Vapor mitigation best management practices

Purpose

The purpose of this best management practices (BMPs) document is to provide guidelines on vapor mitigation approaches for buildings. Effective vapor mitigation approaches can vary based on the building size, building construction, heating ventilation and air conditioning (HVAC) system present and building use. This BMP includes vapor mitigation approaches for smaller residential buildings (e.g. single family residential homes and multi-unit residential buildings with four or less units) as well as larger commercial, industrial, residential and mixed-use buildings. This BMP also provides guidelines on verification testing, institutional controls and long-term operation and maintenance for vapor mitigation systems.

This BMP document is applicable to the following Minnesota Pollution Control Agency (MPCA) programs:

- Resource Conservation and Recovery Act (RCRA)
- Superfund
- Site assessment
- Voluntary Investigation and Cleanup (VIC)
- Petroleum Brownfield Program (PBP)
- Petroleum Remediation Program (PRP)

This BMP does not include the decision making process for when vapor mitigation is necessary for a building. Please refer to MPCA's Vapor investigation and mitigation decision BMP document to determine when vapor mitigation is necessary for a building (https://www.pca.state.mn.us/sites/default/files/c-rem3-06e.pdf for MERLA sites or https://www.pca.state.mn.us/sites/default/files/c-prp4-01a.pdf for PRP sites).

Vapor mitigation systems are installed to address potential vapor intrusion risks to a specific building and are generally not intended to act as a remediation system to clean-up soil vapor contamination. While remediation systems such as soil vapor extraction and methane extraction can be designed to include vapor intrusion mitigation, it is important to keep in mind that long-term vapor intrusion mitigation may be necessary even after the remediation system is turned off.

What are the different types of vapor mitigation?

There are a variety of building mitigation approaches that can be effective at preventing vapor intrusion into buildings. The mitigation approach selected should be based on site specific conditions including but not limited to severity of vapor intrusion risk, use or occupancy of the building, and building construction/design. MPCA considers active vapor mitigation systems as a best management practice for addressing vapor intrusion risk to buildings. Active vapor mitigation systems generally provide more reliable vapor risk reduction and provide a more consistent verification mechanism to evaluate system effectiveness than passive vapor mitigation approaches.

Following is a summary of common active building mitigation approaches that are used to address vapor intrusion along with a brief description of each. Details on implementing and verifying each of these active vapor mitigation approaches is included in the following sections of this document. Please contact the MPCA project team for prior approval if you plan to implement a vapor mitigation system other than those listed below or if you have questions regarding the appropriateness of a mitigation type based on building specific conditions.

Active sub-slab depressurization (SSD) – this mitigation approach uses sub-slab suction pits or sub-slab perforated piping connected to a powered fan to create a low pressure vacuum zone under the entire building [or defined vapor intrusion area of concern (VI AOC) beneath the building] to prevent potential vapor intrusion into the building. The SSD system generates a pressure barrier beneath the building that compensates for the depressurization of the building. This approach includes sub-membrane depressurization (SMD) where a vapor barrier or membrane is used when a concrete slab is not present (e.g. dirt floor crawl spaces).

Active sub-slab ventilation (SSV) – this mitigation approach uses a powered fan to vent the sub-slab soil or crawl space directly beneath the building allowing for dilution of vapor concentrations beneath the building and discharge to the atmosphere. SSV systems are similar to SSD systems; however, instead of using a pressure field to collect and route contaminated vapors, the SSV system sufficiently dilutes VOC levels below the building by advective air flow. These systems typically consist of a venting layer (e.g. filled with porous media such as sand or pea gravel) and a vent pipe array with fresh air intakes on one exterior side of the building and discharges on the opposite side of the building. The venting layer allows lateral soil-gas movement to the pipe array where soil-gas is collected and vented to the atmosphere.

Active indoor air building controls – this mitigation approach uses the building's HVAC system or indoor air building controls to maintain a consistent higher indoor air pressure relative to the ambient outdoor air, including and most importantly, below the building floor slab. It can be difficult and costly to maintain positive pressure in spaces and buildings that are not designed for these conditions. This vapor mitigation approach is best implemented for buildings already operating under positive pressure and new construction buildings designed to operate under positive pressure. Consult a certified HVAC contractor and/or a mechanical engineer if implementing this vapor mitigation approach.

Parking structures – underground enclosed parking structures use enhanced building construction and ventilation techniques associated with vehicle exhaust mitigation to also address vapor mitigation from the sub-surface. Open-air above grade parking structures typically interrupt the completed vapor intrusion pathway to the occupied building space above. For open-air above grade parking structures, discrete vapor entry points (e.g. stairwells and elevator shafts extending from the parking structure to the occupied building space) should be evaluated individually and mitigated as necessary.

MPCA does not consider passive mitigation systems, passive vapor barriers, indoor air filtration, and/or interim completed pathway evaluation as long-term, stand-alone vapor mitigation approaches.

Passive vapor barriers – passive vapor barriers (including sheet and spray-applied membranes) are typically placed beneath a building to reduce the migration of contaminated vapors into the occupied building space. Passive vapor barriers are not considered a standalone vapor mitigation approach by MPCA due to the difficulty in verifying the installation and performance of the vapor barrier after building construction. Passive vapor barriers may be used to enhance the efficiency and performance of an active vapor mitigation system (e.g. for sub-membrane depressurization). Active mitigation system performance verification will require sampling and diagnostic testing from beneath the passive vapor barrier.

Indoor air filtration – indoor air filtration typically consists of removing contaminants from the indoor air using a filter media (i.e. granular activated carbon) contained within a portable, powered filtration unit. MPCA does not consider indoor air filtration a stand-alone or long-term vapor mitigation approach. Indoor air filtration does not prevent vapor intrusion into the building. Indoor air filtration is typically used to temporarily reduce indoor air concentrations below ISVs when active mitigation cannot be installed **in an expedited timeframe** and the **building is still being occupied.**

Partial building mitigation – Building mitigation is necessary for all areas of the building where sub-slab concentrations exceed 33X ISVs (VI AOC) or where soil vapor concentrations exceed the ISVs when the attenuation factor is not valid. Partial building mitigation (PBM) may be appropriate for larger existing or new construction buildings (footprint larger than 30,000 square feet) where the VI AOC is defined beneath the building and does not encompass the entire building footprint.

Conditions when PBM is appropriate:

- Building footprint is larger than 30,000 square feet. The area needing mitigation (VI AOC) may end up being smaller than 30,000 square feet; however, the initial building vapor assessment must start with a minimum of 30,000 square feet.
- There are no preferential vapor migration pathways beneath the building beyond the PBM area.
- The VI AOC (concentrations greater than 33X ISV or ISV if attenuation factor is not valid) beneath the building has been adequately defined with two sub-slab sampling events conducted in opposite seasons (one heating season and one non-heating season).
- Installation of an SSD system can commence based on the first round of sub-slab sampling out to the VI AOC boundary. However, the second seasonal sub-slab sampling event is still necessary to confirm that the VI AOC boundary is defined. If the second seasonal sub-slab sampling event indicates the VI AOC needs to be expanded, the mitigation area will also need to be expanded.

Steps for partial building mitigation

1. Determine the area(s) of the building that need(s) mitigation (VI AOC beneath building) based on the sub-slab sampling data collected for the initial building vapor assessment.
2. All areas beneath the building with sub-slab concentrations exceeding applicable 33X ISVs (or ISVs if attenuation factor is not valid) require mitigation.
3. The partial building mitigation area should extend to the nearest points with two seasonal rounds of data with VOCs less than applicable 33X ISVs (or ISVs if attenuation factor is not valid), or to the exterior building walls.
4. Install building mitigation to cover the entire VI AOC(s) beneath the building.
5. Collect post mitigation analytical samples and diagnostic testing to verify effectiveness of the mitigation system within the originally defined VI AOC.
6. Conduct any follow-up seasonal sub-slab sampling to confirm the VI AOC boundaries, if necessary.

Interim completed pathway evaluation for vapor intrusion

Interim completed pathway evaluation includes collecting paired sub-slab, indoor and outdoor air samples along with evaluating the existing building conditions to determine if sub-surface vapors are migrating into the indoor building air. Interim completed pathway evaluation is not considered a stand-alone, long-term vapor mitigation approach. However, interim completed pathway evaluation may be an appropriate interim measure for the following situations:

- A property is up for sale and the fate of the existing building is unknown (e.g. whether a new owner will demolish or renovate the existing building).
- To evaluate potential imminent short-term exposure risk to building occupants from vapor intrusion (e.g. TCE is the contaminant of concern or sub-slab VOC concentrations exceed the expedited 33X ISVs and a sensitive receptor is present) and mitigation cannot commence under an expedited timeframe.

An interim completed pathway evaluation for vapor intrusion can determine if vapor levels above ISVs are present in indoor air creating an exposure risk to building occupants. If a completed pathway for vapor intrusion is confirmed (ISV exceedances in indoor air), temporary building control measures (i.e. indoor air filtration, limiting building occupancy, active building controls) need to be implemented immediately to protect occupants from the indoor air exposure conditions. In addition, active building mitigation needs to be implemented to address the long term exposure risk. If a completed vapor intrusion pathway is not present, a building owner may be able to temporarily postpone installation of the vapor mitigation system until the fate/occupancy of the building is known. A minimum of quarterly monitoring of paired sub-slab and indoor air along with outdoor air testing is required for ongoing confirmation that a completed pathway is not present. A general outline of the completed pathway evaluation process is provided below. Contact the MPCA project team if you are planning to conduct interim completed pathway evaluation for vapor intrusion.

Interim completed pathway evaluation process

1. Interim completed pathway evaluation consists of the following:
   a. Conduct a VI building survey (see Appendix D of the Vapor investigation and mitigation decision BMP) to assess building susceptibility to VI and identify potential VI entry points including:
      - Floor slab conditions (thickness, excessive cracking and/or deterioration)
      - Crawl spaces with earthen floors
      - Unsealed groundwater sumps
      - Floor drains open to the subsurface
      - Utility penetrations with significant openings to the sub-surface

   b. Document the operating characteristics of the HVAC system for the building on the MPCA VI building survey form (Appendix D of the Vapor investigation and mitigation decision BMP).
   c. Identify and evaluate potential vapor contributions from indoor and ambient background sources (i.e. chemical storage inventory, known use of chlorinated VOCs within the building)
   d. Conduct quarterly seasonal sampling events (two heating season and two non-heating season) a minimum of 30 days apart that includes concurrent paired sampling of; sub-slab, indoor air and outdoor ambient air.
   e. Evaluate whether VI is occurring by comparing indoor air concentrations to:
      - Applicable ISVs (residential or commercial/industrial)
      - Sub-slab concentrations
      - Outdoor air concentrations

   f. In addition to the above analytical sampling, for each sampling event, monitor the pressure differential between the indoor building air and the air beneath the building at each sub-slab sampling location under various occupancy conditions to determine if a pressure differential exists that would cause movement of vapors from the subsurface into the building.
   g. Submit the interim completed pathway evaluation results to MPCA for review and determination of a completed pathway. MPCA will evaluate the following general criteria for determining whether the VI pathway is complete or likely to be complete:
      - Are there Indoor air concentrations above ISVs in any of the indoor air samples that are not attributable to an indoor or outdoor source?
      - Are there building conditions that indicate the 33X ISV screening level is not valid and the building is susceptible to VI?
      - Do the differential pressure measurements indicate positive pressure between the building indoor air and the sub-surface?
      - What are the source and sub-surface concentrations and stability of soil gas and groundwater plumes?

   h. If evidence of a confirmed completed pathway including vapor concentrations exceeding ISVs is observed, the MPCA should be notified immediately and prompt building mitigation is necessary. If the building is occupied, immediate temporary mitigation measures are also necessary to protect building occupants from the identified vapor intrusion exposure risk.
   i. Additional investigation, interim completed pathway evaluation or building mitigation is necessary if the completed pathway evaluation is inconclusive that:
      - VI is not occurring.
      - There is no VI risk to the building.

2. An additional important part of the mitigation decision process is determining if expedited actions are needed to protect human health. Expedited action decisions are discussed in the Vapor investigation and building mitigation decisions BMP.

3. Illustrate vapor mitigation decisions for buildings on MPCA GIS Template 4.

Which vapor mitigation approach should I use for my building?

It is important to select a mitigation system approach that will be effective in protecting the building occupants from vapor intrusion. Not all types of vapor mitigation systems included in this document are effective for all building types. Items to consider when selecting an effective mitigation system for your building may include level of vapor intrusion risk, building size, building construction, building use, building HVAC controls and building occupancy.

For single-family residential and small multi-family (4 units or less) residential buildings, active SSD systems have proven to be an effective vapor mitigation approach. An active SSD system should be the vapor mitigation approach for these types of buildings. Any other vapor mitigation system approach for single-family residential and small multi-family (4 units or less) residential buildings other than an active SSD system must be approved by the MPCA Project Team prior to implementation.

For commercial, industrial, large multi-family residential (5 units or more) and mixed use buildings, multiple mitigation system options may be effective for addressing vapor intrusion risk. Table 1 below summarizes vapor mitigation approaches based on building type.

Table 1 – Vapor mitigation approaches based on building type

Building type	Vapor Mitigation Approach			
	Active SSD[1]	Active SSV[2]	Active indoor air building controls[3]	Parking structures
Single-family and small multi-family (4 units or less) residential	X			
Commercial, industrial, large residential (5 units or more) and mixed use	X	X	X	X

Notes:

1 – May also include active (SMD) system components to address earthen crawl spaces.

2 – Active SSV is typically only feasible for new construction buildings due to the need for an engineered base layer beneath the lowest layer of flooring. Crawl spaces with earthen floors is another possible application for active SSV mitigation.

3 – Indoor air building controls are typically not effective in buildings that do not have controlled access to all openings to the exterior (i.e. doors and windows) or where tenants have control over individual HVAC components. Some examples include buildings with large bay doors that are routinely opened and closed and buildings where tenants can freely open windows throughout the building and/or alter HVAC system components at-will.

If your site is in the MPCA Brownfield program, prepare and submit a Vapor Mitigation Response Action Plan (RAP) to the MPCA Project Team for review and approval prior to installation of a vapor mitigation system. If your site is in an MPCA Superfund or RCRA Program, prepare and submit a Vapor Mitigation Work Plan to the MPCA Project Team for review and approval prior to installation of the vapor mitigation system. The Brownfield vapor mitigation RAP and Superfund/RCRA vapor mitigation Work Plan should include the following elements, as applicable:

- Building use and occupancy (i.e. residential, commercial, industrial, any sensitive receptors, etc.)
- Initial sub-slab testing results compared to relevant 33X ISVs based on building use and occupancy
- Any pre-mitigation diagnostic testing results
- Building construction information (i.e. additions, slab-on-grade, slab thickness, footing breaks, etc.)
- Vapor mitigation approach (i.e. SSD, SSV, underground parking, etc.)

- If partial building mitigation is proposed, include a figure illustrating the proposed partial mitigation area based on the vapor intrusion area of concern (VI AOC) beneath the building defined by sub-slab locations below applicable 33X ISVs (or ISVs if attenuation factor not valid) and/or exterior building walls.
- Proposed post mitigation verification testing including pressure field extension (PFE) monitoring points (number and location) and paired sub-slab, indoor air and ambient outdoor air sample locations.
- If expedited mitigation is necessary, please call the MPCA Vapor Hotline at 651-757-2040. Please refer to the MPCA expedited action criteria located in the Vapor investigation and mitigation decision BMP to determine if expedited action is necessary.

MPCA approval of a Vapor Mitigation RAP or Work Plan is <u>not</u> endorsement of a specific design, but rather concurrence with the proposed performance objectives.

The final mitigation system design and/or approach may change based on conditions encountered during installation and diagnostic testing.

Vapor mitigation system installation

This section provides details on the installation of the various vapor mitigation system approaches **summarized in Table 1**. All active vapor mitigation systems should be installed to avoid creation of other health, safety and environmental hazards to building occupants including but not limited to; backdrafting combustion appliances, constricting or blocking building exits with pipe runs or degradation of fire rated assemblies with pipe and/or cable penetrations. All elements of any mitigation system installed must meet with all State and local building codes and regulations.

If the contaminants of potential concern (COPC) include flammable or explosive compounds (i.e. petroleum compounds), the active vapor mitigation system must be intrinsically safe. Special safety considerations, which are not included in this document, are required if methane is a COPC. If methane is a COPC, please contact MPCA staff to discuss further safety considerations prior to system installation.

Active SSD system installation – existing buildings

Pre-mitigation diagnostic testing

Prior to installation of an active SSD system, diagnostic testing should be performed to assist in determining the following information: number and placement of suction points, size of system piping, sizing of vent fan, tightness to the floor slab and evaluating the overall effectiveness of the system to provide adequate protection of the building occupants from vapor intrusion. Pre-mitigation testing includes collection of PFE measurements. PFE measurements are obtained by measuring the pressure differential between the indoor air space and the air space directly beneath the floor slab, floor membrane and/or outside the foundation wall.

Pre-mitigation diagnostic testing should be conducted in accordance with Section 3 of U.S. Environmental Protection Agency (EPA) 1993. Pre-mitigation diagnostic testing measurements, building floor plan and system information should be recorded on Attachment A – Pre-mitigation Diagnostic Testing Checklist. Following is a summary of procedures for conducting pre-mitigation diagnostic testing.

1. Prepare a floor plan (to-scale, with north arrow) of the lowest level of the building including any crawl spaces and floor-slab additions of different elevations (if present) prior to any diagnostic testing for system installation. This includes foundation and footing locations.
2. Conduct backdraft testing in accordance with all State and local building codes on all combustion appliances inside the building. Procedures for checking combustion appliance backdrafting can be found in section 11.5 of EPA, 1993. If backdraft conditions are identified, notify the building occupants and the building owner immediately. DO NOT conduct pre-mitigation diagnostic testing or commence with mitigation system installation until all backdraft conditions have been corrected. A heating, ventilation and air conditioning (HVAC) contractor should evaluate and correct any backdraft conditions and verify proper appliance installation and performance.

3. Confirm the locations of any underground utilities beneath or within the floor slab with the property owner and/or hire a utility locating contractor to identify and mark the utilities prior to drilling through the floor slab.
4. Seal potential vapor intrusion points in the floor (e.g. gaps, cracks, cold joints, utility penetrations) to the extent practical.
5. All suction points and proposed system piping locations should be confirmed with the property owner prior to installation.
6. Select a suitable location for a suction point based on building layout and utilities and property owner approval and make a hole in the concrete floor slab to open communication with the soil space beneath the floor slab.
7. The diameter of the suction point hole should correspond to the type of diagnostic testing equipment you are using (shop-type vacuum, mitigation fan, etc.).
8. Connect the suction source (shop-type vacuum, mitigation fan, etc.) to the suction point and seal against the floor slab.
9. The vacuum applied at the suction point should generally be similar to the vacuum developed by the fan that is selected for use in the building. Therefore, if using a shop-type vacuum you may need to reduce the vacuum by bleeding in fresh air.
10. Make sure that the exhaust from the shop-type vacuum or mitigation fan is vented to the outside to prevent vapor emissions into the building.
11. Drill ¼ inch to ½ inch diameter PFE test holes in the floor slab with a masonry drill bit. Sub-slab vapor monitoring points may also be used to measure PFE.
12. A sufficient number of PFE test points should be conducted to confirm that the mitigation system will effectively address vapor intrusion risk across the entire building slab or the VI AOC beneath the building for partial building mitigations. The total number of PFE test points will vary based on building size, building construction and area needing mitigation.
13. Conduct the PFE diagnostic testing with all natural draft appliances (older non-high efficiency furnaces, stove/range hoods, clothes dryers, bathroom fans, etc.) operating and all windows and exterior doors closed to provide “worst case” conditions.
14. Measure the pressure differential between the area below the floor slab and the indoor air space above the floor slab at each PFE test hole using a calibrated micromanometer.
15. Measure the air flow from or into the vacuum to assist in proper selection of the fan size for the active system.
16. The pre-mitigation PFE diagnostic testing should demonstrate a pressure differential at each PFE test point that is greater than the following default pressure differential criteria:
    - -3 pascals (0.012 inches of water) during heating season (November 1 through March 31)
    - -5 pascals (0.020 inches of water) during non-heating season (April 1 through October 31)
17. Additional suction points and/or adjustments to the suction point (e.g. removal of soil, increasing vacuum) may be needed to obtain the required PFE across the building footprint.
18. The results of the pre-mitigation system PFE diagnostic testing are necessary to assist in selecting the active system components including: determining the correct fan size, number of suction points and diameter of the suction/vent piping.
19. The PFE test points should be left in place and used for post-mitigation diagnostic testing where appropriate. The PFE test points should be temporarily sealed with an air tight cap between diagnostic tests and final sealed (remove sampling insert and backfill hole with cement) upon completion of testing to prevent vapor intrusion from the sub-slab into the living space.

20. Pre-mitigation diagnostic testing results should be documented on Attachment A and included with the final Property Summary Report (PSR).
21. In the event that the building has existing combustion appliances that draw room air from inside the building and a direct source of make-up air from outside the building is not present, make-up air to the combustion appliance room should be installed prior to conducting pre-mitigation diagnostic testing. Providing outside make-up air for combustion appliances significantly reduces the potential for backdrafting in addition to reducing the potential for vapor intrusion into the building. Modifications to combustion appliances, including providing make-up air, may require a permit.
22. Any building construction/reconstruction work must be completed in accordance with all State and local building codes and regulations. All elements of any mitigation system installed must meet with all State and local building codes and regulations, as well.

Active SSD system installation – existing structures

Active SSD systems should be installed in general accordance with the most current versions of ASTM International and EPA technical documents (ASTM, 2013, ASTM, 2009, EPA, 1993, EPA 1994a, 1994b, 1994). The following procedures can be applied to both existing buildings as well as new construction. For new construction buildings, an engineered depressurization layer is typically installed beneath the lowest level floor slabs which may reduce the overall number of suction points/risers penetrating the floor.

Active SSD system installation information should be recorded on Attachment B – Active System Installation Checklist. Following is a summary of active SSD system installation methods and procedures:

1. The placement of all suction points and piping should be confirmed with the property owner prior to installation of the active SSD system.
2. A minimum of one suction point should be installed in each level (e.g. multi-level basements, crawl spaces, etc.) and in each area where there is a building addition or the foundation would restrict the air flow from one area to another.
3. PFE diagnostic testing should be conducted prior to installation of the active system to evaluate PFE across the building footprint and determine how many suction points are required (see pre-mitigation diagnostic section above).
4. If the required pressure differential is not achieved at all PFE test points, additional suction pits, higher vacuum fans, additional fans, or alternative vapor mitigation techniques should be employed.
5. Install piping to connect the suction point(s) to the fan(s). Piping material should be compatible with the site specific contaminants of concern. Common piping material for SSD systems include schedule 40 polyvinyl chloride (PVC) and galvanized steel. Piping diameter will vary based on system design. Typical pipe diameter for single family residential homes is three to four inches where larger commercial/industrial systems may use six inch or larger diameter piping.
6. The fan(s) should be located in an unconditioned space with limited occupancy like the attic or garage or outside if there is no available unconditioned space. If the stack piping and/or fan(s) need to be located outside, they should be chased and insulated to reduce the potential for condensation and frost build-up.
7. The circuit breaker box should indicate which breaker the active system electrical supply is connected to.
8. Electrical connections for the fan should be conducted by a licensed electrician in accordance with all State and local building codes.
9. The stack discharge should be located a minimum of 10 feet from any building openings to prevent vapor re-entrainment.
10. The discharge height of the stack should be a minimum of two feet above the roof line.
11. The exhaust discharge should be vertical with no elbows or deflectors.

12. Active system piping should have labels identifying it as vapor mitigation system piping, and should have flow direction arrows on the piping in all visible locations on each floor/level.
13. A manometer should be installed in a visible and accessible location on at least one suction point stack/riser associated with each fan so the system performance can be monitored.
14. A label should be placed in a visible location on the stack/riser containing the manometer. The label should contain the following information:
    - Active system installer's name, telephone number and National Radon Proficiency Program (NRPP) or National Radon Safety Board (NRSB) certification number
    - Initial vacuum reading on the manometer upon active system installation
    - Active system installation date
    - Fan model
15. Active system installation activities and diagnostic testing results should be recorded on Attachment B and included in the final PSR.

Active SSD system installation – new construction

Active SSD system installation in new construction is similar to existing structures; however, new construction provides the opportunity to design a connected venting layer beneath the building slab to allow for efficient depressurization of the slab. An active SSD system in new construction can be designed using suction points as described above for existing structures or with a continuous venting layer as described below.

The continuous venting layer should be installed directly beneath the floor slab in all areas of the building where vapor mitigation is necessary (VI AOC). The venting layer generally consists of porous material (e.g. pea gravel or sand) and a slotted PVC pipe array (or MPCA approved equivalent) to allow movement of soil-gas beneath the building floor slab. A vapor barrier/membrane may also be used beneath the floor slab to isolate the venting layer from the building space and provide an upper boundary condition for the venting layer.

Prior to completion of building construction, conduct PFE diagnostic testing to evaluate PFE across the building footprint requiring mitigation and determine if the system is affecting all areas at the required pressure differential as follows:

- -3 pascals (0.012 inches of water) during heating season (November 1 through March 31)
- -5 pascals (0.020 inches of water) during non-heating season (April 1 through October 31)

Post-mitigation diagnostic testing will also be required upon completion of building construction and with the buildings HVAC system operating to ensure the above PFE readings are maintained during building operating conditions.

For crawl spaces with earthen floors, air-tight seal all potential vapor intrusion entry points (e.g. utility penetrations and any open access to the crawl space) into the building. A vapor barrier/membrane may also be used to isolate the lowest layer of building flooring from the earthen crawl-space floor creating a layer to actively depressurize and vent contaminated soil-gas from beneath the occupied building space.

Follow steps 5 through 15 from the Active SSD system installation – existing structures above.

Active SSV system installation

Active SSV involves placement of a venting layer beneath the building floor slab to allow for actively moving soil-gas from beneath the building and discharging it to the atmosphere via a continuously active powered fan(s) while replacing/diluting the soil-gas with outdoor ambient air. Active SSV is typically only feasible for new construction buildings due to the need for an engineered base layer beneath the lowest layer of flooring. Crawl spaces with earthen floors is another possible application for active SSV mitigation.

Active SSV System Installation for new construction and crawl spaces with earthen floors

1. For new construction buildings, install a continuous venting layer directly beneath the floor slab in all areas of the building where vapor mitigation is necessary (vapor intrusion area of concern). The venting layer generally consists of porous material (e.g. pea gravel or sand) and a slotted PVC pipe array (or MPCA approved equivalent) to allow movement of soil-gas beneath the building floor slab and provide dilution from the outdoor ambient air intakes. A vapor barrier/membrane may also be used beneath the floor slab to isolate the venting layer from the building space and provide an upper boundary condition for the venting layer.
2. For crawl spaces with earthen floors, air-tight seal all potential vapor intrusion entry points (e.g. utility penetrations and any open access to the crawl space) into the building. A vapor barrier/membrane may also be used to isolate the lowest layer of building flooring from the earthen crawl-space floor creating a layer to actively vent contaminated soil-gas from beneath the occupied building space.
3. Install outdoor ambient air intakes on one side of the building or crawl-space connected directly to the slotted PVC pipe array/venting layer.
4. On the opposite side of the building or crawl-space, install vent/discharge pipes connected to the slotted PVC pipe array/venting layer beneath the building on one end and a powered electric ventilation fan on the other end.
5. The powered ventilation fan(s) must be located in unconditioned building space with limited occupancy or outside of the building. If the fans (and associated piping) are located outside, they should be chased and insulated to reduce the potential for condensation and frost build-up.
6. The circuit breaker box should indicate which breaker the active system electrical supply is connected to.
7. If the rated electricity requirements of a mitigation system fan exceed 50% of the circuit capacity into which it will be connected, or if the total connected load on the circuit (including the mitigation vent fan) exceeds 80% of the circuit's rated capacity, a separate, dedicated circuit shall be installed to power the fan.
8. The stack discharge should be located a minimum of 10 feet from any building openings to prevent vapor re-entrainment into the building.
9. The discharge height of the stack should be a minimum of two feet above the roof line.
10. The exhaust discharge should be vertical with no elbows or deflectors.
11. Active system piping should have labels identifying it as vapor mitigation system piping, and should have flow direction arrows on the piping in all visible locations on each floor/level.
12. A manometer should be installed in a visible and accessible location on at least one suction point stack/riser associated with each fan so the system performance can be monitored.
13. A label should be placed in a visible location on the stack/riser containing the manometer. The label should contain the following information:
    - Active system installer’s name, telephone number and NRPP or NRSB certification number
    - Initial vacuum reading on the manometer upon active system installation
    - Active system installation date
    - Fan model
14. Active system installation activities and diagnostic testing results should be recorded on Attachment B and included in the final PSR.

15. To ensure connectivity of the engineered venting layer beneath the building, measure air flow at each of the SSV system outlet locations with the system turned off and again with the system turned on. With the system turned on, there should be a noticeable increase in the flow rate in the downstream direction at each of the measured outlet locations compared to when the system is turned off. Document flow rate diagnostics on Attachment C.

Active indoor air building controls system installation

This vapor mitigation approach is best implemented for buildings already operating under positive pressure and new construction buildings designed to operate under positive pressure. This approach effectively prevents advective flow of soil-gas into the building by maintaining a higher indoor air pressure relative to the outdoor ambient air through use of the buildings heating, ventilation and air conditioning (HVAC) system. Continuous, adequate positive pressurization is necessary for all areas of the building where sub-slab concentrations exceed MPCA screening criteria (i.e. areas within the VI AOC). MPCA defines adequate positive pressurization as pressure differential (negative from the indoor air to the outdoor ambient [sub-surface]) equal to or greater than the following:

- -3 pascals (0.012 inches of water) during heating season (November 1 through March 31)
- -5 pascals (0.020 inches of water) during non-heating season (April 1 through October 31)

Any non-ventilated or passively ventilated rooms (e.g. mechanical rooms) should be specifically evaluated to determine if modifications are necessary to achieve positive pressurization of these spaces relative to the outdoor ambient air. Specific building construction and uses that will significantly reduce the effectiveness of this approach include buildings where tenants can freely open and close windows, large bay doors and individual adjustable HVAC components throughout the building.

This vapor mitigation approach may result in a significant increase in energy use for buildings not designed to operate under positive pressure. This vapor mitigation approach is not allowed for small (4 units or less) residential buildings. Consult a certified HVAC contractor and/or a mechanical engineer if implementing this vapor mitigation approach. Any HVAC system adjustments for vapor mitigation must be in compliance with all State and local building codes.

Parking structure active system installation

For the purposes of this BMP, MPCA is defining a parking structure as a parking structure consisting of nine or more stalls located beneath the occupied spaces of the building. The parking structure can be fully enclosed and underground or open air and above ground. The parking structure may be present beneath the entire building footprint or only a portion of the building footprint. For situations where the parking structure is not present beneath the entire building footprint, and full building mitigation is necessary, multiple vapor mitigation approaches will likely be necessary.

Above ground open air parking structures

Above ground, open-air parking structures generally provide sufficient ventilation to prevent vapor intrusion into the occupied portions of the building above the parking structure. However, there may be vapor intrusion risk associated with specific components of the above ground open-air parking structure including stairwells, elevator shafts and utility penetrations that extend from at or below the ground surface up into the occupied building space. These components should be constructed with a concrete base and walls and not earthen floors/walls. These components should be evaluated for vapor intrusion risk (sub-slab sampling) and mitigated as necessary per the MPCA vapor intrusion BMPs.

Underground enclosed parking structures

Underground parking structures typically consist of fully enclosed, single or multi-level parking located beneath a building. Underground parking structures are designed to ventilate exhaust fumes from vehicles; however, there are additional building construction and ventilation system considerations to be implemented beyond a typical underground parking structure design when using the underground parking structure as an active vapor mitigation approach. **Table 2** below summarizes additional building component design upgrades for when an underground parking is being utilized to address vapor intrusion risk.

Table 2 – Building component design upgrade considerations for vapor intrusion mitigation using underground/enclosed parking structures

Building Component	Design upgrades for vapor intrusion mitigation
Floor slab	Epoxy/urethane coating, seal all cracks and saw cuts
Concrete block walls (sub-surface)	Fill voids with concrete/insulation, paint block walls
Ceilings/walls of underground parking structure	Waterproofing membranes, coat or paint walls
Stairwells and elevator shafts	Additional ventilation/positive pressurization, subsurface concrete floors or walls
HVAC/ventilation units for underground parking	Continuous operation, minimum air exchanges per hour, digital control system
Utility penetrations	Upgrade firestop/sealing to extend replacement period
Vapor retarder/barrier	Upgrade thickness of barrier or vapor intrusion specific barrier
Radon system (if required for building type)	Upgrade system for vapor intrusion mitigation (i.e. make passive radon system active)
Operations and maintenance	Minimize "human error/control," building-specific operations and maintenance plan to evaluate condition of building materials and ventilation systems, periodic effectiveness testing

Source: *Parking Facilities and Vapor Intrusion Mitigation, Table 9.1. pg. 27, dated February 22, 2019, prepared for the MPCA by Braun Intertec*

Mitigation system installation activities and any associated pre-mitigation diagnostic testing during construction should be documented and submitted with the Property Summary Report (PSR) found on MPCA's website at https://www.pca.state.mn.us/waste/vapor-intrusion-best-management-practices-0.

For more information on parking structures as vapor intrusion mitigation, please refer to the document: Parking Facilities and Vapor Intrusion Mitigation, dated February 22, 2019, prepared for the MPCA by Braun Intertec (https://www.pca.state.mn.us/sites/default/files/c-rem3-06i).

How do I verify the effectiveness of a vapor mitigation system?

Regardless of the type of mitigation system implemented, performance verification testing is necessary to determine if the mitigation system is operating as designed to prevent vapor intrusion into the building. Evidence of successful operation and performance of a mitigation system is required for MPCA to issue a Completion of vapor mitigation response actions for on-site building(s) letter or a No Further Action letter on sites where vapor mitigation is necessary.

Three types of verification testing are discussed below including; construction verification, diagnostic testing and analytical testing. Table 3 below summarizes the types of verification testing necessary based on the vapor mitigation approach. Additional details regarding how to conduct the different types of verification testing are provided below the table.

System performance verification is necessary for all mitigation types during the MPCA defined heating season (November 1 thru March 31), regardless of when the system was installed or constructed.

Table 3 – Summary of performance verification for vapor mitigation systems

Performance Verification		Mitigation Approach: Active SSD	Active SSV	Active indoor air building controls	Parking structures
Construction verification	Visual verification and documentation	X	X	X	X
Post-mitigation diagnostic testing	Pressure Field Extension (PFE)	X			
	Building Pressurization			X	X[2]
	Connectivity test		X		
Post-mitigation analytical testing	Paired sub-slab, indoor air[1] and outdoor air sampling	X	X	X	X

Notes:

1 – Indoor air testing should be conducted in the lowest level(s) of the building. If there are both basement and slab-on-grade levels present, both levels should be tested for indoor air along with paired sub-slab sampling for each level. For underground parking structures, indoor air should be collected in the lowest level of the parking structure as well as the first occupied level of the building above the parking structure.

2 – Confirm building pressurization for areas connected to or inside the parking structure space that have separate HVAC/ventilation systems including but not limited to; stairwells, elevator shafts and occupied spaces inside that may be located in the parking structure area such as ticket booths, offices, exercise rooms, etc.

Active SSD system performance verification

Construction verification

Visually verify and document that the active SSD system components were installed in accordance with the MPCA approved RAP/Work Plan, State and local building codes and per all applicable sections of EPA, 1993. Construction verification can be documented in Attachment B.

Post-mitigation diagnostic testing

A primary diagnostic performance verification method for active SSD systems is to confirm that the system is creating adequate pressure field extension (PFE) across the building floor slab(s) where mitigation is necessary (VI AOC beneath the building). PFE must measure per the MPCA defined seasonal condition (-3 Pascal in heating season, -5 Pascal in non-heating season).

Post-mitigation diagnostic testing should be conducted upon installation of the system by the installation contractor to confirm the system is operating effectively. Post-mitigation diagnostic testing should be repeated a minimum of one week (seven calendar days) after system installation and no more than 30 days after system installation in conjunction with post-mitigation analytical testing. For new construction, post-mitigation diagnostic testing is required under typical operating conditions of the building (i.e. construction complete and HVAC is operating). If the initial post-mitigation verification event was conducted in the MPCA defined non-heating season, a second round of post-mitigation diagnostic testing will be necessary in the MPCA defined heating season.

Post-mitigation diagnostic testing should be conducted in accordance with Section 11 of EPA, 1993. Post-mitigation diagnostic testing measurements, building floor plan and system information should be recorded on the Attachment C checklist. Following is a summary of the procedures to be followed for conducting post-mitigation diagnostic testing after installation of an active SSD system.

1. With the active system running and all internal combustion appliances and exhaust fans operating, the post-mitigation PFE diagnostic testing should demonstrate a pressure differential (negative from the indoor air to the sub-surface) at each PFE test point that is equal to or greater than the following default pressure differential criteria:
   - -3 pascals (0.012 inches of water) during heating season (November 1 through March 31)
   - -5 pascals (0.020 inches of water) during non-heating season (April 1 through October 31)
2. A sufficient number of PFE test points are necessary to demonstrate pressure field extension across the entire building slab or the entire area where vapor mitigation is necessary (VI AOC) for partial building mitigations. The total number of PFE test points will vary based on the mitigation system design, building size and building construction. PFE test points should be located at the maximum distances from all suction points within the building footprint.
3. Sub-surface building footings can disrupt PFE and sub-surface utility corridors can create a short circuit for mitigation systems both resulting in a loss of PFE at these features. PFE should be measured on both sides of these features where mitigation is necessary.
4. Conduct PFE testing with all combustion appliances and natural draft appliances (older non-high efficiency furnaces, stove/range hoods, bathroom fans, etc.) operating and all windows and doors closed to provide "worst case" conditions.
5. The PFE test points installed during the pre-mitigation diagnostic testing can be re-used for post-mitigation diagnostic testing; however, additional PFE test points may be required to confirm PFE across the floor slab and/or membrane and the PFE test points need to be temporarily sealed between tests to prevent vapor intrusion to the building. Upon completion of the post-mitigation PFE diagnostic testing, the PFE test points need to be sealed to prevent vapor intrusion to the building.
6. Smoke/tracer gas testing may be conducted along interior floor cracks and wall joints while active system is operating to check for air leakage. This method can be used to trouble-shoot when PFE cannot be obtained.
7. With the active mitigation system, all combustion appliances and vent fans running, conduct backdraft testing on all combustion appliances to ensure backdraft conditions were not created within the building due to the installed active system or HVAC system modifications. This is a critical step from a health and safety standpoint. If backdrafting conditions are observed, the active system or HVAC modifications must be turned off until the backdrafting condition is corrected. Report any backdrafting to the building owner and document the conditions. If the backdraft condition is not corrected, building occupants may be at risk from carbon monoxide poisoning. Procedures for checking combustion appliance backdrafting can be found in Section 11.5 of EPA, 1993 and ASTM 2007a.
8. Diagnostic testing results should be documented on a field checklist form (Attachment C) and included with the final PSR.

Post-mitigation analytical testing

The purpose of post-mitigation analytical testing is to evaluate the effectiveness of the mitigation approach by confirming that vapor intrusion is not resulting in unacceptable human exposure to contaminants of concern in indoor air. Post-mitigation analytical testing information and a checklist can be found in Attachment D.

Regardless of seasonal conditions, post-mitigation analytical testing is required after installation of the mitigation system. Post-mitigation analytical testing should be conducted after a one week (seven calendar days) equilibration period and must be completed within 30 days after mitigation system installation.

If the post-mitigation analytical testing is not collected in the MPCA defined heating season, a second round of post-mitigation analytical testing during the MPCA defined heating season is necessary to evaluate system performance under worst-case conditions

Procedures for conducting post-mitigation analytical testing include:

1. Collect concurrent sub-slab, indoor air and ambient outdoor air samples. The purpose of collecting paired sub-slab and ambient outdoor air samples is to assist in evaluating the source of any indoor air impacts, if detected.
2. The number of paired sub-slab and indoor air samples necessary will vary based on specific mitigation system design, building size and building construction. The Vapor Mitigation Response Action Plan (RAP) for Brownfield sites or Vapor Mitigation Work Plan for Superfund sites should include the proposed number and locations of paired post-mitigation analytical samples for MPCA review and approval prior to mitigation system installation. Following are considerations for determining where to collect paired sub-slab and indoor air samples for post-mitigation confirmation testing:
    - Within areas of highest known sub-slab vapor concentrations (i.e. source areas beneath the building)
    - Both areas of the building separated by sub-surface barriers to air flow (i.e. footing breaks) and/or preferential air flow pathways (i.e. sub-surface utility corridors)
    - All lowest level portions of a building that may be at differing elevations (i.e. sub-surface basement and adjacent slab-on-grade)
    - Stairwells and elevator shaft areas
    - All areas of the building with separate or discontinuous mitigation systems
    - A sufficient number of sample locations should be completed to provide coverage across the originally identified VI AOC
3. Indoor air samples and ambient outdoor air samples should be collected over a twenty-four hour period. Both indoor air and outdoor ambient air sampling require the use of individually certified clean canisters by the laboratory. The canister certification laboratory results should be included with the analytical data package received from the laboratory.
4. Indoor air samples should be collected from the basement or lowest level of the building near suspected vapor entry points (if present) to assess the worst-case vapor intrusion locations. If there are multiple lower levels in the building (i.e. basement and slab-on-grade), indoor air samples (with paired sub-slab samples) should be collected from each of the lower level areas.
5. The indoor air sample collection point should be located in the breathing zone, approximately three to five feet above the floor.
6. Complete the twenty-four hour indoor air and ambient outdoor air samples prior to purging and sampling of the paired sub-slab sample points to prevent sub-slab sampling activities from cross contaminating the indoor air samples.
7. Sub-slab samples should be collected with a canister equipped to collect the sample at a maximum flow rate of 200 milliliters (ml)/minute and the canister should be individually certified clean by the analytical laboratory.
8. All confirmation samples should be analyzed using EPA Method TO-15 (full scan) by a fixed base Minnesota Department of Health certified laboratory for the full Minnesota Soil Gas List compounds. The use of other analytical methods will require prior MPCA staff approval.
9. Follow-up PFE diagnostic testing should also be completed at the same locations as the test points completed for post-mitigation PFE diagnostic testing upon system installation.
10. Collect PFE readings at all sub-slab locations during post-mitigation analytical testing. Concurrent collection of this information will assist in distinguishing indoor air contaminants resulting from vapor intrusion versus those originating from other background contaminant sources.

Active SSV system performance verification

Construction verification

Visually verify and document that the active SSV system components were installed in accordance with the MPCA approved RAP/Work Plan, State and local building codes. Construction verification can be documented in Attachment B.

Post-mitigation diagnostic testing

Two key components of an effective active SSV system include continuous air exchange beneath the building and connectivity of the engineered venting layer beneath the building. Following are the post-mitigation diagnostic testing procedures for active SSV systems:

1. The amount of air exchange necessary beneath the building will depend on the sub-slab soil gas concentrations present and the source of the soil gas contamination. A continuous minimum air exchange rate of one air exchange per day (based on the square footage of the mitigated building area and the thickness of the venting layer) is necessary for the active SSV system to maintain beneath the building. The air exchange rate should be maintained at a level that results in dilution of the sub-slab soil-gas concentrations to below the applicable 33X ISVs. The air exchange rate of the active SSV system should be measured at the time of post-mitigation analytical testing (both heating and non-heating seasons) to confirm the air exchange rate is sufficient to reduce sub-slab soil-gas concentrations to below the applicable 33X ISVs.
2. To ensure connectivity of the engineered venting layer beneath the building, measure air flow at each of the SSV system outlet locations with the system turned off and again with the system turned on. With the system turned on, there should be a noticeable increase in the flow rate in the downstream direction at each of the measured outlet locations compared to when the system is turned off. Document flow rate diagnostics on Attachment C.
3. Smoke/tracer gas testing may be conducted along interior floor cracks and wall joints while active SSV system is operating to check for air leakage. Any identified leakage should be sealed to increase the efficiency of the active SSV system and prevent additional costs associated with the loss of conditioned air from the building.

Post-mitigation analytical testing

The purpose of post-mitigation analytical testing is to evaluate the effectiveness of the mitigation approach by confirming that vapor intrusion is not resulting in unacceptable human exposure to contaminants of concern in indoor air and that sub-slab concentrations are being diluted to below applicable mitigation action levels.

Regardless of seasonal conditions, post-mitigation analytical testing is required after installation of the mitigation system. Post-mitigation analytical testing should be conducted after a one week (seven calendar days) equilibration period and must be completed within 30 days after mitigation system installation.

Post-mitigation analytical testing is necessary in both the heating and non-heating seasons to evaluate SSV system operation in both seasons and confirm that the system is capable of maintaining dilution of sub-slab levels below applicable 33X ISVs under both heating and non-heating seasons.

Post-mitigation analytical testing information should be recorded on the Attachment D checklist. Procedures for conducting post-mitigation analytical testing are summarized in the Post-mitigation analytical testing for active SSD system performance verification section above.

Active indoor air building controls performance verification

Post-mitigation diagnostic testing

A primary diagnostic performance verification method for active indoor air building controls is to confirm that the building controls are creating adequate pressure differential across the building floor slab(s) where mitigation is necessary (VI AOC beneath the building). Pressure differential across the slab (or VI AOC beneath the building) must measure per the MPCA defined seasonal condition (-3 Pascal in heating season, -5 Pascal in non-heating season). Pressure differential testing should be conducted concurrent with post-mitigation analytical testing.

Post-mitigation diagnostic testing should be conducted upon initiation of the building controls for vapor mitigation to confirm the system is operating effectively. Post-mitigation diagnostic testing should be repeated a minimum of one week (seven calendar days) after system installation and no more than 30 days after system installation in conjunction with post-mitigation analytical testing. If the initial post-mitigation verification event was conducted in the MPCA defined non-heating season, a second round of post-mitigation diagnostic testing will be necessary in the MPCA defined heating season.

Post-mitigation diagnostic testing should be conducted in accordance with Section 11 of EPA, 1993. Post-mitigation diagnostic testing measurements, building floor plan and system information should be recorded on the Attachment C checklist.

Additional procedures for conducting post-mitigation diagnostic testing (pressure differential testing) are summarized in the Post-mitigation analytical testing for active SSD system performance verification section above.

Once the building control settings for vapor mitigation are established and verified, the building control settings should be documented and not be adjusted or modified without re-verification of the post-mitigation diagnostic testing. Building maintenance staff and anyone with access to adjusting the building control settings should be notified of the need to maintain these settings for vapor mitigation purposes. Signage documenting the building control settings for vapor mitigation and the need to maintain these settings should be placed in the immediate vicinity of the building controls, visible to anyone attempting to adjust the building controls.

Post-mitigation analytical testing

The purpose of post-mitigation analytical testing is to evaluate the effectiveness of the mitigation approach by confirming that vapor intrusion is not resulting in unacceptable human exposure to contaminants of concern in indoor air.

Regardless of seasonal conditions, post-mitigation analytical testing is required after initiation of the mitigation approach. Post-mitigation analytical testing should be conducted after a one week (seven calendar days) equilibration period and must be completed within 30 days after initiation of the building controls for mitigation.

If the post-mitigation analytical testing is not collected in the MPCA defined heating season, a second round of post-mitigation analytical testing during the MPCA defined heating season is necessary to evaluate system performance under worst-case conditions.

Post-mitigation analytical testing information should be recorded on the Attachment D checklist. Procedures for conducting post-mitigation analytical testing are summarized in the Post-mitigation analytical testing for active SSD system performance verification section above.

Parking structure performance verification

Above ground open-air parking structures

For above ground open-air parking structures the only features that would need performance verification are stairwells and elevators that extend from the sub-surface into the occupied building space above the parking structure. These features should have either continuous ventilation or indoor air controls adjusted to positive pressurization as allowed by building codes. Construction verification includes documenting the presence of concrete floors and walls to the stairwells and elevator shaft. Post construction diagnostic testing includes verifying positive pressurization or continuous ventilation at an air exchange rate of 0.05 CFM per square foot of area. Post-construction analytical testing consists of paired sub-slab, indoor air and outdoor ambient air sampling for stairwells and elevator shafts that extend from the subsurface into the occupied building space. Indoor air samples should be collected as close to the bottom of these structures as possible.

If additional ventilation and/or positive pressurization of these structures was necessary to address vapor intrusion, verify that the additional ventilation air exchanges is adequate, collect positive pressure measurements and confirm vapor intrusion risk has been addressed by collecting paired sub-slab, indoor air and ambient outdoor air testing.

Underground parking structures

Construction verification and post-mitigation diagnostic testing

For underground parking structures, there are multiple building components that are not typically part of a standard parking structure design which are critical to vapor mitigation. These vapor mitigation building components need to be evaluated and verified. Additional building components of a parking structure necessary for vapor mitigation include the following:

1. Verify any construction design upgrades implemented for vapor mitigation as identified in Table 2 above.
2. Verify that the air exchange system for the underground parking structure is designed to operate continuously and not intermittently. A continuous minimum air exchange rate of 0.05 CFM per square foot of area is necessary for the underground parking structure.
3. If concrete block is used for the sub-surface foundation, verify the blocks are filled (i.e. concrete filled or air-tight foamed) and not hollow or an appropriate vapor barrier/membrane is installed to seal this potential vapor intrusion pathway into the building space.
4. Verify that elevator shafts, stairwells and any occupied structures within the parking structure area (i.e. ticket booths, office space, work-out facilities) are positively pressurized to the parking structure space in accordance with the State and local building codes. Positive pressurization of these spaces should also be verified by collecting pressure differential readings (where feasible) that correspond to the MPCA defined heating season (-3 Pascals) or non-heating season (-5 Pascals).
5. Verify that all penetrations (i.e. utility conduits) from the parking structure space into occupied building spaces are appropriately sealed against vapor intrusion.

Post-construction analytical testing

The purpose of post-construction analytical testing is to evaluate the effectiveness of the underground parking structure to prevent vapor intrusion into the occupied portions of the building by confirming that vapor intrusion is not resulting in unacceptable human exposure to contaminants of concern in indoor air.

Post-construction analytical testing information should be recorded on the Attachment D checklist. Procedures for conducting post-construction analytical testing include:

1. Post-mitigation analytical testing for underground parking structures consists of collecting concurrent sub-slab, indoor air in the lowest level of the parking structure, first level of occupied building space above the parking structure and ambient outdoor air samples. Regardless of seasonal conditions, post-mitigation analytical testing is required after building construction. Post-mitigation analytical testing should be

conducted after a one week (seven calendar days) equilibration period and must be completed within 30 days after mitigation system installation.

2. If the post-mitigation analytical testing is not collected in the MPCA defined heating season, a second round of post-mitigation analytical testing during the MPCA defined heating season is necessary to evaluate system performance under worst-case conditions.
3. Indoor air samples and outdoor ambient air samples should be collected over a twenty-four hour period. Both indoor air and outdoor ambient air sampling require the use of individually certified clean canisters by the laboratory. The canister certification laboratory results should be included with the analytical data package received from the laboratory.
4. Sub-slab samples should be collected with a canister equipped to collect the sample at a maximum flow rate of 200 milliliters (ml)/minute and the canister should be individually certified clean by the analytical laboratory.
5. Indoor air samples should be collected from the lowest level of the parking structure near suspected vapor entry points (if present) to assess the worst-case vapor intrusion locations as well as in the first occupied space above the parking structure. If there are multiple lower levels in the building, indoor air samples (with paired sub-slab samples) should be collected from each of the lower level areas.
6. The number of paired sub-slab and indoor air samples necessary will vary based on specific building design, building size and building construction. The Vapor Mitigation Response Action Plan (RAP) for Brownfield sites or Vapor Mitigation Work Plan for Superfund sites should include the proposed number and locations of paired post-mitigation analytical samples for MPCA review and approval prior to mitigation system installation. Following are considerations for determining where to collect paired sub-slab and indoor air samples for post-mitigation confirmation testing:
    - Within areas of highest known sub-slab vapor concentrations (i.e. source areas beneath the building)
    - Both areas of the building separated by sub-surface barriers to air flow (i.e. footing breaks) and/or preferential air flow pathways (i.e. sub-surface utility corridors)
    - All lowest level portions of a building that may be at differing elevations (i.e. sub-surface parking structure and adjacent slab-on-grade
    - Stairwells and elevator shaft areas
    - All areas of the building with separate or discontinuous mitigation systems
    - A sufficient number of sample locations should be completed to provide coverage across the originally identified vapor intrusion area of concern
7. The indoor air sample collection points should be located in the breathing zone, approximately three to five feet above the floor.
8. All confirmation samples should be analyzed using EPA Method TO-15 (full scan) by a fixed base Minnesota Department of Health certified laboratory for the full Minnesota Soil Gas List compounds. The use of other analytical methods will require prior MPCA staff approval.

Vapor mitigation system documentation

Upon successful installation and verification of a vapor mitigation system, submit a Vapor Mitigation RAP Implementation Report (for Brownfield sites) or a Vapor Mitigation Work Plan Implementation Report (for Superfund sites) documenting the vapor investigation and mitigation work completed to the MPCA. Prepare a building specific PSR for each building where vapor mitigation was conducted and/or where vapor investigation was conducted as part of the submittal. A building specific PSR should be prepared for each building investigated for vapor intrusion risk, regardless of whether vapor mitigation was conducted or not. A PSR template for documenting building specific vapor investigation and mitigation can be found on the MPCA website at: https://www.pca.state.mn.us/waste/vapor-intrusion-best-management-practices-0

Institutional controls

When vapor mitigation is installed for a building there are long-term considerations that need to be addressed to ensure the vapor mitigation system continues to protect building occupants from vapor intrusion risk. Two important long-term considerations include:

- Notification to future property owners that a vapor mitigation system is present
- Continued operation and maintenance of the vapor mitigation system

An Environmental Covenant (EC) is required to be recorded and filed on all commercial, large multi-family residential, industrial and mixed-use commercial/residential properties where a vapor mitigation system is present. The EC is necessary to ensure that the mitigation system remains operational and effective. Future property owners should be notified of the presence and operation of the vapor mitigation system and who is providing ongoing operation and monitoring of the system. Documentation that an EC was filed for the property where vapor mitigation was completed shall be provided to MPCA prior to issuance of any vapor related technical assistance letters or no further action letters.

A condition of the EC is that an Annual Report be submitted to the MPCA to ensure the mitigation system remains in place and operational and to document the ongoing mitigation system operation and maintenance. Annual Reports are due to the MPCA by July 1 and should be emailed to: instcontrols.pca@state.mn.us.

Long-term operation and maintenance

Preparation of a long-term operation and maintenance (O&M) manual is necessary to ensure that the mitigation system remains operational and effective at mitigating vapor intrusion. A long-term O&M manual should be prepared for all mitigation systems and include the following items at a minimum:

1. A description of the system design, construction and operating parameters, with building-specific PSR attached along with attached manuals and specifications of the installed mitigation equipment
2. Mitigation system as-built drawings illustrating building construction, all mitigation system components as well as locations of diagnostic testing, manometers, alarm settings, fans, electrical connections, suction points, and sub-slab system components (i.e. vent pipe arrays)
3. A schedule for how and when mitigation system monitoring and building condition inspection will be conducted and the party(s) responsible to complete these tasks
4. Commitment to submitting annual reporting to the MPCA by July 1 of each year as per the Environmental Covenant, emailed to: instcontrols.pca@state.mn.us
5. A sub-section on mitigation system troubleshooting
6. As-built plan for the vapor mitigation system and building construction
7. Contact information for the property owner/occupant if there are questions or issues regarding the mitigation system
8. Placards/signage for visual components of the mitigation system

System monitoring

Verify the system is operating (i.e. powered fan is active) and conditions are consistent with when the system was originally verified (i.e. verify system manometer or Magnehelic gauge reading is within acceptable range of the initial reading collected at the time of original system verification per the site specific O&M Manual). Verify there is no evidence of damage to the system fans or piping and no blockage of system piping. At a minimum, system monitoring should be conducted semi-annually in alternating MPCA defined heating/non-heating seasons.

Building conditions

Evaluate building conditions to determine if any changes to the building have occurred since the mitigation system was installed and verified that could compromise the effectiveness of the mitigation system. Examples of building changes that could affect a mitigation system include; building additions, building renovations, changes to the HVAC system, installation of range or fume hoods venting large volumes of air and building use/occupancy changes (i.e. commercial to residential). Building conditions evaluation should be conducted semi-annually in alternating MPCA defined heating/non-heating seasons at a minimum.

Analytical testing

In general, ongoing analytical testing for the vapor mitigation system is not necessary once the system is installed and verification diagnostic and analytical testing is completed to demonstrate system effectiveness. Additional analytical testing may be appropriate in situations where you are trying to re-evaluate system effectiveness based on a changed building condition, system reconfiguration or when system monitoring indicates there may be issues with system effectiveness.

Contractor certification

The MPCA recommends only qualified professionals trained and experienced in performing the requirements and duties described herein should conduct vapor mitigation and verification testing work. Examples of training options for contractors performing pre and post-mitigation diagnostic testing and active system installation for commercial, industrial and mixed-use buildings include the NRPP and NRSB for installation of mitigation systems. Contractors must also have current certification for Occupational Safety and Health Administration (OSHA) 40 hour Hazardous Waste Operations and Emergency Response (HAZWOPER) to conduct pre- and post-mitigation diagnostic testing and mitigation system installation on Superfund sites. MPCA also recommends that mitigation contractors complete training on chemical vapor intrusion mitigation.

Attachments

Attachment A – Pre-Mitigation Diagnostic Checklist

Attachment B – Active System Installation Checklist

Attachment C – Post-Mitigation Diagnostic Checklist

Attachment D – Post-Mitigation Analytical Testing Checklist

Acronym list

AOC	Area of Concern
ASTM	ASTM International
BMPs	Best Management Practices
CFM	Cubic Feet per Minute
EC	Environmental Covenant
EPA	Environmental Protection Agency
HAZWOPER	Hazardous Waste Operations and Emergency Response
HVAC	Heating Ventilation and Air Conditioning
ISVs	Intrusion Screening Values
MPCA	Minnesota Pollution Control Agency
NRPP	National Radon Proficiency Program
NRSB	National Radon Safety Board
O&M	Operation and Maintenance
OSHA	Occupational Safety and Health Administration
PBM	Partial Building Mitigation
PBP	Petroleum Brownfield Program
PFE	Pressure Field Extension
PRP	Petroleum Remediation Program
PSR	Property Summary Report
PVC	Poly Vinyl Chloride
RAP	Response Action Plan
RCRA	Resource Conservation and Recovery Act
SMD	Sub-membrane depressurization
SSD	Sub-slab depressurization
SSV	Sub-slab ventilation
VI	Vapor Intrusion
VI AOC	Vapor Intrusion Area of Concern
VIC	Voluntary Investigation and Cleanup
VOCs	Volatile Organic Compound

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