2002-03

DESIGNING COMMERCIAL SUB-SLAB DEPRESSURIZATION SYSTEMS

Bill Brodhead
WPB Enterprises, Inc., 2844 Slifer Valley Rd., Riegelsville, PA USA

ABSTRACT

Designing radon mitigation systems for commercial buildings or schools is significantly more complicated than designing for residential buildings. This paper describes the methodology used in designing two different radon systems for commercial buildings. One of the buildings is an 18,000 sf school building in New Jersey. The other building is a classical three story stone faced building at Lehigh University in Bethlehem, PA. The remediation design was based on sub-slab communication testing , occupant requirements and aesthetic considerations. The remediation systems were installed as per this design and the systems effectively reduced the radon levels well below the EPA guideline.

INTRODUCTION

The first building is a large single story building in New Jersey with a slab foundation. The initial radon measurements were done with fifteen long term alpha track detectors that were left in place from 11/27/2000 to 2/27/2001. Most rooms in the building measured between 7.5 pCi/L and 14.1 pCi/l . Since only two of the rooms in the building measured below 4 pCi/L, the total building was to be remediated except for the boiler room. The foundation layout depicted in Figure 2 indicated that the building was divided up into multiple sub-slab areas.

The second building is an 100 year old large stone two and a half story building at Lehigh University in Pennsylvania. The lowest level is half in the ground. One wing of the building had radon levels above the EPA guideline. The area with elevated radon levels was completely finished into office space.

COMMERCIAL BUILDING CONCERNS

The EPA has published radon mitigation standards for residential buildings but there are no published mitigation standards for commercial buildings or schools. It is generally accepted practice, however, to use the residential standards as a minimum for commercial buildings.

Commercial buildings obviously have complicated heating and cooling systems. An important component of the HVAC system that needs to be checked is how much outdoor air is the HVAC adding to the ground contact rooms (any occupied areas that have adjacent foundations in contact with the soil), and does this amount vary. In addition the HVAC system will often create zones in areas of ground contact that are negative in pressure in comparison to the soil. HVAC systems can then effectively mine radon from the soil and distribute it through out the building.

Commercial buildings are often built with compacted fill beneath the slab. The interior partitions can be supporting walls that penetrate through the slab. These walls are typically made of block and extend several courses below the slab to a supporting footer. Utility penetrations routed through these sub-slab foundations as well as little if any block wall surface sealing allow easy airflow between the sub-slab and the block walls.

Slabs are typically divided into sections that have an expansion material around the perimeter that allows easy airflow from the sub-slab into the building. These expansion strips are often loosely covered by finish materials, such as perimeter base moldings or permanent walls. Although these openings may be small there are typically long lengths of them. One thousand feet of even 1/32th of an inch crack is an opening of 375 sq inches or 17" X 22".

REMEDIATING LARGE BUILDINGS

Although sealing foundation openings has occasionally been successful for reducing radon levels, it is not considered a permanent or practical solution. The only method that has consistent been successful at remediating radon levels in buildings is changing the pressure of the ground contact room from negative to positive in relationship to the soil beneath the slab. This can be accomplished by either increasing the amount of air entering the ground contact room or by removing air from the soil, also know as sub-slab depressurization. The choice between which method to use is typically determined by economics but other issues need to be considered. Although adding additional outdoor air to an HVAC system may be the less expensive option there are often issues with the HVAC's ability to handle both the added heating and cooling load. There may also be considerations that require rooms in ground contact to be negative in relationship to adjoining rooms to prevent contaminated air transfer. An HVAC adjustment may also be prone to future modifications that nullify its performance. These consideration often make sub-slab depressurization the preferred choice. This is not to imply that the building might require both an HVAC modification and a sub-slab depressurization to be permanently effective.

Both buildings have large boilers that provide hot water heat for the whole building. The New Jersey school had window air conditioners in the office. The classrooms were not air-conditioned. The Lehigh building did have a central air conditioner above the office drop ceiling. Sub-slab depressurization was chosen as the re-mediation method for both buildings because converting the existing heating system into an air handling system that could pressurize the building would have been too costly and prone to tampering.

METHODS: SUB-SLAB COMMUNICATION TESTING

Sub-slab communication testing is a method that tries to emulate a finished sub-slab depressurization system in order to determine the number of suction holes that may be needed and the performance requirements of the radon fan and piping to be used. It is accomplished by first picking out locations that would be practical spots for sub-slab suction piping. A 0.75 to 1.5 inch hole is then drilled through the concrete floor with a rotary hammer drill. The risk of damaging sub-slab utility piping needs to be considered before doing any slab drilling. You can minimize the risk of hitting sub-slab utilities by studying all building mechanical plans, logically try to deduce where utilities might be located from visible slab utility penetrations, consulting with anyone who might have knowledge of utility pipe locations, and using metal sensing equipment such as floor/wall metal scanners or grounding relay boxes.

A standard shop vacuum is used to draw air out of this small suction hole. At varying distances from the shop vacuum suction a smaller test hole, typically 3/8" in size, is drilled through the slab. A digital micro-monometer is used to measure the pressure change between the sub-slab and the room with the vacuum off and then on. The digital micro-monometer has to measure changes as small as 0.001 inch of water column or even down to 0.1 pascals (one pascal is equal to 0.004 inches of water column). Any change in building or soil pressure other than the shop vacuum can make interpreting the results difficult or impossible. Building pressure changes can be easily induced by air handler operation or the more common problem of outdoor wind. Wind pressurizing or depressurizing the soil can be especially problematic if the building is on a slope. Wind induced building pressures are related to the size and location of openings into the building. In the case of this building, the Multi-purpose room had large garage doors opening to the outside. These doors needed to be left closed during the test to reduce wind effect.

When the pressure difference across the slab is first measured, before the vacuum is started, it is often indicating a sub-slab positive reading. This is an indication of the buildings negative condition in relationship to the soil and the tightness of the slab. The tighter the slab, the closer the slab differential will be to the differential across the building shell. If the slab has openings and the sub-slab is porous then there may be little if any pressure difference across the slab before the vacuum is turned on. The communication test does not need to indicate a pressure reversal to indicate sub-slab communication but rather any change in pressure induced by the vacuum. This is why an instrument needs to be used rather than a chemical smoke tracer. In addition, the instrument displays actual pressure changes. 3/8 inch holes are drilled in the slab at varying distances from the suction point to map out the pressure field extension. Refer to Figure 1 and Figure 3 for the results of the communication tests done at both buildings. The Lehigh building was very finished and only a minimal number of test holes were installed.

A communication test in addition to determining how far pressure field extension can be measured from the suction hole can also be used to determine the appropriate radon fan and system pipe sizing. A shop vacuum, however, produces static pressure from 60 to 80 inches of water column at zero flow. If there is no resistance to air flow below the slab a shop vacuum can move from 100 to 125 cfm through a 1" to 1.5" hole through the slab. Radon fans typically have a maximum suction of 1.5 to 4.0 inches of water column. To better determine what sub-slab pressure the vacuum is creating in the soil, a measurement of the differential pressure across the slab is made 12 to 18 inches from the suction hole. This is approximately the size of the final suction pit excavation and the true performance of the shop vacuum at that airflow.

The unknown factor is how much will the pressure field extension improve when all visible slab leaks are sealed. Sealing can have a dramatic impact on the system performance. In most cases the communication test will typically under predict the final performance.

The communication test done in both buildings indicated that there was a high flow situation with limited sub-slab pressure field extension. It was assumed that a major portion of the high air flow was due to the perimeter expansion joint at the Lehigh building and the openings in the interior block walls that went through the slab of the NJ school. It was anticipated that after the expansion joints were sealed at the NJ school, the system performance would be improved. The fact that there was significant air flow out of the shop vacuum and some pressure field extension over large distances at both buildings indicated that there was most likely aggregate under the slab.

Although initial communication testing at the Lehigh building indicated some communication at the far test holes, the high airflow with no opportunity to do any sealing dictated that multiple suction holes would be necessary.

SYSTEM PIPING DESIGN

At the New Jersey school the communication testing revealed that it was necessary to have suction points on both sides of the interior block wall since sub-slab communication across the wall was very limited. The size of the building, amount of sub-slab leakage and building construction dictated twelve suction points and five separate fans be used rather than larger piping and fans in order to consolidate systems. See Figure 2. (Brodhead, Messing 1997) (Brodhead, Saum 1996)

Two fans were used to depressurize the sub-slab of the multi-purpose room and the adjoining classrooms. The East and West walls of the multi-purpose room offered convenient locations to route the trunk. Splitting the system into two fans also allowed use of four inch pvc piping which made piping installation simpler. Each of these two systems had four or five suction points so high flow Radon Away RP265 fans were chosen. These fans can move about 200 cfm at 1" of static pressure and use about 120 watts. The other three fan locations were single suction points and consequently required less capacity fans. In this case RadonAway RP260 fans were specified. These fans move 100 cfm at 1" of static pressure at a minimal 65 watts of power. The contractor, however, decided to standardize with the larger RP265 fan for all five locations. The final slab differential pressure readings indicate that the fans originally specified would have been more than adequate.

At the Lehigh building it was not possible to route piping so that multiple suction holes could be installed using a single fan. The initial system was designed instead with multiple fans. Each fan would draw on a single suction hole. This also minimized the piping that would need to be routed inside. The initial phase called for two fans each drawing on a single suction hole. The third fan and suction hole would be installed if further testing indicated it was needed.

The Lehigh building is a classical design with ornate copper gutters running up the side of the building. The initial design called for using copper downspout that was fabricated to match the ornate copper downspout used on the building. There was however a large compressor about 20 feet from the building. It was decided that the radon piping would be routed below grade to this compressor where the radon fan would be installed at grade and the exhausted routed ten feet in the air. Special brackets were constructed to support the fan and the exhaust.

It is especially critical that the piping for the radon system between the exhaust point and the first suction hole be sloped towards the suction hole for drainage because of the condensation that collects in the pipes from condensing saturated soil gas whenever portions of the pipe are below the soil temperature. This is especially important when routing radon under ground. The piping has to be carefully planned and installed so that it drains back to the first suction hole and does not accumulate in the radon pipe. An inch or two out of level in combination with a high air flow can seriously restrict the final air flow through the system.

The following table defines the minimum slope per foot of run at different airflows as measured by the radon fan manufacturer RadonAway.

Table 2 Minimum slope per foot of run for varying pipe size and CFM

Pipe Diameter	25 cfm	50 cfm	100cfm
4"	1/8"	1/4'"	3/8"
3"	1/4'"	3/8"	

Let's assume an inch of water has accumulated in two different systems. In one system with 4" piping, the water has reduced the piping size to 3" and the airflow is at 60 cfm. The pressure drop increases by a factor of 4. In another system, with 3" piping that is reduce to 2", the airflow of 40 cfm is actually creating almost twice the pressure drop of the 4" piping even though the airflow is 30% less. The numbers in the table below were obtained from ASHRAE's table of friction loss from airflow in round pipes.

Table 3 Pressure drop in 10 feet of pipe at varying airflows and pipe sizes

Pipe size	Airflow	Pressure drop in 10 feet of pipe
4"	60 cfm	0.025"
3"	60 cfm	0.100"
3"	40 cfm	0.05"
2"	40 cfm	0.37"

A coring company was hired to cut 5" wide holes through the 24" stone wall at the Lehigh Building. After spending a whole day with two diamond coring machines and destroying one diamond bit, the coring company was only able to cut one of the holes through the foundation. Testing of the one excavated suction pit with a spare radon fan indicated that a single suction hole was getting flow reversal under the whole floor. The second suction hole was cemented shut and the radon pipe to this suction hole was capped outside building, below grade.

FINAL SYSTEM VACUUM READINGS & RADON LEVELS

After all the sealing at the NJ school was completed and all fans operating, a final measurement of the building to sub-slab differential pressure was made and recorded. These records need to be available to anyone hired to check the system performance. Note that the final readings for both systems are significantly better than the communication testing. See Figure 1, 3, and 4. This is due to the sealing at the NJ school, the installation of large suction pits and the use of high capacity fans and adequate pipe size.

The final radon levels were again measured in the same locations as the initial readings and were all below 1 pCi/L, well below the EPA action level guideline. This information along with the excellent pressure field reversal assures all parties that the radon levels should continue to be well below the guideline. The EPA recommends that mitigated residential housing be tested every two years however for schools that have been remediated they recommend testing every year.

CONCLUSION AND IMPLICATIONS

Designing radon mitigation systems for large commercial buildings or schools requires more extensive considerations than residential buildings. Commercial mitigation system design requires: knowledge of a buildings HVAC operation and foundation components, knowing the limited ability to seal openings especially into block walls or in finished rooms, the ability to make differential pressure measurements and interpret results, and the ability to size fan and piping based on sub-slab communication testing, pressure drop tables and anticipated airflows.

REFERENCES

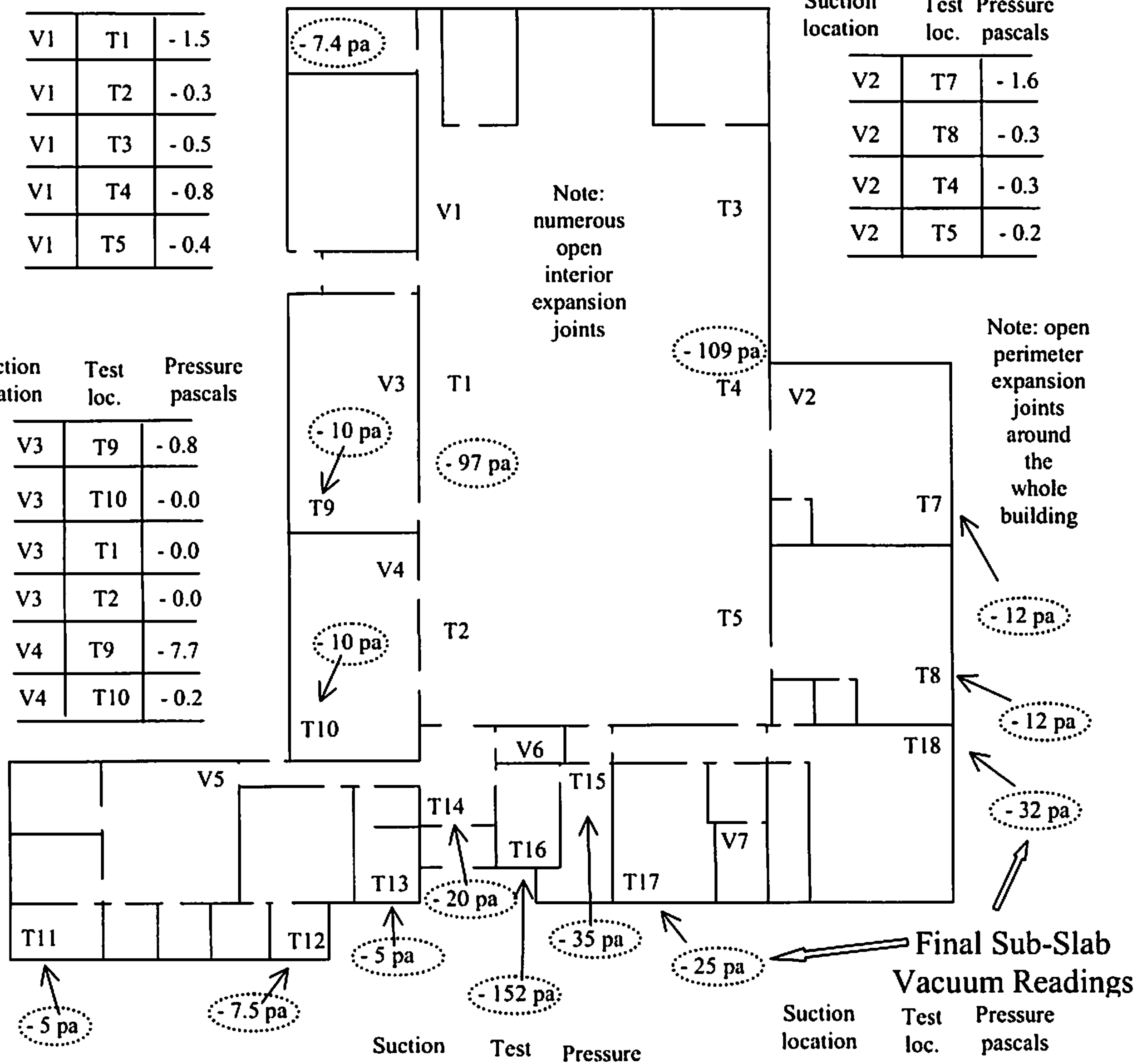
Brodhead B, and Messing M. 1997, Radon Fan Performance, *Proceedings of the 1997 International Radon Symposium*, III-3, Cincinnati, OH USA
Brodhead, B, and Saum D. 1996, Airflow Pressure Drop in Typical Radon Piping, *Proceedings of the 1996 International Radon Symposium*, III-7, Orlando, FL USA

New Jersey School

Initial Communication Tests

Suction location	Test loc.	Pressure pascals
V1	T1	- 1.5
V1	T2	- 0.3
V1	T3	- 0.5
V1	T4	- 0.8
V1	T5	- 0.4

Suction location	Test loc.	Pressure pascals
V2	T7	- 1.6
V2	T8	- 0.3
V2	T4	- 0.3
V2	T5	- 0.2



Note: numerous open interior expansion joints

Note: open perimeter expansion joints around the whole building

Suction location	Test loc.	Pressure pascals
V3	T9	- 0.8
V3	T10	- 0.0
V3	T1	- 0.0
V3	T2	- 0.0
V4	T9	- 7.7
V4	T10	- 0.2

Final Sub-Slab Vacuum Readings

Suction location	Test loc.	Pressure pascals
V5	T11	- 0.1
V5	T12	- 0.4

Suction location	Test loc.	Pressure pascals
V6	T12	0.0
V6	T13	- 1.5
V6	T14	- 11
V6	T15	- 15
V6	T16	- 125
V6	T17	0.0

Suction location	Test loc.	Pressure pascals
V7	T5	- 0.0
V7	T17	- 1.4
V7	T18	- 0.8

Note: Slab settlement at T12

Note: These rooms had sealed expansion joints

Figure 1. **Communication test and final subslab to room pressure**

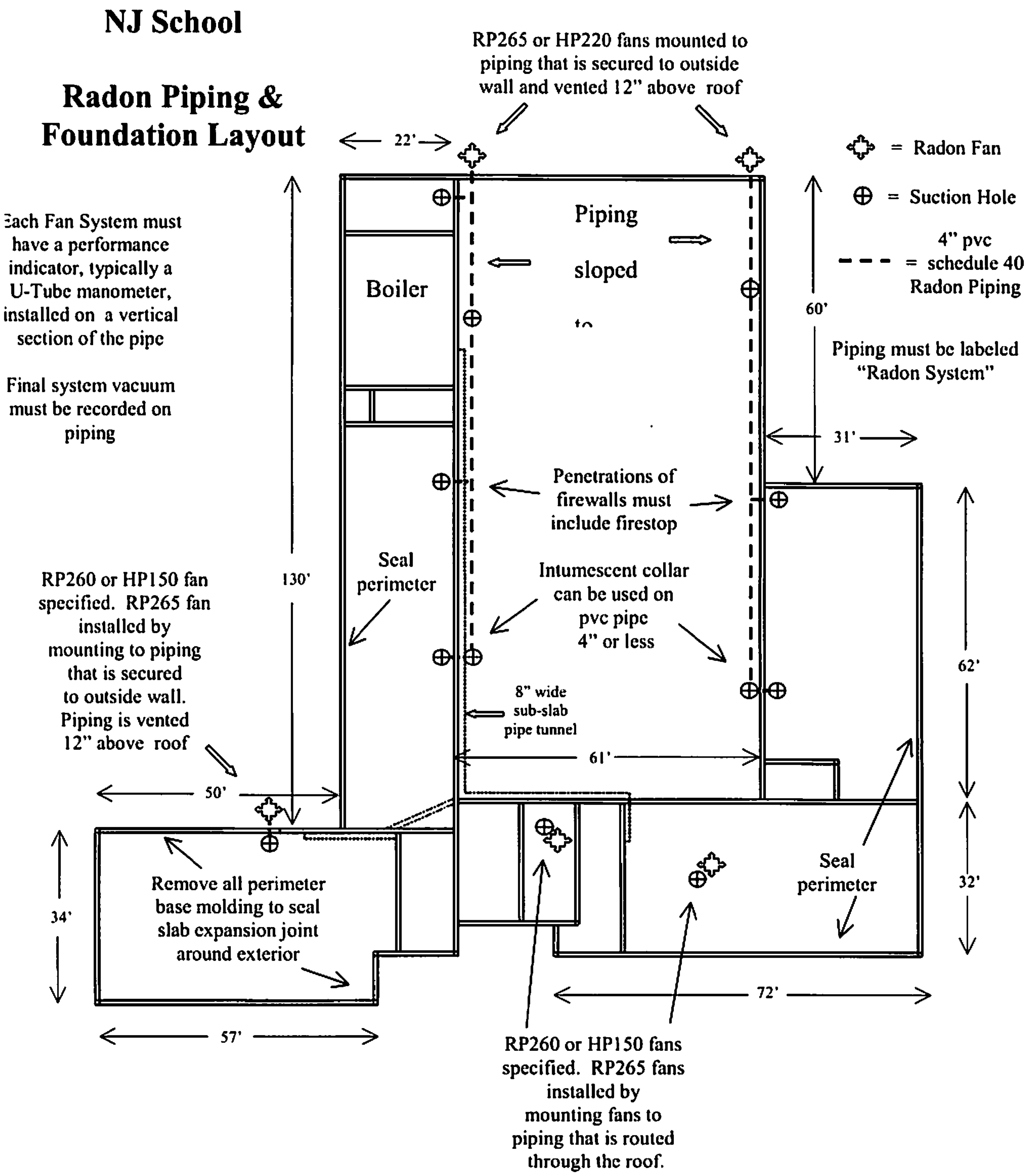
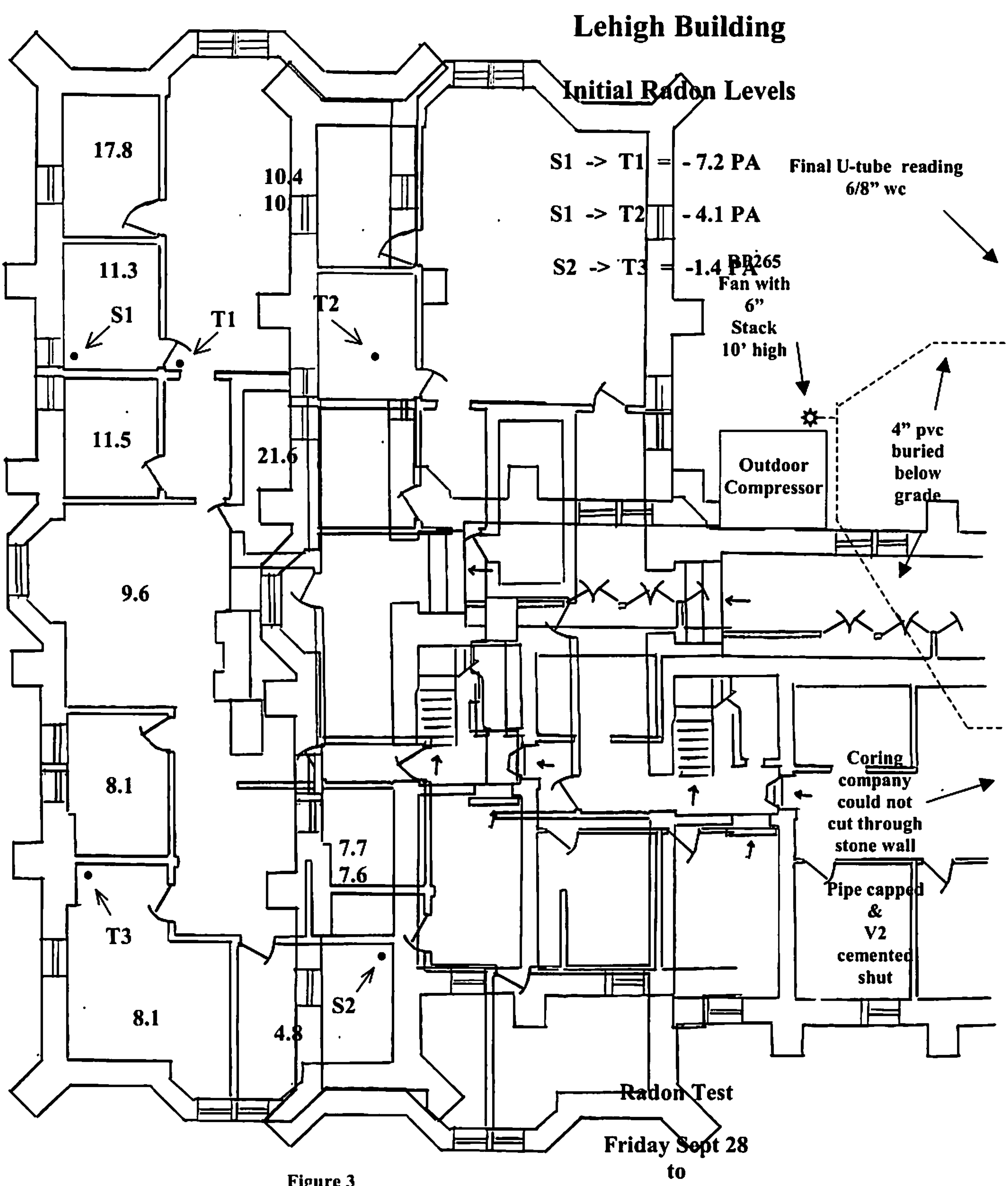


Figure 2. **Foundation plan showing sub-slab divisions and final radon remediation piping and fan locations. Total interior perimeter and visible**



Lehigh Building

Initial Radon Levels

S1 -> T1 = -7.2 PA

S1 -> T2 = -4.1 PA

S2 -> T3 = -1.4 PA

Final U-tube reading 6/8" wc

RP265 Fan with 6" Stack 10' high

4" pvc buried below grade

Coring company could not cut through stone wall

Pipe capped & V2 cemented shut

Radon Test

Friday Sept 28
to
Monday October 1

Figure 3