Naval Facilities Engineering Command

ENVIRONMENTAL RESTORATION

Vapor Intrusion Mitigation in Construction of New Buildings Fact Sheet

Introduction

Vapor intrusion (VI) is the migration of volatile chemicals from subsurface soil and/or groundwater into the indoor air of overlying buildings. Most VI events occur when volatile organic compounds (VOCs) are released into the subsurface from sources such as underground storage tanks, dry cleaners, gasoline stations, or industrial processes such as degreasing metals. VOCs typically associated with VI are chlorinated solvents, including carbon tetrachloride, tetrachloroethene (PCE), trichloroethene (TCE), and methylene chloride, and gasoline derivatives such as benzene. Hazards presented by these chemicals are typically chronic human health effects such as cancer, organ toxicity, or reproductive toxicity. Gases, such as methane migrating from landfills, may also present potential explosive hazards.

If the contaminants present in the subsurface are predicted to result in indoor air concentrations above acceptable risk levels, VI mitigation measures should be incorporated into the design of any new buildings. This fact sheet provides an overview of VI mitigation methods used in new buildings along with important factors to consider when selecting and designing these mitigation systems. In new construction, VI mitigation can include passive methods such as vapor barriers and natural venting systems; active systems such as sub-slab depressurization (SSD) systems; or a combination of passive and active methods. VI mitigation systems integrated during construction of new buildings are more cost effective, function better and are less obtrusive than mitigation systems retrofitted into existing buildings.

This fact sheet was prepared by the Navy Alternative Restoration Technology Team (ARTT) workgroup for use by Navy personnel such as remedial project managers (RPMs) and planners. RPMs may want to consider it for inclusion in Land Use Controls (LUCs) or provide it to base personnel or the public for informational purposes. Typically, Environmental Restoration, Navy (ER,N) funds shall not be used to install VI mitigation systems for new construction; however, RPMs and other Navy personnel should consult the Navy Environmental Restoration Program (NERP)/Defense Environmental Restoration Program (DERP) manuals for the latest guidance.

Key Factors When Considering VI Mitigation

Once the vapor sources have been assessed and it has been determined that there is potential for VI to pose an unacceptable risk in buildings constructed on the site, the next step is to select which preconstruction mitigation strategies should be implemented to prevent VI. Three primary factors drive the occurrence of VI in buildings:

- contaminant properties, concentrations and locations,
- potential entry routes (e.g., floor drains, French drains, sumps, seams or cracks in the floor slab, utility penetrations, and open top blocks in the foundation walls) and
- pressure differentials between the building and the subsurface that could draw contaminants from the soil into the building.

Understanding these components and the effects that they have on the transfer of subsurface VOCs to indoor air will help to determine which VI mitigation strategies should be integrated into the construction of a new building.

Prevention of VI in New Construction

New construction provides many opportunities to prevent VI that are not available for existing buildings. For example, at some sites, the area most likely to produce unacceptable VI can be avoided and set aside for another purpose such as green space. Also, new buildings can sometimes be designed to include a highly ventilated, low occupancy area at ground level, such as an open parking garage. It should be noted, however, that if contaminated areas of the site are to be covered with pavement, the resultant effects on migration of vapors should be considered in order to avoid effects on adjacent structures.

Methods for VI mitigation in new construction can be passive (such as vapor barriers and natural venting systems) or active (using blowers to depressurize the sub-slab area). Frequently in new construction, elements of both passive and active methods are combined (e.g., a vapor barrier may be installed along with active SSD) or a passive ventilation system may be designed to allow for conversion to an active system (e.g., by adding blowers) at a later time if the passive system fails to prevent VI.

For construction of new buildings, there are five basic components to effective VI resistant construction:

- permeable sub-slab support material (e.g., gravel),
- venting all sub-slab areas below occupied spaces,
- properly-sized sub-slab and riser piping,
- a sealed vapor barrier, and
- if an active system is specified, a properly-sized blower to maintain sufficient negative pressure beneath the slab.

Passive venting systems typically have the first four components above, but do not have a blower to mechanically draw soil gases from sub-slab collection piping to above the roof. Rather, they rely on thermal and atmospheric effects to draw the soil gases into the piping and vent it outside. Active SSD systems are powered by blowers that create a vacuum beneath the slab and actively vent sub-slab gases through solid conveyance piping to above the roof line. A typical active mitigation system is illustrated in Figure 1. A passive system would be similar but would not include a blower.

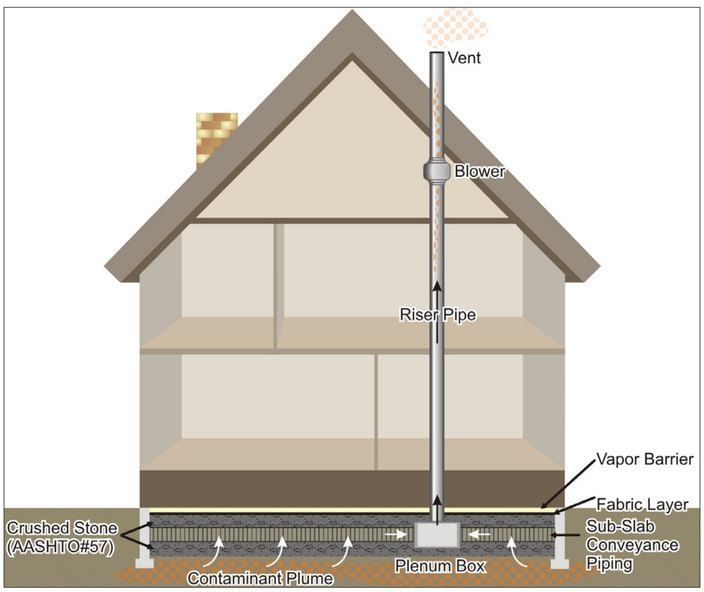

Figure 1. VI mitigation system with a vapor barrier and active SSD.

Permeable Sub-slab Support Material

After the ground has been proof-rolled by removing undesirable items, drying, leveling and compacting the soil, a permeable layer of crushed stone should be installed (Figure 2).

Figure 2. Proof-rolled ground covered with 8 inches AASHTO #57 stone.

Eight inches or more of a highly permeable, coarse aggregate such as American Association of State Highway and Transportation Officials (AASHTO) #57 stone is preferred. There should be a minimum of 2 inches of crushed stone above and below any sub-slab conveyance pipe to prevent slab cracking. If 6-inch pipe is used, the ground beneath the pipe may need to be trenched to ensure sufficient crushed stone for slab support (Figure 3).

Figure 3. Gravel placed over proof-rolled site with trenching for vent piping.

Venting

The most efficient way to vent sub-slab soil gas is using perforated ventilation pipes that run beneath the slab and direct the vapors to a centrally located plenum box. The plenum box is constructed of hollow concrete blocks turned on their sides with an empty space in the center (Figure 4).

Figure 4. Connecting isolated slab areas with a central plenum box.

The box is connected to vertical riser piping that transports soil gases to vents above the roof line. There should be a minimum of 8 inches of crushed stone beneath and beside the plenum box. All slab areas within the occupied portions of the building need to be included in the sub-slab vapor collection system and connected to the plenum. Footings at grade changes and thickened slabs beneath concrete masonry walls often create isolated sub-slab areas (Figure 5). These isolated areas need to be addressed by placing adequate gravel below them or adding ventilation pipe to connect them to the system. Commercial venting products such as those consisting of a thick rectangular-shaped roll-out plastic and fabric-covered conveyance plenum, or perforated collection pipe can provide a conduit to connect isolated slab areas to a central sub-slab plenum box (Figure 6).

Figure 5. Isolated gravel beds.

Figure 6. Commercial venting product has properties similar to 4-inch PVC pipe with lower installation costs.

Sizing the conveyance pipe is based on the square feet of the area to be vented and the number of pipe fittings used between the sub-slab plenum box and the vent termination point. Drag coefficient tables exist for different pipe diameters and assorted fittings. Since coordinated drawings are usually not part of the design phase, the person designing the system should plan for twice the number of pipe fittings when calculating the pressure drop associated with a riser pipe system. The most commonly used riser pipe material is polyvinyl chloride (PVC) because of its availability, low cost, and low airflow drag coefficients. No-hub cast iron pipe is used when there is concern of exceeding the flame spread or smoke index. This is a concern when conveyance piping passes through a return air plenum. Protective pipe enclosures or steel pipe is used in areas of vehicle or fork lift traffic.

Conveyance piping can be joined together beneath the slab to minimize vertical risers (Figure 7). A 3-inch riser pipe can service up to 1,500 ft^2, a 4-inch riser can service up to 4,000 ft^2 and 6-inch riser pipe can service up to 15,000 ft^2. Sub-slab conveyance pipe should have 5/8-inch condensate drain holes that face down at 4-inch intervals. If factory perforated pipe is used, one set of holes should face down.

Figure 7. Risers grouped for future pairing and efficient construction.

Vapor Barriers

Selecting the right vapor barrier is a critical part of the VI mitigation system and the vapor barrier can be the most expensive part of the system. The type of vapor barrier and the quality of the seal will determine the efficiency and effectiveness of the protective measure. After the contaminants of concern (COCs) have been identified, the protective qualities of the vapor barrier material should be matched to the identified compounds to minimize potential for chemical breakthrough. The types of vapor barriers available and their advantages and disadvantages are summarized in Table 1.

The most important part of the effectiveness of any vapor barrier system is achieving a tight seal to foundation walls and around utility penetrations through the membrane. A filter fabric layer is recommended to protect all vapor barriers from punctures associated with construction debris and the underlying stone. The concrete slab installer must not be allowed to puncture the vapor barrier to drain off extra water that may be associated with the concrete finishing process.

Table 1. Types of vapor barriers used in VI mitigation.

Vapor Barrier Material	Advantages	Disadvantages
6-mil polyethylene or polyolefin (Figure 8).	• Inexpensive • Often made from post-consumer recycled materials.	• Permeance water vapor transmission rate (WVTR) is between 0.1 to 0.3 perms; considered a vapor retarder not a true vapor barrier - slows down vapor transmission but does not completely block vapors • May not be chemically resistant • Difficult to seal at walls and utility penetrations • Low puncture and tear resistance compared to reinforced materials • Standard applications with unsealed seams are only partially effective for preventing VI • Not recommended for most VI applications.
>10-mil polyethylene or polyolefin (Figure 9).	• Relatively inexpensive • Permeance WVTR is <0.1 perms (considered a true vapor barrier; almost completely blocks vapors) • Often made from post-consumer recycled materials.	• May not be chemically resistant • Difficult to seal at perimeter walls and utility penetrations • Low puncture and tear resistance compared to reinforced materials of similar thickness.

Table 1. Types of vapor barriers used in VI mitigation. (continued)

Vapor Barrier Material	Advantages	Disadvantages
Cross laminate polyethylene or polyolefin; generally 3-ply materials with woven scrim between two polyethylene sheets.	• Permeance WVTR is <0.1 perms (considered a true vapor barrier; almost completely blocks vapors) • Puncture/tear resistance up to 50 times greater than 6-mil polyethylene/polyolefin vapor retarder. • Improved sealing at perimeter walls and utility penetrations because manufacturer-supplied tapes and cloth binders are generally used.	• Moderately expensive • May not be chemically resistant.
Spray-applied vapor barrier: Non-woven geotextile fabric base over stone layer followed by a spray-applied coating. The coating material binds to the support fabric, column pads, side foundation walls; minimum thickness of 60 mil; total thickness including support fabric is 73 mil (see Figures 10, 11, and 12).	• Permeance WVTR is <0.1 perms (considered a true vapor barrier; almost completely blocks vapors) • Provides a nearly gas-tight seal since coating material binds to column pads and side foundation walls. • Leak test is performed following installation and any leaks are repaired. • Installers must be licensed by manufacturer. • Coating selected for chemical resistance to specific contaminants.	• Generally more expensive than other types of barriers.

Note: Information on the chemical resistance and ability of a particular vapor barrier material to block a particular contaminant should be obtained from the manufacturer of the specific product being considered. Some information may be available on the Web sites for specific vapor barrier products.

Figure 8. Standard vapor barrier with unsealed seams.

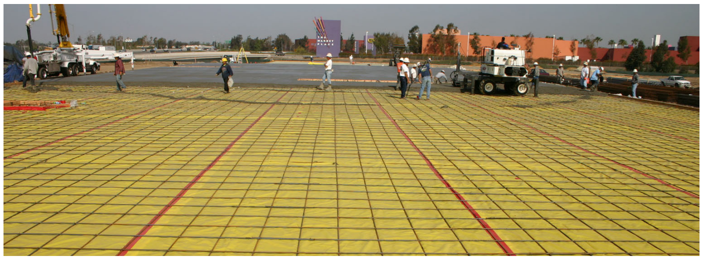

Figure 9. Polyolefin vapor barrier with sealed seams shown with rebar and concrete slab being installed over top.

Figure 10. Geotextile fabric is placed over stone followed by spray application of the sealant.

Figure 11. Spraying an emulsified asphalt latex barrier.

Figure 12. Installation of a spray-applied barrier at a large site.

Active VI Mitigation Systems

Active VI mitigation systems in new construction generally consist of a sub-slab depressurization system with ventilation piping connected to a blower that depressurizes the sub-slab and vents the vapor above the roof level. Depending on the leakage associated with the vapor barrier, the configuration of the sub-slab conveyance piping and the design of the plenum box, a single properly-sized collection system can service up to 15,000 ft^2 of floor space. The design goal is to create a minimum sub-slab negative pressure of -0.02 inches of water column (in. w.c.) at the area that is most distant from the plenum box using a blower that consumes no more than 140 watts and can move 200 cubic feet per minute (CFM) at 1.0 in. w.c. static pressure. Even though lower pressure differentials may be able to successfully arrest the soil gases, a pressure of -0.02 in. w.c. is recommended as a design goal to provide a safety factor for construction conditions that could potentially reduce the efficiency of vacuum distribution (e.g., sand particles mixed in with the crushed stone, elevated sub-slab utility conduits, presence of overburden from trenching, and conveyance piping that has been crushed or distorted by unscheduled vehicle traffic).

When designing a depressurization system and specifying blowers, it is important to include the projected piping pressure losses. Speculating the final active system airflow is one of the most difficult parts of the design process. Airflow is a function of blower capacity, piping size, fittings and layout, sub-slab aggregate resistance, soil permeability and slab and foundation leakage. The performance required from the blower to achieve the specified vacuum field is largely determined by the slab leakage and quality of the vapor barrier seal. If there is clean crushed stone and 4-inch conveyance piping, a blower that can move 200 CFM at -1.0 in. w.c. can create a vacuum field of -0.02 in. w.c. or greater over a 4,000 ft^2 area. Reducing the slab leakage can significantly increase the coverage area. The primary design goal should always be highly permeable sub-slab material and minimal slab leakage.

During the construction phase, soil probes should be embedded in the crushed stone to allow testing of system effectiveness after the slab has been poured (Figure 13). Probes are embedded because drilling through the concrete creates an unnecessary risk of damaging sub-slab utilities and will void most vapor barrier warranties. Probes should

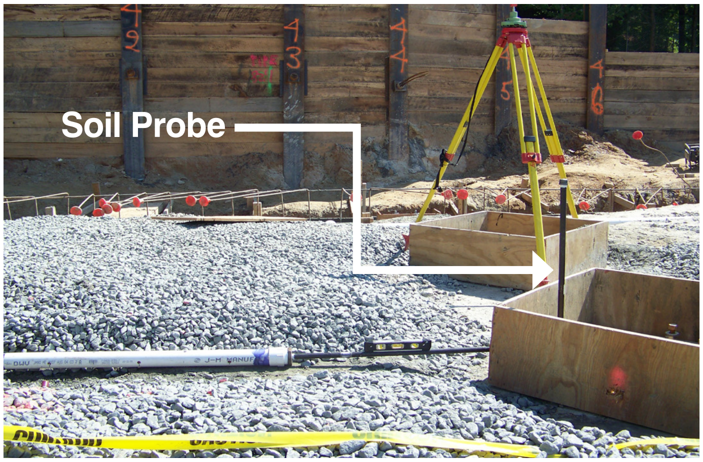

Figure 13. Forms for vertical column support pad with embedded soil probes.

be located distant from the plenum box near the projected end of the negative pressure field. These probes are typically made of heavily perforated PVC pipe that is 2 inches in diameter or less and connected to rigid, smaller diameter pipe that extends to a sampling port above the slab. Typically, this is 0.5-inch gas pipe that is embedded into a column pocket to protect it from damage during the concrete pour and power trowel process. Depending on the potential for soil vapor entry, these probes could be as numerous as one per isolated foundation area. At least one probe should be installed per 5,000 ft^2 of slab area and for each different slab elevation. Each blower system should have at least one soil probe.

The effectiveness of any soil depressurization system should be quantified after the slab is poured and allowed to cure for at least 14 days. The test is performed by temporarily installing the specified blower and measuring the extension of the negative pressure field. The efficiency of the system is measured by temporarily activating the system after hooking up the blower that has been specified for permanent installation. The pressure field extensions should be measured at the sample ports that are at the end of the embedded probes. A micromanometer that can measure to a sensitivity of -0.001 in. w.c. should be used. If vacuum field measurements at the probe most distant from the blower exceed 0.036 in. w.c. (9 pascals), the top of the acceptable vacuum range specified by ASTM, the procedure can be repeated with a blower that uses less electricity. If favorable test results are obtained, the blower can be downgraded to a lower wattage blower that will save energy and reduce operating expenses. The minimum induced sub-slab vacuum field in an unfinished, unheated building should be -0.02 in. w.c. The selected blower model, vacuum field and exhaust airflow values should be recorded and included in the construction documents that are presented at the end of the project. Sampling for indoor air contaminant concentrations should occur once the building is weather tight and the air handling systems are operational.

Passive Mitigation Systems

As noted above, passive VI mitigation methods do not require an electrical power source to operate. These include physical vapor barriers and piping systems that rely on natural ventilation to move air from the subsurface to prevent the buildup of contaminated vapors. The integrity of the vapor barrier and efficiency of a passive vent system are two main variables in determining the effectiveness of a passive system. Punctures or tears in the vapor barrier that can occur during the construction process will diminish the effectiveness of a passive system. Efficiency of passive venting can be affected by weather, functioning better in some conditions than others. However, the benefit of a well-designed passive system is that it can be converted to an active system if indoor air concentrations are determined to exceed acceptable risk levels.

It should be noted that passive mitigation methods alone may not be acceptable to state regulators when human health risk is above acceptable limits. For example, in California, the installation of a vapor barrier alone is not an acceptable VI mitigation method where indoor air risk is greater than or equal to 1 x 10^{-6} or the hazard index is greater than or equal to 1.0. In these situations, a vapor barrier can only be used in combination with an active VI mitigation system such as SSD.

Energy and Sustainability Considerations

When designing a system to prevent VI, long-term energy considerations need to be factored into the design. Greater design efficiency reduces operational costs and extends the time that an active venting system can be sustained for a fixed capital expenditure. A streamlined sub-slab collection plenum system with minimal conveyance piping fittings will increase the efficiency of sub-slab vacuum distribution and reduce the energy required by the blower. Three components need to be considered when attempting to lower the operational energy costs of a VI mitigation system. They are: the cost of operating the blower(s) that will maintain the negative pressure beneath the slab, the cost of the heat that is being drawn out of the building and the cost of the cooled conditioned air that is being drawn out of the building. An additional cost that must be considered is the cost of replacing the blowers themselves. Additional blowers will result in higher operations and maintenance costs. Selecting a sealed vapor barrier system that minimizes leakage is the largest variable in reducing ongoing energy costs. The cost to heat or cool the conditioned air that is drawn into the collection system can be a greater operational expense than the electrical cost to operate the blowers. Installing a tightly-sealed vapor barrier system and optimizing the blower size can save up to $1,000 annually in heating, cooling and electric costs per 10,000 ft^2 of floor space. Also, a new type of mitigation control system is currently being piloted that will optimize the blower speed on active mitigation systems. This new control system has pressure sensors in the soil and in the building and uses software to adjust the blower speed to attain the targeted pressure differential between building and soil. This allows the blower to run at reduced speeds while still achieving the desired mitigation results. Optimizing the blower speed in this way is expected to reduce energy costs of active mitigation systems by as much as 50 percent. These systems are expected to be commercially available soon.

Cost for VI Mitigation Systems in New Construction

Designing and implementing a VI mitigation system as part of planning and construction is far more cost effective than a retrofit installation midway through construction or after construction is complete. The cost of installing a VI mitigation system during construction can vary significantly based on the COCs, the soil properties, and construction style of the building. The design and installation costs can range from $2.50/$ft^2$ to $6.75/$ft^2$; however, for most buildings, the cost of a combination vapor barrier/venting system is in the $3.00/$ft^2$ to $4.00/$ft^2$ range. For comparison, installation costs to retrofit mitigation systems into existing buildings typically range from $5/$ft^2$ to $8/$ft^2$.

Several variables affect these costs and every building will be different. The type of vapor barrier required and construction style of the building are the variables that have the greatest impacts on cost. For example, spray-applied asphalt latex vapor barriers, which are extremely effective, can be eight times the per square foot cost of 10 mil polyethylene. However, polyethylene may not be an effective option for some COCs. The soil variables to consider are the concentrations of the COCs, the permeability of the soil and the potential for the contaminant plume to move toward the building after construction. The primary construction variable is the area of the open foundation, since smaller segmented foundation areas and frequent utility penetrations will drive up the labor cost of sealing the vapor barrier. Also, the type of riser pipe used on the interior of the building affects cost. PVC riser pipes are more economical; however, metal riser pipes may be required to meet smoke index and flame spread requirements. There are greater costs associated with piping through a multistory building when compared to a single story building. Whether the system will be active or passive is another cost variable. The more gas tight a vapor barrier is, the greater the energy savings and the lower the long-term operational cost. It is best to plan out each component with a mitigation expert, select the materials and venting options, then calculate the costs.

Case Study for Joint Expeditionary Base Little Creek

This case study describes a VI mitigation system installed at Joint Expeditionary Base (JEB) Little Creek, Virginia during construction of its new Commissary (Building 3445). The Commissary is a supermarket-style building with approximately 150,000 to 200,000 ft^2 of floor space. The VI mitigation system includes both a passive soil venting system and a spray-applied elastomeric urethane vapor barrier.

Background

Site 12 is the location of the former Navy Exchange laundry/dry cleaning facility (Building 3323), which was demolished in 1987. The site is situated in the eastern portion of JEB Little Creek just south of the new Commissary (Figure 14). In the 1970s, dry cleaning wastes, including PCE sludges, were discharged from Building 3323 to the storm sewer. Environmental investigations of Site 12 indicated that the groundwater contained VOCs including PCE and its breakdown products; TCE, cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride. The highest concentrations of VOCs were present beneath the planned parking lot next to the location of the new Commissary, although the plume did not extend beneath the Commissary itself (Figure 15). Because of this close proximity to the plume, it was decided that a VI mitigation system should be installed during construction of the new Commissary as a precautionary measure.

Figure 14. Location of Site 12 on JEB Little Creek.

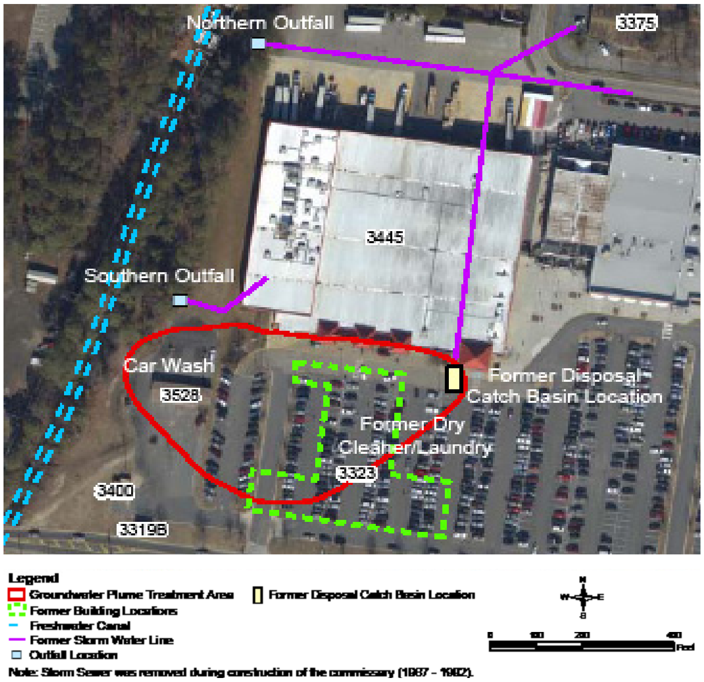

Figure 15. Arial photo of Building 3445 adjacent to Site 12 groundwater plume.

Mitigation System

The VI mitigation system included a passive subsurface venting system installed under the floor of the new Commissary to depressurize the subsurface and prevent the intrusion of VOC vapors into the building. The venting system installed beneath the Commissary consists of five rows of 4-inch perforated PVC piping running north-south at 60-ft intervals. The piping was placed in a layer of gravel (#57 stone) and surrounded by filter fabric. The piping connects to three riser pipes, which extend through the roof and are topped with wind-driven turbines to create a slight negative pressure in the vent system (Figure 16). A spray-on elastomeric urethane vapor barrier was applied above the soil gas venting layer before the building's concrete slab was poured. The slab is approximately 8 inches thick. Additionally, all new sewer manholes were sealed with waterproofing, and any existing sanitary sewer lines that were to be abandoned were grouted in place.

In addition to the mitigation system in the Commissary, groundwater remediation has been implemented to treat the source and reduce the extent of the groundwater plume beneath the adjacent parking lot. The selected remedial action was enhanced reductive dechlorination using injection of a trademarked emulsified oil substrate along with land use controls and groundwater monitoring.

Figure 16. Roof vents fitted with wind turbines provide slight depressurization of the sub-slab area and prevent the buildup of contaminants beneath the building.

In the Commissary's VI mitigation system, the vapor barrier is the principal component for preventing VI. Its purpose is to prevent the diffusion of soil gas and associated contaminants into the building. The passive venting system serves as augmentation for the vapor barrier, rather than as the primary mitigation measure. This passive system is suitable for a site such as Site 12 where the plume is not immediately beneath the building and is not causing a significant threat to the building occupants and where remedial action is underway to further reduce the potential risk to occupants in the future. In situations where there are high VOC concentrations below the building and human health risks are predicted to be significant, an active system such as an SSD with blowers would most likely be required.

Post-Mitigation Inspection

A site inspection of the VI mitigation system at the Commissary was conducted several years after installation. This inspection found that the concrete slab was competent with no apparent penetrations that could be conduits for intrusion of subsurface vapor. The rooftop wind turbines exhibited some corrosion and would spin intermittently in a wind of about 10 mph, rather than spinning freely. Maintenance such as lubricating the shaft and bearings of the turbines or, if necessary, replacement with aluminum turbines would improve the functionality of the venting system. However, in the future, if groundwater sampling indicates that the remedial action is effective in reducing the VOC contaminants, these inspections and maintenance may no longer be necessary for protection of human health.

Resources

Additional information on VI mitigation for new construction can be found in the following sources:

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

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

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

Photos and drawings throughout provided courtesy of Clean Vapor, LLC, CETCO, and CH2M Hill.

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