commissioned, and OM&M performed by the responsible party for a given time (e.g., 2 years). A property owner is generally not accustomed to engineering diagrams or scientific nomenclature. While complex diagrams and language in an OM&M plan may be appropriate for use by the responsible party's environmental consultant during the first years of operation, it is not appropriate for the end user—the property owner. In addition, if the property owner sells the home after a period of time (e.g., 5 years), the new property owner will need adequate instruction and documentation available to learn the purpose and requirements of the VIMS. The purpose of a VIMS is to protect the occupants of a structure from the potential for VI. Audience-specific instruction for OM&M is imperative for a successful VIMS.

The ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet*** provides additional information to plan communications with property owners and building occupants.

Active Mitigation	**Medium Impact:** Long-term monitoring of active VIMS usually requires continued contact and communication with property owners and tenants. Early and frequent communication with these stakeholders is important so that proper operation of the VIMS is maintained.
Passive Mitigation	**High Impact:** Communication with a property owner or tenant is critical throughout the OM&M phase. Long-term monitoring, including inspections, takes the cooperation of the homeowner or tenant. Good communication ensures that collaboration.
Environmental Remedial Technology	**High Impact:** Implementation of the SVE/MPE, including OM&M activities, typically involves an extensive interaction with the property owners. Access agreements are required.
Rapid Response	**High Impact:** Contact and communication with property owners, tenants, and other stakeholders is critical during rapid response given the relatively fast-paced nature of the approach and potentially significant impact to building occupants.

Community Engagement: Community and other stakeholders should be engaged as early and often as possible. After installation of a VIMS, ongoing communication regarding OM&M of a specific system is typically limited to the property owner and tenants and may include reporting to the regulatory agency. See the Building Owner/Tenant Engagement section above. Otherwise, refer to the ***Public Outreach During Vapor Intrusion Mitigation Fact Sheet*** for additional information on conducting community engagement.

Active Mitigation	**Low Impact:** Typically, active VIMS do not involve tremendous community engagement unless they are installed on buildings frequented by the public or occupied by sensitive receptors such as children in schools and day care centers. In these cases, engagement with the community may be more important.
Passive Mitigation	**Low Impact:** Once a VIMS is installed in an individual building, communication is primarily directed at the individual property owner or tenant. Thus, the OM&M phase has limited community outreach.
Environmental Remedial Technology	**High Impact:** Implementation of SVE/MPE typically involves an extensive interaction with the stakeholders, including discussions about such issues as the effect of the system noise and treated

	stream discharge. System elements may need to be modified based on the stakeholders' feedback during operation.
Rapid Response	**High Impact:** Contact and communication with property owners, tenants, and other stakeholders is critical during rapid response given the relatively fast-paced nature of the approach and potentially significant impact to building occupants.

Regulatory Reporting: Documentation of mitigation design; installation, including commissioning; and long-term OM&M required by the environmental regulatory oversight agency will vary depending on the jurisdiction. Required reporting during OM&M of the VIMS will also vary. It is important to research the requirements specific to your state or agency prior to developing a mitigation strategy and include the required reporting in the OM&M plan.

Reporting may be more frequent (e.g., quarterly) during the first year of operation and then decrease in frequency thereafter. A telemetry system may also change/reduce the need or type of reporting since the telemetry system may inform the responsible party or the agency directly as to the status of the VIMS. The details of the type and frequency of reporting should be summarized in the OM&M plan, including plans to reduce frequency in the future. Distribution of any required reporting should also be detailed in the OM&M plan (e.g., responsible party, regulatory agency, property owner, building manager).

Some jurisdictions require specific reporting on a form or via a system designed by the regulatory agency. This should be detailed in the OM&M plan and updated as necessary (e.g., reference the most recent revision of an agency reporting form or update a reporting procedure).

The purpose of any reporting is to communicate details of the VIMS with the interested stakeholders and address their short- and long-term concerns. For example, while the primary stakeholder for construction and commissioning documentation may be the regulatory oversight agency in the short-term, reporting also serves as a reference document for persons responsible for OM&M in the long-term to assure the VIMS continues to operate as intended for long-term protectiveness. Similarly, documentation of routine inspections may be important in the short-term for the regulatory agency but also useful for the persons responsible for OM&M of a VIMS to identify changes in system effectiveness over time. In addition, a regulatory agency may perform inspections or audits of VIMS. For this and other purposes, it is important for all stakeholders to keep records of all reporting.

Active Mitigation	**Low Impact:** Reporting for documentation of active system operation may be required by a regulatory agency or may be requested by the responsible party to document consistent system operation. Reporting may range from simple documentation of OM&M logs to larger reports documenting system performance measurement data trends, air sampling results, and mass flux calculations.
Passive Mitigation	**High Impact:** As with active mitigation, reporting for documentation of passive mitigation system operation may be required by a regulatory agency or may be requested by the responsible party to document consistent system operation. Reporting may range from simple documentation of OM&M logs to larger reports.
Environmental Remedial Technology	**High Impact:** Reporting on the compliance with the discharge permits is typically required as part of the OM&M of SVE/MPE systems. Additionally, reporting on the progress of the site

	remediation is generally performed as part of the exit strategy toward the site closure.
Rapid Response	**Medium Impact:** The type and frequency of reporting are expected to depend on the type of interim mitigation approach, associated time frame, regulatory requirements, severity of condition, and building use (e.g., sensitive use).

3 EXIT STRATEGY

Unlike radon, the source of VOC vapors can be remediated within the lifecycle of a VIMS in some cases, rendering the system unnecessary. Termination and implementation of an exit strategy for a vapor mitigation action occur when the objectives of cleanup activities have been met, or when VIMS that were presumptively installed are investigated and found no longer necessary.

When mitigating VI through subsurface source remediation, building mitigation, and ICs, it is important to develop termination criteria, including the rationale for their selection, early in the remedy planning (e.g., design phase) process. Termination criteria generally refer to numeric cleanup levels for each site-specific contaminant and narrative cleanup objectives that are to be attained by the response actions. The termination criteria are generally recorded in decision documents, design reports, and commissioning reports and should specify how it will be determined that the termination criteria have been attained (e.g., monitoring data and associated statistics that will be used to demonstrate attainment). Concurrence from the appropriate regulatory authority should be obtained for the termination criteria and for termination of remediation, VIMS, and ICs once those criteria are met.

Stakeholders should be provided with a clear and comprehensive set of termination criteria for the remediation, VIMS, and ICs. If site conditions (e.g., building usage, vapor flux) change during the cleanup activities, it may become necessary to modify the termination criteria and/or strategy. When reviewing VI activities, considerations for evaluating termination activities may include termination of:

- subsurface remediation activities
- engineered exposure controls (building mitigation)
- monitoring
- associated ICs

3.1 Termination of Subsurface Remediation Activities

Where feasible, the preferred response to address VI is to eliminate or substantially reduce the level of volatile chemical contamination in the source media (e.g., groundwater and subsurface soil) to levels that eliminate the need to mitigate or monitor VI. If subsurface remediation activities are being conducted at the site, termination of these activities will likely be contingent on demonstrating that the chemical-specific cleanup levels for the subsurface media have been attained.

Typically, monitoring will continue until the source(s) are remediated to cleanup levels that eliminate the need to mitigate VI at the point of exposure. As appropriate, the exit strategy may provide criteria for phased remediation, resulting in a termination evaluation as source cleanup levels are achieved in parts of the contaminated area. If the subsurface vapor source(s) is not remediated, it is generally anticipated that remediation (and monitoring and any building mitigation) will continue.

If evaluation of the site-specific data indicates an increase in subsurface vapor concentrations during the monitoring period, it may be appropriate to evaluate whether the subsurface remediation plan and the CSM are adequate and appropriately protective.

Once it is established that the subsurface VIMS may be terminated, a period of attainment monitoring is typically required. During the attainment period, the remediation system (e.g., reagent delivery equipment, SVE wells) will not be operated for a sufficient period to allow subsurface vapors to reach equilibrium and indicate post-remediation conditions. The types and frequency of data collected during attainment monitoring entail site-specific determination. In order to be able to effectively establish the equilibrium time necessary, a detailed understanding of the source of vapors is required as well as an estimated rate of vapor migration.

Most states and the U.S. Environmental Protection Agency (USEPA) recommend that criteria be described and documented, as part of exit strategy development, to determine when ending the attainment monitoring period is appropriate. To develop an exit termination strategy, site-specific fate and transport data may be used to identify an appropriate time period to allow the vapor concentrations to equilibrate. In addition, the termination of the attainment monitoring period may involve an evaluation of the contaminant attenuation in the vadose zone.

3.2 Termination of Building Mitigation

For purposes of this Process Fact Sheet, "termination of building mitigation" refers to ending the use of an engineered exposure control(s) that reduces or eliminates human exposure via the VI pathway. Typically, vapor mitigation is implemented when it is determined that:

- the potential exists for unacceptable human health risk to inhabitants or
- the VIMS was installed as part of an early action strategy

As described in ***An Introduction to Vapor Intrusion Mitigation Fact Sheets,*** a vapor mitigation strategy can be implemented using active, passive, or environmental remediation technology (or a combination thereof).

Active Building Mitigation: Generally, building VIMS are implemented in conjunction with the investigation and remediation of a subsurface vapor source(s). Typically, building VIMS will be operated until the source(s) is remediated to attain the cleanup levels [e.g., for the subsurface vapor source(s)] that eliminate the need to mitigate VI at the point of exposure. If subsurface vapor source(s) are not remediated, it is generally anticipated that mitigation activities will continue indefinitely. As appropriate, the termination strategy may provide criteria for phased evaluation of system cessation as source cleanup levels are achieved in parts of the contaminated area.

Once the subsurface vapor source(s) is remediated to levels that meet the remedial objectives and protect human health from the VI pathway, it is recommended that the site-specific monitoring data be evaluated to determine if the termination criteria for the building VIMS have been met. These monitoring data, in part, could be based on data similar to those that were used for characterizing human health risk or for supporting the decision to undertake pre-emptive mitigation/early action during the VI investigation (e.g., sub-slab soil gas sampling and/or indoor air sampling). It is normally recommended that the party proposing to implement the exit strategy identify and document target concentration(s) that would allow for system termination, along with recommended monitoring/sampling frequencies. In addition, certain site-specific performance assessment data (e.g., standpipe vapor sampling) may also warrant consideration to make this determination.

When it is determined that the termination criteria have been met for a building VIMS as identified above, a period of attainment monitoring is conducted. During the attainment period, it is recommended that the VIMS (e.g., sub-slab suction wells or ventilation fans) be offline for a sufficient period to allow vapors beneath the structure to reach equilibrium and indicate post-remediation conditions. The types and frequency of data collected during attainment monitoring entail site-specific determination. Additionally, criteria should be established in the exit strategy to determine when ending the attainment monitoring period is appropriate. Many of these issues may be dictated by the regulatory agency.

For example, a recent review of existing VI regulatory guidance documents (Eklund et al., 2018) included an evaluation of various state provisions for termination. States such as Massachusetts (MADEP, 2016), New York

(NYSDOH, 2006), New Jersey (NJDEP, 2018), and Wisconsin (WDNR, 2018) include recommendations for certain data collection efforts to support the closure decision, such as:

- temporary shutdown of system operation prior to the verification sampling, to allow vapor concentrations to rebound to potential levels that might be expected after system closure (e.g., 7–30 days) (MADEP, 2016; NJDEP, 2018)
- verification sampling and analysis of sub-slab vapors and/or indoor air and outdoor air and comparison to protective screening levels over a prescribed sampling interval (e.g., 4–24 months (MADEP, 2016; WDNR, 2018)
- operation of the VIMS between verification monitoring events, or indoor air monitoring to maintain protectiveness

These approaches can effectively demonstrate that a VIMS is no longer necessary. Alternative approaches may also be considered such as the mass loading and mass flux assessment methodologies (McAlary et al., 2018; Dawson, 2016).

To develop an exit termination strategy, site-specific fate and transport data may be used to identify an appropriate time period to allow the vapor concentrations to equilibrate. In addition, the termination of the attainment monitoring period may involve an evaluation of the contaminant attenuation in the vadose zone.

If the attainment criteria evaluation indicates that cleanup levels and objectives are not being met, it may be necessary to continue or resume subsurface remediation and mitigation activities. Once it is determined that the cleanup levels and objectives have been met, the active components of the VIMS may be removed from the building. On the other hand, the building owner may elect to continue to operate the mitigation system under their own discretion and for their own purposes (e.g., radon reduction and moisture control). Once the cleanup levels and objectives have been met, all OM&M and monitoring of the VIMS specified can cease.

Passive Building Mitigation: The termination of passive VIMS will typically be similar to the criteria established for the termination of active VIMS. In summary:

- Like active VIMS, passive VIMS are typically implemented in conjunction with the investigation and remediation of subsurface vapor source(s).
- Generally, once the subsurface vapor source(s) is remediated to levels that meet the cleanup objectives that will protect human health from the VI pathway, it is recommended that the site-specific monitoring data be evaluated to determine if the termination criteria have been met.

If the site-specific criteria evaluation indicates that cleanup levels and objectives are not being met, it may be appropriate to evaluate the current system's effectiveness or the possible application of an active mitigation system. Once it is determined that contaminant cleanup levels and objectives have been met, all OM&M specified can typically cease. Generally, most states and the USEPA do not have a need to seek removal of barriers or seals that comprise a passive mitigation system as part of termination activities and they are typically left in place.

Environmental Remediation Technology: In the case of remediation implemented as part of a VI mitigation approach, the consideration of terminating the system component of the remediation is based on the effective removal of the VI source (e.g., groundwater contamination, NAPL, or soil contamination). The removal of the VI source does not necessarily mean that residual soil gas contamination has been addressed. Thus, it is recommended that the site-specific monitoring data discussed for active and passive building mitigation (above) be evaluated to determine if the system termination criteria have been met.

3.3 Termination of Monitoring

For purposes of this process fact sheet, monitoring includes activities conducted to verify that the VI pathway does not pose a health concern to building inhabitants while remediation and mitigation activities are underway and in the event that the remediation and mitigation activities are terminated. "Termination of monitoring," for purposes of this process fact sheet, refers to ending any monitoring that is needed to verify that no further response action, including IC-related activity, is necessary to protect human health from indoor air exposures posed by VI. When developing termination criteria for monitoring, the decision is generally based on data collected from all the affected media.

As noted above, monitoring is generally implemented in conjunction with the remediation of subsurface vapor sources(s) and to evaluate performance of a VIMS. Typically, monitoring will continue until the source(s) is remediated to cleanup levels that eliminate the need to mitigate VI at the point of exposure (i.e., allow building VIMS to be terminated). If the subsurface vapor source is not remediated, it is generally anticipated that any associated monitoring of both the source area and VIMS will continue. As appropriate, the exit strategy may provide criteria for phased monitoring, resulting in a termination evaluation as source cleanup levels are achieved in parts of the contaminated area.

3.4 Termination of ICs

"Termination of ICs" as used in this process fact sheet refers to discontinuing any and all ICs because restrictions on land or resource use and/or notices and other informational devices are no longer necessary to help ensure protection of human health (i.e., human health risk from exposures to VI, if any, are expected to be acceptable in the absence of all IC(s)). Generally, ICs are implemented in conjunction with the investigation and remediation of the source(s). It is anticipated that ICs selected and implemented will be needed until (1) the subsurface vapor source(s) is adequately remediated, or (2) restrictions on land, resource, or building use are no longer necessary based on current and reasonably anticipated future exposure scenarios. Therefore, when developing a termination strategy for ICs that have been selected as part of a response action, the strategy is typically based on data collected from the affected media.

The exit strategy must consider and identify cleanup levels for the subsurface vapor source(s). As long as the subsurface vapor source exceeds such cleanup levels, it is generally anticipated that the associated ICs will continue. As appropriate, the termination/exit strategy may provide criteria for a phased IC termination evaluation as source cleanup levels are achieved in parts of the contaminated area.

If the site-specific criteria evaluation indicates that terminating the ICs is appropriate, the regulatory agency may conclude that site conditions no longer warrant ICs being used as part of the response action for the VI pathway. At this point, the regulatory agency could notify the appropriate entity(s), such as local or state government, tribe, affected landowner, or responsible parties, in writing that the response objectives have been met and that the IC need not be maintained.

Active Mitigation	**Medium Impact:** The exit strategy is an important component to OM&M of an active VIMS and should be considered frequently during the operation of the VIMS. As active mitigation performance data are collected they may be evaluated against criteria that may indicate that a VIMS may be ready for shutdown.
Passive Mitigation	**High Impact:** An exit strategy is typically developed as part of the design documents and is agreed to by all parties. This early consensus on the exit strategy avoids a moving target so that all sides should agree when the VIMS can be terminated.
Environmental Remedial Technology	**High Impact:** SVE/MPE systems are typically operated for a limited time; therefore, a clear exit strategy must be developed.
Rapid Response	**Low Impact:** Interim VI mitigation is intended to occur on a short-term basis prior to long-term mitigation. While there is no direct exit strategy associated with interim mitigation, consideration should be given to transitioning to long-term mitigation (e.g., reasonable implementation timeline, potential delays) so that interim mitigation does not run indefinitely.

4 REFERENCES AND ACRONYMS

The references cited in this fact sheet are included in a combined list with references cited in other fact sheets and technology information sheets prepared by the ITRC VI Mitigation Training team. This reference list, along with an acronym list and glossary, is available on the ITRC web site.

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Acronyms

Vapor Intrusion Mitigation Team | December 2020

Vapor Intrusion Mitigation Acronym List

Greek Characters

μg/m3 micrograms per cubic meter

A

AARST American Association of Radon Scientists and Technologists

AER air exchange rate

AHU air handling unit

ALM asphalt latex membrane

ANSI American National Standards Institute

APU air purifying unit

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASTM American Society for Testing and Materials

ASTSWMO Association of State and Territorial Solid Waste Management Officials

ATD analytical thermal desorption

ATSDR Agency for Toxic Substances and Disease Registry

ATU air treatment unit

AVMB aerobic vapor migration barrier

B

BWD block wall depressurization

C

CAPEX capital expense

CM composite membrane

CMU concrete masonry unit

CO carbon monoxide

COC contaminant (or constituent or chemical) of concern

CQA construction quality assurance

CSM conceptual site model

CSP concrete surface profile

CSV crawlspace ventilation

D

DOD United States Department of Defense

DNAPL dense non-aqueous phase liquids

DTD drain tile depressurization

DTSC California Department of Toxic Substances Control

E

EC engineering control

EFC epoxy floor coating

EPDM ethylene propylene diene monomer

ESTCP Environmental Security Technology Certification Program

EVOH ethylene vinyl alcohol

F

FDA United States Food and Drug Administration

FID flame ionization detector

G

GAC granulated activated carbon

H

HDPE high-density polyethylene

HVAC heating, ventilation, and air conditioning

I

IC institutional control

IDEM Indiana Department of Environmental Management

ITRC Interstate Technology and Regulatory Council

L

LLDPE linear low-density polyethylene

LNAPL light non-aqueous phase liquid

LUC land use control

M

MADEP Massachusetts Department of Environmental Protection

MLE multiple lines of evidence

MPCA Minnesota Pollution Control Agency

MPE multiphase extraction

N

NAPL non-aqueous phase liquid

NJDEP New Jersey Department of Environmental Protection

NO2 nitrogen dioxide

NREL National Renewable Energy Lab

NYDOH New York Department of Health

O

O2 oxygen

OM&M operation, maintenance, and monitoring

OSWER USEPA Office of Solid Waste and Emergency Response

P

PADEP Pennsylvania Department of Environmental Protection

PAH polycyclic aromatic hydrocarbons

PCB polychlorinated biphenyls

PCE perchloroethylene or perchloroethene

PFAS per- and polyfluoroalkyl substances

PFE pressure field extension

PID photoionization detector

PVC polyvinyl chloride

PVI petroleum vapor intrusion

Q

QA/QC quality assurance/quality control

R

ROI radius of influence

S

scfm square cubic feet per minute

SDR standard dimensional ratio

SMD sub-membrane depressurization

SSD sub-slab depressurization

SSV sub-slab ventilation

SVE soil vapor extraction

T

TCE trichloroethylene or trichloroethene

TPH total petroleum hydrocarbons

TM thermoplastic membrane

U

USDA United States Department of Agriculture

USDOE United States Department of Energy

USEPA United States Environmental Protection Agency

V

VAV variable air volume

VG vented garage

VI vapor intrusion

VIMS vapor intrusion mitigation system

VOC volatile organic compound

W

Glossary

A

Advection/Advective flow
Bulk motion of fluid in the environment defined by direction and velocity

Aerobic
Pertaining to or characterized by the presence of oxygen

Aquifer
A body of permeable rock that can contain or transmit groundwater

Air dispersion modeling
The use of mathematical formulations to characterize pollutant dispersion processes

Anaerobic
Pertaining to or characterized by the absence of oxygen

ANSI/AARST standards
National consensus practices utilized by federal and state agencies

Attenuation factor
A ratio of the indoor air concentration to soil gas or groundwater concentration; sometimes used to estimate the indoor air concentration from soil gas or groundwater concentration

B

Back drafting
The reverse flow of gas in the flues of fuel-fired appliances that results in the intrusion of combustion byproducts into the living space

Biodegradation
The breakdown of chemicals by microorganisms

Building envelope
The physical boundary between the conditioned and unconditioned environment of a building, including the resistance to air and water transmission

Building pressurization
The air pressure within a building relative to the air pressure outside

C

Capillary fringe/Capillary zone
The pore spaces in soil just above the water table that may contain water above the static level from interactive forces between the water and soil

Chemicals of concern
Compounds derived from hazardous substances that are subject to evaluation for purposes of applying risk-based corrective action decision making

Community engagement
The process of communicating with local residents and other stakeholders to provide information throughout the investigation and clean-up of a contaminated site; provide opportunities for offering input about site investigation/cleanup plans; and to facilitate the resolution of community issues related to a contaminated site

Concentration gradient
The change of concentration over a certain distance

Conceptual site model
A three-dimensional visualization of site conditions that allows for evaluation of contaminant sources and affected media, migration pathways, and potential receptors

Confining unit
A layer of rock or soil of very low hydraulic conductivity that hampers the movement of groundwater in and out of an aquifer

Coupon testing
A specimen of an installed material collected for testing or verification

D

Dense nonaqueous phase liquid (DNAPL)
A liquid that is not soluble in and has a higher density than water

Depressurization
To remove the air pressure from

Diffusion
Movement of vapors away from areas of higher concentration

Discharge criteria
Generic term used to describe emission regulatory limits

E

Emission controls
Means employed to limit the discharge of gases

Expansion joints
An assembly designed to hold parts together while safely absorbing expansion and contraction

F

Floor drain
A plumbing fixture that is installed in the floor of a structure, mainly designed to remove any standing water near it

Flow velocity
Vector field that is used to describe fluid motion in a mathematical manner

French drain
A trench filled with gravel or rock or containing a perforated pipe that redirects surface water

Flux
Flow per unit area

H

Heating, ventilation, and air conditioning (HVAC)
The technology of indoor and vehicular environmental comfort, including heating, cooling, and air movement

Human exposure pathway
Refers to the way a person can come into contact with a hazardous substance

I

Inorganic compounds
Substance in which two or more chemical elements (usually other than carbon) are combined

L

Laser screed
A self-leveling head that is mounted on a telescopic boom used to smooth and level concrete

Light nonaqueous phase liquid (LNAPL)
A liquid that is not soluble in and has a lower density than water

Long-term stewardship
Activities implemented for the management of contaminated environmental media that are necessary to protect human health and the environment over time

M

Mitigation strategy
An approach used to reduce the severity of something, such as vapor intrusion

N

Natural draft
The use of natural atmospheric pressure to force gases of combustion out through a ventilation system

O

Operation, maintenance, and monitoring (OM&M) plan
Refers to the routine inspection, servicing, and repairing or replacing of necessary equipment of an operating system

P

Perched aquifer

A water-saturated zone that is above or not directly connected to the regional aquifer; may develop when saturated conditions are present above a low-permeability layer

Phreatic (saturated) zone

The part of an aquifer, below the water table, in which all pores and fractures are essentially saturated with water

Plenum

Continuous void space under the slab that can facilitate air circulation

Petroleum vapor intrusion

The process by which volatile hydrocarbons partition from petroleum-contaminated soils and/or groundwater and migrate through the vadose zone in gaseous form to receptors

Phase partitioning

Separation of fuel into solid, liquid, and gas phases

Post-installation verification

A testing procedure used to show that something is functioning properly after an initial installation or an upgrade

Preferential pathway

A high-permeability conduit for vapor migration, such as a utility penetration, line, or drain; building sump or drainage pit; elevator shaft; fracture in bedrock; or gravel

Pressure field extension

An area beneath a concrete slab or foundation where a sufficient amount of negative pressure (vacuum) has been obtained

R

Redox potential

Chemical reduction-oxidation processes and conditions that can result in the alteration of a chemical compound

Risk communication

Actions, words, and other messages, responsive to the concerns and values of the information recipients, intended to help people make more informed decisions about threats to their health and safety

S

Smoke pen

A hand-held device that creates a puff or a trail of white smoke used to identify leaks or air flow direction

Smoke and tracer gas testing

A nondestructive testing method that detects leaks

Surrogates

Variables with a quantitative relationship to the target compound for a study sufficient to be useful as a substitute for directly measuring the target compounds

T

Telemetry

Process of recording and transmitting the readings of an instrument

Tracer

Substances that migrate similarly to the volatile organic compounds (VOCs) of interest for VI

U

Utilidor/Utility tunnel/Utility corridor

A passage used for routing utility lines, such as electric lines, water supply pipes, sewer pipes, and communications lines

V

Vadose zone

The unsaturated zone of soil in which the pore space is filled with both air and water

Vapor control technologies

Technologies employed to mitigate real or potential impacts from vapor intrusion

Vapor intrusion

The process by which volatile vapors partition from contaminated groundwater or other subsurface sources and migrate upward through vadose zone soils and into overlying buildings

Vent stack

A pipe placed vertically or nearly vertical for ventilation

Volatile organic compounds

A variety of chemicals, some of which may have short- and long-term adverse health effects, that are prone to evaporation at ambient temperatures

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Vapor Intrusion Mitigation Team | December 2020

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