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### **DESIGNING EFFICIENT SUB SLAB VENTING AND VAPOR BARRIER SYSTEMS FOR SCHOOLS AND LARGE BUILDINGS**

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#### **ABSTRACT**

The author discusses the basic components of designing efficient sub slab radon venting and vapor barrier systems for schools and large buildings. There are two new construction case study schools: one located in Georgia and the other in New Jersey. Both have active radon venting plans as supplied by the architect. Both architect designs required considerable review and plan amendments. The school in New Jersey has a conventional under slab pipe collection system, multiple riser pipes and a standard polyethylene vapor barrier. The school in Georgia has an efficient under slab plenum box collection system, a single riser pipe and a Liquid Boot vapor barrier system. This paper compares sub slab vacuum field extension, the leakage associated with the different vapor barrier systems, electrical consumption, as well as heat and cooling efficiencies. An energy consumption cost analysis demonstrates support for efficient designs and long term sustainability.

#### **INTRODUCTION**

For professionals involved in the construction of new commercial and school buildings or an addition to an existing building and there is a potential for radon or vapor intrusion exposure, the information in this paper will provide design considerations for the purpose of integrating cost effective preconstruction engineered controls to prevent entrainment of soil gases.

There are many factors that need to be considered when deciding to build a new building. The health and safety of the occupants should be in the forefront of the planning and design process. Understanding radon and vapor intrusion and how soil gas entrainment can be prevented is a key item in constructing a building that has safe indoor air. Protecting human health by preventing radon and soil gas impacts needs to be addressed during the planning and construction phase. Radon removal systems for commercial buildings that are integrated with construction are far more cost effective, function better and are less obtrusive than retrofit systems.

The integration and enforcement of indoor air quality standards for vapor intrusion are increasingly becoming Certificate of Occupancy requirements for new commercial buildings. Since many schools and commercial buildings are constructed over reclaimed properties of former industrial sites, vapor barrier and ventilation systems that were originally designed to control radon may need to serve a dual capacity of a radon and vapor intrusion mitigation system. The author has participated in upgrading two ventilation systems that were originally designed to vent only radon at school sites but needed to also serve as vapor intrusion mitigation systems.

## **WHAT CAUSES RADON TO BE DRAWN INTO A BUILDING?**

Air pressure in the lowest level of buildings is usually lower than pressure in the soil beneath the building. Negative pressures that are induced by buildings draw both radon and other soil contaminants into occupied building space where inhalation and human health risk from exposure occurs. Radon can enter the building through expansion joints, sumps, slab cracks, open block joints, utility penetrations or any opening that can serve as a pathway. <sup>1, 2</sup>

Radon entering a building is the result of three primary variables: (1) source strength of radon in the soil; (2) entry routes; and (3) pressure differentials that draw radon gas from the soil into the building. Understanding these components and the effects they have on the transfer of soil gas to indoor air will help determine which preconstruction countermeasures should be integrated into the building.

## **WHEN IS VAPOR INTRUSION ALSO A CONCERN?**

The potential for vapor intrusion should be assessed at all properties when the owner is performing due diligence early in the property evaluation process. The starting point is thorough Phase I and Phase II studies. A consultant needs to be chosen who is familiar with the geographic area and who has provided radon and vapor intrusion assessments for similar properties. The consultant should investigate the history of all properties within 100 feet of the site. If there is an existing building on the site that is targeted for redevelopment, indoor air, radon and soil gas samples should be conducted even if the building itself is scheduled for demolition. This will provide valuable information about a new building's potential for radon and vapor intrusion.

On site groundwater and soil gas samples should be collected. Vapor intrusion pathways can be a concern from 100 feet vertically and laterally. The risk associated with a chemical depends on its toxicity, concentration and potential to migrate into a building. The site's complexity, geology and characteristics of the building will all influence the rate at which soil gases are drawn into a building. The Johnson Ettinger or J&E model is often used to project the attenuation rates of soil contaminants into a building. Data uncertainty is always an issue when interpreting the results of a model. The other unknown factor is the quality of building construction. Items such as small unsealed floor wall joints or minor openings around utility penetrations can create entry pathways and have a significant influence on the rate at which soil gases are transferred into a building. Both EPA and many state agencies recognize the importance of identifying the

potential for vapor intrusion and have established guidance for sampling and data evaluation. The Federal EPA has published the *Brownfields Technology Primer: Vapor Intrusion Considerations for Redevelopment*, March 2008,<sup>3</sup> and a *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings*, February 2004.<sup>4</sup> At this time, at least 21 states have Vapor Intrusion Guidance documents. Your state regulator should be contacted to determine the regulations that would apply to the subject property. Once the chemicals of concern, construction variables and state regulations have been understood, a decision can be made on how to move forward with integrating radon and vapor intrusion resistant construction

If it is determined that there are also vapor intrusion concerns, the designer of the sub slab ventilation system needs to choose a vapor barrier that is chemically resistant to the contaminants of concern. Chemical vapor barriers represent a significant expense and the building owner should be encouraged to use a Professional Engineer for this aspect of the project. This will allow the designer of the vent system to optimize the venting installation and to coordinate with other trades to minimize damage to the liner. A coordination meeting should occur sometime during the design phase to determine the sequence of construction and maximize efficiencies of all the components. Pipe routes through the building need to be planned so vent locations are sufficiently away from fresh air intakes and passive relief vents. An early and proactive evaluation of vapor intrusion impacts will make panning easier and provide more time to design the best mitigation solution.

## **RADON SHOULD ALWAYS BE CONSIDERED WHEN CONSTRUCTING A NEW BUILDING**

A wide variety of strata and soils have been determined to be radon emitters. Check the EPA map for radon potential. Many states will have databases with radon testing statistics that are grouped by zip code. Some states, such as New Jersey, have Tier classifications and mandatory radon code requirements for new school construction. If there is an existing building on the site that is targeted for redevelopment, conduct a radon test. This will provide valuable information about a new building's potential for radon.

## **HOW IS RADON ENTRY AND VAPOR INTRUSION PREVENTED?**

Once the soil contaminants potential for entering a building has been assessed, the next step is to select which preconstruction countermeasures should be implemented to minimize radon or vapor intrusion. There are five basic components to effective radon resistant construction. They are: 1) permeable sub slab support material, 2) venting all occupied ground contact slab areas, 3) properly sized under slab and riser piping, 4) a sealed vapor barrier and 5) if an active system is specified, a properly sized blower is needed to maintain sufficient negative pressure beneath the slab.

Passive vent systems have components one through four but do not have a blower to mechanically draw soil gases from under the slab collection piping to above the roof. Active Soil Depressurization Systems (ASD) are powered by blowers that create vacuum beneath the slab

and actively vent sub slab gases through solid conveyance piping to above the roof. If there is a significant vapor intrusion concern or if geological or statistical test data supports the likely possibility of indoor elevated radon, it is prudent to take a conservative approach and include the activation of the system piping.

The integrity of the vapor barrier and efficiency of passive vent systems are two main variables in determining the effectiveness of a passive system. Punctures or tears in the vapor barrier that may occur during the construction process will diminish the effectiveness of a passive system. Passive systems do not address the pressure differentials that are the main driving forces that draw radon and soil vapors into buildings. The benefit of a passive system is that it can be activated after an indoor air exceedance has been detected.

After the sub grade has been proof rolled by removing undesirable items, drying, leveling and compacting the soil, a permeable layer of crushed stone should be installed. Eight inches or more of ASSHTO #57 stone is preferable. ASSHTO #57 stone is a highly permeable, coarse aggregate with 95% to 100% passing through a one inch (25mm) sieve, 25% to 60% passing through a half inch (12.5mm) sieve and less than ten percent passing through a Number 4 (4.75mm), 3/16" sieve. It has been the observation of the author that if there is not sufficient crushed stone above and below the pipe,



Figure 1: Areas Isolated by Thickened Slabs

then the slab directly above the pipe is prone to cracking. To minimize slab cracking that is associated with the pipe, there should be a minimum of four inches of crushed stone in addition to the diameter of any conveyance piping. If six inch pipe is used, the ground beneath the pipe may need to be trenched to assure sufficient stone for slab support. There should be a minimum of two inches of crushed stone above and below any sub slab conveyance pipe. All slab areas within the occupied area that have contact with the soil need to be included in the sub slab vapor collection system. Grade changes and thickened slabs beneath concrete masonry walls often isolate under slab areas (Figure 1). Because the radon collection system is usually the last item to be incorporated into the construction plan, a thorough review should occur to make sure all areas have been included. There should be no under slab areas that are outside of the influence of the radon collection system.

The most efficient way to vent sub slab soil gas is through a centrally located soil gas collection plenum box. A plenum box is embedded in the crushed stone layer and constructed of hollow concrete blocks turned on their side with an empty space in the center from which a conveyance or vent pipe transports soil gases above the roof line. See Figure 2 below. There should be a minimum of eight inches of crushed stone beneath and beside the plenum box. Ground floor classrooms, offices and storage rooms are often partitioned by Concrete Masonry Unit (CMU)

walls that are supported by haunches or thickened slabs. If the architect does not specify a depression in the ground beneath the thickened slab for stone then the thickened slab will be in direct contact with the soil creating a “mini foundation” around the perimeter of the thickened slab that is isolated from the vented areas beneath the slab. Interior footings at grade changes will also create isolated sub slabs. GeoVent<sup>®</sup>, which is a one 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 (See Figure 2). Depending on the leakage associated with the vapor barrier, the configuration of the under slab conveyance piping and the design of the plenum box, a single properly sized collection system can service up to 15,000 square feet of floor space. If the service area of the plenum box is greater than 4,000 square feet, the main vent pipe to the roof should be six inches in diameter.



Figure 2: Connecting Isolated Slab Areas with a Central Plenum Box

The design goal is to create a minimum sub slab negative pressure of  $-0.016''$  of water column (W.C.) (4 pascals) 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  $1.0''$  W.C. static pressure. Even though it has been demonstrated that pressure differentials as low as  $-0.004''$  W.C. (1 pascal) can successfully arrest the attenuation of soil gases,  $-0.016''$  W.C. (4 pascals) is used as a design goal because the design specialist has no control over construction conditions that can reduce the efficiency of the system. Factors that can obstruct the free flow of sub slab soil gas through the stone layer and truncate the extension of the vacuum distribution are sand particles mixed in with the crushed stone, elevated sub slab utility conduits that are in the stone, soil that is left over from burying utility lines after the ground has been leveled (trench overburdening), and conveyance piping that has been crushed or distorted by unscheduled vehicle traffic.

## **SIZING THE CONVEYANCE PIPING**

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 under slab plenum box and the vent termination point. Drag coefficient tables exist for different pipe diameters and assorted fittings.<sup>5</sup> Since coordinated drawings are usually not part of the design phase, the person designing the system should plan on twice the number of pipe fittings as anticipated when calculating the pressure drop associated with a riser pipe system. A pressure drop table for common pipe sizes and air flow is included in Figure 3 below. Equivalent footage of pipe for each fitting is included in Table 2 below. The most commonly used riser pipe material is PVC because of its availability, low cost and low air flow drag coefficients. No Hub Cast Iron pipe is used when there is concern of exceeding the flame spread or smoke index especially if the conveyance piping passes through a return air plenum. Protective pipe enclosures or steel pipe should be considered in areas of vehicle or fork lift traffic.

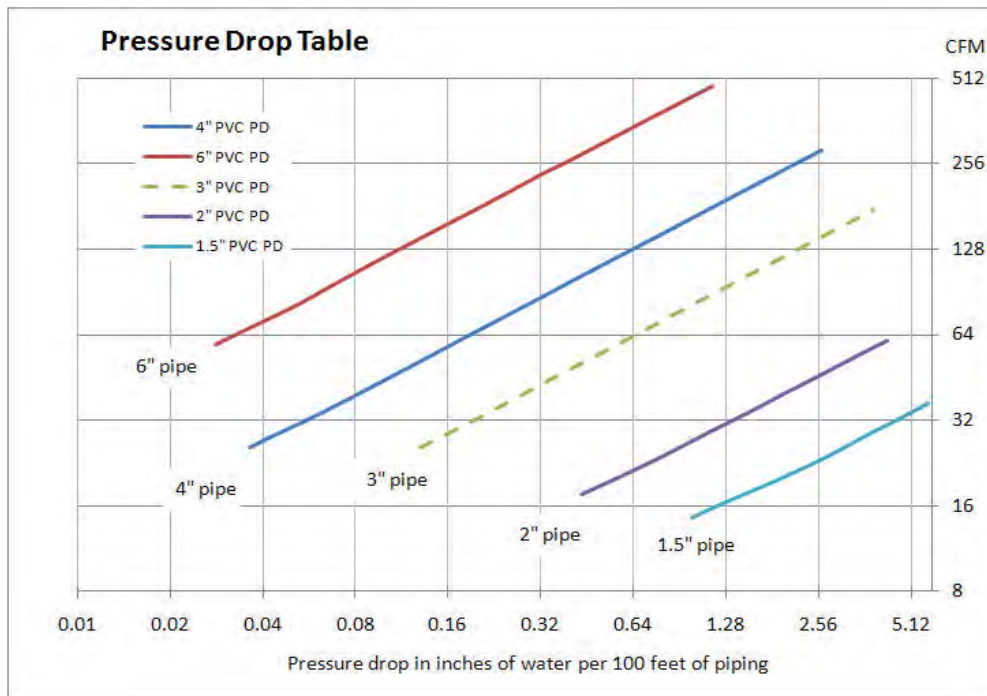


Figure 3: Pipe and Airflow Pressure Drop Table

Source: Brodhead

Conveyance piping can be joined together beneath the slab to minimize vertical risers. A three inch riser pipe can service up to 1500 square feet, a four inch riser can service up to 4000 square feet, and six inch riser pipe can service up to 15,000 square feet.<sup>6</sup> Sub slab conveyance pipe should have 5/8" condensate drain holes that face down at four foot intervals to minimize water blockages inside the pipe. If factory perforated pipe is used, one set of holes shall face down. Note that significantly larger sub slab areas have been depressurized when the slab barrier and perimeter foundation is very air tight and the soil has low permeability.

<b>Pipe Diameter</b>	<b>Per 100' of PVC Pipe at 100 CFM</b>
6"	0.007
4"	0.04
3"	1.4

Table 1: Inches of Water Column Pressure Drop in 100 feet of Pipe at 100 CFM

Source: Brodhead

<b>Pipe Diameter</b>	<b>Straight Pipe Resistance</b>	<b>Per 100' of PVC Pipe at 100 CFM</b>
6" – 90 elbow	15'	0.00105
4" – 90 elbow	6'	0.0024
3" – 90 elbow	4'	0.056

Table 2: Inches of Water Column Pressure Drop from 90 degree Elbows

Source: Brodhead

When designing a depressurization system and specifying blowers, it is important to include the projected piping pressure losses. Speculating the final active system air flow is one of the most difficult parts of the design process. Air flow is a function of blower capacity, piping size, fittings and layout, sub slab aggregate resistance, soil permeability and slab and foundation leakage. <sup>7</sup> Clean ASSHTO #57 stone is highly permeable and can provide excellent slab support material through which to extend vacuum. As demonstrated by the comparison of the two case study schools, 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 four inch conveyance piping, a blower that can move 200 CFM at -1.0" W.C. can create a vacuum field of -0.02" W.C. or greater over a 4000 square foot 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.

## **SELECTING A VAPOR BARRIER**

Selecting the right vapor barrier is a critical part of the project. The vapor barrier can also 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. The most commonly used material that is often referred to as a vapor barrier is 6 mil polyethylene. Under American Concrete Institute (ACI) standards, 6 mil (0.15mm) polyethylene is not classified as a vapor barrier but as a vapor retarder.<sup>8</sup> This is because polyethylene and polyolefin vapor barriers generally have a permanence (water vapor transmission rate) (WVTR) of less than 0.3 perms, as

determined by ASTM E 96. A number of vapor retarder materials have been incorrectly referred to and used by designers as vapor barriers. True polyethylene and polyolefin vapor barriers are products that are generally not less than 10 mil (0.15 mm) have a permeance WVTR of 0.1 perms when tested in accordance with ASTM E 96. Polyethylene vapor barrier material is often made of “post consumer” recycled materials. The main limitations of these commonly used polyethylene and polyolefin vapor retarders is that they are not chemical resistant and the available sealing tape and lapping procedures make them difficult to seal at perimeter walls and around utility penetrations. These vapor retarders will often pull back from the attachment points during the concrete pour and cure process, leaving significant gaps for radon and vapor intrusion. These types of vapor retarders provide the lowest level of protection.

The second most commonly used vapor barrier materials are 10, 12, and 15 mil polyethylene or polyolefin vapor barrier material such as Stego-Wrap which has a WVTR of less than 0.1 perms. These are true vapor barriers. The limitations to these materials are limited chemical protection and low puncture and tear ratings when evaluated against reinforced products of similar thickness.

A third group of vapor barriers is reinforced and cross laminate polyethylene and polyolefin materials such as the Raven Vapor Block 15<sup>®</sup>. They are generally three ply materials with woven scrim between two polyethylene sheets. These vapor barrier materials have puncture and tear resistant ratings that can be as much as 50 times greater than a 6 mil polyethylene vapor retarder. If radon is the main soil gas contaminant of concern, thicker and cross laminated materials can provide greater efficiency than a standard polyethylene vapor retarder. This is largely because the materials are less likely to be punctured or torn and the seams and utility penetrations are usually sealed to a higher standard using manufacturer supplied tapes and cloth binders.

The Liquid Boot<sup>®</sup> is a spray-applied gas vapor barrier product that provides a near gas tight seal. It was designed to provide an impenetrable vapor membrane for water, volatile organic compounds and methane gas.<sup>9</sup> The Liquid Boot<sup>®</sup> application process involves first applying a base non-woven geotextile fabric over the stone and then spraying a hot emulsified asphalt/latex top covering. This hot material binds to the support fabric, column pads and side foundation walls to provide a minimum thickness of 60 dry mil. The total thickness including the support fabric is 73 mil. Once the application process is completed and top emulsion has cured, a port in the vapor barrier is accessed and the underside is pressurized by using centrifugal blowers to supply colored indicator smoke. This will identify leaks for repair or enable the installer to certify that there are no leaks. Installers of this material must be licensed by the manufacturer.

The most important part of the effectiveness of any vapor barrier system is a tight seal to foundation walls and around the utility penetrations of 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 liner to drain off extra water that may be associated with the concrete finishing process.

## **QUANTIFYING THE EFFECTIVENESS OF THE RADON SYSTEM**

The effectiveness of any soil depressurization system should be quantified after the slab is poured and allowed to cure for at least 28 days. The test is performed by temporarily installing the specified blower and measuring the sub slab vacuum field. During the construction phase, soil probes routed through the slab are embedded in the crushed stone prior to installing the vapor barrier. Probes are embedded because drilling through the concrete slab creates an unnecessary risk of damaging sub slab utilities and will void most vapor barrier warranties. Probes should be located distant from the plenum box near the projected end of the negative pressure field. Depending on the potential for radon or soil vapor entry, these probes could be as numerous as one per isolated foundation area. At least one probe should be installed per 5000 square feet of slab area and for each different slab elevation. Each blower system should have at least one soil probe.

Soil test probes can be as simple as ¼ inch polyethylene tubing with a polyester particulate filter on the end that is in the stone. More durable probes are constructed of perforated two inch PVC pipe connected to ½ black iron gas pipes. These probes usually go from the gravel bed through the concrete form that surrounds a support column and terminates inside the column pocket a few feet above grade. The lines are then capped to prevent debris from blocking the tubing. Gas line can be purchased in a variety of lengths with a threaded end that is fitted with a cap. The more durable PVC and steel probes have a greater probability of surviving the concrete pour and power trowel process because small plastic tubing is easily damaged.

The efficiency of the system is measured by temporally activating the system by hooking up the blower that has been specified for the system activation. The pressure field extension is measured at the embedded probes. A micromanometer that can measure to a sensitivity of -0.001" W.C. should be used. The micromanometer tubing is temporarily sealed inside the soil gas probe. If vacuum field measurements at the probe most distant the sub slab collection piping exceeds 0.036" W.C. (9 pascals) the top of the acceptable vacuum range specified by ASTM<sub>10</sub> the procedure can be repeated using a blower that uses less electricity. If the piping is incomplete at the time of testing, pressure drops as a result of the additional piping should be included in the calculation. Lower wattage blowers that will save energy should be installed to reduce operating expenses. Airflow exhaust measurements should be conducted using a pitot tube or vane anemometer. The selected blower model, final static riser pipe vacuum, vacuum field measurements at the embed probe locations and final exhaust airflow values should be recorded and included in the construction documents that are presented to the owner as part of the project record. Unless provisions are made during the design phase, soil probes shall remain capped and will become encased artifacts of the building and not accessible for future use. Indoor air sampling should occur once the building is weather tight and the air handling systems are operational. There is value in having one consultant working all the way through the design installation and application phase. This maintains continuity throughout the project and should provide a single standard of measurement methodology and quality control.

## **GREEN ENERGY AND SUSTAINABILITY CONSIDERATIONS**

EPA defines Green remediation as “considering all the environmental effects of a remedy implementation and incorporating options to maximize the net environmental benefit ...” (EPA 2008). When designing a new construction radon system, long term energy considerations need to be factored into the design process. Greater design efficiency reduces operational costs and extends the time that an active venting can be sustained for a fixed capital expenditure. A streamlined under 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.

There are three main components that need to be considered when attempting to lower the operational energy costs of a radon or vapor intrusion mitigation system. They are: the cost of operating the blower(s) that will maintain the negative pressure field 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 addition cost that must be considered is the costs of replacing the blowers themselves. More 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 radon fans. Installing a tightly sealed vapor barrier system and optimizing the blower size can save up to \$1,000.00 annually in heating, cooling and electric costs per 10,000 square foot of floor space.

After every reasonable attempt has been made to prevent radon entry by selecting the best vapor barrier and vent system design, there are still convective forces that are working to draw soil gases into a building. Even with the best vapor barrier system, soil contaminants can still be drawn in through the hollow cores of block walls and unsealed electrical conduits that penetrate the slab.

## **COMPARATIVE CASE STUDY**

The case study compares the efficiencies of two active radon systems that were installed as part of new construction at two schools. The first school is a three story school with 38,000 square feet of ground coverage and is located in New Jersey. The original design specified a standard 6 mil polyethylene vapor barrier and vent pipes compliant with New Jersey’s Radon Hazard Sub Code. The New Jersey Radon Hazard Sub Code was originally drafted to apply to residential homes. <sup>11</sup> Education facilities were included immediately prior to the 1995 ratification and the inclusion was intended to serve as an interim vehicle until the Radon Hazard Sub Code for Schools could be drafted and codified. This code, that was originally intended to be applied to homes, does not facilitate cost effective or energy efficient venting practices for schools or large buildings.

The second school is a three story new school that was constructed in Georgia. Several “Green Energy” concepts were integrated into the construction of this school including indoor air quality goals. The size of the new construction footprint is 24,000 square feet. A decision was made by the architect early in the design process to select a vapor barrier that would be as gas tight as

possible to minimize the entrainment of radon. The Liquid Boot<sup>®</sup> vapor barrier system was selected.

At both schools, Clean Vapor was consulted to improve the original architects design and implement venting efficiencies as a part of construction process. In both cases, a condition of accepting the design improvements was that they could not alter the owner approved construction costs since the budgets had been finalized.

## NEW JERSEY SCHOOL

The specifications in the New Jersey school originally called for 4 inches of crushed stone over proof rolled ground, Schedule 80 PVC sub slab piping, 39 three inch plumbing T's set into the gravel, 6 mil polyethylene vapor barrier with limited sealing instructions, 39 vertical three inch risers routed from the T's in the gravel to the roof and 39 -145 watt roof mounted centrifugal blowers. The proscribed method of measuring the pressure field extension testing was to drill holes through the slab and measure the vacuum fields with a micromanometer.

The New Jersey School design was amended to replace the schedule 80 PVC pipe with schedule 40 PVC pipe. The 39 3" T fittings set in the gravel were replaced by a four inch under slab pipe collection system that included all previously isolated areas. At the end of each sub slab solid pipe run is a "T" fitting with chamfered extensions to increase the intake surface area of the fitting. The new design reduced the number of risers from 39 three inch risers to 14 four inch risers and blowers. The standard vapor barrier was installed per the original specification. Sub slab vacuum was still measured by drilling holes through the slab and collecting measurements with a micromanometer. Careful notes were made on the location of all electrical conduits and sub slab utilities prior to pouring the slab to determine where test holes could be installed. See 14 system riser layouts in Figure 4 below.

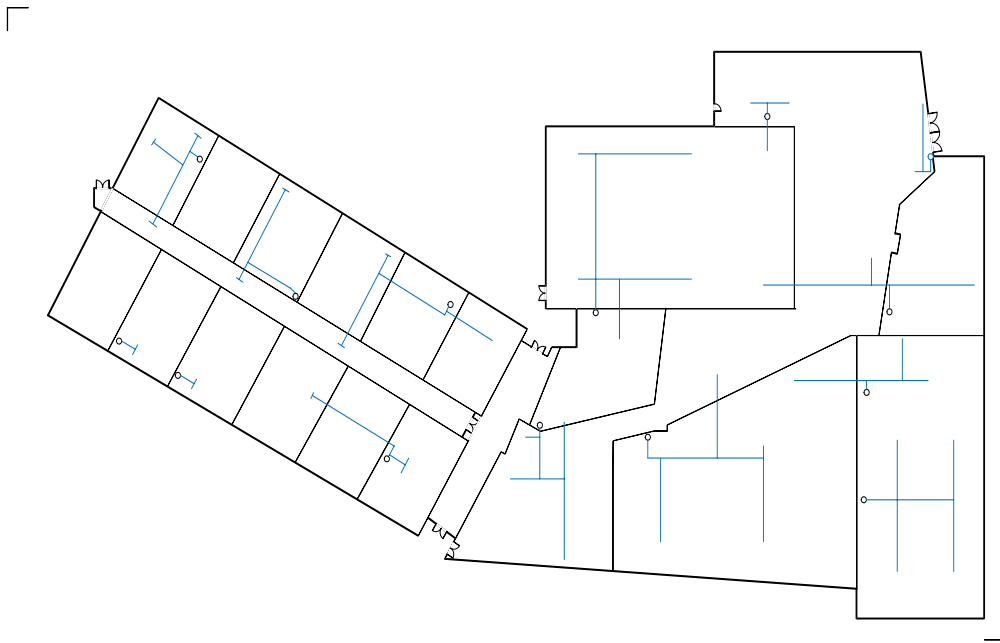


Figure 4: New Jersey School Amended Sub Slab Layout Design

After the slab was poured, RadonAway RP-265 blowers were installed and the systems were tested for exhaust airflow and vacuum distribution. The exhaust airflow for all fourteen risers averaged 74 cubic feet per minute CFM. The vacuum field extension results averaged -0.0792" W.C. All test locations exceeded the -0.02" W.C. specified pressure differential under weather tight heated building conditions. The testing was conducted in the early spring at approximately 45 degrees Fahrenheit outside temperature. It was observed that the air exhausted from the blowers was relatively warm when compared with the outside air temperature. An analysis of the additional cost of the conditioned air being discharged was undertaken. Note that this type of school new construction radon mitigation design is commonly used in New Jersey.

## **GEORGIA SCHOOL**

The original design for the Georgia school included a low permeable compacted road bed material beneath the slab. Road bed material is mechanically fractured, coarse gravel mixed with coarse and fine sands. The matrix of the material has almost no void spaces with 35% to 90% of the material passing through a Number 10 (2.0 mm) sieve. It can be tamped into a very hard low permeability fill material that is structurally very good for supporting concrete slabs but is not suited for extending a sub slab vacuum field. The risers and collection sumps consisted of three separate six inch riser pipes with one, 145 watt blower for each riser. Each riser was specified to be connected to a collection sump that consisted of a six inch section of twenty-four inch diameter pipe set vertically in the road bed material. 3/8" holes on 1 1/4" centers were to be drilled in a staggered pattern through the side walls of the twenty four inch pipe to transfer the soil gas from the sub slab, through the perforated pipe. See Figure 5 below. The perforated two foot diameter pipe was to serve the function of a perforated collection sump. The radon from each two foot diameter sump was to be vented through six inch conveyance pipe to a location above the roof. There were several areas of the slab that were isolated from the three collection sumps. The specified vapor barrier was Liquid Boot<sup>®</sup>. The plan called for drilling holes through the concrete and the Liquid Boot<sup>®</sup> vapor barrier to allow measurement of the sub slab negative pressure field once blowers were installed. Note that drilling these holes would have voided the Liquid Boot<sup>®</sup> warranty. Clean Vapor was consulted to redesign the system and install an effective energy conserving system that would minimize the entrainment of radon from the soil into the building.

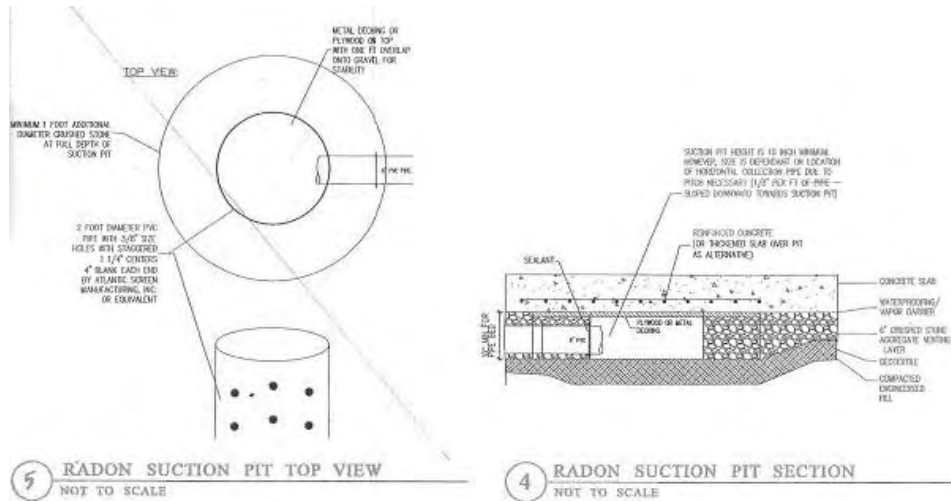


Figure 5: Original 24 inch Collection Sump Design

The compacted road bed material was replaced with ASSHTO #57 stone. The three perforated twenty-four inch diameter pipes were each replaced with concrete block soil gas collection plenum boxes. See photo of this collection plenum in Figure 2 above and the location of the collection plenums in Figure 6 below. Four inch perforated sub slab conveyance piping was installed in the gravel bed from all separate slab areas to the collection plenum box. Six inch soil gas conveyance pipes were routed from each of the three sub slab collection plenums to a common area where the three separate riser pipes came through the concrete. The plan for drilling test holes through the slab and vapor barrier was abandoned. Five vacuum test soil probes were installed in the stone bed during construction. See their location in Figure 6 below.

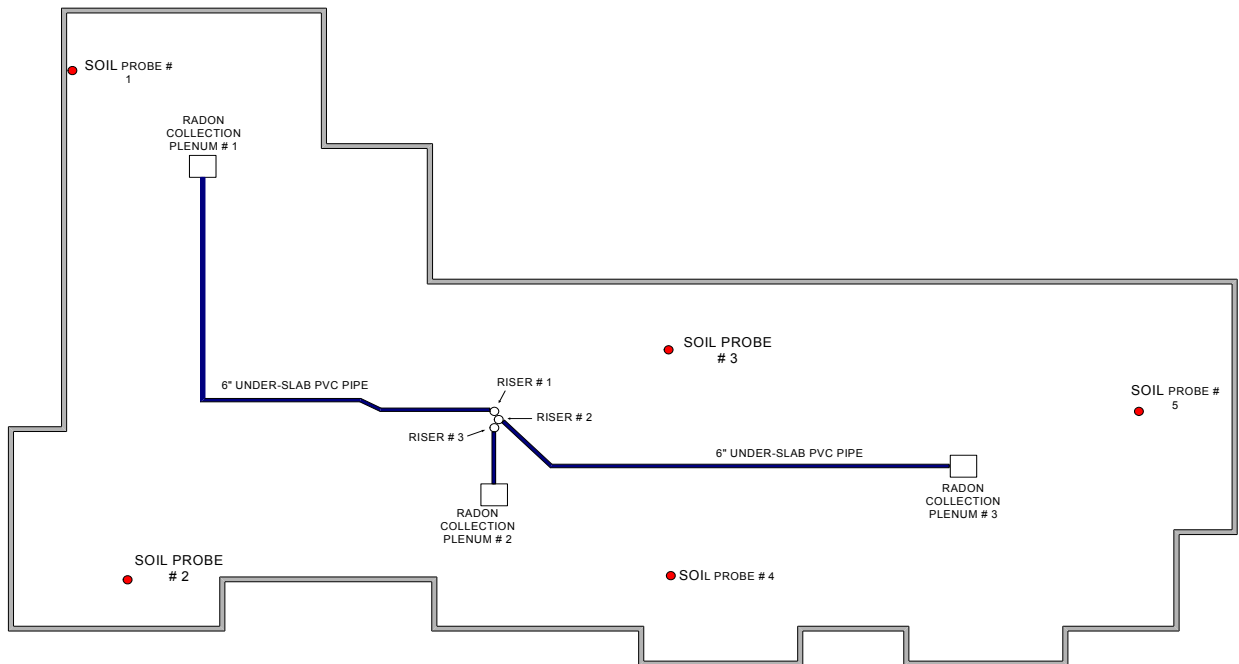


Figure 6: Georgia School Amended Design - Three Riser Systems Joined Together with One Blower

After the slab was poured, the three risers were individually tested for air flow and vacuum distribution. The vacuum field extension results were significantly greater than any measurements previously recorded by Clean Vapor for similar applications. A decision was made to join all three riser pipes together and repeat the measurements.

A single Fantech HP 220 blower capable of creating 2.7” of static vacuum operating at 125 watts created a nearly uniform vacuum field beneath the 24,000 square foot slab of -1.8167” W.C. The total exhaust air flow was only 119 CFM. The vacuum distribution and minimal leakage design goals were substantially exceeded.

Suction Device	Suction System	Static Vac " WC	Air Flow CFM	Exhaust Diameter	Test Probe	Suction Device On
	S-1	-1.825			T-1	-1.8167
<b>HP 220</b>	S-2	-1.826	119	6"	T-2	-1.7806
	S-3	-1.827			T-3	-1.8174
					T-4	-1.8120
					T-5	-1.7904

Table 3: Sub Slab Static Vacuum Distribution

The Georgia school with the efficient conveyance piping design and Liquid Boot<sup>®</sup> vapor barrier had twenty times the static vacuum of the New Jersey school (-1.816” versus -0.079”). The New Jersey school’s fourteen blowers were moving a total of 1036 CFM versus the 119 CFM from one blower at the Georgia school. Using the Liquid Boot<sup>®</sup> appeared to reduce the CFM requirement from 0.027 CFM/ft<sup>2</sup> for the New Jersey school to 0.005 CFM/ft<sup>2</sup> for the Georgia school and it created a sub slab vacuum that was twenty times stronger. Clearly, the Green Energy initiatives would result in operational energy savings. The savings and net benefit were evaluated against the increased capital expenditure of installing the Liquid Boot. To create some consistency in the model, a cost of \$0.14 kWh was used for electricity and \$12.50 per 1,000 cubic feet of natural gas. Since the New Jersey school would have more heating days and the Georgia school more cooling days, the latitude of the schools was standardized to the degree days of a six month heating season. The operational cost of blower motors required to distribute the additional conditioned air from Roof Top Ventilators (RTU’s) to the classrooms and the costs of replacing the radon blowers after a projected six year life span were not included in the operational cost calculations. The costs were standardized to 10,000 square feet for the purpose of illustration and easy math for those who would be tasked with evaluating costs for future school construction.

	<b>New Jersey School</b>	<b>Georgia School</b>
Approx. Square Feet	38,000	24,000
Riser per Sq Ft	One 4" per 2,700	One 6" per 24,000
Average Vacuum Sub Slab	-0.0792	-1.8167
Blowers	Fourteen Blowers Operating at 118 watts	One Blower Operating at 125 watts
Annual Blower Electrical Cost *	\$516	\$77
Est. Leakage per 10,000 sqft	272.6 CFM	49.5 CFM

Table 4: Operational Cost Analysis

	<b>New Jersey School</b>	<b>Georgia School</b>
Heating: Factor H/E	1.4703	2.25
Cooling: * Factor C/E	0.2108	0.323
Overall Factor (E+H+C)/E =	2.681	3.57

Table 5: Energy Cost Analysis per 10,000 Square Feet of Floor Area

	<b>New Jersey</b>	<b>Georgia</b>	<b>Savings</b>
Electric*	\$457	\$63	\$394
Heating: **	\$ 672	\$77	\$595
Cooling: *	\$96	\$11	\$85
<b>Total Savings</b>			<b>\$1,074</b>

Table 6: Operational Cost Analysis per 10,000 ft<sup>2</sup> of Floor Area  
Standardized to a 6 month HDD and CDD

\*Electric Cost \$ 0.14 per kWh

\*Natural Gas Costs \$ 12.50 per 1000 ft<sup>3</sup>

The next step in the evaluation was to compare the benefits derived from the energy savings with the increased construction costs and determine if this Green Energy Initiative is also fiscally sound.

The comptroller of a North Jersey Construction Company was contacted and the installation costs for both the standard vapor barrier and Liquid Boot acquired. Union labor rates were applied to the installation of both materials. The Liquid Boot cost for this model is \$5.50/ft<sup>2</sup> versus the traditional vapor cost of \$0.25/ft<sup>2</sup>. A 5% finance cost over 20 years was applied to the project. The results are plotted in Figure 7 below which reveals in just less than ten years the Green Energy Initiative with the efficient vent system and the Liquid Boot<sup>®</sup> paid for itself in operational savings. Note in the chart the initial cost for 10,000 ft<sup>2</sup> for the Liquid Boot<sup>®</sup> is \$55,000.00 versus traditional vapor barrier costs of \$2,500.00. The decision to issue energy credits or use public funds to finance energy saving projects is usually based on a twenty year return. The findings of this case study indicate that the additional costs expended to design and install highly efficient sub slab vent systems for the purpose of preventing radon entry and vapor intrusion are fiscally sound.

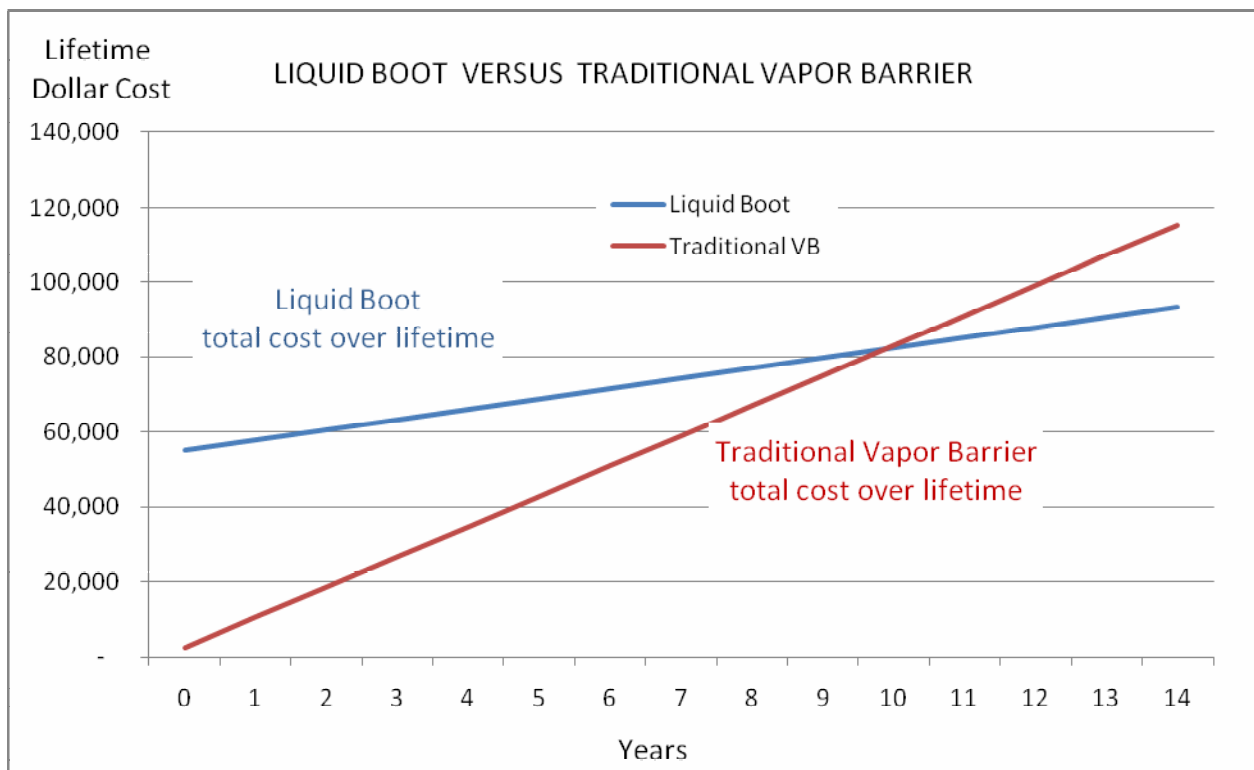


Figure 7: Initial Capital Expenditure Versus Operational Energy and Finance Costs

Depending on the square feet of ground coverage and labor rates, Liquid Boot<sup>®</sup> costs can be as low as \$3.00/ft<sup>2</sup>. It is recommended that the installation cost variables be considered when modeling specific sites.

## **SUMMARY and CONCLUSIONS**

Both the Georgia and New Jersey school used ASSHTO #57 stone as a sub slab material. The New Jersey school used four inch perforated pipe in the stone to collect soil gas and included no central collection plenum boxes. The New Jersey school used a standard 6 mil polyethylene vapor barrier. The level of vacuum achieved at the Georgia school was twenty-two times greater than the New Jersey school. The difference was an efficient under slab soil gas collection plenum box and a near gas tight vapor barrier provided by the Liquid Boot<sup>®</sup> System.

The annual savings associated with the efficient collection plenum and Liquid Boot per 10,000 square feet of floor area was estimated to be \$ 1,074.00. The additional installation cost of a sealed hot spray emulsified vapor barrier (Liquid Boot<sup>®</sup>) should pay for itself in energy savings in approximately ten years.

Energy efficient radon and vapor intrusion mitigation systems that are designed and integrated during the planning and construction phases have demonstrated to be cost effective, energy efficient and highly effective in preventing radon entry and vapor intrusion.

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## **KEY WORDS**

Vapor Barrier  
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Radon Hazard Sub Code for Schools  
ASSHTO # 57 Stone  
Liquid Boot  
Green Energy  
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