Soil Gas Collection for Radon Control Systems in New Building Construction

COLORADO
Hazardous Materials & Waste Management Division
Department of Public Health & Environment

Technical Document-09-21-1

September 2021

Introduction

Several standards, guidance documents and building codes address the control of radon laden soil gas by installing a means by which soil gases can be routed from beneath a structure to the atmosphere. By doing so, indoor radon exposures can be dramatically reduced.

One of the key elements of such a radon control system is the means by which soil gases are collected within the fill beneath a concrete slab. This element is referred to as the Soil Gas Collector (SGC). Its purpose is to facilitate the capture of radon laden air within the soil when a vacuum is applied to the Soil Gas Collector that is greater in strength than vacuums that can exist inside the building. By virtue of this negative differential pressure under the foundation, radon entry is retarded.

The applied vacuum can be created by routing a vent pipe from the SGC beneath a slab up through the interior of the building and exiting above the roof. By having the vent pipe inside the building, a slight negative pressure is exerted on the sub-grade due to a chimney effect. This is referred to as a Passive Radon System.

If post-construction testing reveals indoor radon levels above the EPA action level of 4 pCi/L, the vacuum imparted to the sub-grade can be augmented by a continuously operating mechanical fan. This is referred to as an Active Radon System.

Although studies in Larimer and El Paso County have shown reductions in indoor radon levels with Passive Systems, their sole use as a means of reducing radon to less than the EPA Action Level of 4.0 pCi/L is not assured. What is assured, however, is the ability of Active Radon Systems to reduce radon levels, when properly designed and installed, to well below the 4.0 pCi/L Action Level and approaching outdoor exposures. Consequently, the prime focus of a proper radon system design is how well it will perform when the system is activated with a fan.

Many of the key aspects of radon systems, including field inspections are covered in other Colorado Department of Public Health and Environment (CDPHE) Technical Bulletins (see related Technical Bulletins listed in the Reference Section).

Passive vs Active System Effectiveness

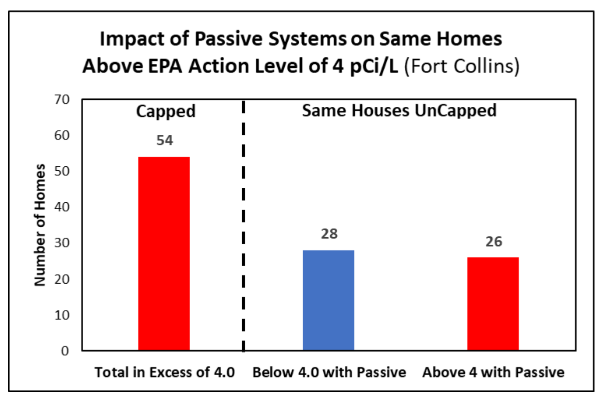
Studies were conducted in Fort Collins, CO in 65 homes constructed utilizing Appendix F of the 2003 IRC as adopted by the City of Fort Collins in 2005. These were passive systems with a length or loop of perforated pipe in a 4-inch-thick gravel layer under the slab serving as the SGC. A radon vent pipe was routed from the SGC up to and through the roof as prescribed by Appendix F.

Two sets of short-term, radon measurements were made in the homes following final construction; one with the vent systems disabled to measure what the radon would have been without a system and a second with the passive system enabled.


Passive system disabled


Passive system enabled

Overall, the passive systems reduced radon levels by 49%. However, as the criterion of acceptance is to be less than 4.0 pCi/L, of the 65 homes studied, 54 demonstrated radon levels in excess of 4.0 with the system disabled, and of those 54, only 28 (52%) had their levels reduced to less than 4.0 when the passive system was enabled.



As pointed out in this study and observed in a similar study in El Paso County, CO, all the houses would be reduced to less than 4.0 pCi/L with the addition of a radon fan.

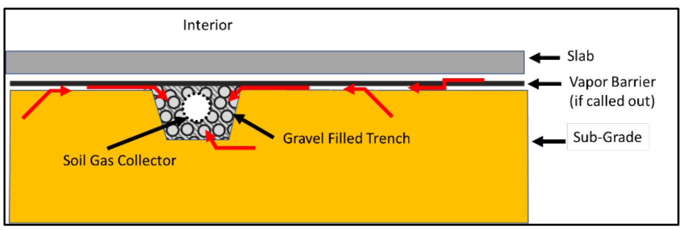
The relevance of this study and Colorado experience is that, in the end, the system must be properly designed and installed as an active system.

Evolution of New Home Construction Practices in Colorado

In the late 1980s it was discovered that existing homes in Colorado could be successfully mitigated for radon by drawing a vacuum on exterior perimeter drains. Although outside the foundation, the systems could create a sufficient negative pressure to counteract vacuums occurring inside the homes.

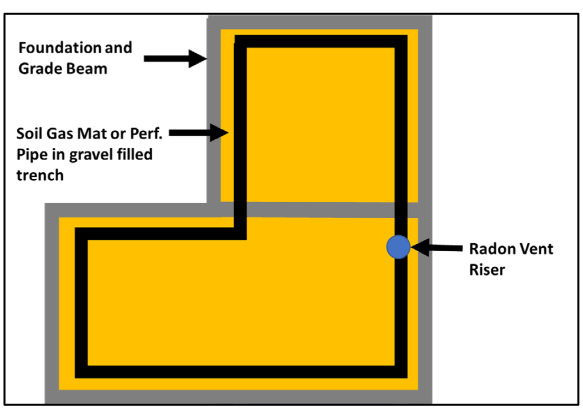
This experience led to the installation of an interior loop of 4-inch diameter perforated pipe to the inside of newly constructed foundations to act as the radon Soil Gas Collector independently from the exterior drain. It also eliminated unsightly routing of exterior piping by routing the vent pipe up through the house and roof.

In turn, this led to using an interior drainage collection system to also function as the soil gas collector. As was the practice, no additional gravel was brought in other than that which was required for water collection. The layout of the soil gas collector was also such that it passed beneath all portions of slab exposed to the interior. In other words, it passed through intermediate foundations and grade beams to allow treatment of 100% of occupied areas.



The next iteration was to provide a flat mat with the same cross-sectional area as the 4-inch perforated pipe to ensure the same air flow characteristics for soil gas collection. This resulted in the development of 1-inch tall by 12-inch-wide soil gas mat.

Since the mid-1990s when the soil gas mat was developed, builders had the option of either digging in a trench, nominally 12 inches from the foundation, and laying in a perforated pipe and filling the trench with gravel or laying the flat mat on the compacted subgrade. In either case, it was determined the soil gas collector had to communicate with the air space directly beneath the slab or optional vapor barrier. This allowed the vacuum to be applied to the small interstitial air space directly beneath the concrete slab.



Effectiveness of Non-Gravel Systems in Reducing Radon

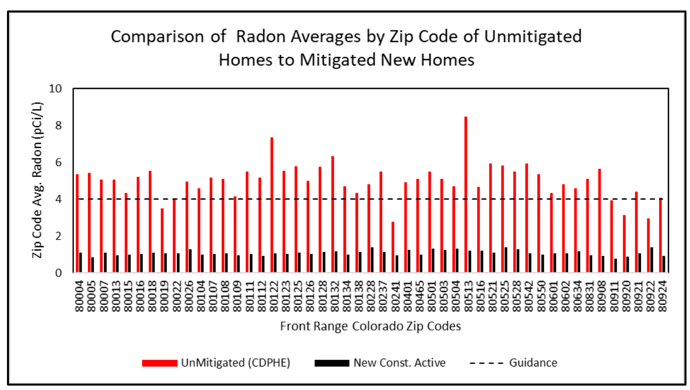
Since 2010 a national home builder has been constructing homes with active radon systems along the Front Range of Colorado. As of the date of this Technical Bulletin they have constructed over 12,425 homes having basement or slab-on-grade foundations utilizing the interior trench method described in the previous section. Furthermore, they have had all of these homes inspected for proper installations as well as having third party radon testing performed on all homes prior to or at closing.

Of these 12,425 homes 100% had radon levels less than 4.0 pCi/L after non-compliance issues identified during inspections were corrected (See Technical Bulletin 06-20-1 Inspecting Radon Systems in New Construction).

To determine how effective the radon reductions were in the homes constructed with this method, a comparison of post-construction radon measurements was made to CDPHE radon survey data on a zip code by zip code basis. Note that CDPHE data included only existing homes and homes that did not have mitigation systems. This allowed the CDPHE data to represent radon potential for a given zip code if a home within it had not been constructed with the radon control systems for comparison to radon levels in the new homes constructed with radon systems. To increase confidence only zip codes having 10 or more radon measurements were considered.

Minimum number of homes per zip code	10
Zip codes that matched both data sets	50
Unmitigated homes in common zip codes	137,700
New homes with systems in common zip codes	11,909

The zip code by zip code comparison of all 50 Colorado zip codes, common to both data sets, is provided below. As can be seen, the average radon levels of new homes having the radon systems were markedly lower than averages of unmitigated existing homes within the same Zip Code.

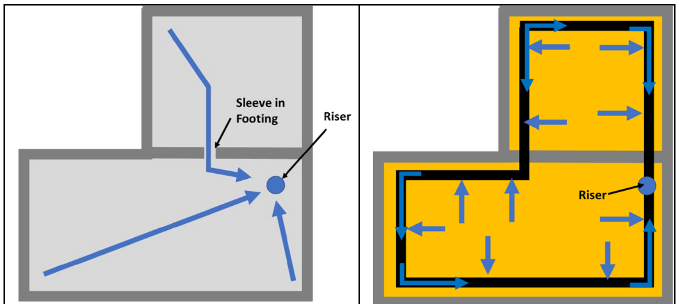


Per CDPHE data, the average radon level for the unmitigated homes was 5.04 pCi/L and the mitigated homes using the loop method without gravel throughout was 1.04 pCi/L, which after subtracting ambient levels (0.4 pCi/L), indicates an 86% reduction in indoor radon with the systems as installed. It is also noteworthy that none of the mitigated homes had levels above 4.0 pCi/L.

Without Gravel-How Does Radon Get to the Soil Gas Collector?

In the early 1990s when the initial recommendations were developed by US EPA for radon resistant construction features, it was suggested a 4-inch layer of ¾ inch rock spread completely under the slab would aid soil gas collection. There is no doubt this would indeed facilitate soil gas collection, especially if one assumed there would be a single point of air extraction such as a "TEE" fitting as called out in Appendix F of the International Residential Code (IRC).

However, a loop of either perforated pipe or drain mat laid around the perimeter of the foundation greatly reduces the distance that soil air from the interior soil must travel before it gets to the Soil Gas Collector (SGC). Assuming the perforated pipe or the soil gas mat has adequate cross-sectional area (nominal 12 square inches) once the soil gases reach the SGC it can easily pass to the collection riser. See illustration below.



Gravel Throughout Single Point Riser	Soil Gas Mat or Per Pipe in Gravel Trench around Perimeter

As a further validation, eight model homes along the Front Range of Colorado were investigated. In addition to having active systems with pipe loop and trench method, as described earlier, extra efforts were taken to seal a 10-mil vapor barrier at seams, penetrations and to foundation walls. The slab was cast upon the vapor barrier and the concrete floor-to-wall joints, control joints and penetrations were sealed with polyurethane caulk. After the model homes had been completed for a year, some deep stress cracks were visible which would have passed from the surface down to the 10-mil vapor barrier.

With the radon system on, in all cases chemical smoke was drawn <u>down</u> into the sub-grade through the larger cracks. This suggests that even though there was a 10-mil membrane and no gravel under the slab, there was a small space below the slab through which air could be drawn to reach the soil gas collector. This occurred even at locations away from the soil gas collector.

This interstitial air space may be due to wrinkles and leaks in the poly or more likely due to the small amount of contraction that occurs when the concrete cures. In either case, a gap existed that was sufficient in size to convey air to the soil gas collector.

It should be noted this "smoke" study was part of a larger investigation and is the basis of Technical Bulletin 06-20-1 regarding the value of sealing the concrete slab over installing an exhaustively sealed vapor barrier.

Effect of Gravel vs No Gravel on Air Flow

Another consideration in the design of active radon systems is the amount of air that must be extracted to create a sufficient vacuum under the slab to counteract vacuums created within the house. Interior vacuums can be caused by mechanical exhaust fans, unbalanced forced air systems as well as thermal stack effects.

It is generally accepted that a negative differential pressure of 0.020 inches of water column under the slab relative to the interior of the home is sufficient to retard the entry of radon laden soil gases (ASTM 1465). To determine the amount of air that is needed to be extracted to achieve this negative pressure, 13 homes in Douglas County, CO were studied. All 13 were constructed by the same builder and were of comparable footprint size. They also had the same active radon systems consisting of the trench with perforated pipe around the interior with gravel in the trench but not throughout the entire sub-grade.

Concurrently three homes in Virginia/Maryland, also constructed by the same builder were studied. They also had active radon systems but rather than a trench, there was 4 inches of clean gravel throughout the sub-grade with a 20-foot length of perforated pipe laid within it.

Differential pressures were measured at a minimum of two locations on the slabs, while air was extracted at different flow rates. This allowed for the determination of how much negative pressure could be developed under the slab per cubic foot of air extracted. Results are summarized below.

System	Negative Pressure per CFM Extracted (IN. W.C./CFM)
Looped SGC in gravel trench	**14.6**
Length of Perf. Pipe in 4-inch layer gravel throughout sub-grade	**1.5**

Based upon this data, a slab with gravel completely underneath may require as much as <u>10 times</u> the volume of air to be extracted as does a slab on compacted soil with a soil gas collection loop in a trench to produce the same vacuum.

The reason for this is not definitively known, but radon professionals have seen similar effects where gravel throughout increases contact with air pathways from the underlying soil or via utility penetrations through sidewalls that increases the amount of air that must be removed by the system. In fact, in areas of highly permeable soils, such as karst geology, the practice is to install a layer of highly compacted material beneath the soil gas collector to reduce the entry of external air into the collection system.

However, in the cases where gravel was not laid throughout but rather just a soil gas collector that contacts the interstitial area under the slab, have a much lower void space to evacuate and hence requires much smaller fans to create the requisite vacuum. So, there is an indication that gravel throughout may be a detriment.

Mat on Sub-Grade vs. Perforated Pipe in Trench

Based upon the success of a loop of 4-inch perforated pipe in a gravel filled trench in reducing radon, a flat soil gas conduit was developed that would have the same air flow characteristics but also eliminate the need to dig a trench. This is particularly helpful with large slabs as would occur in multi-family structures and office buildings and where gravel is not readily available.

The criteria for laying out a flat mat is the same as is used for laying out a perimeter trench with perforated pipe:

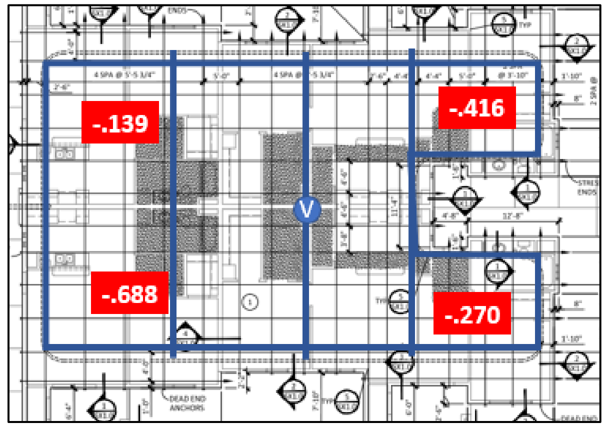
- Locate nominally a foot away from outside walls.
- Spacing of no further than 20 feet between runs.
- Ensure that pipe or mat enters all sub-grade areas separated by intermediate foundation walls or grade beams beneath occupied space.
- Communicate with the bottom of the concrete slab or optional vapor barrier.
    - Pipe Trench: Gravel extends up to vapor barrier
    - Mat: Laid directly beneath the vapor barrier
- Both ends of loop should enter a TEE connection from either side to reduce restrictions at the point of connection to the riser.
- Either perforated pipe or mat should be fabric wrapped to reduce entry of fines.

Both mat and perforated pipe/trench approaches have been installed with comparable success relative to negative pressure generation as well as post-construction radon measurements. This is to be expected since both approaches provide the same cross-sectional area for soil gas conveyance to the riser.

Cross-sectional area of 4-inch pipe:	12.73 sq. in.
Cross-sectional area of 1 x 12-inch mat:	12 sq. in.

In fact, smaller thickness mats appear to work as well, provided the riser connection is not restricted and air flow enters both sides of a TEE. The following figures illustrate installation of a 12-inch-wide flat mat on compacted sub-grade prior to vapor barrier and concrete pour.

The following figure depicts pressure field measurements made on the same structure after the slab was cast over the soil gas mat and a temporary radon fan connected. As shown, all measurements were at least an order of magnitude more than the -0.020 inches of water column needed.



Flat Mat Layout and With Negative Pressures Developed with Temporary Radon Fan (IN W.C.)

Summary Points

- Passive Systems can reduce radon but are not assured to reduce to less than 4 pCi/L
- Active Systems installed from the outset or Passive Systems that have been activated, are assured to reduce levels well below 4.0 pCi/L.
- All systems (Passive or Active) should be inspected and tested after the home has been completed and under occupied conditions to verify reductions.
- Alternatives to gravel fully under the slab, as suggested by Appendix F of the IRC, have been developed and proven in terms of radon reduction performance for Colorado home construction practices.
- Alternatives provide architect/engineer options in designing cost-effective approaches for Colorado structures.

References and Suggested Reading

CDPHE Technical Guidance:
https://cdphe.colorado.gov/radon-and-real-estate:

- **Measuring and Mitigating Radon in Colorado,** CDPHE Technical Guidance
- **Sealing the Top of Radon Soil Gas Collection Systems in New Construction,** CDPHE Technical Bulletin 06-20-1
- **Inspecting Radon System in New Construction,** CDPHE Technical Bulletin 06-20-1

Effectiveness of passive radon-reduction systems in new Fort Collins Homes, Available upon request.