# RADON MITIGATION IN A DIFFICULT TO MITIGATE SCHOOL

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## ABSTRACT

This paper describes radon diagnostics and mitigation in a school the U.S. Environmental Protection Agency (EPA) classified "difficult to mitigate." The school had subslab utility tunnels that served as the outside air and return air mixing chamber for the heating and ventilation system. The heating and ventilation system depressurized the tunnel, sucked radon from the soil, and distributed it to school rooms. Extensive diagnostics were conducted to test mitigation options and to provide mitigation design parameters. The final radon mitigation technique involved pressurizing the utility tunnel. The findings indicate that: active soil depressurization systems can be overpowered by heating, ventilation, and air conditioning (HVAC) operations; in some cases, increased ventilation can increase radon entry and indoor concentrations; and, if properly implemented, additional ventilation can reduce indoor radon concentrations without significant energy penalties.

## INTRODUCTION

Radon reduction research and demonstration in schools have produced two important findings: first, HVAC systems can overwhelm active soil depressurization (ASD) mitigation if the HVAC systems are not assessed; and second, increased ventilation in some schools can increase radon entry and indoor concentrations. The latter finding is an important factor in EPA's classification of "difficult to mitigate" schools.

This paper focuses on radon testing, diagnostic experiments, and mitigation in an Ohio elementary school with elevated radon. The school is a 2,050 square meter, one story, slab-on-grade building containing approximately 30 classrooms, offices, and related facilities serving about 410 students and 30 staff members. The school was built in 1961 with additions in 1964 and 1966. The northern portion of the school receives conditioned and ventilation air through fan coil units (FCU) hung in a 1.8 by 2.4 meter utility tunnel located below hallways. The tunnel has a concrete floor and concrete block walls and serves as the mixing chamber for outside air and return air. The FCUs draw conditioned air from the utility tunnel and deliver it through subslab clay tile ducts to the exterior perimeter of the classrooms and to the office area. The utility tunnel return air characteristic is classified by EPA as difficult to mitigate (Henschel, 1993). The southern portion of the school is served by packaged air handlers that are designed to deliver conditioned air through ceiling mounted duct work as opposed to the utility tunnel and subslab ducts.

Initial radon test results were 1700 and 1775 Becquerel per cubic meter (Bq/m$^3$) in two classrooms served by the utility tunnel-subslab duct ventilation system versus 1370 and 925

Bq/m$^3$ in two classrooms served by ceiling mounted ducts that delivered outside air from roof-top intakes. Follow-up four month testing results were 925 Bq/m$^3$ in one of the previously measured classrooms served by the utility tunnel and subslab duct ventilation system versus 670 Bq/m$^3$ in one of the previously measured classrooms served by a roof-top air handler.

A diagnostic team investigated conditions at the school and found block wall concentrations of radon were about 11,000 Bq/m$^3$. The soil under the tunnel contained concentrations of about 2800 Bq/m$^3$ while the tunnels had concentrations of about 2600 Bq/m$^3$. Pressure field extension (PFE) measurements were made in the utility tunnels, below the floor and in the block walls as well as below a classroom. The soil below the utility tunnels was found to be relatively tight and, under existing conditions, a suction point every 5.5 meters would be required if an active subslab depressurization (SSD) system was installed through the tunnel floor to control radon entry. Alternatively, a suction point every 12 meters would be required for a tunnel block wall depressurization (BWD) system and one suction point per classroom would be required if a SSD system was installed through the classroom floors.

During diagnostics, it was learned that an energy management firm had been contracted by the school district to install an energy management system and thus, it was recommended that school officials consult with the firm to increase outdoor ventilation rates. The energy management firm had proposed to check operation, calibrate, and adjust HVAC controls as well as replace defective controls and equipment.

The initial mitigation work in the school included sealing openings between the utility tunnel and the soil and installing a block wall depressurization (BWD) system that was intended to reverse the pressure-driven flow of radon from the soil into the tunnel. After the BWD system was installed, the contractor reported that the pressure-field extension was lost within a meter of each suction point. It was then discovered that the tunnel air pressure was more than 80 Pascal (Pa) negative in relation to the outdoors . . . which was six times more negative than ten months earlier when the initial diagnostics had been completed. It was suspected that the energy management firm had replaced defective HVAC controls and equipment and made other changes that resulted in greater suction on the tunnel by classroom fan coil units (FCU) that drew conditioned and ventilation air from the tunnel.

Investigators returned to the school to assess the performance of the BWD system and it was concluded that modifications were required in the air handling system in order to meet the EPA's guideline of 148 Bq/m$^3$ or lower. Two options for additional radon reduction were presented: 1) hard ducting the return air/outdoor air to the low pressure side of the classroom fan coils in order to isolate the ventilation system from the source of radon; or 2) a combination approach to reduce tunnel depressurization by adding return air/outdoor air grills and increased block wall suction by installing larger size mitigation system headers, further sealing of tunnel air leaks, and adding further exhaust fan capacity.

Based upon the diagnostics, a request for proposals for additional mitigation was released with the expectation that the successful proposal would cost \$40,000 to \$50,000 and involve about \$2,000 per year in additional energy expenses. The best construction proposal was in excess of \$400,000 and the estimated increase in annual energy was about \$25,000. Without the benefit of better detailed existing performance criteria, this response covered a variety of contingencies.

The principal investigators recommended that the over-budget proposed mitigation should not proceed. The investigators recommended that experiments should be conducted to clarify the best mitigation techniques for the school. They noted, that experimentally, it would be possible to: vary the proportion of outside air using temporary fans; a temporary duct could be installed to directly connect the mixed air source with one existing classroom fan coil unit to eliminate any air being drawn from the tunnel; and a temporary subslab depressurization system could be installed in one or more rooms served by the utility tunnel and one or more rooms not served by the tunnel to determine the effect of subslab depressurization by itself and in combination with other radon reduction techniques.

## METHODS

A matrix of 12 experiments was defined for testing the effectiveness, individually and in combination, of pressurizing the tunnel mixed air system, hard ducting the classroom fan coil units (FCUs), classroom subslab depressurization (SSD), tunnel block wall depressurization (BWD), and tunnel block wall pressurization. Due to time limitations, the matrix required a minimum of 24 hour baseline conditions (i.e., BWD off, mixed air fans to tunnel off, SSD off, no hard ducting of the FCU) before and after each 24 hour test. By using this flip-flop technique, the effects of one operational configuration would have little, if any, impact on the effect of a subsequent experimental configuration. Since the condition of greatest concern was during peak heating load, the system operation was set for that situation. The fans would be on and the dampers set to bring in 7.5 liters per second per student (ASHRAE Standard 62-89). This required about 20% outside air mixed with 80% return air. The test condition would run all the school fans (all FCU's and also three supply fans in the south end of the building) continuously with the outside air dampers set at the expected minimum of 20% outside air.

Environmental conditions that were monitored included: subslab pressure between the music room and two classrooms with the hallways; room pressure between the paper supply room, tunnel, BWD system and outside with the hallway; continuous radon concentrations in three classrooms and the Principal's office; temperature in the hallway, paper supply room and outside; and barometric pressure. Two blower door fans were installed in a mixed air shaft to simulate a mixed air fan. Subslab depressurization systems were installed in a classroom and the music room. A temporary duct was installed connecting a FCU to the mixed air shaft.

## RESULTS

### Experimental Phase

The continuous radon measurements in the tunnel and in a classroom prior to installation of testing systems showed a clear relation between the daily cycle of the FCUs in the utility tunnel with fans being started at 0700 and stopped at 1600. The radon concentration patterns were nearly identical in the tunnel and classroom, with the classroom values lower and slightly delayed. When the fans started, the radon concentration rose from about 110 $Bq/m^3$ to about 925 $Bq/m^3$ in two hours. When the fans stopped, the radon concentration dropped from 925 to 110 $Bq/m^3$ over about six hours. Short-term radon readings, taken over four day periods several weeks before the installation of testing systems, revealed classroom radon levels averaging 740 to 1110 Bq/m$^3$. With the tunnel fans on and 0% outside air, the tunnel was about 112 Pa negative to the outside and the BWD was about 100 Pa negative to the tunnel. This pattern was consistent with the BWD fan curve which provided the measured 140 liters per second (l/s) exhaust at 200 Pa. Total exhaust air flow from the four BWD system fans was about 600 l/s.

The preliminary findings at the end of the 12 tests appeared to support the conclusions that additional ventilation and pressurization of the tunnel would reduce radon. The experiment was expanded to include ten additional tests to determine the effects of FCU operation and to find if tunnel pressurization would force radon out of the ventilation system but move it into rooms (even those not served by the FCU's) through other pathways. The additional tests were run for several days without a "flip back" to the base case so that extended effects could be assessed. These added tests provided a picture of possible problems which would come from extended operation with the proposed ventilation changes.

The 22 experiments and the resulting average radon concentrations are listed in Table 1. The radon concentrations exclude the first two hours of each experiment to reduce the effects of changing the operating conditions of the building. The greatest radon reductions, 62% to 97%, were observed in experiments 3, 6, 9, 12, 13, 17, and 21. In six of these eight tests, mixed air fans were on and the utility tunnel was probably slightly pressurized although we do not have access to that data. Test 17 indicates that radon concentrations can be controlled by the blockwall depressurization as long as the tunnel is not depressurized by the FCUs removing air from the tunnel.

These experimental findings provided the basis for a mitigation plan involving adding mixed air fans to the mixed air shafts and a corresponding reduction in the fan coil unit suction. In concept, this plan involved shifting the energy load from the fan coil units to the new mixed air fans as well as shifting the negative pressure from the soil to above grade.

**HVAC Focused Mitigation Phase**

The specific measured values of air pressure and flow rates provided a much clearer picture of the needed design criteria. Appropriately sized fans could be specified and installed as pressure make up fans. A heating contractor prepared an estimate to provide and install 4700 l/s, 124 Pa static pressure supply fan in each mixed air shaft. Installation was completed and detailed testing and balancing of the HVAC system were performed on each fan coil units (FCU). For most FCU fans, a 70% smaller drive wheel provided the correct flow. Because of the mixed air fan pressure, even slowing the FCUs still resulted with an air flow increase. The final cost of the HVAC focused mitigation, including testing and balancing, was $29,900.

Occupants reported that the school was more comfortable after radon mitigation. School facilities personnel and occupants praised improvements in the overall perception of ventilation and heating uniformity. Measurements of average radon levels revealed radon concentrations were 30 to 122 Bq/m$^3$. Continuous radon monitoring showed that the indoor radon concentration dropped when the mixed air fans were started. This is the opposite of measurements taken prior to installation of the fans. Post mitigation radon testing was performed using short-term electret ion chambers (ES). The results of the ESs all were below the EPA level of 148 Bq/m$^3$. In addition, a continuous radon monitor was used in the principal's office that measured an average concentration of 44 Bq/m$^3$ during the test period.

**Table 1** Average Radon Concentrations During Trials and Percent Radon Reductions Compared to Previous Base Conditions

| | Variables | | | | | | Average Radon Conc. ($Bq/m^3$) | | Radon Reduction | |
|---|---|---|---|---|---|---|---|---|---|---|
| | BWD | MA | SSD | MA | Fan | East | | | | |
| Experiment | Fans | Fans | Fans | Source | Coils | BWD | Tunnel | Occupied | Tunnel | Occupied |
| 00. Base Condition Average | off | off | off | tunnel | on | off | 1121 | 285 | | |
| 01. Orginal Operation with BWD | ON | off | off | tunnel | on | off | 1110 | 241 | 7% | 19% |
| 02. Blockwall Pressurization (BWP) | REV | off | off | tunnel | on | off | 281 | 139 | 75% | 52% |
| 03. Tunnel Pressurization | off | ON | off | tunnel | on | off | 322 | 95 | 61% | 62% |
| 04. Subslab Depressurization | off | off | ON | tunnel | on | off | 1043 | 249 | -9% | 9% |
| 05. Hard Duct Mixed Air (MA) | off | off | off | DUCT | on | off | 1055 | 242 | 6% | 12% |
| 06. BWD + MA Fans | ON | ON | off | tunnel | on | off | 274 | 66 | 76% | 73% |
| 07. BWD + SSD Fans | ON | off | ON | tunnel | on | off | 873 | 162 | 5% | 41% |
| 08. BWD + MA Duct | ON | off | off | DUCT | on | off | 1106 | 237 | 11% | 12% |
| 09. MA Fans + SSD Fans | off | ON | ON | tunnel | on | off | 300 | 82 | 63% | 65% |
| 10. MA Fans + MA Duct | off | ON | off | DUCT | on | off | 529 | 181 | 63% | 38% |
| 11. BWD + MA + SSD Fans | ON | ON | ON | tunnel | on | off | 377 | 136 | 74% | 67% |
| 12. BWD + SSD Fans + Duct | ON | off | ON | DUCT | on | off | 1058 | 102 | 27% | 67% |
| 13. BWD + MA Fans on, FCUs off | ON | ON | off | tunnel | OFF | off | 126 | 58 | 89% | 80% |
| 14. BWD + FCUs on Setback | ON | off | off | tunnel | SET | off | 910 | 234 | | |
| 15. BWD + Duct + FCU Setback | ON | off | off | DUCT | SET | off | 1221 | 177 | | |
| 16. BWD + MA Fans + FCU Setback | ON | ON | off | tunnel | SET | off | 614 | 205 | | |
| 17. BWD on + FCUs off | ON | off | off | tunnel | OFF | off | 41 | 29 | 96% | 90% |
| 18. BWD + Outside Air @ 20% | ON | off | off | tunnel | on | off | 1043 | 276 | | |
| 19. BWP + FCU Setback | REV | off | off | tunnel | SET | off | 770 | 190 | 31% | 33% |
| 20. BWP + MA Fans + 6 of 12 FCUs | REV | ON | off | tunnel | 6 on | off | 200 | 212 | 82% | 25% |
| 21. BWP + MA Fans + FCU Setback | REV | ON | off | tunnel | SET | ON | 74 | 102 | 94% | 64% |
| 22. BWP + FCU Setback | REV | off | off | tunnel | SET | off | 500 | 242 | | |

BWD = block wall depressurization
BWP = block wall pressurization
FCU = fan coil units
MA = mixed air
REV = reversed
SET = setback at night and week-ends
SSD = subslab depressurization

The tunnel concentrations of radon were 40 to 60 Bq/m$^3$.

A review of energy use for both electricity and gas indicated no significant change. The time frame was not long enough to determine the exact effect, but it was clear that the change had, as predicted, shifted energy use from being less controlled to being more controlled. Also, energy use had not markedly increased. The system operated during some of the coldest weather experienced in many years and capacity was sufficient to meet peak load. The energy use remained constant even with the increased amount of outside air. It appeared that the initial evaluation of air circulation was correct. Uncontrolled ventilation, equal to about 20% outside air, was moving through the building. The total energy use was not expected to increase with the same air flow controlled in its delivery through the mixed air fans. The energy use of three similar schools within two miles of each other was compared. After mitigation, energy use in the mitigated school changed little and, if at all, it decreased.

## CONCLUSIONS

While one cannot generalize from one case, our findings suggest that:

1. School radon mitigation must consider the operating characteristics of the HVAC system. In this case, an HVAC approach was required and it cost less than ASD.
2. The cost of school radon mitigation does not need to be expensive even in difficult to mitigate schools.
3. It is important to invest in thorough diagnostics in order to acquire a detailed mitigation design that is effective and reasonable in cost. In this case, proper engineering application of simple HVAC design principals resulted in an inexpensive radon mitigation solution that identified and corrected the problem without reinventing an entire HVAC system.
4. Pressurization of the occupied space may be more important than dilution and it does not necessarily increase energy use.
5. In other schools, it may be helpful to use a simplified version of the research matrix used in this school.
6. HVAC focused radon mitigation achieved radon reductions greater than those suggested by EPA guidance and thus, EPA should continue the Agency's research in radon reduction in schools using HVAC approaches.

## REFERENCES


1. Henschel, B. 1993 ***Planning Document for Difficult to Mitigate Schools Project***, Research Triangle Park, NC, U.S. EPA, Air and Energy Engineering Research Laboratory.


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