

Vapor Intrusion Mitigation in Existing Buildings Fact Sheet

Introduction

Vapor intrusion (VI) is the migration of volatile chemicals from subsurface soil and/or groundwater into the indoor air of overlying buildings. Most VI events occur when volatile organic compounds (VOCs) are released into the subsurface from sources such as underground storage tanks, dry cleaners, gasoline stations, or industrial processes such as degreasing metals. VOCs typically associated with VI are chlorinated solvents including carbon tetrachloride, tetrachloroethene (PCE), trichloroethene (TCE), methylene chloride, and gasoline derivatives such as benzene. Hazards presented by these chemicals are typically chronic human health effects such as cancer, organ toxicity, or reproductive effects. Gases, such as methane migrating from landfills, may also present potential explosive hazards. If it is determined that VI is occurring at your site and the contaminant concentrations attributable to VI are above acceptable risk levels, mitigation measures should then be implemented to reduce the indoor air concentrations to below the acceptable threshold.

This fact sheet provides a brief overview of methods that can be used to mitigate VI in existing buildings along with important considerations for selecting and designing an appropriate mitigation system for your site. The methods discussed include sub-slab depressurization, sub-membrane depressurization, building pressurization, and indoor air treatment; however, the focus is on sub-slab depressurization since that is currently the method most frequently used for VI mitigation in existing buildings. Note that this does not mean that sub-slab depressurization is preferred over other mitigation methods or that it will be the best option for every site. More detailed information on VI mitigation systems for existing buildings can be found in the resources listed at the end of this fact sheet.

Key Factors When Considering VI Mitigation

Developing an effective VI mitigation plan depends on understanding and quantifying the relationship between three key factors that contribute to VI: (1) the properties,

concentrations, and locations of the contaminants of concern; (2) the pressure differentials that draw contaminants from the soil gas into the building; and (3) the pathways that allow vapors to pass from soil gas into the building (e.g., cracks, joints, utility penetrations).

Properties, Concentrations, and Locations of VOCs

The first step in developing a VI mitigation plan is to understand as much as possible about the contaminant plume.

- What are the contaminants and what are their physical characteristics?
- What are the concentrations in groundwater and/or in the soil gas adjacent to or beneath the slab?
- What are the concentrations in the indoor air and ambient air outside of the building?
- Are methane or other explosive gases present? If so, explosion proof equipment will need to be integrated with the diagnostic investigation and mitigation specifications.
- How close is the contaminant plume to the building?
- Are the areas where subsurface vapors are infiltrating the building known? If so, are there mitigation measures that can be taken to reduce infiltration?

It is important that investigations performed prior to mitigation have adequately delineated and characterized the vapor plume and conditions inside the building have been adequately assessed. Also, because materials and products commonly found in buildings can cause false positives in indoor air sampling, a careful survey is needed to catalogue potential background sources of VOCs. DON has developed new guidance on assessing background concentrations for VI, which will be released in the near future.

Pressure Differentials

It is important to understand the pressure differentials within the building before designing a mitigation system. For some buildings, exhaust blowers mechanically induce significant negative pressure loads on the interior of the building; such blowers often accelerate the rate at which contaminant vapors are drawn into the building. For example, buildings used for industrial processes, laundromats, and restaurants typically exhaust large volumes of air, creating negative pressures throughout the building envelope. Because of their multiple exhaust blowers, strip malls with businesses such as dry cleaners, restaurants, and beauty salons may have multiple negative pressure zones that influence the migration of sub-slab contaminant plumes.

Temperature differentials affect the pressure between the inside and outside of the building. When warm air inside the building rises, the building undergoes a stack effect, inducing a negative load on the building interior that is applied to the surface of the floor slab. Stack effects are greater during the heating season. Also, wind can produce a complex pressure field around a building, creating a positive pressure on the windward side and a negative pressure on the leeward side. Wind-induced negative pressures can be transferred into the structure, inducing the intrusion of contaminant vapors.

Completed Pathways

It is also important to try to identify the areas or building characteristics that allow the entry of subsurface vapors into the building. Floor drains, French drains, sumps, cracks and open seams in the floor slab, unfinished slabs, utility penetrations, and open top blocks in the foundation walls are among the most common pathways that allow subsurface vapors to enter buildings.

Preliminary Mitigation Design Steps

To design effective mitigation measures, it is important to perform both a building inspection and a mechanical investigation.

Building Inspection

Detailed information about the building construction is required to provide crucial information regarding subsurface characteristics and is a critical component for designing and constructing a mitigation system. For example, if the building was used for industrial processes, there may be very thick concrete machine pads located just beneath the slab, presenting a variety of VI design challenges. Also, in these industrial settings, there may be a combination of active and abandoned utility lines; therefore, an under-slab utility markout identifying the locations of utility lines and areas to be avoided should be completed prior to invasive activities.

The subsurface characteristics may be different under different sections of a building that were built at different times. For example, building additions may have been constructed over a former parking lot or a materials staging yard, resulting in highly compacted soil beneath the slab. It is often valuable to interview active or retired maintenance personnel as they may have valuable information regarding building features.

The walk-through inspection phase is an important part of the investigation. Construction features and building materials should be documented since changes in construction styles and building materials often indicate an addition to the building. The changes indicating additions can be as subtle as a slightly different pattern in the metal roof decking or a small change in a roof truss design. Each addition represents a segmented building foundation and soil conditions from one foundation area to another can be significantly different.

The next step is to carefully catalog all potential contaminant entry points such as slab penetrations, conduit openings, expansion joint openings, floor/wall joint openings, plumbing penetrations,

block wall openings, open block tops, slab or wall cracks, or anything that could be considered a soil gas vapor entry point.

Also, the building inspection is an opportune time to assess how the mitigation system can be concealed or blended with its surroundings. For instance, vapor vent pipes may be enclosed behind walls or routed through closets.

Mechanical Investigation

Heating, ventilation and air conditioning (HVAC) systems generally impact the potential for VI and should be examined prior to designing a mitigation system. Many industrial buildings have a history of multiple uses and may have exhaust equipment no longer in use. All exhaust blowers should be cataloged whether functioning or not, and the cubic feet per minute (CFM) of operating blowers recorded. The supplied air ventilation should be examined and the operational status and location noted so that if contaminant vapors are vented, the air supply system does not pull the vapors back inside the building.

Mitigation System Design Plan

Before a VI mitigation system is installed, a system design plan should be prepared. The plan may require approval by the state and/or federal regulators, depending on the situation. The mitigation system should be designed conservatively to mitigate the highest concentrations that are reasonably expected to occur. The mitigation plan should include a written scope of work and corresponding drawings. It should be a code compliant, complete, understandable, easy to follow construction document that minimizes the number of requests for information (RFIs) during the construction phase. The written scope should also include a schedule of materials and hardware. The drawings should include a detailed sealing plan and specific details on the planned layout for various features of the system (e.g., piping, vents, blowers, etc., depending on the type of system), mechanical details, and, if necessary, a separate sheet for electrical work. Prior to submittal of design documents to regulatory agencies for approval, all documents should be reviewed and approved by the facility's Department of Public Works or facility resident engineer.

Sealing VI Pathways

Sealing pathways between the sub-slab soil and the building interior is a basic part of a VI mitigation system (see Figure 1). Sealing makes VI mitigation systems more effective and cost-efficient by limiting the flow of vapor into the building and reducing the loss of conditioned air. Generally, sealing pathways by itself is not an adequate mitigation measure because it does not lower vapor levels significantly or consistently, and sealing does not address the negative pressures that draw soil contaminants into buildings.



Figure 1. Sealing floor cracks.

All areas to be sealed should be addressed in the mitigation plan. A separate plan sheet and cross-sectional detail indicating areas to be sealed should be provided. The method of sealing and sealants should be specified.

Types of Mitigation Systems

There are several types of mitigation measures available to address VI in existing buildings. These include:

- Sub-slab Depressurization
- Sub-membrane Depressurization
- Building Pressurization
- Indoor Air Treatment

Of these types, sub-slab depressurization (SSD) is the most frequently used and has been shown to be a reliable, cost-effective, long-term solution for lowering VI contaminant concentrations in many situations. Also, SSD systems have been widely used for radon mitigation and, thus have a well-established performance record in that industry. Therefore, this fact sheet provides a more detailed discussion of design considerations for SSD systems, with a brief description of the other mitigation systems and their applications and limitations.

Sub-Slab Depressurization

SSD (which is sometimes referred to as active soil depressurization) will reverse or mitigate the upward migration of soil gas by creating negative pressure beneath the building floor slab, thereby preventing vapors from entering the building. The SSD system draws contaminants from beneath the slab, through piping, to the exterior of the building where they are vented above the roof line and quickly diluted with ambient air (see Figure 2). An added benefit of an SSD system is that it also improves the overall quality of the indoor air by removing moisture and naturally-occurring radon.

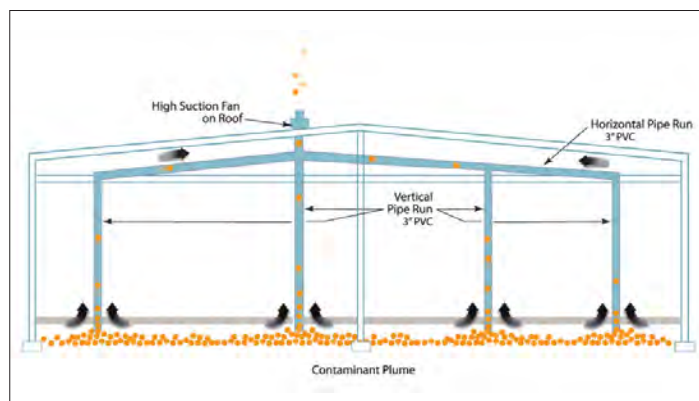


Figure 2. Schematic of an SSD system.

Pressure Field Extension Testing

In preparation for designing the SSD system, pressure field testing of the soil beneath the slab should first be performed to determine vacuum field extensions; this is accomplished by drilling suction test holes in the slab, auguring out some soil (see Figure 3), and applying vacuum to simulate future vacuum fields. The suction test holes should be located in areas that will be best suited for future suction points. In most cases, the primary hole is drilled just off

an interior column pad where soil has the lowest permeability due to compaction during construction activities. Areas along the perimeter typically produce higher air flow but may have limited impact on the more compacted soil near the interior of the building and can have interference from air leakage at the floor-wall joints.



Figure 3. Suction point installation.

The physical characteristics of the sub-slab material should be noted and recorded. Pressure field testing should not be conducted on gusty days and exterior doors throughout the building should be kept closed.

The static vacuum is first measured (see Figure 4) by applying known quantities of vacuum to the test suction hole. Smaller test holes should be drilled through the slab at selected distances from the suction hole and a micro-manometer capable of reading down to 0.0001 inches of water column (in. w.c.) used to measure pressure differential (see Figure 5). By applying different amounts of vacuum to the same suction hole, the relationship between applied vacuum and pressure field extension is established. Pressure testing should be repeated at least once for each separate foundation such as when a building addition has been added.



Figure 4. Static vacuum test.



Figure 5. Measuring sub-slab vacuum.

The data from the pressure field testing (in 10^{-4} in. w.c.) and the measured volume of exhaust system (in CFM) are then extrapolated to project an expected radius of influence. Once this has been completed, the number of suction points, the types and capacity of suction blowers, and costs are determined. The success of the VI mitigation system and thousands of mitigation dollars depend on correctly and accurately interpreting these data.

SSD Mitigation System Design

As noted above, all VI mitigation systems should have a design plan prepared before installation. For an SSD system, the drawings should include a detailed sealing plan, suction points, pipe and blowers, mechanical details, and, if necessary, a separate sheet for electrical work. The scope of work should address the following items and any other specifications required by regulators.

- Sealing plan including details of locations and methods for sealing. If sealing is incomplete, building air is drawn into the subslab and then into the mitigation system, which reduces the vacuum available for removing contaminated vapors and increases the loss of conditioned air to the subsurface.
- Suction hole locations, diameter of the holes, method of sealing the suction point to the slab, quantity of soil removed from beneath the slab, and directions for testing and disposing of any removed soil. Cross-section drawings should be provided in the details section.
- Pipe locations, diameter, material (polyvinyl chloride [PVC], cast iron, or steel) including American Society for Testing and Materials (ASTM) specifications, method of joint welding (ASTM method), slope, attachment intervals, balancing and valve installation. Specify methods of controlling smoke or flame spread such as may be appropriate for piping that penetrates a return air plenum.
- Number of roof penetrations and location(s) on a roof plan, the type of roof material, the method of flashing and who is responsible to maintain the roof warranty if one exists.
- Number of blowers, models and manufacturers, location on a plan sheet, performance information, ASTM specifications, and a full materials list including mounting methods and attachment hardware. Figure 6 depicts a standard high-vacuum blower. Also, low pressure sensors should be included for each blower system. They should be placed at locations that are easy to monitor. Figure 7 depicts a mounted low-pressure sensor.
- Wiring specifications including the gauge of wire, conduit shielding, switches, panel locations, and types of breakers. A separate electrical drawing may be necessary.
- Alarm panel locations and design specifications. These panels usually have red and green indicator lights with manual audio shut off alarms. They are activated either by mechanical switches or fully electronic sensors. The fully-electronic versions are more reliable and can also display the power consumed by each blower. They can be equipped with autodialers and integrated with building management systems.



Figure 6. High vacuum blower.



Figure 7. Low-pressure vacuum gauge and sensor.

- Labeling instructions for pipes, sensors and alarms. All vertical riser pipes should be labeled at least once per floor. Horizontal pipes should be labeled in 20-ft intervals and be readable from 3 feet. Low pressure sensors and alarm panels should be placed in accessible locations and labeled with appropriate contact information.

System Startup and Operations

The person who designed the system should participate in the startup. The following data should be recorded: sub-slab vacuum at the original test holes, riser pipe airflow (see Figure 8) and total system airflow (see Figure 9). The riser pipes should be balanced for maximum distribution of sub-slab vacuum.



Figure 8. Riser pipe airflow test.



Figure 9. Blower exhaust airflow performance testing for total system.

The mitigation design plan should also provide post-mitigation performance evaluation criteria as well as operations and maintenance requirements for the system. Monitoring of low pressure sensors should be integrated with the maintenance schedule. Operations, maintenance, and monitoring should be coordinated with the Department of Public Works or facility maintenance engineer. Where possible, the operations and maintenance functions should be turned over to Base personnel, although it is important that these personnel receive adequate training in the operation of these systems.

Other VI Mitigation Methods

Although SSD is the most frequently used mitigation method, other types of mitigation may be appropriate for specific conditions where SSD does not work properly (e.g., high water table or a slab poured directly on rock) or as temporary measures until a more permanent system can be designed or fine-tuned.

Sub-membrane Depressurization is very similar to SSD; however, it is applied to crawl spaces and basements with earthen floors. An impermeable membrane is applied to cover and seal the exposed soil surface, then suction is applied to depressurize the area below the membrane and vapors drawn through the system are vented to the atmosphere. Design considerations are similar to SSD. It is critical that the membrane be sealed gas tight to the foundation wall and additional care must be taken to maintain the

integrity of the membrane. Sub-membrane depressurization is most commonly used in residential structures.

Building Pressurization is applied with SSD systems usually in open finished office spaces where vacuum cannot be sufficiently extended beneath the slab. It is also used in buildings such as daycare facilities where no amount of VI is deemed acceptable. Building pressurization involves adjusting the HVAC system or installing a new system to maintain a positive indoor pressure relative to the sub-slab area. This approach is more commonly used in commercial buildings and can be cost-effective if the existing HVAC already maintains a positive pressure. Increasing the pressure will result in higher energy costs, particularly if significant heating or cooling is required. The interior of most buildings are under negative pressure loads ranging from -0.004 to -0.012 in. w.c. In order to be effective, building pressurization must exceed the forces that induce negative pressures and draw vapors into buildings. Only a select minority of relatively “tight” buildings, with few doors or other openings, would be good candidates for the application of this method and it is not recommended for use in residential structures. Regular maintenance, changing of filters on fresh air intakes, and air balancing is required and appropriate pressure tests and monitoring should be incorporated into the design to ensure that sufficient positive pressures are maintained throughout the areas of the building that might be subject to VI. If the HVAC system is shut off during nights and weekends, the VI impact during the downtime should be evaluated in determining the system’s operating requirements.

Indoor Air Treatment functions by directing indoor air through air pollution control equipment to remove toxic air contaminants, rather than by preventing their entry into the building. Types include zeolite or granular activated carbon (GAC) filters or photocatalytic oxidation units. Systems can be either in-duct models or portable air cleaners. This generally is not the preferred mitigation method because it does not prevent vapors from entering the building. It encourages the collection of contaminant vapors within the structure and is dependent on the treatment system’s uninterrupted performance to protect receptors. However, indoor air treatment may be useful as a temporary solution until another type of mitigation system can be installed. It can also be used in combination with other methods or for treatment of a particular problem room within a building. These systems require periodic maintenance, such as changing the filter cartridges, with frequency depending on the concentrations encountered and on the manufacturer’s recommendations. In addition, the high volume of air movement required for these units to be effective is generally not ideal for an office environment (e.g., blowing papers off desks). More frequent indoor air monitoring is required to determine that the system is achieving acceptable indoor air concentrations.

Final Report

Once the VI mitigation system has been installed and tested, a final report should be prepared. The final report should include the following information: startup documentation, operation and

maintenance (O&M) procedures, project documentation, materials cut-sheets, alarm system information, photos, breaker numbers, electric panel locations, as-built drawings, building permit, and electrical inspection documentation.

Maintaining the VI Mitigation System

Similar to other building systems, VI mitigation systems require monitoring as specified in the written O&M procedures. Monitoring should be done regularly by trained building maintenance personnel with checklists and schedules for documenting system static vacuum gauges and exhaust volumes and testing alarm systems. Depending on their stress load, vapor blowers may need to be replaced every few years.

Post-Mitigation Building Renovation

Structural modifications, major renovations, or changes in the HVAC systems made after a VI mitigation system has been installed could affect the system’s performance and warranties. Information about the mitigation system should be incorporated into the building changes. When the changes are complete, the mitigation system should be re-tested to verify operational effectiveness.

Design Considerations for Residences

Some design considerations will be different for residences than for commercial/industrial settings. Often the size of the system installed will be smaller and less complex; however, the aesthetics of the system may be more important. Locations for vent piping and blowers should be selected to minimize disturbance to the residents and to be less noticeable, particularly inside the home. The noise of the blower should be considered and may require a cover to minimize the sound. Inspections can be disruptive to residents; therefore, when possible, it may be desirable to mount monitors on the outside of the building to reduce the need to enter the home.

Costs for VI Mitigation Systems

Costs for VI mitigation systems will depend on the building size and structure, subsurface conditions, and type of system installed. Costs for SSD and sub-membrane depressurization systems are similar and are largely driven by permeability of the underlying soil. Buildings underlain by compacted low permeability soil typically have higher costs than those underlain by a high permeability substrate such as crushed stone. Representative costs for industrial style buildings and strip malls are on the order of \$5/ft² to \$7/ft²; houses can be up to \$10/ft²; schools and daycare facilities are generally \$7/ft² to \$8/ft². However, SSD costs have ranged from as low as \$3/ft² to as high as \$20/ft². For building pressurization, there will be no capital costs if the existing HVAC system can be used to achieve positive pressure; however, annual O&M costs are estimated at \$200 to \$750/yr and energy costs for heating and cooling may increase substantially. Indoor air treatment tends to be expensive compared to other types of VI mitigation. Capital costs in the range of \$20,000 and annual operating expenses of \$15,000 to \$20,000 are not uncommon for indoor air treatment.

Case Study for SSD: Electronics Store in a Shopping Mall

The subject for this case study is a former big-box electronics store downgradient of a dry cleaning operation that spilled tetrachloroethylene (PCE) over a 20-year period through inadequate recapture procedures. The store, now vacant, is approximately 29,000 ft² total area, with 21,000 ft² in the original structure and 8,000 ft² in the addition.

First, the utility markout was completed, the sampling (soil gas, groundwater, and ambient air) was performed, and an access agreement was put in place. Next, the building inspections took place. The sub-slab material beneath the original building is compacted silt clay; the addition consisted of crushed stone beneath the slab. Perimeter foundation walls were block, with interior vertical steel column supports. The ceiling was 20 ft high and constructed of a steel deck and truss system; the roof was constructed of built-up asphalt material.

After the building inspection, the pressure field testing proceeded. Suction hole and vacuum test hole transect locations are shown on Figure 10. Using the vacuum data collected during the pressure field testing, suction blower(s) were specified to achieve the right balance of vacuum and airflow required to develop a negative pressure field sufficient to arrest soil gas attenuation. Once the radius of influence was calculated, the number and location of suction points were determined. The location of suction points, pipe runs and blowers, exhausts, future air handlers and fresh air intakes were planned around the future use of the building.

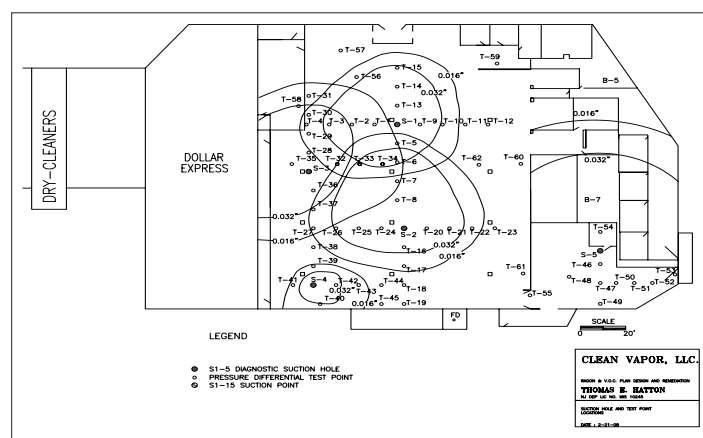


Figure 10. Results of sub-slab pressure field tests.

System Design

The system designed for this building had 15 suction points and seven blowers (see Figure 11). The tight soils under the original structure required high-vacuum, low-flow blowers, while the more permeable materials under the addition required low-vacuum, high-flow blowers. The design included a custom alarm panel that triggers a visual and audible alarm if a blower is operating out of the desired performance range. The design was later amended to include some trenching and lateral drilling to create a negative pressure field beneath an adjacent store.

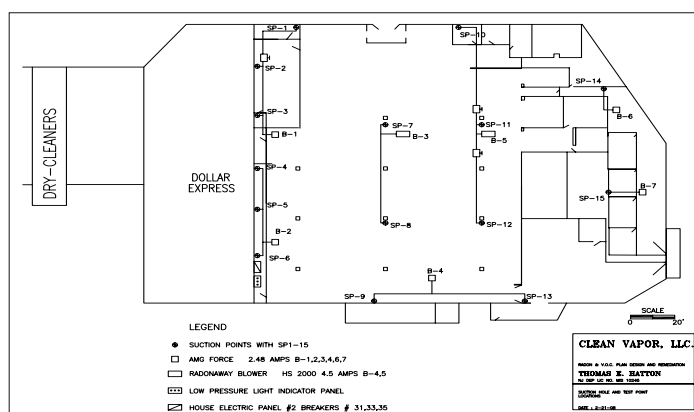


Figure 11. Blower and suction point design.

System Startup

After the VI mitigation system was installed, the start-up process included adjusting the gate valves at individual riser pipes to balance air flow and the distribution of the sub-slab vacuum. Most of the vacuum field data indicated negative sub-slab pressures greater than -0.01 in. w.c. Sub-slab vacuum readings at one corner of the building were closer to -0.004 in. w.c. An open floor/wall joint behind a sheetrock wall was identified, resulting in leakage responsible for the loss of vacuum pressure. The sheetrock wall was opened, the joint sealed, and the negative pressure field increased.

Post-mitigation indoor air samples were collected using Summa canisters and analyzed by EPA Method TO-15. Indoor air concentrations were below the 3.0 µg/m³ indoor, non-residential screening level for PCE in New Jersey where the building is located.

Resources

Additional information on VI mitigation for existing buildings can be found in the following sources:

California Department of Toxic Substances Control. 2009. Vapor Intrusion Mitigation Advisory. http://www.dtsc.ca.gov/sitecleanup/upload/VI_Mitigation_Advisory_Apr09.pdf

Interstate Technology and Regulatory Council (ITRC). 2007. Vapor Intrusion: A Practical Guideline. <http://www.itrcweb.org/Documents/VI-1.pdf>

U.S. Environmental Protection Agency. 2008. Engineering Issue: Indoor Air Vapor Intrusion Mitigation Approaches. EPA/600/R-08-115. <http://www.clu-in.org/download/char/600r08115.pdf>

Photos and drawings throughout provided courtesy of Clean Vapor, LLC.

For the most current information, please contact the NAVFAC Alternative Restoration Technology Team or e-mail the NAVFAC Engineering Service Center at PRTH_NFESCT2@navy.mil.