

# **PROPOSED NEW JERSEY RADON RESISTANT SCHOOL CONSTRUCTION CODE**

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## **ABSTRACT**

Schools being built in Tier One areas of NJ are required to install radon piping using the RRNC code written for residential buildings. New Jersey DEP Radon Division with assistance from EPA Region II and Rutgers Regional Radon Training Center has drafted a new separate radon hazard code for the construction of all new education buildings built in Tier One areas of New Jersey. The revisions came from a one day meeting of code officials, school architects, school construction companies and radon remediation experts. The recommendations from the meeting were included in the new draft radon code to be used in school construction. A significant difference between this new document and previous residential new construction documents is the system sizing requirements depending upon the slab size. Another unique feature is the inclusion of a performance requirement to be completed during the construction of the school.

## **ONE DAY WORKSHOP ON RADON RESISTANT NEW CONSTRUCTION IN SCHOOLS**

New Jersey Department of Community Affairs and the Department of Environmental Resources (NJ DCA & NJ DEP) oversees and enforces a requirement that all residential homes and educational buildings built in Tier One must include radon resistant and radon mitigation ready features. NJ has been divided into three Tiers. Tier One is defined by the NJ DEP as an area with high potential for elevated indoor radon. A one day workshop in August of 2003 was convened by the Eastern Regional Radon Training Center at Rutgers University with guidance from the US Environmental Protection Agency, Region II to discuss creation of a separate new construction code for schools. This workshop was attended by NJ DCA officials, NJ and NY radon department officials, EPA Region II officials, the owner of a NJ school architecture company, a NJ school construction contractor and several radon experts familiar with school construction.

## COMMENTS FROM WORKSHOP ATTENDEES

Each member of the workshop was allowed time to present issues they considered important in regards to radon resistant new construction (RRNC) in schools. The following comments were given.

Philip Anthes, Mass. DOH-Radon Control

- Schools in need of radon remediation must be identified.
- The current New Jersey code is insufficient because it fails to address a wide range of variables.

Peter McGlinchy, NJ School Construction Corporation (SCC)

- School administrators argue with builders about whether to have operable windows because administrators often do not recognize how windows affect mechanical design.
- School maintenance is given low priority in terms of time and money, so passive systems are preferable.
- All recommendations must be cost effective.

Jerry Collins, NYS DOH

- Code enforcement must be addressed.

Mike Clarkin, Camroden Associates

- New Ventilation systems are checked for mechanical operation rather than measuring their effectiveness.
- HVAC system operation is often overseen by the school business manager, who is not sufficiently familiar with radon issues.
- RRNC is often shortchanged in budgetary decisions.
- A school-specific code, rather than a large building code, is needed because schools' needs differ from the needs of hi-rise buildings.

Larainne Koehler, USEPA Region II

- Pressurization may work in large buildings.
- One cannot assume RRNC will remediate radon.
- Steps must be taken to ensure passive systems can be activated easily.

Bill Brodhead, WPB Enterprises

- Architects should be educated about radon. They often assume they can pressurize a building to address radon without realizing the need for a back-up passive system as a safety measure.
- Consensus is needed on how systems should be constructed.
- The term RRNC should stand for Radon-Ready New Construction.

Judy Morgan, NJ DEP-Radon Section

- Radon testing must be completed in New Jersey schools 2005—what are the ramifications?

- Codes must also address mitigation for existing buildings because building additions trigger subcode-mandated alterations.

Anita Kopera, NJ DEP-Radon Section

- Until recently, school mitigation has taken second place to residential remediation, and the time is right to address the issue.
- How many pipes can be interconnected? How many fans are required? The current document offers no guidance on these or other essential issues pertaining to schools.
- NJDEP is developing a program for school mitigation contractors in response to complaints that contractors find it difficult to interpret the code or adapt residential solutions to schools.

Jeanne R. Dunn, Manager of Policy Research & Data, NJ Dept. of Education, Division of Finance

- A need exists to create a school-testing program, but without enforcement capabilities, the testing may be meaningless.
- RRNC guidelines are needed for new construction in all tiers, when radon remediation is cost effective, not just Tier I.

Scott Spiegle, Spiegle Architectural Group

- Without testing minimal pressure gradients, no one knows whether a system is working; therefore, construction vigilance is essential.
- The variability of construction quality dictates a need for testing of the subslab. The installation of fans in new construction will ensure subslab depressurization.
- Some school district facilities managers lack sufficient knowledge of radon systems and can undermine them inadvertently.

John Terry, Dept. of Community Affairs, NJ Div. of Codes and Standards

- Cost containment is one of the DCA's core issues on new code development.
- All new construction can be done by builders and trades people, but only state-certified mitigators can install permanent fans. Anyone can install a test fan. A 1989 letter from NJDEP and DCA covers this issue. Fans can be installed during construction to test the system for pressure field extension (PFE), but the question remains whether the fan should be permanent rather than temporary. The fan creates PFE, and only a certified mitigator knows how to create and judge PFE.
- Design must take into account the need for radon systems to run continuously. They cannot be tied to systems turned off at night or during school breaks.
- The people designing the systems must truly understand what the system is intended to accomplish.
- Should schools install passive systems automatically or do the testing and mitigate later? If it is done automatically, schools will be running fans constantly, which increases operating costs.

## WORKSHOP RECOMMENDATIONS

The workshop attendees reached a consensus on the following recommendations.

- Schools require their own code, separate from a code on other large buildings.
- The code should not state that RRNC will effectively mitigate as a passive system.
- All recommendations should be cost effective.
- Fans: Builders can install fans for testing purposes; only state-certified mitigators may install permanent fans for the purpose of radon mitigation in Tier I construction.
- Aggregate: Spread at a minimum depth of 6”.
- Crushed stone: 10% of the gravel is to be #4; the remaining 90% should be comprised of clean stone, minimum ¾”.
- Slab penetrations: All penetrations must be sealed. This needs to be incorporated into training for design and installation professionals, not just in UCC training materials for code enforcement officials. This is an opportunity to educate the construction public as to definition of “air tight” for radon vs. other uses.
- Crawl spaces: School building crawl spaces must have a minimum 4” concrete slab over aggregate.
- Suction points: The current standard remains in place for areas less than 1,500 sq ft., and requires a minimum 3” pipe with a T-fitting below the slab. For areas up to 15,000 sq. ft., the requirement is one suction point with a 6” (or equivalent) pipe, free of barriers to sub-slab airflow.
- Pressure field extension testing: Use a 4’x’4’x’8” suction pit or another test to demonstrate pressure field extension of 4 pascals at the perimeter of the system no sooner than 30 days after the slab construction is complete. For the test, use a fan capable of moving no more than 325 cfm at 1” of static pressure.
- Exhaust pipes: If you join vent pipes, the area of the output pipe must be equal to the sum of the areas of the input pipes. The height of exhaust pipes will be consistent with UCC Plumbing Codes.
- In Section 14 of the existing code, which refers to electrical junction boxes, remove the term “attic spaces”.

## DRAFT RADON HAZARD SUB-CODE FOR SCHOOLS

The following is a draft of the proposed new radon hazard sub-code written for construction of schools.

Comments about the possible changes to the draft are included as underlined text.

### 5:23 – 10.1 TITLE, SCOPE; INTENT

(This section needs to be updated to reflect its status as a separate school code)

- (a) This part of the regulations, adopted pursuant to the State Uniform Construction Code Act, P.L. 1975, c.217, as amended and as supplemented by P.L., 1989, c.186 (N.J.S.A. 52:27D-119 et seq.), and entitled Radon Hazard Subcode, shall be known, and may be cited throughout the regulations as, N.J.A.C. 5:23-10 and, when referred to in this subchapter, may be cited as “this subchapter”.
  - 1. This subchapter is intended to complement rules adopted by the New Jersey Department of Environmental Protection at N.J.A.C. 7:28-27 which provide for certification of persons who sell radon or radon progeny devices, test for radon or radon progeny, or mitigate radon in buildings.
    - i. Copies of N.J.S.A. 26:2D-70 et seq. And N.J.A.C. 7:28-27 may be obtained from the New Jersey Department of Environmental Protection, PO Box 411, Trenton, NJ 08625-0411.
- (b) This subchapter pertains to the construction of all buildings in Use Groups E, (group E is Educational buildings) as defined in the building subcode, within recognized radon prone areas defined as Tier One by the New Jersey Department of Environmental Protection and shall control matters relating to construction techniques to minimize radon gas and radon progeny entry and facilitate any subsequent remediation that might prove necessary.
- (c) This subchapter seeks to protect and ensure public safety, health and welfare insofar as it is affected by radon entry into schools.
  - 1. It is the purpose of this subchapter to establish standards and procedures to ensure that construction techniques that minimize radon entry and that facilitate any post-construction radon removal that is required shall be incorporated in the construction of all buildings in Use Groups E in Tier One areas and are permitted to be incorporated elsewhere in New Jersey.

2.Radon is a colorless, odorless, tasteless, radioactive gas that occurs naturally in soil gas, underground water, and outdoor air. Prolonged exposure to elevated concentrations of radon and its progeny (that is, substances formed as a result of the radioactive decay of radon) has been associated with increases in the risk of lung cancer. An elevated concentration is defined as being at or above the guideline of 4 pCi/L average annual exposure.

(Note: WL was not included because NJ DEP does not allow WL measurements to define mitigation effectiveness)

3.Inasmuch as it is deemed to be more cost-effective to build schools that resist radon entry than to remedy a radon problem after construction, design and construction techniques shall be employed in Tier One areas to minimize pathways for soil gas to enter and features shall be incorporated during construction in Tier One areas that will facilitate radon removal after completion of the structure, if prevention techniques prove to be inadequate.

4.The installation of radon mitigation systems in existing portions of buildings shall not be subject to the construction technique requirements set forth in N.J.A.C.5:23-10.4

## **5:23-10-2        DEFINITIONS**

The following words, terms and abbreviations, when used in this subchapter, shall have the following meanings unless the context clearly indicates otherwise.

“Crawl Space” - Non-habitable space located below the lowest habitable level that is used to route utility piping or to gain access to another area. This space generally has enough room for a person to crawl in although it could have enough height to walk in. Shallow utility trenches used only for routing piping below a slab are not considered crawl spaces.

“Foundation pipe drain” - A perforated pipe placed around the perimeter of a foundation. An “interior foundation pipe drain” is one placed around the internal perimeter of a foundation. An “exterior foundation pipe drain” is one placed around the external perimeter of a foundation.

“French drain” or “channel drain” - A path used to assist with water drainage which is installed in basements of some structures during initial construction, which consists of a gap (typically one-half to one and one-half inch in width) between the basement foundation wall and the concrete floor slab around the entire inside perimeter of the basement.

“Gravel bed” - A minimum six inch course of gravel or crushed stone that is placed under each

concrete slab that has habitable space either directly above the slab or has habitable space above a crawl space. The area of a gravel bed will be measured by the square footage area that is un-interrupted by blockages to the movement of airflow through the gravel bed. Gravel beds separate by a barrier can be considered one gravel bed if the adjoining gravel beds have 140 square inches of effective opening between the beds for gravel beds up to 15,000 square feet or 60 square inches of effective opening for gravel beds up to 4000 square feet and 20 square inches for gravel beds up to 1500 square feet. The effective opening is the square inch of adjoining area times the percentage of gravel or crushed stone void area. The words gravel, aggregate and crushed stone shall be used interchangeably throughout the document.

The word effective area versus actual area may be too confusing. Need to define “effective area” in definition section. Or it might be preferable to change to actual area and define “actual area” as the cross sectional area of the opening between gravel beds or between a gravel bed and a collection box or collection piping.

“Habitable” - Area that is occupied or could be occupied.

“PicoCurie per liter (pCi/L)” - pCi/L is equal to 2.2 disintegrations per minute of radioactive material per liter. It may be used as a measure of the concentration of radon gas in air. One picocurie is equivalent to  $10^{-12}$  Curies.

“Radon” - The radioactive noble gas radon-222.

“Radon progeny” - The short-lived radionuclides formed as a result of the decay of radon-222, including polonium-218, lead-214, bismuth-214 and polonium-214.

“Sump” - A pit installed through a floor slab that is designed to collect water and is wide enough and deep enough to contain a sump pump.

“Sump pump” - A pump used to move collected water out of the sump to an above grade discharge remote from the structure.

“Radon Vent Piping” - Gas tight, water resistant fittings and piping used to vent radon from the soil to above the roof. Radon Vent piping shall be at least schedule 40 solid or foam core PVC piping. Leak proof, water resistant metal piping can be substituted as required to comply with code requirements. Minimum pipe size is three inch diameter or as specified.

### **5:2310.3 ENFORCEMENT**

- (a) The provisions of this subchapter shall be enforced by the enforcing agencies having responsibility for the enforcement of this chapter.

- (b) Enforcement responsibility shall be divided among subcode officials in the following manner:

(Updated the following references as necessary)

1. For new structures and additions:
  - i. Except as otherwise indicated in (b) 1ii below, plan review and inspection with regard to compliance with N.J.A.C. 5:23-10.4(b) shall be the responsibility of the building subcode official;
  - ii. Plan review and inspection with regard to work performed under N.J.A.C. 5:23-10.4(b) that is otherwise subject to the plumbing, electrical or fire protection subcode shall be the responsibility of the plumbing, electrical or fire protection subcode official, respectively.
2. For existing structures:
  - i. Construction enforcement responsibility for verification that radon mitigation work in all school structures is in conformance with the adopted subcodes shall be as set forth in N.J.A.C. 5:23-3.4(a), (c), (d) and (f).

#### **5:23-10.4 CONSTRUCTION TECHNIQUES**

- (a) Tier One radon hazard areas shall be identified in accordance with the county/municipal radon listing established by the Department of Environmental Protection. The current list of municipalities in Tier One areas is set forth in Appendix 10-A of this subcode.
- (b) The construction techniques set forth in this subsection shall be the minimum radon hazard protective features required to be incorporated into construction of buildings in use Groups E in Tier One areas, and may be incorporated in other tier areas, in order to minimize radon and radon progeny entry and facilitate any post-construction radon removal that may be required. Enumeration of these construction techniques is not intended to preclude voluntary use of additional or more extensive techniques. Full compliance with these construction techniques is required for school additions.
1. A continuous vapor barrier not less than six-mil (.006 inch; 152 mm) polyvinyl chloride or polyethylene with any seams overlapped not less than 12 inches (305 mm), or other approved materials, shall be installed under the concrete slab of basement, slab-on-grade and crawl space



construction. Crawl spaces will have a minimum 4 inch concrete slab installed over the vapor barrier.

In areas of highly permeable soil it may be necessary to install an air barrier under the gravel bed in order to obtain adequate pressure field extension.

2. Concrete floors of basements, slab-on-grade and crawl space construction shall be placed over a gravel bed. The gravel bed shall be no less than six inches (152 mm) in thickness, consisting of gravel or crushed stone no smaller grade size than AASHTO #57. (90-100 percent passing through 1" sieve, 25-60 percent passing through 1/2" sieve and 0-10 percent passing through a No. 4 sieve.) A minimum of 2" of gravel or crushed stone shall be placed above or below any utility piping installed in the gravel bed. Gravel bed is defined in N.J.A.C. 5:23-10-2.

(Note: AASHTO #57 is commonly available at most quarries throughout the state)

3. Radon vent piping shall be a minimum three-inch inside diameter for gravel bed areas less than 1,500 square feet, at least four-inch inside diameter for gravel bed areas between 1,500 and 4,000 square feet and at least six inches inside diameter for gravel bed areas between 4000 and 15,000 square feet. Radon vent piping shall be routed from a radon collection box or collection fitting to an approved location on the exterior of the building as specified in N.J.A.C. 5:23-10-4 (b-4, b-12). Multiple gravel beds can be vented into a single radon vent exhaust pipe that is sized according to the total gravel bed area it is venting. Radon vent piping and gravel bed areas are defined in N.J.A.C. 5:23-10-2.

Alternative gravel bed areas, pipe sizes or collection plenums can be used if the sub-slab negative pressure defined in N.J.A.C. 5:23-10-4 b14 is achieved.

4. The collection fitting for gravel bed areas less than 1,500 square feet shall, as a minimum, be a three-inch "T" fitting placed so that the horizontal openings of the "T" fitting are in the sub-slab aggregate.

A three-inch Tee embedded in gravel significantly reduces maximum possible airflow. See Table 3 in the final section. A far less restricting four-inch Tee could easily be substitute.

The collection box for gravel bed areas between 1,500 and 4,000 square feet shall be a plenum in the sub-slab gravel that is constructed by turning at least six open core 16 inch by 16 inch by 8 inch cement blocks on their

side in a square so as to create an open plenum that is at least 16 inches by 16 inches by 8 inches high. A 4-inch minimum size radon vent pipe will be routed from inside this plenum to an approved exhaust location.

Define “open core” in the definitions section using the ASTM definition of “Hollow Core Block” having greater than 25% cross sectional void area.

The collection box for gravel bed areas between 4,000 and 15,000 square feet shall be a plenum in the sub-slab gravel that is constructed by turning at least 10 open core 16 inch by 16 inch by 8 inch cement blocks on their side in a square so as to create an open plenum that is at least 32 inches by 32 inches by 8 inches high. A 6-inch minimum size radon vent pipe will be routed from inside this plenum to an approved exhaust location.

The open top of all plenums shall be covered with appropriate metal decking or pressure treated plywood to support the concrete slab. Each collection box will be located towards the center of the gravel bed area.

If the length of a gravel bed is more than 10 times the width of the gravel bed, then a perforated pipe will be embedded in the gravel bed down the long length. The perforated pipe will be at least as large as the radon venting pipe.

The final portion of this paper presents reasoning for the above sizing requirements

5. Basement slabs with French drains or channel drains shall not be allowed.
6. Joints in foundation walls and concrete slabs, including, without limitation, control joints between slab sections poured separately, and between the foundation wall and the slab, as well as openings through or penetrations of the foundation walls and slab including, but not limited to, utility penetrations, shall be substantially sealed by utilizing a non-cracking polyurethane caulk, or equivalent, in order to close off the soil gas entry routes.
7. Untrapped floor drains shall be provided with removable stoppers which shall substantially close off the soil gas entry routes.
8. A sump cover which substantially closes off the soil gas entry routes shall be provided for all sump installations.
9. Any ductwork that is routed through a crawl space or beneath a slab shall be properly taped or sealed.

10. Openings or penetrations of the floor over any crawl space shall be substantially sealed in order to close off the soil gas entry routes. Any entrance to crawl spaces below habitable areas from a basement or floor above the crawl space shall include an air tight door. Other openings between a crawl space and basement shall be substantially sealed.

Note: Is it necessary to have the crawl space isolated from a basement area with an access door?)

11. The tops of foundation walls, including, without limitation, interior ledges, that are constructed of hollow masonry units shall be capped or the voids shall be completely filled. Any masonry walls that are exposed to the gravel bed shall be solidly filled at the concrete slab elevation(s).
12. The radon vent piping shall be adequately supported at least every 6 feet of horizontal run and 8 feet of vertical run. The pipe shall be routed in a manner that makes it accessible for the installation of a future in-line vent pipe fan above a flat roof or in a non-conditioned (not heated or cooled) space that has no habitable space above it. The radon vent piping shall be installed in a configuration, and supported in a manner, that will ensure that rain water or condensate accumulation within the pipes will drain downward into the ground beneath the slab or vapor barrier. The radon vent piping shall meet the following termination requirements:

- i. Radon vent piping shall terminate at least 12 inches above a sloped roof or flat roof, measured from the highest point where the vent intersects the roof. Exception: Buildings more than three stories in height shall be allowed to extend vent pipe terminals through a wall provided that the termination is at least 20 feet above grade, and provided there are no openings into the building in any direction within 10 feet, and provided the outlet is effectively screened.

(Note: There is no need to protect workers from occasional exposure to radon exhaust on a flat roof therefore there needs to be no height restriction other than 12 inches above the roof)

- ii. No radon vent terminal shall be located directly beneath any door, window, or other ventilating opening of the building or of an adjacent building nor shall any such vent terminal be within 10 feet horizontally of such an opening unless it is at least 2 feet above the top of such opening. Radon vent terminals shall not be located within 20 feet of a building outdoor air intake grill.

(All the distance requirements may need further discussion)

- iii. No radon vent terminal shall be closer than 10 feet horizontally from any lot line. Where this 10 foot horizontal distance is not possible due to lot width, the vent terminal shall be placed as remote from the lot line as practical.
13. Radon vent piping shall be identifiable and clearly labeled at intervals of not more than 10 feet in concealed locations, not more than 20 feet in exposed locations and not less than once in any room or space.
  14. A fan shall be temporarily installed on or in the radon vent piping no sooner than 30 days after completion of the concrete slab. The fan shall be rated at no more than 400 cfm at one inch of static pressure for all six-inch piping or a maximum of 210 cfm at one inch of static pressure for four-inch piping or 110 cfm at one inch of static pressure for three-inch piping. A 3/8-inch test hole will be drilled through the slab at opposite ends of each gravel bed area that the activated fan is connected to. A digital differential pressure gauge will be used to measure the pressure difference between the test hole and the room.

(Note: airflows were chosen based on common radon fan sizes)

Each test hole shall have a negative condition induced by the fan that is at least 4.0 pascals or 0.016 inches of water column in strength. Only NJ certified mitigation specialist's who are listed with the state as certified to do school mitigation can do the sub-slab pressure test. If this sub-slab negative pressure is not induced, additional sealing or radon vent piping shall be installed and additional pressure readings made to ensure the previously defined pressure is achieved.

Four (4.0) pascals may be too stringent of a standard. The EPA document "Radon Prevention in the Design and Construction of Schools and Other Large Buildings" recommends a sub-slab pressure of 0.01 inches of static water pressure or 2.5 pascals.

15. In order to reduce stack effect, air passages that penetrate the upper portion of the conditioned envelope of the building, such as electrical or plumbing pipes, attic access openings, or other openings installed in top-floor ceilings, shall be closed, gasketed or otherwise sealed with materials approved for such applications.

## Illustration of a Radon Sub-Slab Collection Plenum Box

Gravel beds from 4000 to 15,000

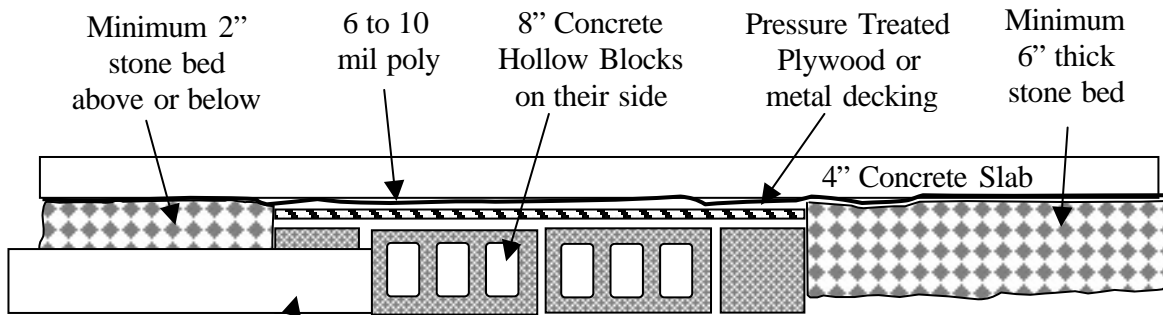


Figure 1

6" solid schedule 40 pvc pipe routed from collection box to the roof

Chip out block to allow 6" PVC pipe to pass into the plenum

375 si of actual opening versus 28 si for 6" pipe

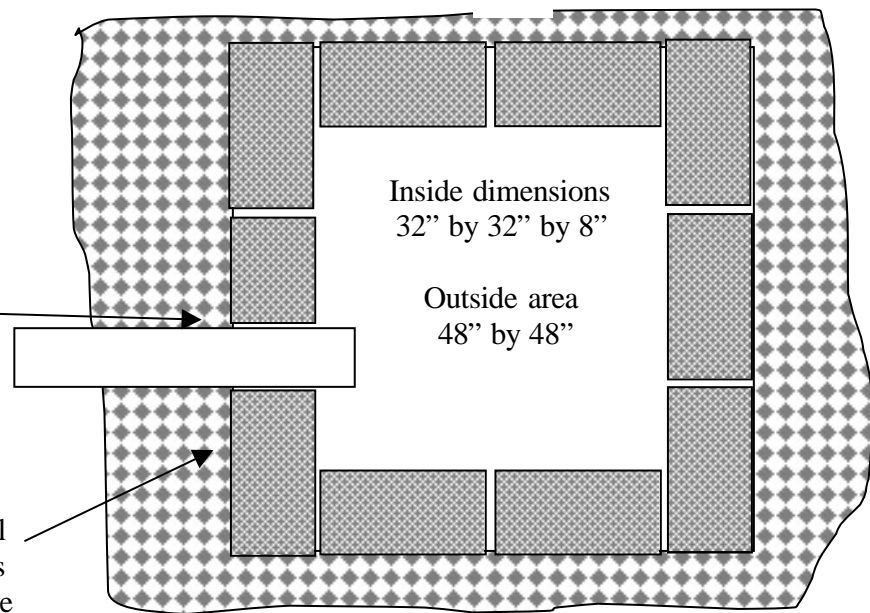


Figure 2

Gravel beds under 4000 sf

4" solid schedule 40 pvc pipe routed from RnCB to the roof

175 si of effective opening versus 12 si for 4" pipe

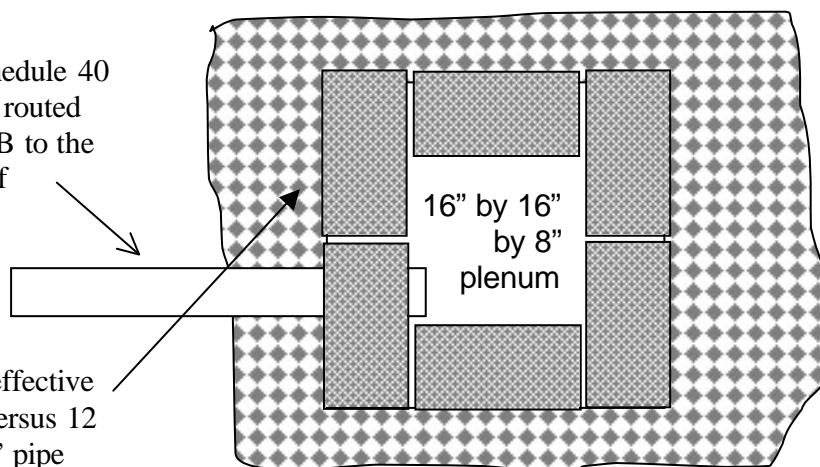


Figure 3

## DISCUSSION OF THE CODE CHANGES

### GRAVEL BED SIZE VERSUS PIPE SIZE

The present New Jersey RRNC code was written for residential buildings. In the present code 3" PVC is the minimum size for gravel beds up to 1500 square feet with only a 3" Tee in the gravel bed. When this recommendation is used on larger gravel bed installations it requires multiple vent stacks. An alternative to the Tee is to substitute four inch perforated PVC piping laid in the gravel bed around the entire perimeter. Perforated piping, however, is not easily installed in commercial and school sub-slab gravel beds because of the extensive amount of utility piping installed in the gravel bed of new schools or additions to schools. It is more practical to use as few vent stacks as possible.

There are four primary factors to take into consideration when sizing piping and collection boxes for larger gravel beds

1. Porosity of the soil under the gravel bed
2. Leakage into the gravel bed through the slab and foundation
3. Barriers in the gravel bed
4. Type of gravel in the bed.

Pipe diameter influences maximum airflow more than the size of the fan. The author measured the airflow through 60 feet of three different pipe sizes using radon fans commonly used with each pipe size. The results are displayed in Table 1 below. Notice that the airflow in Table 1 more than doubles for both 3" to 4" and 4" to 6".

Pipe Size	area	Typical fan	Airflow in 60' of piping
3"	7.1 si	55 watt	80 cfm
4"	12.6 si	120 watt	180 cfm
6"	28.3 si	190 watt	375 cfm

Table 1 - Typical maximum airflow with different pipe sizes

In sizing gravel beds, the total perimeter edge is more important than the total square foot area because most leakage through the slab happens at the perimeter edge. The total perimeter edge of a gravel bed however does not increase linear to its area increase. The bed size from 4000 sf to 15000 sf is almost 4 times larger but its perimeter edge increases less than double. The gravel bed sizes were determined by increasing their total perimeter size in a similar ratio to the amount of increased airflow from the next larger pipe. See Table 2 below.

Gravel Bed area	dimensions	Perimeter	Possible Air flow
1500 sf	40' x 38'	156'	80
4000 sf	60' x 68'	256'	180
15000 sf	120' x 125'	490'	375

Table 2 - Gravel bed size versus total perimeter length versus possible airflow.

A primary factor to consider with larger airflow systems is the restriction caused by the airflow through the gravel bed. This restriction is directly related to the velocity of the air moving through the gravel. The greatest velocity happens at the piping to gravel bed connection. The velocity decreases significantly as the distance to the collection area increases. Increasing the piping to gravel bed connection area can significantly improve system performance.

### COLLECTION BOX DESIGN

In the EPA document “Radon Prevention in the Design and Construction of Schools and Other Large Buildings” (EPA/625/R-92/016), a collection box below the slab is recommended. The collection box is fabricated on site by making a rectangle in the gravel bed with hollow concrete blocks turned on their side so that air can easily move from inside the collection box to the gravel bed. No gravel is placed inside the collection box. The collection box is located in the center portion of the gravel bed area. The top of the collection box is covered with pressure treated plywood or metal decking. The top of the collection box is flush with the top of the gravel bed. Extra reinforcing can be used in the concrete above the collection box. A solid PVC pipe, the same size as the riser, is routed from the collection box to the riser location in the building and then up to the roof. See Figure 1, Figure 2 and Figure 3 above.

There are a number of good reasons to consider using a collection box rather than perforated piping in the gravel bed. Perforated piping is often difficult to install in commercial and school sub-slab gravel beds because of all the conduit and utilities being installed in the same space. The collection box can be located in the center of the slab so that leakage around the perimeter has less influence on overall pressure field extension. A solid pipe can be routed from the collection box to a location where a riser can be routed up to the roof line.



Photo 1 – Hollow Concrete Block

The EPA document, listed above, recommends an exposed aggregate surface area in the collection box equal to 30 times the pipe size area. This was based on treating slabs that were as large as 100,000 square feet. In the initial EPA design the gravel outside the collection box was allowed to fall into the collection box. This draft code recommends that the box be lined with 8” by 8” by 16” hollow concrete blocks to avoid settling of the gravel bed around the box. See Figure 1, 2, and 3 above. ASTM specifications define hollow concrete blocks as having greater than 25% of their gross cross sectional area open. ASTM defines solid concrete blocks as having less than 25% of the cross sectional area open. The hollow

concrete block in Photo 1 has 50 si of cross sectional opening which is 42% of the total cross

sectional area. If the gravel bed aggregate has 50% void area then the actual void space will be 6 to 7 times larger than the pipe size. See Table 3 below.

Possible airflow	Pipe Size	Piping FPM	Connection to Gravel	Actual opening to gravel	Effective opening	Connection FPM
80	3"	1600	3" Tee	7.1 si	3.5 si	3200
180	4"	2000	16" x 16"	175 si	88 si	286
375	6"	1900	32" x 32"	375 si	188 si	286

Table 3 - FPM airflow in piping versus collection boxes

It is critical to reduce the FPM flow at the connection between the gravel and the collection box. The same feet per minute airflow is more restricting the smaller the space the air is moving through. The proposed collection boxes are obviously less restricting than the present system of using a 3" Tee for every 1500 sf of slab area.

### USE OF 3" TEE FOR GRAVEL BEDS UNDER 1500

Since the draft code was written, the author tested the airflow restriction of a 3" Tee in a gravel bed. The test was done by installing nine feet of 3" PVC piping above an RP145 (50 watt) radon fan and a 4" flow grid below the fan to measure the airflow. Below the flow grid, a 3" Tee and then a 4" Tee were installed. The airflow difference between using a 3" Tee versus a 4" Tee was measured. In each case the airflow was measured with the Tee fitting open to the air and then with the tee embedded in 3/4 crushed stone (#57). The results are listed in table 4 below.

Fitting	Actual si area	Open Tee	Tee embedded In gravel	Restriction
3" Tee	14.1 si	107 cfm	57 cfm	47%
4" Tee	25.1 si	119 cfm	96 cfm	20%

Table 4 – Loss of airflow from 3" versus 6" Tee with 10 feet of 3" pipe

Using a 4" Tee in a gravel bed instead of a 3" Tee increases the airflow potential by 68%, from 57 cfm to 96 cfm. This increase takes place even though the remaining portions of the system are 3" PVC.

### CONNECTING ADJOINING GRAVEL BED AREAS

If the sub-slab gravel bed is divided with foundation walls or other barriers to sub-slab communication then a connection opening between the gravel beds needs to be installed. The "gravel bed" definition in section 5:23-10-2 defines the required opening as



“Gravel beds separate by a barrier can be considered one gravel bed if the adjoining gravel beds have 140 square inches of effective opening between the beds for gravel beds up to 15,000 square feet or 60 square inches of effective opening for gravel beds up to 4000 square feet and 20 square inches for gravel beds up to 1500 square feet. The effective opening is the square inch of adjoining area times the percentage of gravel or crushed stone void area.”

Table 5 below defines the number and size of the pipes or the alternative of turning a hollow concrete block on it’s side to obtain the area listed in the “gravel bed” definition between an adjoining gravel bed and the gravel bed the collection box is located in. The actual and effective opening created by the connecting pipes or hollow concrete blocks is compared to the collection box effective opening.

Adjoining Gravel Bed	Minimum connection	Actual opening to gravel	Effective opening	Collection Box opening
Less than 1500 sf	3 - 4” pipes or 1 blk	38 si	19 si	3.5 si
1500 to 4000 sf	10 – 4” pipes or 3 bks	126 si	63 si	88 si
4000 to 15,000 sf	10 - 6” pipes or 6 blks	282 si	141 si	188 si

Table 5 – Adjoining gravel bed connection requirements versus collection box opening

### SUB-SLAB AGGREGATE SIZE

EPA recommended ASTM/AASHTO #5 aggregate. This size is difficult to work with and not readily available in NJ. AASHTO #57 is readily available in NJ. The next size is AASHTO #67 but this size has less void area and is less common.

AASHTO defines aggregate as follows.

Total percent passing through the following sizes

Gravel size	1 1/2”	1”	3/4”	1/2”	3/8”	#4	#8
#5	100%	90-100%	20-55%	0-10%	0-5%	-	-
#57	100%	95-100%	-	25-60%	-	0-10%	0-5%
#67	-	100%	90-100%	-	20-55%	0-10%	0-5%

Table 6 – AASHTO aggregate sizing

### PERFORMANCE TESTING DURING CONSTRUCTION

The draft code has a performance component in order to ensure that the radon collection system will work. The Construction Contractor must test the collection system by installing a common radon fan onto the radon system piping and have a licensed radon mitigation contractor measure

the negative pressure induced under the slab at the farthest corners from the collection area. See section 5:23-10.4 b-12. The proposed standard of 4 pascals was based upon common negative pressures measured inside school buildings. The fan size used to make this test measurement is defined in the code depending upon the gravel bed size. The fan size was determined by using the performance of radon fans that would be typically used for the piping size defined for each gravel bed area. This sub-slab pressure requirement may be too stringent a requirement. The EPA document "Radon Prevention in the Design and Construction of Schools and Other Large Buildings" recommended a final sub-slab pressure reading of at least 0.010 inches of static water pressure or 2.5 pascals.

## **CONCLUSION**

A separate code is definitely needed for RRNC in new schools and additions to schools. EPA has shown in research projects that it is possible to obtain negative pressure under very large slabs from a single collection area. This approach is simple in its design and also the least expensive to install. Although it is a straight forward design there will always be the problem of openings left in the slab, barriers placed in the gravel bed, improper gravel used, blockages in the piping, etc. The performance code will allow the contractor to rectify problems with the RRNC performance before the building is finished. Requiring a performance standard will ultimately minimize these problems as contractors and state code officials become familiar with all the code requirements.