# ALTERNATIVE APPROACHES TO MANAGING SCHOOL MITIGATION AND SUB-SLAB DIAGNOSTIC TESTING

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**Abstract**

As industrial hygienists who measure many contaminants (including radon) in varying environments, we typically measured and/or surveyed the environment, then prepared a corrective action plan. As the owner's independent authority, we often manage the bid process and post-mitigation verification. However, when mitigating radon in schools, information about radon levels is insufficient for mitigation contractors to estimate effort required for mitigation. Contractors refused to provide bids due to uncertainty about sub-slab conditions. Also, mitigation in schools often occurs during the summer break when the robust post-mitigation test data needed to prove a low radon levels (and to certify the contractor preformed their job, thus allowing payment) is not available. In response, two major adjustments were made; (1) We conduct diagnostic sub-slab testing, which provides information needed to characterize various sub-slab conditions and estimate costs, and is particularly important when school renovations have occurred, and (2) We now specify sub-slab pressure as the primary deliverable to allow summer-time payment to the contractor. Follow-up comprehensive radon testing is conducted during the heating season to validate the system design and installation. We are currently using this process in approximately ten schools with results and experiences to be documented in this paper.

## Introduction

Industrial hygienists (IH) often serve as third-party troubleshooters, project managers, and occupant advocates for various indoor air quality issues. The troubleshooting process for determining the root cause of any hazardous environment can be compared to peeling layers of an onion. When the IH does the job perfectly, they peel the cheapest layers first as quickly as possible, measure the effect and repeat as needed. In the case of school facilities the mitigation/abatement/remediation contractor and IH, whether dealing with radon, asbestos, mold, VOCs, etc., often encounter a situation where budgets and timing are not within their control, and are accompanied by intangible factors that affect the decision-making process.

The school used a radon screening test method that applied representative sampling (a common tool in industrial hygiene, internal auditing, quality control, and lead paint assessments, to name a few applications besides radon) to identify problem schools. It is important to note that radon screening test methods are designed to identify a problematic structure (HUD, 2103; HUD, 2016; Neri, 2014). Screening tests do not address the same hypothesis as radon testing designed to diagnose and repair the structure.

Past attempts to competitively bid Active Soil Depressurization (ASD) systems in large commercial/institutional settings were met with resistance from potential radon contractors due to the unknown sub-slab conditions. Attempts to separate the slab diagnostics from the remedial work and to bid the two tasks separately were met with firm distrust by the contractors of each other's work. However, contractors were willing to work with data that was provided by an independent third party.

For this group of schools, the timeframe and budget were limited, and occupant awareness was high, dictating an expedited, streamlined approach. Below is a timeline of the radon mitigation process:

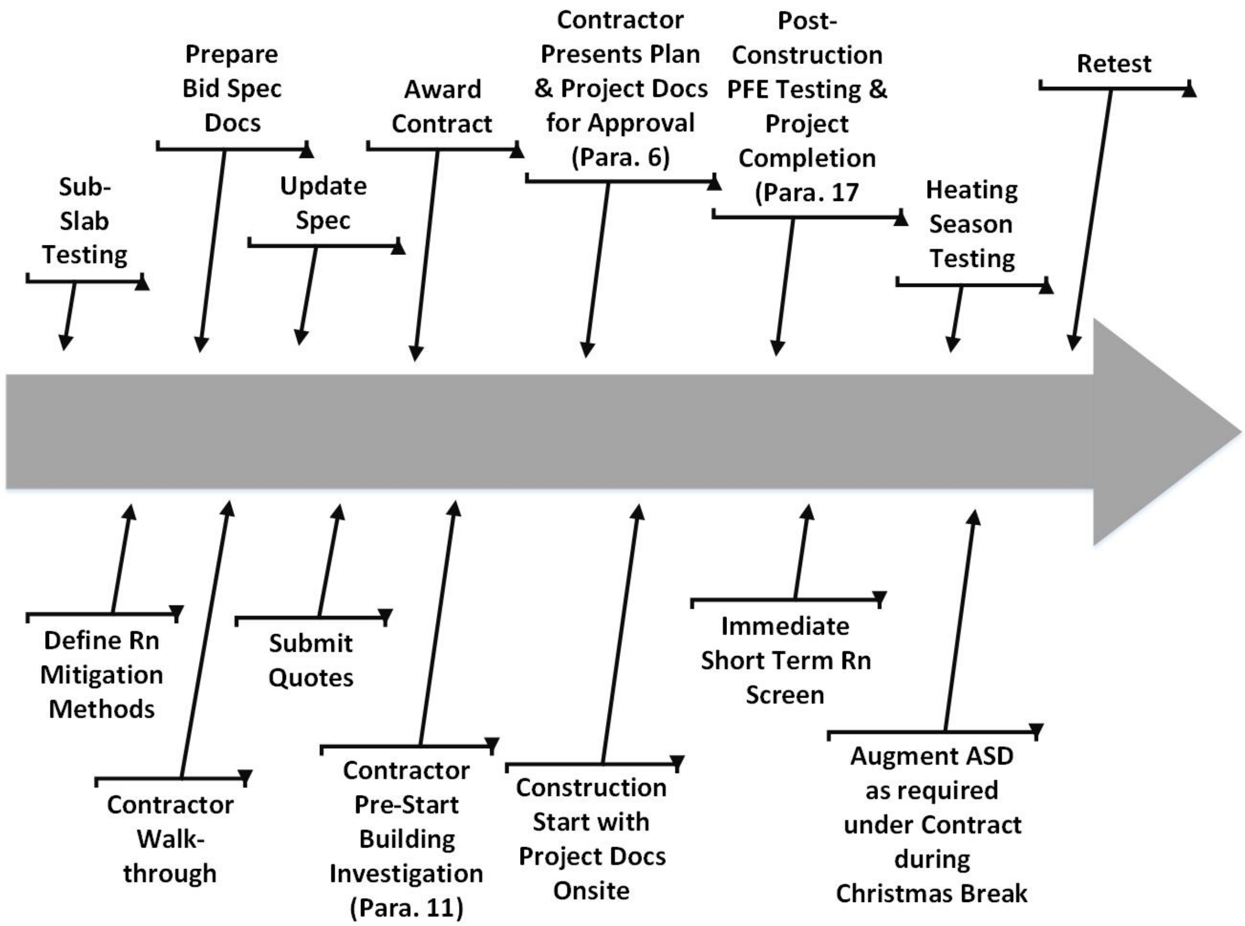


Figure (1): Radon mitigation project timeline [1]

A summertime completion schedule does not support robust post-mitigation radon data as required and described in Section 11 of the applicable AARST standard (AARST, 2015). For this project a performance-based specification is written that defines success in terms of measurable system performance criteria, separate from variable radon measurements. AARST and ASTM installation standards define the contractor means and methods. The project specification defined the ASD scope of work and the bid documents required a line-item detail cost sheet for change orders, if required. This enabled the contractor to be paid upon completion of work performed, while supporting a competitive bid environment in case additional work was deemed necessary after radon testing during the heating season. The project is not complete until comprehensive, heating season radon tests that are conducted in accordance with ANSI/AARST RMS-MALB 2014 standard can confirm success (AARST, 2015).

*(2) The paragraph numbers in Figure (1) refer to paragraphs in the radon specification.*

## Methods

*Diagnostic Slab Testing for Bid Purposes*

Based on input from local mitigation contractors and research, we made arrangements to perform testing to define sub-slab conditions in parts of the facility where ASD appeared be the mitigation system of choice. Slab diagnostic test results would later dictate whether alternative mitigation methods should be employed initially. It cannot be over-emphasized that the sub-slab diagnostic testing was designed to support the bid process and was not sufficient to design the system. Slab diagnostic testing (SDT) in several schools indicated that ASD would not be the preferred first method due to conditions observed, supporting decisions regarding the scope of work during the scope definition phase of the project.

Traditionally, project engineering documents and specifications should be sufficient to define the scope of work, identify the installation standards, and define acceptable performance by the contractor. Engineering costs should be a fraction of total project costs to maximize the leveraging of costs for direct materials and direct project labor.

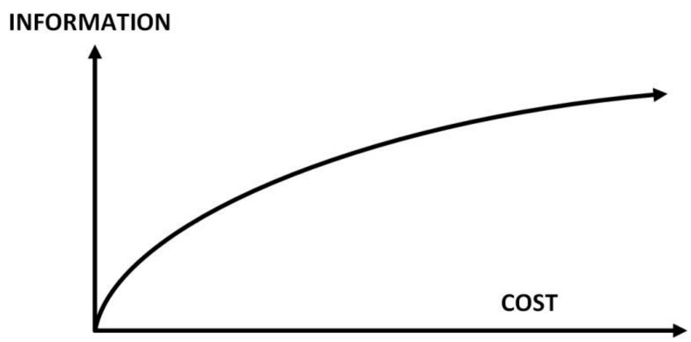


Figure (2): Engineering costs versus information

Figure (2) shows the concept of "analysis paralysis" or over-engineering. Figure (2) could also apply to the concept of not allowing perfect to be the enemy of good [2]. The limited timeframe and limited radon testing demanded a do-no-harm approach to provide relief to the schools as soon as possible, while meeting requirements for minimal disruption, lowest cost, and value.

Very briefly, the contents of the SDT report consisted of the following deliverables:

- Description of measurement and observation protocols
- Conducting pressure field extension (PFE) measurements, visual description/images of sub-slab matrix (Figure (3)),and various test parameters (Figure (4))
- Providing any available documentation and applicable drawings
- Providing structure history and recent radon test results

*(2) Voltaire: "The best is the enemy of the good." Confucius: "Better a diamond with a flaw than a pebble without." Shakespeare: "Striving to better, oft we mar what's well."*

Figure (3): Image of sub-slab matrix

**TABLE 1: PRESSURE FIELD EXTENSION (PFE) TEST RESULTS**

| Test # | Suction Point ID | Reference Pressure (“$H_2O$) | Suction Volume (CFM) | Test Point ID | Test Point Pressure (“$H_2O$) | Additional Comments |
|---|---|---|---|---|---|---|
| 1 | A | 2.7 | 130 | 1 | 0.019 | RM 146 |
| 2 | B | 4.2 | 150 | 1 | 0.063 | RM 146 |
| | | | | 2 | 0.024 | RM 147 |
| 3 | A | 2.8 | 140 | 3 | 0.007 | RM 154 |
| 4 | C | 1.2 | 150 | 4 | 0.009 | GYM |
| 5 | D | 0.75 | 160 | 5 | ND [1] | RM 127 [1] |
| 6 | D | 0.70 | 160 | 6 | 0.13 | RM 125 |
| 7 | E | 1.9 | 150 | 7 | 0.047 | CAFETERIA |
| 8 | C | 1.06 | 140 | 4 | 0.01 | GYM |
| 9 | C | 2.5 [2] | 190 | 4 | 0.017 | GYM |
| | | | | 8 | 0.01 | GYM (FAR END) |
| 10 | 8 | 0.67 | 140 | 6 | 0.12 | RM 125 |
| | | | | 5 | 0.04 | RM 127 [1] |
| 11 | D | 0.67 | 140 | 6 | 0.13 | RM 125 |
| | | | | 5 | 0.04 | RM 127 [1] |
| | | | | 9 | 0.018 | RM 129 |
| 12 | D | 0.67 | 140 | 10 | 0.009 | “STORAGE” RM |

NOTE 1: Follow-up measurements showed communication after probing test point hole with 12inch bit, which apparently penetrated the vapor barrier under the slab. This section was thicker at approximately 8+ inches.
NOTE 2: Dual vacuum cleaners are used to provide more volume.

Figure (4): Example PFE table of results

The specification used foundation, HVAC, and floor plan drawings, accompanied by client-provided radon test results to define slab segments and zones for SDT purposes. The results of SDT work, in combination with considerable study of facility drawings and structure history, were used to define slab segments for the contractor. For the purposes of quoting the work, defined slab segments were “warranted” by the owner to be continuous. If a defined slab segment was found to be more segmented than described in the specification, the line-item list in the bid documents enabled a structured change order.

For example, one such slab segment was further segmented due to water table issues that invalidated the SDT testing results. This discrepancy was discovered during the contractor’s

Pre-Start Building Investigation three months after SDT testing. A review of weather history revealed a nearly three-fold difference in rainfall in the month prior to SDT when compared to the month prior to construction. SDT testing had indicated excellent communication across the slab, which deteriorated with summer rainfall. That particular slab segment is isolated from the structure's perimeter on all four sides, making perimeter drain management impractical. Available foundation drawings did not show a boundary between the slab segments.

Of thirty-six specification-defined segments in the nine schools mitigated, two segments were determined to be further segmented during the contractor's Pre-Start Building Investigation.

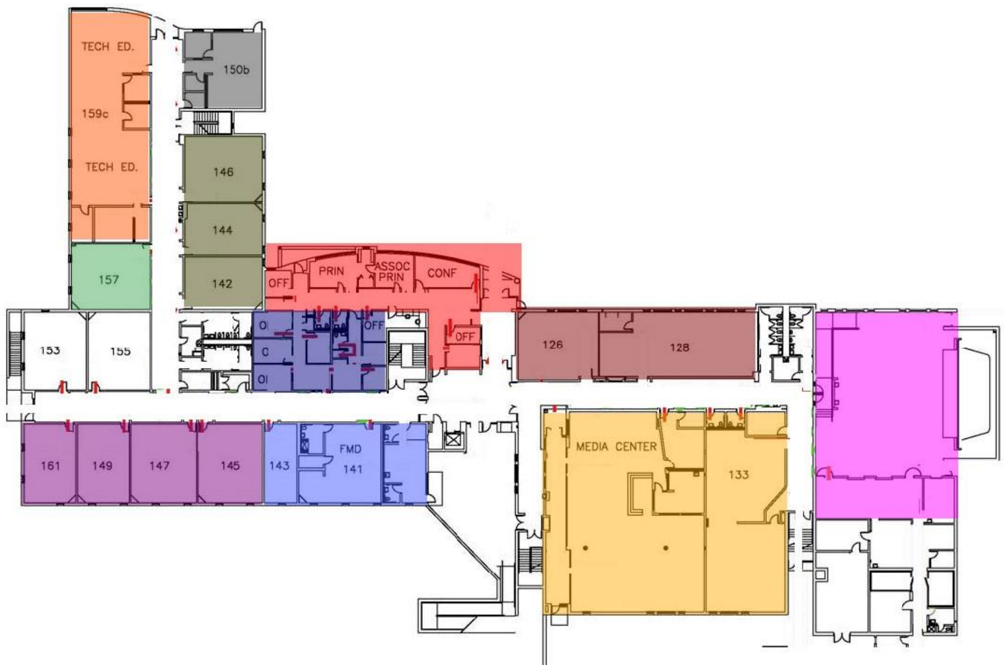


Figure (5): Example of specification-defined slab segments

While one of the more complicated segment drawings, Figure (5) is a good example of a school with four major renovation/additions in its history, which was not unusual. SDT indicated potential karst activity in one of the segments. Later follow-up SDT testing and sampling with a radon grab sampler did not repeat the initial unusual readings or indicate unusual sub-slab conditions, but yielded more typical PFE test results. Consequently, that slab portion was deemed a separate segment to allow more focused ventilation, if indicated by follow-up radon monitoring.

SDT results in several other schools indicated heavy clay without a gravel sub-slab matrix, implying an environment difficult to predict relative pressure required for success, particularly when recalling the previous failed PFE measurement event. While clay resistivity to flow has been measured (Moorman, 2008), water table issues can make the sub-slab environment particularly unpredictable for a large slab segment versus residential-sized slabs. For example, two schools had evidence of severe water table issues, making consistent sub-slab depressurization unreliable without major disruptive work, including sub-slab water management and slab work. When available radon test results were studied and the HVAC systems were evaluated, an alternate radon reduction method of room pressurization was implemented in selected portions of the buildings in lieu of a difficult ASD project.  The HVAC systems were slightly reconfigured to alter relative pressure, affecting room boundary exchange rates (Burkhart, 2002; Park, et. al., 2016).  These schools had dedicated outside air delivery systems (with energy recovery enthalpy wheels and pre-conditioning coils) that are separate from localized temperature management HVAC systems.  Air exchange rates could be increased to complement room pressurization with dilution (Akbari, et. al., 2012; Brodhead, 2009).

It is important to note that comprehensive radon testing, which is required to verify occupant safety, can also be a valuable tool to further refine the mitigation method. (Moorman, 2015)  In one school, 14 electret tests were used over a 12 hour test period to successfully identify suspect point sources in a basement.

Upon completion of the SDT evaluations, specifications were written for each school, bid documents were prepared, and contractor walk-throughs were conducted.  Great feedback was received, respected, and incorporated into bid documents from contractors who participated in the walk-throughs.  (Side note:  One lesson learned from over 35 years of overseeing projects as an engineering manager is that the specification always gets better with feedback from the contractor participants.)

## Results

*Performance-Based Specification*

While ultimately reduced radon levels are the requirement, presenting radon measurements made during the summer months to “prove a negative” is an unreasonable expectation.  Peer-reviewed studies have attempted to estimate and extrapolate “off-season” measurements into usable data and seasonal correction factors (SCF) or quantify seasonal variations with limited success (Denman, 2006; Miles, et.al., 2012; Krewski, et.al., 2005).  To cite an example, one chart from

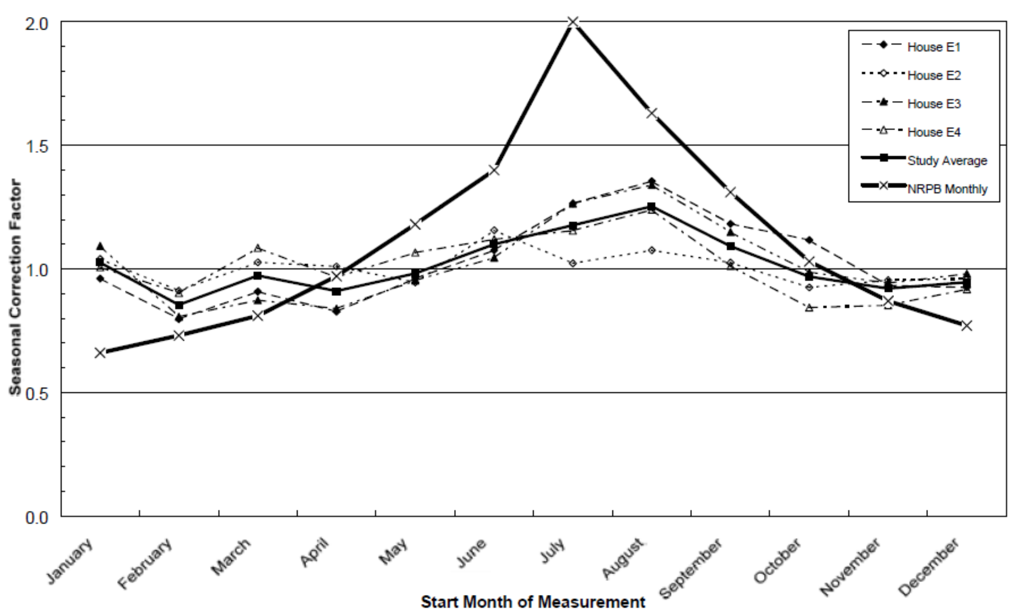


Figure (6):  SCFs from 4 houses in Brixworth, Northamptonshire, with NRPB SCF (Denman, 2006) such a study is shown in Figure (6), although the same study carefully describes caveats regarding the application of seasonal correction factors (Denman, 2006).

Our firm has measured up to ten-fold differences in summer short term tests and winter short term tests. Obviously, there are many influences at work during any given test period, but the facts remain. We are trying to measure a varying contaminant in a varying environment with equipment that has measurement tolerances specified as high as 25%. The consistent use of two significant digits in our measurements can lead to complacency regarding the accuracy and precision of the radon measurement. However, such measurements have been beneficial when used in a relative sense as part of a diagnostic process where single digit precision measurement variations between locations were sufficient to find isolated “hot” spots as shown in Figure (7). These variations were used to support moving substantial contents, revealing points of infiltration.

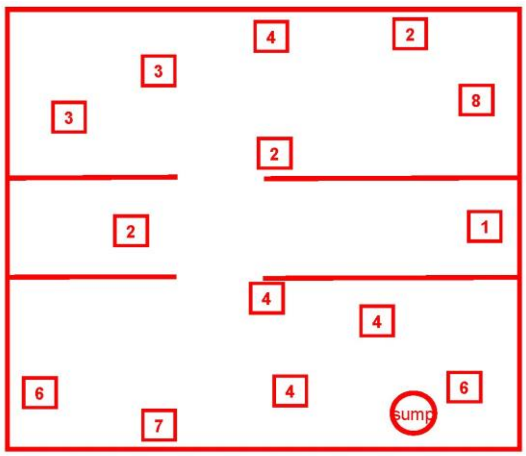


Figure (7): Example short term electret field data

Without a method to extrapolate summer data into reliable exposure data for the contractor to get paid within a reasonable time-frame, the do-no-harm approach was to specify ASD systems that would improve conditions with a high degree of certainty. Such systems would deliver a defined differential pressure across the slab that would provide a high likelihood of reducing radon within the mitigated slab segment. ASTM E2121-13 specifies sub-slab depressurization goal for soil vapor intrusion to be between -6.0 pascals (-0.024” water column (WC)) and -9.0 pascals (-0.036” WC). However, recent research has suggested that differential pressures ranging from 2 Pa (0.008 WC) to 4 Pa (0.016 WC) in systems with constant fan speed can be effective (Brodhead, 2010). For this project, an average differential pressure of 0.015 WC across the slab segment was selected as the target, as determined by averaging measurements that were more than half the distance of the slab from the extraction point. A minimum measurement 0.005 WC was defined as acceptable at the fringes of the slab (Moorman, 2015).

One school required Sub-Membrane Depressurization (SMD) to mitigate crawlspaces. For this environment, the crawlspace vents were required to remain open (1) to equalize pressure between the crawlspace and the outdoors and (2) to decouple the building stack effect from the SMD membrane. These two factors serve to reduce the differential pressure requirement across the membrane. The mitigation specification detailed a pressure differential of 0.005 WC across the SMD membrane. Any doubts by the contractor of the efficacy of this test method were silenced when the first test attempt revealed hidden defects at the perimeter. With a close and careful inspection, the contractor found subtle defects and subsequent pressure testing was successful.

## Conclusions

As of the writing of this paper, the school district is conducting short term retesting of selected test locations with results pending. To be clear, this paper is not to be construed in anyway as reducing the need for the immediate test requirement of the ANSI/AARST radon Mitigation Standards for Schools and Large Buildings (Section 11.2.1 Initial Retests After Mitigation) after mitigation. What is proposed by this paper is the following:

(1) That final judgment of the mitigation systems effectiveness be reserved until robust testing can be performed during the heating season, and

(2) That a method of conducting radon mitigation in a manner is possible to reduce occupant exposure at worst and proves to be effective at best, while allowing the contractor to be paid for their work. The bid process provides a structured, competitive path for compensation, if additional work is needed later after heating season testing.

Realistically speaking, after working with this client (and many other industrial, institutional and commercial clients as an industrial hygienist) extensively over the years, one too often sees that budget constraints often exceed safety concerns. So when radon test results can be better trusted, defensible decisions can be made to augment systems as needed while children are educated in a safer environment. The last thing any school district needs is radon testing in August that says everything is “OK” to be negated by an inexpensive, self-administered test performed by curious staff members in February. That event would definitely cast doubts on the competent radon mitigation contractor and on the whole industry.

*Acknowledgements*

Over the years it has become very apparent that much of the “where the rubber meets the road” research has been done by very special individuals who have studied and measured and researched radon on their own time with their own resources. These curious, unselfish, and ever-seeking professionals richly deserve a sincere acknowledgement for their invaluable contributions to the radon industry. It is their research that provided much of the “backbone” for this paper and for this author’s own learning.

## References


AARST (AARST Consortium on National Radon Standards), 2015, Radon Mitigation Standards for Schools and Large Buildings, ANSI/AARST RMS-LB 2014.

AARST (AARST Consortium on National Radon Standards), 2015, Protocol for Conducting Measurements of Radon and Radon Decay Products in Schools and Large Buildings, ANSI/AARST RMS-MALB 2014.

Brodhead, W.P., 2002, Designing Commercial Sub-Slab Depressurization Systems, Proceedings of 16th International Radon Symposium.

Brodhead, W.P., Hatton, T.E., 2009, Whole Building Ventilation of High Rise Condominium with Elevated Radon from Concrete, 23rd International Radon Symposium, St Louis, MO.

Brodhead, W.P., Hatton, T.E., 2010, High Vacuum, High Airflow Blower Testing and Design for Soil Vapor Intrusion Mitigation in Commercial Buildings, AWMA Symposium, Chicago, IL.

Burkhart, J.F., Camley, R.E., 2002, "The Correlation between Small Ventilation Rates and Indoor Radon Concentrations Using a Multi-Room House Model," Proceedings of 16th International Radon Symposium, Vol. 1, pp. 41-50.

Denman, A.R., et al., 2006, Are Seasonal Correction Factors Useful in Assessing the Health Risk from Domestic Radon, 2006 IRPA Paris.

EPA, 1991, EPA Handbook: Sub-Slab Depressurization for Low-Permeability Fill Material, EPA/625/6-91/029.

Hatton, T.E., Nuzzetti, D.J., 2013, Applying Dynamic Controls and Remote Monitoring to Radon Mitigation Systems to Advance Energy Conservation and the Stabilization of Indoor Radon Concentrations, 27th International Radon Symposium, Springfield, IL.

HUD (U.S. Department of Housing and Urban Development), 2013, Notice H 2013-03, HUD Office of Multifamily Development Radon Policy.

HUD (U.S. Department of Housing and Urban Development), 2016, Multifamily Accelerated Processing (MAP) Guide, 4430.G.

Krewski, D., et. al., 2005, Modeling Seasonal Variation in Indoor Radon Concentrations, Journal of Exposure Analysis and Environmental Epidemiology 15, pp. 234–243.

Miles, J., Howarth, C., Hunter, N., 2012, Seasonal Variation of Radon Concentrations in UK Homes, Journal of Radiological Protection 32, pp.275-287, DOI 10.1088/0952-4746/32/3/275.

Moorman, L., 2008, Solving Turbulent Flow Dynamics of Complex, Multiple Branch Radon Mitigation Systems, 22nd International Radon Symposium, Las Vegas, NV.

Moorman, L., 2015, Advanced Techniques for Radon Mitigation Systems Workbook, Radon Home Measurement and Mitigation, Inc., Fort Collins CO.

Neri, A., 2014, Evaluation of Percentage-based Radon Testing Recommendations for Multi-family Housing, 28th International Radon Symposium, Charleston, SC.

Park, H.J., Kang, D.R., Kim, J., 2016, A review on mathematical models for estimating indoor radon concentrations, Annals of Occupational and Environmental Medicine, 28:7 DOI 10.1186/s40557-016-0091-6.