TECHNICAL GUIDANCE DOCUMENT
INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

Vapor Mitigation Systems

Office of Land Quality

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Notice
The Technology Evaluation Group (TEG) completed this evaluation of vapor mitigation systems based on professional expertise and review of items listed in the "References" section of this document. The criteria for performing the evaluation are generally described in the IDEM OLQ technical memorandum, *Submittal Guidance for Evaluation of Remediation Technologies*.

This evaluation does not approve these technologies nor does it verify their effectiveness in conditions not identified here. Mention of trade names or commercial products does not constitute endorsement or recommendation by the IDEM for use.

Background and Technology Description
Several technologies can reduce indoor air concentrations and/or cut off completed vapor intrusion (VI) pathways. The appropriate technology depends on the vapor source pathway, building construction and indoor air contaminant concentrations. In Indiana, confirmatory sampling is the primary method for assessing a mitigation system's effectiveness; however, the following information is useful in determining if a mitigation technique is likely to be effective for a given situation. The chosen technology should be appropriate and amenable to performance parameters associated with long term monitoring until the VI pathway is no longer complete.

This document describes four mitigation techniques, depressurization systems, indoor air cleaners, building pressurization/HVAC modifications and sealants/barriers and then discusses design criteria which could be expected to be in a work plan and appropriate performance monitoring criteria for each type that would fit into IDEM's Vapor Remedy Selection and Implementation Draft Interim Guidance document. More comprehensive descriptions of the technologies are found in references below. Appendix A includes a description of items to be included in a mitigation system's long term operations, monitoring and maintenance plan. Appendix B is a sample monitoring form. Appendix C describes alternate investigation/mitigation techniques for preferential pathways.

DEPRESSURIZATION SYSTEMS

Depressurization System Description:

Depressurization systems work by creating a pressure barrier which keeps sub-surface air from flowing through a building slab (sub-slab depressurization system – SSDS) or a crawl space sub surface membrane (sub-membrane depressurization – SMDS). Depressurization systems do not treat contamination. Instead, they form a pressure barrier between the source and receptors. A separate Soil Vapor Extraction (SVE) system (or other remediation) should be used if source reduction is desired. Depressurization systems are the most common technology in use and have a consistently successful track record in mitigating vapor intrusion into structures. Several implementations of SSDSs are in use including Suction Point SSDS, Vented Pipe SSDS and Vented Floor Systems.

In existing structures, a sump suction point SSDS is the most commonly used system. Sump collection points are installed through the slab into the base layer beneath the slab. The sump is usually around twelve inches deep, depending on the granular material beneath the slab and a vacuum is applied by manifolding the suction points to a fan which vents to the atmosphere. If the base layer is crushed gravel or other material it is likely to be significantly more permeable than native soil and will require fewer suction pits to be effective. Buildings built directly on native soil will require more points to develop a pressure barrier across the slab. Well designed systems should have pressure monitoring points that allow verification of vacuum across the entire slab. Pressure monitoring points can also serve as permanent monitoring points for collection of sub-slab samples; temporary monitoring points are acceptable also.

For new construction, a vented pipe SSDS consists of a series of vented or perforated horizontal pipes embedded in the base layer beneath a structure. The pipes are sized based on square footage then manifolded through a plenum box to a riser pipe through which suction is applied. A rule of thumb is that a three-inch riser pipe can service up to 1,500 square feet, a four-inch riser can service up to 4,000 square feet, and six-inch riser pipe can service up to 15,000 square feet of slab (NAVFAC, undated). Multiple new construction vented pipe SSDSs are successfully mitigating vapor intrusion in Indiana.

Another variation for new construction is Aerated or Vented Floors. Several methods are available to create easily vented voids either embedded in the slab or directly beneath the slab. This can be accomplished using concrete formed systems (example Cupolex®) where concrete is poured over vented domes creating voids in the slab. A second method replaces all or some of the traditional sand and gravel sub-slab base with a geo-composite vapor transmission mat directly beneath the slab. The easily vented layers allow for smaller fans to be used while still accomplishing venting across the entire slab and may even allow eliminating the fan (see passive systems below).

Depressurization Technology Selection and Implementation

Depressurization systems are the most common vapor mitigation technique and are successfully employed at myriad sites in Indiana. IDEM's Vapor Remedy Selection and Implementation Draft Interim Guidance Document specifically addresses long term monitoring of these systems. System proposals should include an operations and maintenance schedule including items identified in Appendix A of this document.

An SSDS will not mitigate indoor air contamination from preferential pathways or ambient air. Most houses need only one or two suction pits to establish a satisfactory vacuum while larger commercial structures will likely need multiple pits, particularly if footers beneath the slab impede the pressure field development. Because of this, for new construction of large commercial structures, vented pipe SSDS or vented floors are generally a better choice than sumps because it is easier to obtain uniform propagation of the vacuum across the entire slab and because they are more easily optimized for greater efficiency. EPA recommends a minimum vacuum of 4-10 Pascal (EPA, 2008), but field implementations indicate this is likely the high end (Broadhead et al, 2010). Excessive vacuum may pull contamination towards the structure and also requires more energy to run the fan. Slab openings which inhibit vacuum propagation should be identified with a smoke test while a vacuum is applied and then sealed to reduce the energy required to form an adequate pressure field.

In an existing structure, high purge volume sub-slab sampling (McAlary et al, 2010; McAlary, 2011) can provide information about contaminants beneath a structure and also allow for efficient design of a SSDS system. VOC concentrations are measured at timed intervals while a vacuum is applied with a measured flow rate. Multiple vacuum points are monitored to provide information about footers and other structures which would impede flow allowing a more informed decision about the source of the extracted volume. The resulting concentration trend as a function of volume removed provides information about the distribution of vapors/ contamination at distances away from the extraction point allowing for development of a smart sampling plan. Incrementally increasing the flow rate while monitoring the multiple vacuum response points (vacuum step test) optimizes system design by determining the minimum flow rate required to reduce vapor intrusion flux to acceptable levels. This is important as energy use and associated costs are substantial for commercial HVAC systems. In some cases only the step test is used to provide design information and no contaminant sampling is done (Broadhead et al, 2010). High volume purge system design is only applicable to structures with a sub-slab layer that is more permeable than the floor, otherwise sufficient flow and vacuum propagation would not be achieved to make the test useful. High purge volume step tests are an effective way to efficiently design a mitigation system with a properly sized fan.

Telemetry monitoring systems are starting to be used at vapor intrusion sites. Programmable controllers are attached to pressure gauges across the slab or other system components and remotely notify responsible personnel when a negative pressure does not exist across the slab, a system component fails to function or if the telemetry system fails. These systems reduce reliance on building inhabitants to ensure that systems are working properly. Telemetry systems should be considered, particularly when vapor intrusion risks are substantial.

Passive Depressurization Systems:

Passive depressurization systems generally have the same components as active systems but they do not have fans. Thermal and atmospheric effects provide vacuum at the suction points as the upward convection of air through the riser venting system provides airflow and small vacuum to the sub-slab system. Additional convection occurs when the indoor air is at a higher temperature than the outdoor air. Wind driven ventilators can increase passive system airflow. Vented floor and aerated pipe mitigation systems have a greater likelihood of passive system success as reduced vacuum is required to produce substantial airflow across the slab.

Passive System Implementation:
Passive depressurization systems are generally only appropriate for lower risk VI sites as the generated pressure field is likely transient (Ash et al, 2010). Confirmatory sampling should be considered in both summer and winter conditions. Passive depressurization systems are easily converted to active with the addition of a fan; this conversion is a reasonable contingency measure to include with any passive system proposal if confirmatory sampling indicates further mitigation is necessary. Conversely, if the risk of vapor intrusion is reduced through attenuation or remediation, eliminating an active system's fan creates a passive system. To comply with IDEM's Vapor Remedy Selection and Implementation Draft Interim Guidance Document long term system monitoring recommendations, vacuum monitoring points installed across the slab should still show a vacuum, but it will vary more than with an active system.

INDOOR AIR CLEANERS

Indoor Air Cleaners Description:
Indoor air cleaners rely on a filter to trap contaminants. Both whole house HVAC filters and portable stand alone units which can be placed in areas of interest have been used. If an HVAC filter is used, the fan needs to run continuously in order to constantly circulate air through the filter; the HVAC specifications need to be such that the HVAC is able to operate with the added pressure across the filter without mechanical failure.

Stand alone filter units rely on air circulation to clean the area where they are located. Closed doors and other circulation obstructions limit their effectiveness. Indoor air cleaners are easily installed and can have an immediate impact on indoor air. They may be a good solution either when concentrations are high enough to warrant immediate action or if there are problems in determining the VI pathway and an interim solution is needed before a permanent mitigation system is designed. They may be useful for unconventional vapor intrusion pathways such as dry cleaners where chlorinated hydrocarbons have either saturated the environment or are still in use and ambient air is causing issues.

Indoor air cleaning filters are usually carbon based. Filters are available at industrial supply stores. Ozone generators are generally not recommended and EPA research indicates they are not effective at reducing VOCs. (EPA, 2009). No formal standard measurement for the effectiveness of gaseous contaminant filters for removing VOCs is currently in place; performance measures based on contaminant removal and breakthrough time are being developed (NIST, 2008; Sideswharen et al, 2011).

Indoor Air Cleaners Technology Selection and Implementation:
Indoor Air Cleaners provide no barrier or reduction of vapor intrusion into the home. These systems rely purely on indoor air circulation and filter capacity to remove contaminants. The only mechanism to assure they are working is indoor air testing. Use of indoor air cleaners as a long term solution would be complicated by maintenance issues associated with frequent filter changes. The contaminant is still present in the filter and may desorb if the filter is saturated and also may complicate indoor air testing when the filter is changed; in some cases it may be easier to replace the unit and change the filter offsite. Currently, indoor air cleaners are most appropriate as an interim measure. Regular monitoring should follow confirmatory testing to ensure that

filters maintain concentrations at or below acceptable levels over appropriate time frames.

BUILDING PRESURIZATION/HVAC MODIFICATIONS

Building Pressurization/Air Exchange Rate HVAC Modifications Description:
HVAC modifications may sometimes be used to address vapor intrusion. One type of HVAC modification attempts to pressurize the structure relative to the vapor source (usually the sub-surface) so that vapors do not move into the building. In some cases only the vapor entry points (for example the basement) is pressurized. Open doors, windows, etc. make pressurization difficult to maintain. Cracks, sumps and any openings need to be sealed. Older structures may not be air tight enough to maintain pressurization. This method is more appropriate for characterizing vapor intrusion than mitigation; monitoring indoor air concentrations as the building is alternately pressurized and depressurized (using fans and HVAC) can give information on vapor pathways (MacGregor et al, 2011).

A different modification is to run the HVAC with an increase in ambient (clean) air so that the air exchange rate within the structure is increased to the point that the vapor intrusion flux into the building no longer causes exposure levels to be exceeded. This may cause the building to be pressurized, but pressurization is not the goal; increased air exchange is the goal.

The air exchange rate is the ratio of the volume of fresh air introduced per hour divided by the building volume. For example:

$$\frac{\text{600 cubic feet/hour}}{\text{30,000 cubic feet building}} \equiv 0.02 / hour \text{ air exchange rate}$$

The larger the number, the more fresh air is being introduced to ‘dilute’ vapor concentrations.

Commercial facilities are more likely than residences to have HVAC systems amenable to this mitigation approach. This is not a green technology as substantial energy and associated costs are needed to condition the additional outside air and run the system continuously.

Building Pressurization/Air Exchange Rate HVAC Modifications Technology Selection and Implementation:
Building pressurization techniques require confirmation that the building is pressurized at the point of vapor entry. Measuring the pressure differential across the slab in conjunction with HVAC pressure measurements and confirmatory indoor air testing allows use of the HVAC pressure measurement as an interim sign that the system is working between indoor air sampling events.

When implementing air exchange HVAC modifications, keep in mind that the calculated air exchange rate is a theoretical calculation which assumes complete mixing of the air in the structure; in actuality, incomplete mixing will cause the air exchange rate to vary throughout the structure. Care needs to be taken that the necessary exchange rate is being achieved where receptors are present. The ‘true’ air exchange rate can only be measured with a tracer gas as described in MacGregor, 2011. However, if confirmatory indoor air sampling is conducted at a known HVAC air influent rate as measured by an anemometer or pressure gauge installed on the HVAC system, the air flow or pressure could be monitored between indoor air sampling events to see if the airflow rate is continuously maintained.

VAPOR BARRIERS AND SEALANTS

Vapor Barriers and Sealants Description and Implementation:

Vapor barriers usually refer to VOC resistant geo-membranes installed below the slab in new construction. Some spray or paint-on technologies have also been used in existing structures but this is also a supplemental technology and generally should only be done to seal a structure for a more efficient active system. A similar implementation is using sealants as a barrier to eliminate preferential pathways at the entry point into the structure. Foam sealants have been used to seal contaminated utility entry points. The sealant should be a low VOC sealant and likely needs to meet building specific fire rating specifications. Vapor barriers and sealants are considered supplemental measures and generally are not recommended as stand-alone mitigation since there is no way to ensure that the barrier remains intact through construction and as the building settles post construction.

CONCLUSION:

Vapor intrusion mitigation is a rapidly evolving field with new tools constantly being introduced. Depressurization systems are still the only proven long term mitigation system for sub-surface vapor intrusion. Indoor air cleaners can immediately reduce indoor air impacts and may be useful for preferential pathway mitigation. HVAC modifications are possible long term solutions but monitoring similar to depressurization systems must be included to verify that they continually work. Sealants and barriers remain supplemental technologies only.

Further Information;

If you have any additional information regarding vapor intrusion mitigation technology or any questions about the evaluation, please contact the Office of Land Quality ,Science Services Branch at (317) 232-3215. This technical guidance document will be updated periodically or when new information is acquired.

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Appendix A
Long Term Operations, Maintenance and Monitoring Plan Components

Routine indoor air monitoring and system operation and maintenance inspections are necessary until the system is no longer needed. VI remediation work plans should include a site specific Operation Maintenance and Monitoring (OM&M) plan. Keep a copy of the OM&M plan at a location specified in the plan. OM&M plans should include:

Background:
The background section should give a brief site history including a summary of vapor intrusion sampling data, why the mitigation system was the chosen remedy and, if available, confirmatory mitigation system sampling results. This section should clearly note if the system was installed due to confirmed vapor intrusion or if it is pre-emptive mitigation. The party responsible for maintaining the system should be identified.

Indoor Air Monitoring Plan:
Specify the frequency of indoor air monitoring. Describe sampling procedures and locations. Include, if possible, the proposed years for indoor air monitoring.

System Design/Installation:
Include a description of the system components, a system diagram, if possible, and the location where any system manuals will be kept. Include either within the report or as an addendum, system installation summary and any problems encountered.

System Monitoring:
IDEM's Vapor Remedy Selection and Implementation Draft Interim Guidance Document allows indoor air sampling on a less frequent basis as long as system performance is verified on an annual basis (Table 3, IDEM's Vapor Remedy Selection and Implementation Draft Interim Guidance Document). The OM&M plan should specify which performance metric will be used as verification. For depressurization systems, the metric is pressure measurement across the slab. For HVAC modifications, a gauge will likely need to be installed on the system to provide a similar metric as described above.

Section 3.2 of IDEM's Vapor Remedy Selection and Implementation Draft Interim Guidance Document recommends yearly visual inspection of the mitigation system, documentation of the gauge measurement and a determination of whether alterations or augmentations are needed. The OM&M plan should specify the personnel who will perform inspections and what qualifications or training they will have. It should also include a component checklist indicating monitoring frequency and the location of forms containing recorded monitoring data. Record data describing the system monitoring events as well as system component pressure monitoring data.

The system monitoring event form should include:

General Information:

- Contact Information for the party responsible for issues found during the inspection
- Monitoring Date and Time
- Property Address

- Tenant’s Name
- Owner’s Name and Address
- Inspector’s Name
- Inspector’s Company
- Weather conditions
- Is the HVAC operating?

Visual Inspections:
- Is fan intact and operational?
- Is the fan making any unusual noises or vibrations?
- Is the riser piping intact?
- Does the system still appear to be sealed?
- Do the suction points appear sealed?

Comments:
Record any comments about the inspection. If relevant, document conversations with the tenant or owner indicating if the tenant noticed any system changes. Note whether the fan was turned off for any period of time or if any changes were made to the structure. Note any changes in measurements at each system component and describe any actions taken.

Record monitoring data for each component in a manner that any changes in measurements are easily recognized. Record the baseline measurement associated with system confirmatory sampling. Appendix B is a sample monitoring form.

System Maintenance:
The OM&M plan should specify procedures and time frames for maintenance and monitoring issues associated with the system. For example if the fan or other system component quits working, the plan should specify who is responsible for fixing it and the time frame allowed for investigation and repairs. As indicated above, the responsible party contact information should be clearly identified on the monitoring forms.

System Termination:
Site specific mitigation system termination procedures should be outlined in the OM&M plan in accordance with IDEM’s Vapor Remedy Selection and Implementation Draft Interim Guidance Document Section 4.0.

Appendix B: Sample System Component Monitoring Form

	System Manometer	Monitoring Point 1	Monitoring Point 2
Location			
Baseline Reading			
Monitoring Date			

Significant Changes in monitoring data should be reported to:

____

Appendix C
Sewers
Preferential Pathway Identification & Mitigation

Although sewers have long been suspected of containing chlorinated solvents , they have only recently begun to be addressed as a vapor intrusion issue. EPA 2015 acknowledges that vapor intrusion issues can arise from within sewers but provides little guidance on investigation or mitigation. This appendix will attempt to provide guidance on investigations to determine if sewer gases are a source at a particular site and describe some mitigative techniques which may be useful.

INVESTIGATION

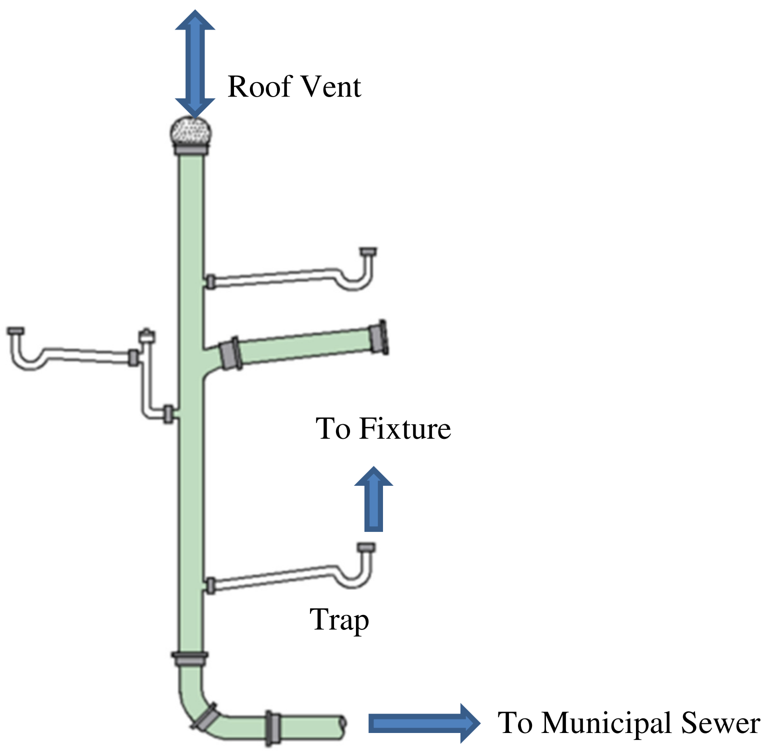

Figure 1. Sewer waste vent system diagram. (Creative Commons license at: https://en.wikipedia.org/wiki/Drain-waste-vent_system#/media/File:SoilStack.PNG)

A brief explanation of sewers:
Household sewer systems rely on gravity to drain wastewater to the municipal sewer. Sewers are filled with odorous gases in addition to potential contaminants of concern that could cause odor issues in houses. Traps are u-shaped pipes which should continually remain filled with water to seal out sewer gases (Figure 1). Individual fixtures have traps and often a ‘whole house’ trap is located near the entry point.Traps function to keep sewer gases out of the house because the retained water acts as a pipe seal. In addition, the entire system needs to be vented to the atmosphere to provide a source of

ambient pressure to keep the system flowing. A roof vent pipe extends from the entry through the roof (Figure 1). Air will flow both ways in the vent pipe depending on what is happening in the system. When water drains through the system, air is pulled into the vent system to avoid vapor lock. When water is not flowing, gases would exhaust through the pipe; therefore air is flowing out the pipe.

The system is designed to be water tight but joints aren't necessarily vapor tight and any contaminants of concern within the sewer may leak out at any joint or break in the vent pipe. It is these indoor entry points that this appendix is addressing. In addition, sewer gases can potentially contaminate the subslab or crawl space if leaks in the system occur at those points. Traditional crawl space or sub slab depressurization mitigation systems discussed earlier would mitigate these instances.

Lines of evidence that sewer gas may be causing VI issues
Determining if sewers are causing indoor air issues is difficult because dramatic fluctuations in concentrations within the sewer would be expected as the sewers operate. A common misconception is that homeowners would smell sewer gases if vapor intrusion were an issue but the low health protective concentration of several VOC's would cause them to be an issue at infiltration rates which will not cause sewer gas odor issues (Pennell, 2013).

Portable VOC detectors:
Indoor air anomolaies such as higher concentrations on higher floors may be a sign of sewer vapor intrusion but indoor air sources would cause these same issues and need to be ruled out. A portable VOC monitor may assist in determining where indoor air VOC's are the highest (ESTCP, 2013). Higher concentrations in vicinity of the sewer system (ex drains, sinks etc) may indicate sewer gas vapor intrusion rather than indoor air sources. Concentrations would need to be confirmed with traditional sampling for use in risk based data evaluations.

Sewer Video
Sewer videos by reputable companies may be capable of determining locations of current and historic laterals, joints and other features. Historic sewer and sewer lateral locations are important because they may provide migration pathways if they are in the vicinity of the source and were not sealed when abandoned. Additionally, the type and condition of the sewer are lines of evidence that they may be leaking causing soil gas issues.

Sewer VOC Testing
The presence of contaminants of concern within the sewer conduit is a line of evidence that the potential for sewer vapor intrusion exists. Vapor concentrations within a sewer may be expected to be extremely high if contaminated water is present as there is nothing to attenuate the expected vapor pressure concentrations. The vapors may either leak into the sub slab/ crawl space or into some point of the structure where breaks in the system exist. Representative reproducible sampling methods in sewer conduits are not currently well defined. Sample data will not be quantitative but instead will be a qualitative line of evidence that contaminants are present and sewer leaks may be causing VI issues. Sampling may be with a canister or adsorbent sampling device. .

Humidity and other environmental factors can dramatically affects sorbent samplers. Suppliers should be consulted for appropriate sampling device which will be less affected by humidity and other environmental factors. Currenlty, no screening attenuation factors exist for sewer samples.

Controlled pressure testing methods

Controlled pressure testing methods are time consuming and can be expensive but could aid in a preferential pathway determination (Guo et al, 2013). Basically, a fan system is used to either blow air into the house (pressurize/ minimize sub slab intrusion) or pull air out of the house (vacuum/ maximize sub slab intrusion) while contaminant concentrations are measured. Trends opposite from what would be expected indicate alternate pathways.

Sewer Smoke Test

A smoke test by a licensed plumber can identify locations where gases may be escaping sewer piping. An artificial smoke generator is attached to the roof vent. Smoke can be visualy observed at leaks in the system.

Figure 1. Compressor and smoke generator with attachment going to the roof vent.


Figure 2. Visual observation of smoke at a potential sewer gas leak.

Mitigation Options
Mitigation options for the inside the sewer preferential pathway will be structure specific and generally consist of limiting gas infiltration through p-traps and drain traps and limiting leaks from joints and other places where a smoke test or indoor air detector has indicated possible leaks. Rerouting or venting the sewer may be an option in extreme cases.In all cases, if contaminants are inside the sewer, sub slab samples should be considered to asses whether sewer leaks have contaminated the sub slab.

P-Traps
Properly functioning p-traps provide a water seal to stop sewer gases/contaminants from entering the house and therefore mitigate vapor intrusion from the sewers. Older traps may be made of cast iron which may corrode until no longer water tight. Plumbing renovations may use the trap access for other purposes or drains may be used so infrequently that the traps become dry allowing gas intrusion. Trap primers, low vapor pressure trap filling liquid or a homeowner maintenance routine that includes periodically dumping a little water down the drain may stop vapor intrusion due to dry traps. Several floor drains are available that allow the drain to function when necessary but provide a seal when not actively draining (http://proventsystems.com/trap-guard-floor-drain-csi-specifications/ , http://www.rectorseal.com/sureseal-plus/). Fixtures and drains that are no longer used should be removed and/or sealed to prevent vapor intrusion. A whole house trap, often part of the sewer cleanout, would seal sewer gases at the point of sewer entry and may help alleviate vapor intrusion issues from breaks or leaks in the system that individual fixture traps would not help. A licensed plumber is needed to determine if traps are present and functioning to stop sewer gas intrusion.

Fix Improper/ broken plumbing.
If a smoke detector or portable VOC meter detects leaking points in the system, a licensed plumber may be able to fix the issue and mitigate the vapor intrusion from that location. Older homes with remodeled plumbing may have multiple oddities making them succeptible, for example, a furnace drain wired directly into the sewer, cleanouts converted to drains which eliminates the whole house trap, absent p-traps, breaks in the vent line etc. Fixing these issues may help alleviate vapor intrusion issues.

Conclusion:
Sewers may need to be investigated to effectively mitigate structures. Current methods are not reliably quantitative to measure COC's within sewers but lines of evidence can be made that the sewer is causing indoor air exceedances. In these instances a sub slab sample may be wise as sewer leaks may have impacted the slab. If sewer gas entry into the house happens at some point in the sewer vent system, ensuring proper plumbing including functional p-traps and drain caps may provide a relatively inexpensive but effective mitigation.

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