Sustainable Vapor Intrusion Controls – Designing an Effective Passive System

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Abstract

Under certain conditions and with the appropriate design, passive systems can be successful in mitigating the vapor intrusion pathway and have the advantage of being greener and more sustainable over the long term. A successful passive vapor intrusion control system is likely to require more extensive construction efforts, particularly for an existing building, because the system requires comprehensive sealing of all vapor intrusion pathways. These efforts are likely to result in higher initial capital costs and short-term disruption to building users, but these elements may be offset by lower long-term operation and maintenance efforts and avoidance of aesthetic and other impacts on property owners that may be inherent in continuous operation of an external fan-based system. These reduced operation and maintenance requirements and impacts are also likely to make passive systems preferable to the building owners, particularly in residential applications. Documenting the effectiveness of these systems is likely to rely initially on indoor air sampling, but long-term monitoring can be limited to confirming that the systems remain intact. In this paper, we describe some of the conditions and design requirements for implementing successful passive vapor intrusion control systems at both residential and commercial buildings. We also present monitoring data collected at residential properties and a commercial office building where passive systems were successfully implemented.

INTRODUCTION

Under certain conditions and with the appropriate design, passive systems can be successful in mitigating the vapor intrusion pathway and have the advantage of being greener and more sustainable over the long term. Active systems, such as sub-slab depressurization systems utilized for radon mitigation, are being used increasingly to mitigate vapor intrusion pathways. While active systems can be effective, they are not the only option, and in some cases may not be the preferred approach.

There are numerous potential vapor intrusion pathways including:

- Poured concrete joints such as control joints and the floor-wall interface
- Fieldstone, concrete block, and brick mortar joints
- The interstitial space between inner and outer courses in above-grade brick courses.
- Utility penetrations (sewer, water, gas, storm water, buried electrical)
- Sumps and interior perimeter drains
- Crawl spaces
- Dirt floors and incomplete concrete floor slabs
- Cracked concrete floor slabs

We have found that appropriately designed passive systems can be effective in mitigating these potential pathways. In fact, we have encountered several cases where active systems have not mitigated these pathways without also incorporating passive sealing components.

The passive vapor intrusion mitigation systems described in this paper generally consist of vapor barrier membranes combined with ventilation piping similar to what would be installed for active venting systems (or typical radon mitigation systems). The key features in each case described in this paper are a comprehensive sealing of vapor intrusion pathways using a High Density Polyethylene (HDPE) liner and engineered wall covering, and sub-slab ventilation piping that discharges above the roofline of the structure.

Design Considerations

The following are some considerations for choosing passive systems, active systems, or a combination thereof:

- Subsurface conditions;
- Foundation type and construction materials;
- Property use; and
- Regulatory environment and site closure strategy.

New construction is an excellent opportunity to install a passive system since it can be easily incorporated into the design process and may even serve other purposes such as water vapor control and waterproofing.

A passive system may be more effective in cases where low permeability soil is located beneath the floor slab. In the northeast, many older buildings are located on soils with low permeability such as glacial till or silt and clay deposits, and do not exhibit a layer of granular material that would permit effective soil gas migration. If a building foundation is constructed on low permeability material, then the likelihood of creating an adequate vacuum field under the slab using an active system is diminished.

Shallow water table conditions can also pose challenges to active systems if the vadose zone beneath the slab is relatively thin and dissolved phase contamination is present close to the slab elevation. In active systems, the sumps or sub-slab piping may be inundated with water causing low air flow and a spike in vacuum. The spike in vacuum can cause water to flow into pipes, possibly necessitating shut down of the system.

Vapor intrusion through the walls of fieldstone or masonry foundations, which are also often found in buildings located in the northeast, can also be a significant pathway and is more easily addressed with passive systems.

Crawlspaces with dirt floors or degraded concrete slabs will likely require installation of a vapor barrier membrane, even if an active system is installed, to ensure vapor capture. Installation of a passive vapor barrier is often an integral component for either passive or active systems.

There are some state regulations which do not provide for permanent site closure if an active system has been employed to mitigate vapor intrusion. For example, the Massachusetts Contingency Plan (MCP) requires sites with active mitigation to have systems inspected and biannual status reports submitted. Conversely, a permanent solution can be achieved for a successful passive system, since it does not rely on active operation and maintenance of a mechanical system to achieve exposure pathway elimination.

Incorporation of redundant and relatively inexpensive design elements such as ventilation piping and wind-driven ventilators can increase the probability of mitigating the vapor intrusion pathway. Furthermore, it often provides the owner with the opportunity to convert a passive system to an active system, should it be required.

Typical Passive Design Components

There are generally two types of vapor barrier membranes commercially available (sheet and liquid). Sheet membranes can be made from HDPE, rubber-asphaltic material, and combinations of polyethylene and insulation material. Liquid vapor barriers can be made from epoxy, rubber, or asphalt.

Passive ventilation is a network of ventilation piping, sumps, trenches, and/or a geo-composite vapor transmission layer. We have utilized several combinations of the aforementioned to design building-specific passive ventilation. We have also utilized wind-driven ventilators to enhance vapor migration via diffusive and convective forces, although we have not relied on them to create negative pressures beneath the slab.

One option for sealing fieldstone walls is by applying a cementitious stucco coating anchored by mesh, followed by application of an elastomeric vapor barrier. Another more extensive option is to install a vapor transmission space between the fieldstone walls and the sheeted vapor barrier, wire mesh, and a protective stucco coating. If foundation walls are cast-in-place concrete, then a vapor barrier could be applied directly to a properly prepared concrete surface.

Active vs. Passive Comparison

Passive systems usually have substantially higher installation costs in retrofit scenarios than conventional active systems that resemble typical radon mitigation systems. Passive systems typically have lower long-term costs because they have no energy consumption and require minimal maintenance. Long-term routine inspection costs are likely similar.

The following are some advantages to passive systems including:

- Provide a mitigation solution amenable to site closure in most states.
- They are less costly over the long term.
- They can seal all subsurface soil vapor intrusion pathways.
- Some property owners (particularly residential) may prefer passive systems because there is no externally-mounted fan.

Active systems may be necessary when site conditions, time constraints, regulatory environment, or financial resources dictate. The following are some examples where active systems may be necessary:

- When the need to mitigate exposures must occur quickly
- Structures that include finished basements, where the floor and walls are not accessible
- When the property owner is not amenable to the time required to install a passive system

Passive System Case Studies

Case Study 1.

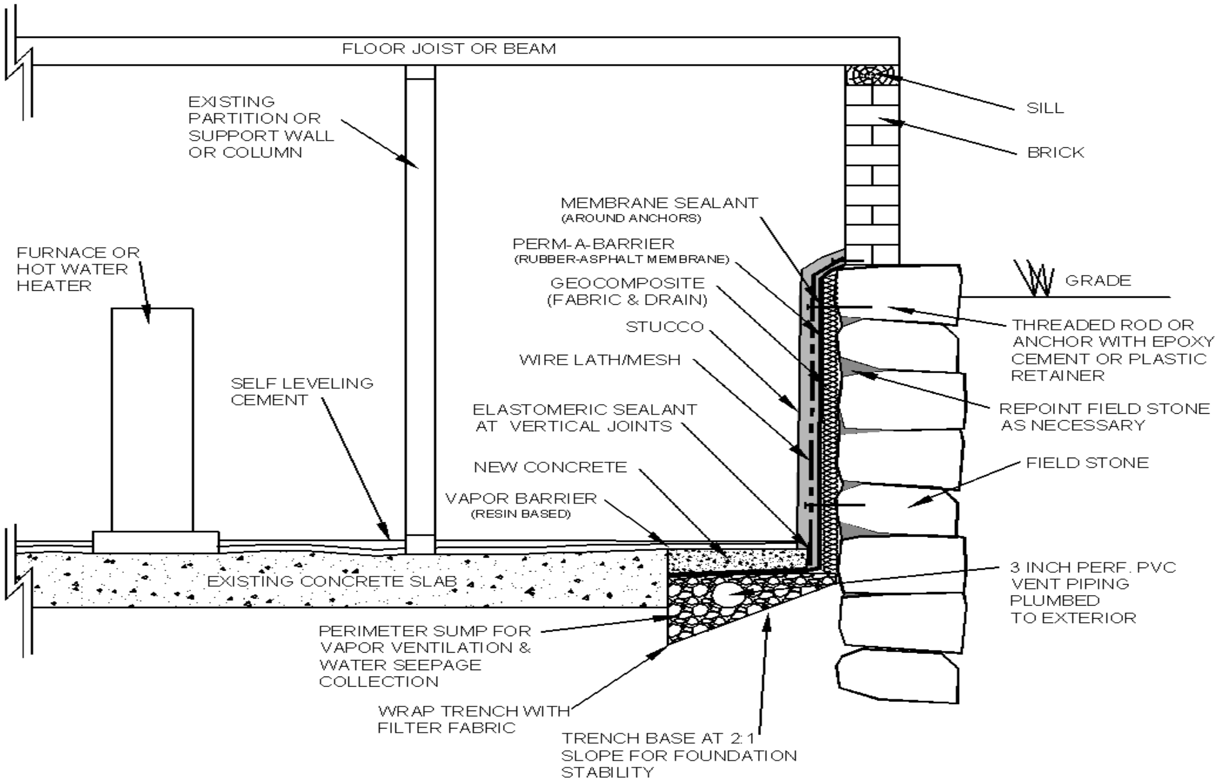
The first example is a residential building constructed in the late 1800s in a dense urban neighborhood. It is a two-story dwelling with wood-frame construction, a fieldstone foundation below grade, brick above grade, a competent concrete slab, and a crawlspace under an addition.

Indoor air concentrations of tetrachloroethylene (perchloroethylene [PCE]) were measured at greater than 100 micrograms per cubic meter ($\mu g/m^3$) in the basement and greater than 30 $\mu g/m^3$ on the first floor. Soil vapor concentrations measured below the slab yielded concentrations greater than 100,000 $\mu g/m^3$ of PCE. Based on the measured concentrations, an active sub-slab depressurization system (SSDS) comprised of two sub-slab vapor extraction points was installed in the basement. The system consisted of 3-inch solid polyvinyl chloride (PVC) piping plumbed outside the building envelope at the sill elevation, a 100-watt radon fan, and discharge piping extending above the eave line. A separate fan and piping network were installed for the crawlspace.

Confirmatory indoor air sampling conducted after the active system was installed indicated concentrations were reduced to 3.5 $\mu g/m^3$ in the basement and 2.3 $\mu g/m^3$ on the first floor. The performance standard at the time of installation was to reduce concentrations to below a detection limit of 1.4 $\mu g/m^3$, to the extent feasible. Because the active system did not meet the performance standard, we designed a more comprehensive system to seal vapor migration pathways, and found that the revised design was able to meet the remedial goals in passive mode.

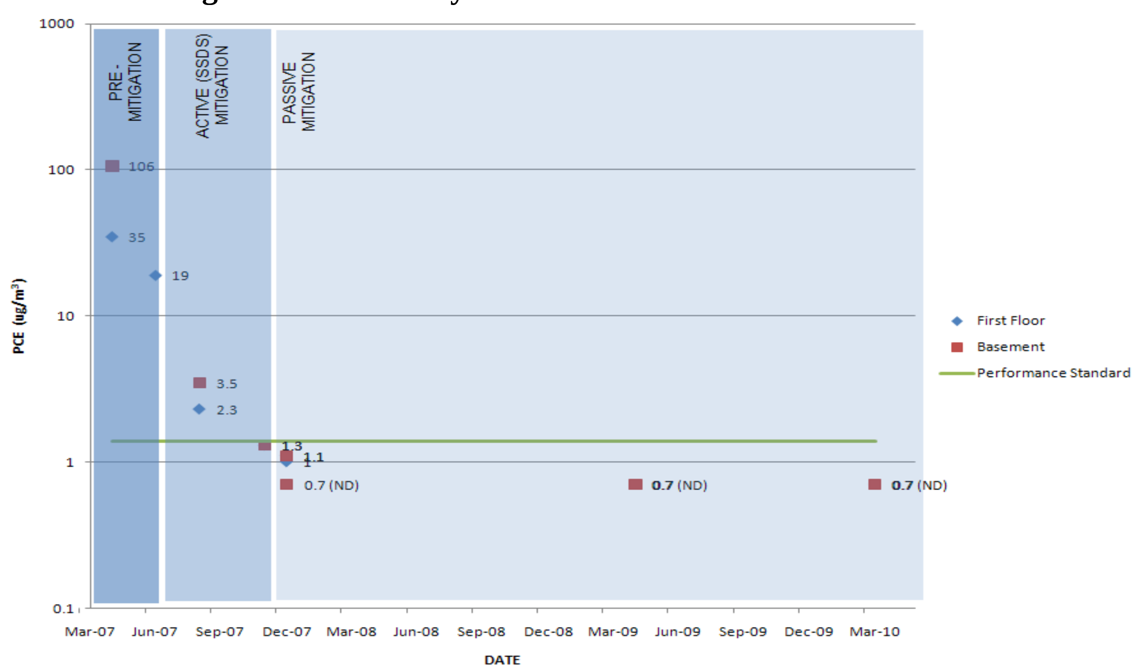
The passive system designed and installed for this property addresses both the foundation floor slab and the foundation walls as vapor intrusion pathways. The perimeter vapor trench and the vapor transmission space on the fieldstone walls allows for the vapor to transmit through the walls but not into the living space. The vapor trench and wall transmission space are vented outside the building envelope using the same piping network that had been installed for the active system. The floor and walls are sealed using an elastomeric epoxy vapor barrier designed for use on new or old clean concrete or cementitious stucco. Figure 1 illustrates the conceptual design for this property.

Figure 1. Residential – Vapor Trench and Epoxy Vapor Barrier Schematic



Since installation of the passive system, indoor air concentrations, for both the basement and first floor, have been reported below laboratory reporting limits during three sampling events, two of which were collected in the winter months. Figure 2 presents the pre and post mitigation results.

Figure 2. Case Study 1 – Indoor Air PCE Concentrations



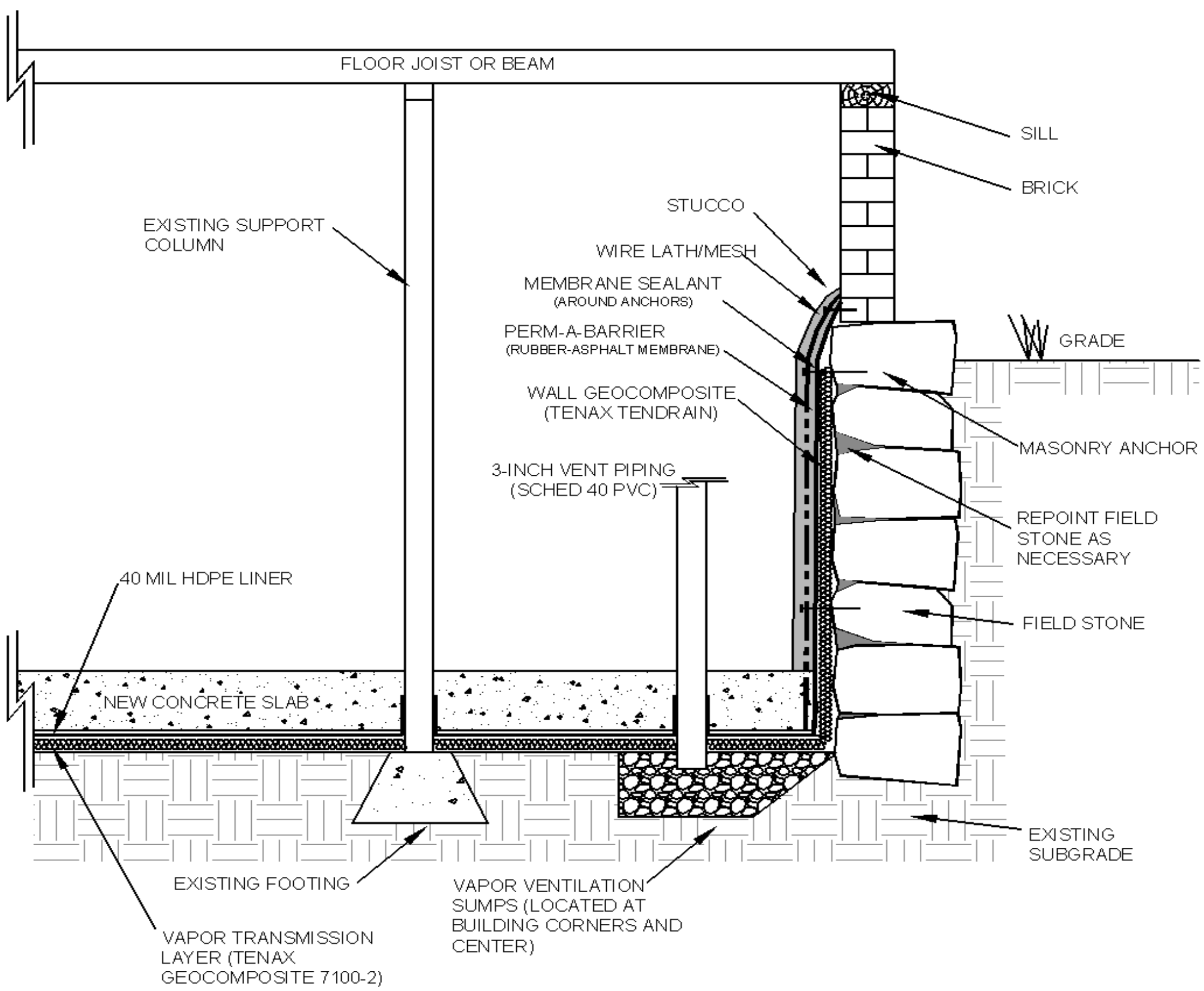
Case Study 2.

The second example is also a residential building constructed in the late 1800s in a dense urban neighborhood. It is a two-story dwelling with wood-frame construction, a fieldstone foundation, and a degraded concrete slab.

Soil vapor concentrations measured below the slab yielded concentrations of 180 $\mu g/m^3$ of PCE. Based on the inconsistent success of active systems in this neighborhood and the presence of the degraded slab, we installed a vapor barrier beneath a new concrete floor slab.

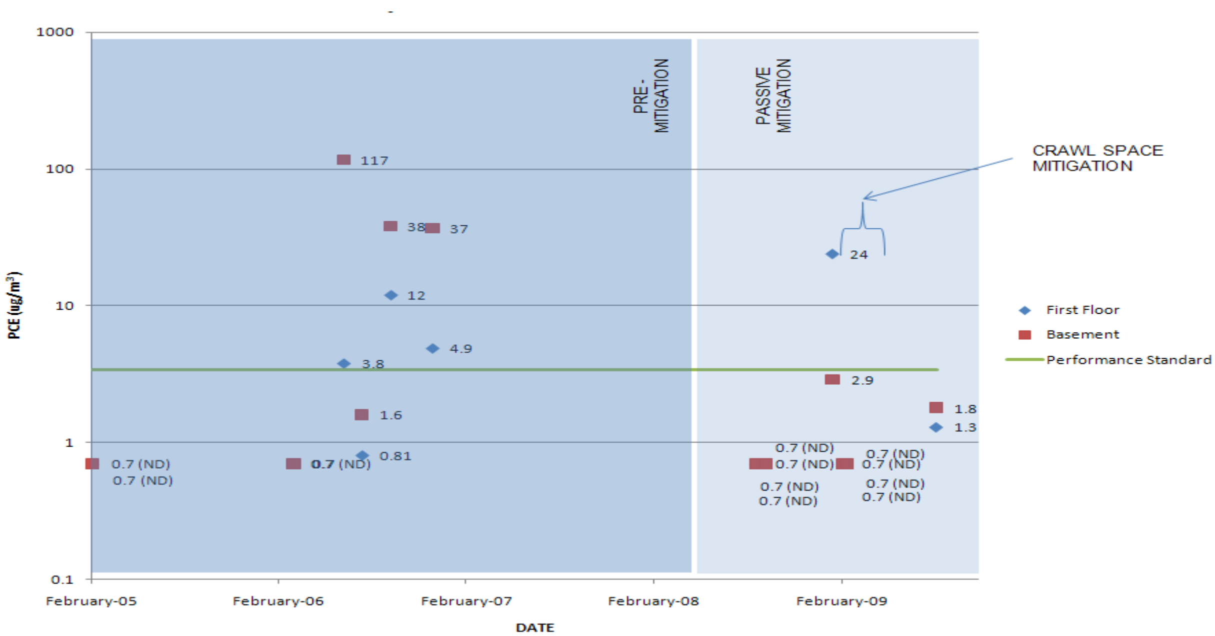
The passive system designed and installed for this property addressed both the foundation floor slab and the foundation walls as vapor intrusion pathways. The sub slab vapor transmission layer in communication with the ventilation piping reduces vapor concentration beneath the barrier. The sub slab vapor transmission layer is vented outside the building envelope using a similar piping network for active systems. The foundation wall system in this example is comprised of anchored wire mesh, cementitious stucco, and an elastomeric vapor barrier coating. Figure 3 illustrates the conceptual design for this property.

Figure 3. Residential – Slab Replacement and Epoxy Vapor Barrier Schematic



Since installation of the passive system, indoor air concentrations have been reported below laboratory reporting limits during four of six sampling events. Three samples were collected in the winter months. One of the winter samples yielded a much higher concentration on the first floor than the basement which was not observed previously. Upon further inspection of the building, a small crawl space was identified. The crawl space was not accessible and an entryway was installed through the foundation to install a vapor barrier and ventilation piping. Samples collected after installation of the vapor barrier in the crawl space yielded concentrations below the performance standard. Figure 4 presents the pre and post mitigation results.

Figure 4. Case Study 2 – Indoor Air PCE Concentrations

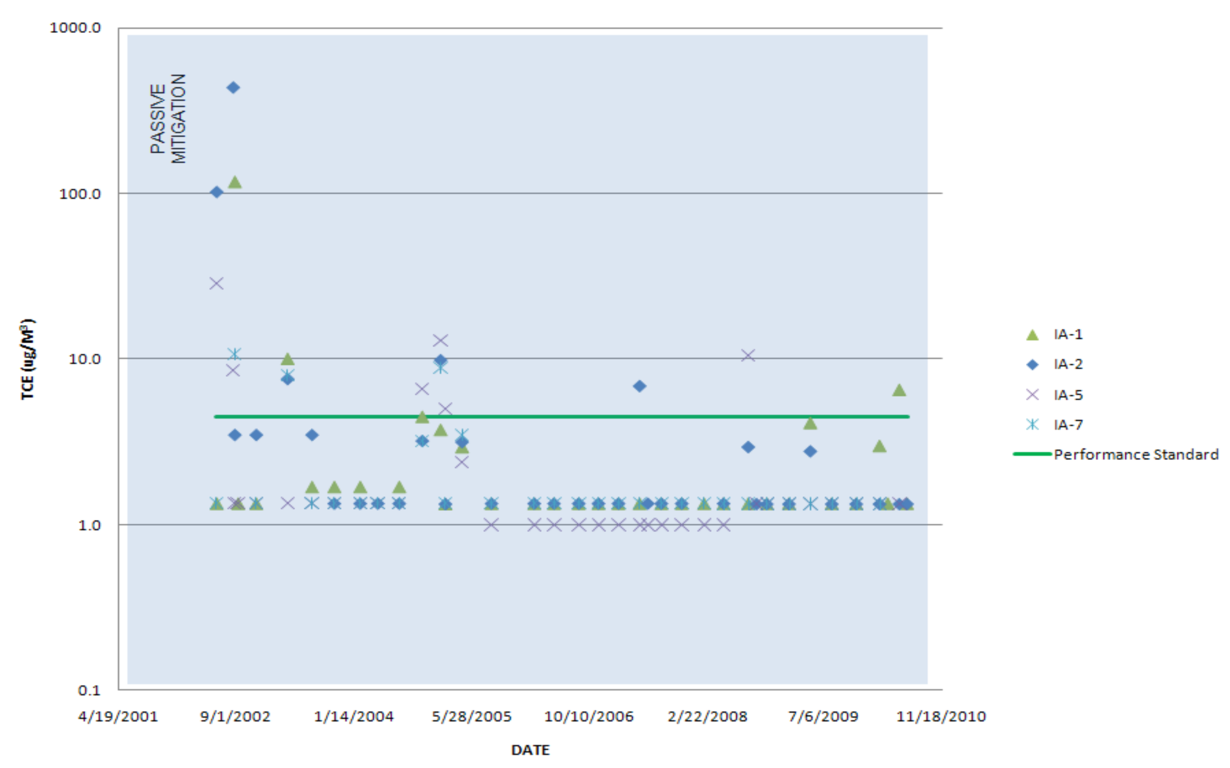


Case Study 3.

The third example is a 70,000 square foot commercial building renovated during a brownfields site redevelopment. High concentrations of chlorinated solvents are present in groundwater beneath the building resulting from historic defense-related manufacturing activities at the site. Prior to redevelopment, elevated tricholoroethylene (TCE) concentrations were present in soil vapor beneath the slab, and significant concentrations were present in indoor air – even with numerous missing doors and windows in the building. According to the risk characterization, the concentrations of chlorinated solvents would not have resulted in unacceptable risks to commercial users of the building. However, a future tenant of the building would not accept detectable concentrations of TCE in the space it would occupy, so mitigation was necessary.

The design included a 40 mil HDPE barrier placed over the existing degraded concrete slab, then covered with a new concrete slab. Utility penetrations and sub-slab monitoring points were fitted with boots and sealed to the liner. Because the 40 mil HDPE liner was relatively stiff and difficult to seal to the foundation walls, a 3-foot wide strip of fluorinated Linear Low-Density Polyethylene (LLDPE) was bonded to the edge of the HDPE, then sealed to the inside edge of the concrete foundation wall using a strip of two-sided polymer adhesive tape. To allow for sub-slab ventilation, and the addition of a potential future active blower system, slotted PVC pipe was placed in gravel filled trenches through the old slab and connected to PVC risers that discharged above the roofline. The system has been in place for more than 5 years, operated in passive mode, and has been successful in eliminating indoor air detections of chlorinated solvents. Initial post mitigation concentrations were attributed to passive vents discharging too close to rooftop Heating, Ventilation, and Air Conditioning (HVAC) system air intakes. Figure 5 presents the post mitigation results.

Figure 5. Case Study 3 – Indoor Air TCE Concentrations



SUMMARY

Passive systems can be successful in mitigating the vapor intrusion pathway and have the advantage of being greener and more sustainable over the long term than active systems. While active systems can be effective, they are not the only option, and in some cases may not be the preferred approach. We have encountered buildings where installation of passive components was required for an active system to meet the performance objectives. Incorporating additional measures such as liquid vapor barriers over joints and seams, sub-slab ventilation piping, or wind-driven ventilators are inexpensive ways to increase the chances for success. Depending on variables like site conditions, the regulatory environment, and building access, passive systems may be the preferred approach.