Evaluation of Indoor Radon Mitigation Systems in the State of Ohio

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ABSTRACT

High levels of indoor radon concentrations are reduced in the state of Ohio, USA, by installing different mitigation systems such as Sub Slab Depressurization System (SSD), Sump-Pit Perimeter Depressurization (SUMP), Drain Tile Depressurization (DTD), Sub Membrane Depressurization (SMD) and their combinations. The radon levels reported by the mitigation contractors to the Ohio Department of Health (ODH) were used by the Department of Civil Engineering at The University of Toledo (UT) to develop a mitigation database from 2001 - present. In this study mitigation data for a period from 2008 to 2010 were used for evaluating mitigation systems in 88 counties. The removal efficiency of each mitigation system was studied with respect to pre- and post- mitigation levels. The performance of each mitigation system was evaluated using standard error of the mean statistical measure.

INTRODUCTION

Radon is a tasteless, odorless, colorless gas, resulting from the radioactive decay of uranium in soil, rock, and water. Radon ionizes into particles which release radiation. The radioactive particles carry static charge that attracts them to particles in the air. These particles get trapped in human lungs when inhaled; thereby, it causes a greater health risk, such as lung cancer, pulmonary fibrosis, silicosis, and respiratory lesions.

Radon typically moves up through the ground to the air above and enters homes through cracks and other holes in the foundation [1]. Thereafter, the gas gets concentrated after getting trapped within the walls of the house. Radon concentration in the air can be increased by 1 pCi/L (picocuries per liter) for every 10,000 pCi/L concentration in the water, from which it can be understood that the risk of cancer due to radon in water is less compared to radon in soil. It becomes a health risk when a person is exposed to high levels of radon over long periods of time. Radon is classified as a Class A carcinogen by the U.S. Environmental Protection Agency (US EPA), proven as a cancer-causing agent in humans. According to the National Cancer Institute, radon can aggravate cancer risk when accompanied with cigarette smoking. Therefore, it is the second most common cause of lung cancer after cigarette smoking. The US EPA estimates that radon gas exposure accounts for about 15,000 to 21,000 cancer deaths per year in the United States.

Elevated radon gas levels have been discovered in virtually every state. The US EPA estimates that as many as eight million homes throughout the country have elevated levels of radon gas [2].

The US EPA continues to support preventive actions for all homes with higher radon activity, with an objective of a healthy living environment. The United States Congress has set a long-term goal that indoor level radon concentrations should be no more than outdoor levels or about 4 pCi/L. The US EPA states that the indoor radon concentration should be reduced immediately to 2 pCi/L if it is found to be 4 pCi/L and above [3]. The World Health Organization recommends that radon concentrations should be less than 2.7 pCi/L [4].

The radon concentrations in Ohio were found to be considerably higher than the national mean resulting in approximately 900 radon induced lung cancer deaths annually[5]. The indoor radon gas program was initiated by the ODH in the late 1980s to reduce the number of deaths attributable to radon. In the 1990s, ODH started encouraging the reduction of radon concentrations in houses and schools to a safe level. In 2001, Ohio passed a law that required radon mitigation contractors to report mitigation data on homes to the ODH [6]. As a result of the indoor radon program at ODH, an Indoor Radon Information System was developed by The University of Toledo (UT) [7, 8, 9, 10].

This paper summarizes results obtained from the analysis of a mitigation database built in the current Indoor Radon Information System over a period of three years from 2008 to 2010. The performance of each mitigation system was evaluated using standard error of the mean.

DATA MANAGEMENT SYSTEM

UT, under several research grants from the ODH/US EPA, developed the Ohio Radon Information Systems (ORIS), and a website [3, 5, 11, 12]. As of February 2012, the radon database developed and maintained by UT has radon observations from homes, schools, and drinking water.

Every year, radon mitigation contractors collect radon data from the Ohio homes and submit them to the ODH on a quarterly basis. The collected radon data are then transferred from ODH to the Department of Civil Engineering at UT. Thereafter the data are organized and entered manually into the radon mitigation database which is an Excel spreadsheet. Currently, there are 31,094 records in the mitigation database, which contains data from 2001.

Queries were developed using MS Access [13]. These queries produce results for the following information:

a) Number of complete records available.
b) Mitigation tests conducted by each contractor.
c) Percentage removal efficiency in each mitigation case by a contractor.
d) Pre-mitigation level greater than 4 pCi/l and less than 20 pCi/l.
e) Pre-mitigation level greater than 20 pCi/l.
f) Systems with radon removal percentage less than 50%.
g) Average percentage of removal by license number of the contractor.
h) Counties with pre-mitigation levels greater than 4 pCi/l.
i) Average percentage of removal by the type of system used.

The data are analyzed using queries consisting of statistical results for each county and zip code. The analysis results are used to create a quarterly report, which is submitted to the ODH for review. Further, results are uploaded to the Ohio Radon Information Systems (http://www.radon.utoledo.edu) for the public awareness. The data consist of the counties, type of systems used, year and efficiency of the system.

MITIGATION SYSTEMS

The mitigation of radon concentrations by Ohio mitigation contractors have been done, generally by using five different types of mitigations systems and combinations of these. A brief description is given below [14].

Sub Slab Depressurization System (SSD)

The SSD system is a radon control technique designed to achieve lower sub-slab air pressure relative to indoor air pressure, by the use of a fan-powered vent drawing air from beneath the concrete slab. The basic SSD consists of a fan that extracts the air from the soil beneath the house or basement and discharges air into the environment. SSD systems are categorized mainly as "Low pressure/High flow" or "High pressure/Low flow," depending on the type of soil in the foundation of the building. These systems work best if air can easily move in material under slab [15, 16].

Sump-Pit Perimeter Depressurization (SUMP)

This system is used frequently when there is a home with a sump pit. The pit usually has a drain tile from the perimeter of the house, which all drains into the sump. This method involves covering the sump pit opening with an airtight cover, which has a removable section for the access to repair the pit. A vent pipe is then installed in the sump pit and the radon is exhausted from around the perimeter of the home to the outside [15].

Drain Tile Depressurization (DTD)

The DTD system is similar to the active soil depressurization system, where the suction point piping attaches to a drain tile. The drain tile may be outside or inside the footings of the building [15].

Sub Membrane Depressurization (SMD)

This system is designed to achieve lower sub membrane air pressure relative to crawl space air pressure using a vent and drawing the air beneath the soil gas retarder membrane. Plastic sheets are used as the gas retarder membrane. The SMD system has less heat loss than natural ventilation in winter climates [15].

Block Wall Depressurization (BWD)

This depressurization system is used when the foundation wall consists of hollow block construction on a poured concrete footer. The PVC piping is penetrated in the foundation wall and suction is applied to the wall. The BWD system can be applied from the interior or exterior of the building. It can be used only in homes with hollow block-walls and requires sealing of major openings [13].

The database contains five types of mitigation systems and their combinations (SSD, SUMP, DTD, SMD, and BWD). Mitigation system types with more than 20 data points were analyzed. Hence, four mitigation systems, SSD, SUMP, DTD, and SMD, and their combinations were considered in the analysis.

RESULTS AND DISCUSSION

The total mitigation records and the complete mitigation quarterly records are tabulated in Table 1. A total of 14,431 records were collected by the mitigation contractors from 2008 - 2010. Among those 13,422 records (about 93 %) were complete. Complete records indicate records having both pre-mitigation and post-mitigation levels. There is a consistency in percentage of complete records between 2008 and 2010, indicating an improvement in the quality of the radon data collected.

Table 1. Number of Mitigation Records for the Years 2008 - 2010

Quarter	Total Number of Records	Number of Complete Records	Total Records Submitted Yearly	Complete Records Submitted Yearly	Percentage Complete Records
Quarter 1 (Jan.-Mar. 2008)	849	800			94.23
Quarter 2 (Apr.-Jun. 2008)	1100	1059			96.27
Quarter 3 (Jul.-Sep. 2008)	1530	1437			93.92
Quarter 4 (Oct.-Dec. 2008)	1126	1083	4605	4379	96.18
Quarter 1 (Jan.-Mar. 2009)	642	590			
Quarter 2 (Apr.-Jun. 2009)	1215	1106			
Quarter 3 (Jul.-Sep. 2009)	1440	1266			
Quarter 4 (Oct.-Dec. 2009)	1423	1282	4720	4244	90.09
Quarter 1 (Jan.-Mar. 2010)	998	920			
Quarter 2 (Apr.-Jun. 2010)	1612	1519			

Quarter 3 (Jul.-Sep. 2010)	1181	1104			
Quarter 4 (Oct.-Dec. 2010)	1314	1256	5106	4799	93.99
Total	14431	13422			94.30

Table 2 represents the radon data with a pre-mitigation level between 4 pCi/l and 20 pCi/l for each year. It also indicates that the number of records with pre-mitigation levels between 4 pCi/l and 20 pCi/l for each year is in the range of 75% to 85% of the total number of records reported for each year respectively in Table 1. This indicates the importance of implementing mitigation systems in Ohio. The US EPA recommends fixing homes with radon levels at 4 pCi/l and above. Table 3 is the summary of the number of records with percentage removal less than 50 % for each year. The percent removal was calculated using Eq. 1.

$$\text{Percent removal} = \frac{(\text{Pr e} - \text{mitigationlevel}) - (\text{Post} - \text{mitigationlevel})}{(\text{Pr e} - \text{mitigationlevel})} \times 100$$

(Eq. 1)

As illustrated in Table 3, the installation of the mitigation systems in Ohio has been successful. One can observe that the percentage of records for the systems with removal efficiency less than 50% are only 2% to 3% of the total number of complete records for the years 2008 - 2010. Post-mitigation radon levels above 4 pCi/l were observed to be less than or equal to 1% of the total number of records after mitigation systems were adopted during the study period, except in the case of SSD/DTD which has 8.57% for the year 2008 (Table 4). The efficiency of different systems in 88 counties is posted on the radon website[12].

Table 2. Number of records with pre-mitigation level between 4 pCi/l and 20 pCi/l for the years 2008 - 2010

Year	Number of Records with Pre-Mitigation Level between 4 pCi/l & 20 pCi/l
2008	3905
2009	3651
2010	4279

Table 3. Number of records with % removal less than 50 for years 2008 - 2010

Year	Number of Records with Removal % Less Than 50	Percentage of Records with Removal % Less Than 50
2008	82	1.87
2009	108	2.54
2010	126	2.63

Table 4. Percentage of records greater than 4 pCi/l post-mitigation level

Type of System	Percentage of records greater than 4 pCi/l		
	2008	2009	2010
SSD	0.76	0.81	0.33
SSD/SMD	0.52	0.58	0.08
SSD/DTD	8.57	0.91	0.02
SUMP/SSD	-	1.08	-

A statistical analysis was carried out to determine the performance of the four mitigation systems and their combinations. The performance of each of these mitigation systems was evaluated by determining its average removal efficiency. In this study, the standard error of the mean for the average removal efficiency of each system was used for ranking the systems. The standard error of the mean was calculated using Eq. 2.

$$\text{Standard error of the mean} = \frac{\text{standard deviation}}{\sqrt{\text{number of records}}}$$ **(Eq. 2)**

In order to determine average removal efficiency of a system, the mitigation system types were sorted according to the number of records, and then the standard error of the mean was calculated for each of the systems. The lower the standard error of the mean, better the removal efficiency of the system. Table 5 shows the standard error of the mean by each system type for the years 2008 - 2010.

Table 5. Standard error of the mean by each type of system for years 2008 - 2010

Type of System	Number of Records			Average % Removal			Standard Deviation			Standard Error of the Mean		
	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
Sub Slab Depressurization System												
SSD	2649	2595	2835	82.83	74.28	82.27	13.65	29.04	13.42	0.27	0.57	0.25
SSD/SSD	576	342	585	86.53	80.72	84.61	10.72	22.96	12.38	0.45	1.24	0.51
SSD/DTD	35	110	70	87.03	84.16	85.6	9.63	12.93	10.15	1.63	1.23	1.21
SSD/ATTIC	-	-	1	-	-		-	-		-	-	
SSD/EXTE-RIOR	-	-	34	-	-	73.49	-	-	17.17	-	-	2.94
SSD/SUMP/DTD	23	29	16	87.16	79.66	82.29	9.88	27.53	12.54	2.06	5.11	3.14
Sump-Pit Perimeter Depressurization												
SUMP	45	-	41	87.33	-	85.28	11.97	-	8.03	1.78	-	1.25
SUMP/DTD	581	640	465	85.71	82.4	84.51	9.71	18.37	10.17	0.4	0.73	0.47
SUMP/SSD	37	93	15	79.53	58.23	81.77	17.39	41.49	12.36	2.86	4.3	3.19
SUMP/DTD/SMD	43	84	43	84.59	80.8	89.04	14.45	22.75	7.03	2.2	2.48	1.07
SUMP VENTI-LATION	-	41	67	-	67.78	82.3	-	38.63	12.05	-	6.03	1.47
Drain Tile Depressurization												
DTD	162	126	250	86.56	70.59	86.26	16.82	34.46	11.49	1.32	3.07	0.73
Sub Membrane Depressurization												
SMD	19	21	34	78.93	68.92	80.98	15.64	29.48	13.18	3.59	6.43	2.26

It was found that the sub slab depressurization (SSD) system and sump/drain tile depressurization system (SUMP/DTD) had lowest and second lowest standard errors of the means respectively, for all the years. This indicates that the SSD system had better average removal efficiency among all the systems used in the years 2008 - 2010. It can be tentatively concluded that the SSD mitigation systems have better performance over other mitigation systems in the state of Ohio. The reader should keep in mind that other systems have shown more removal efficiency in a number of cases. However, the total number of such mitigation systems is too small to draw conclusions.

Figure 1. Radon levels in Ohio Zip Codes before installing the SSD system.

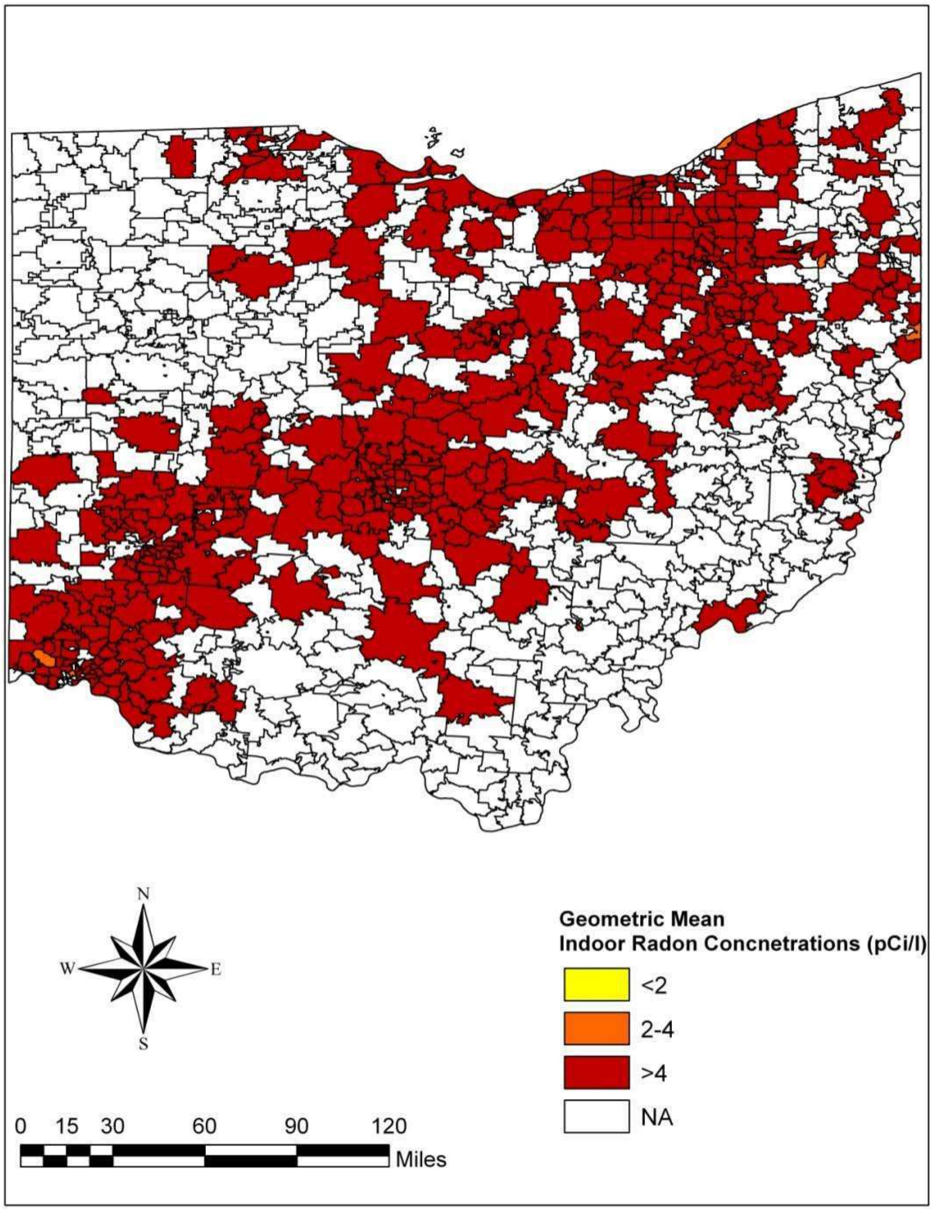
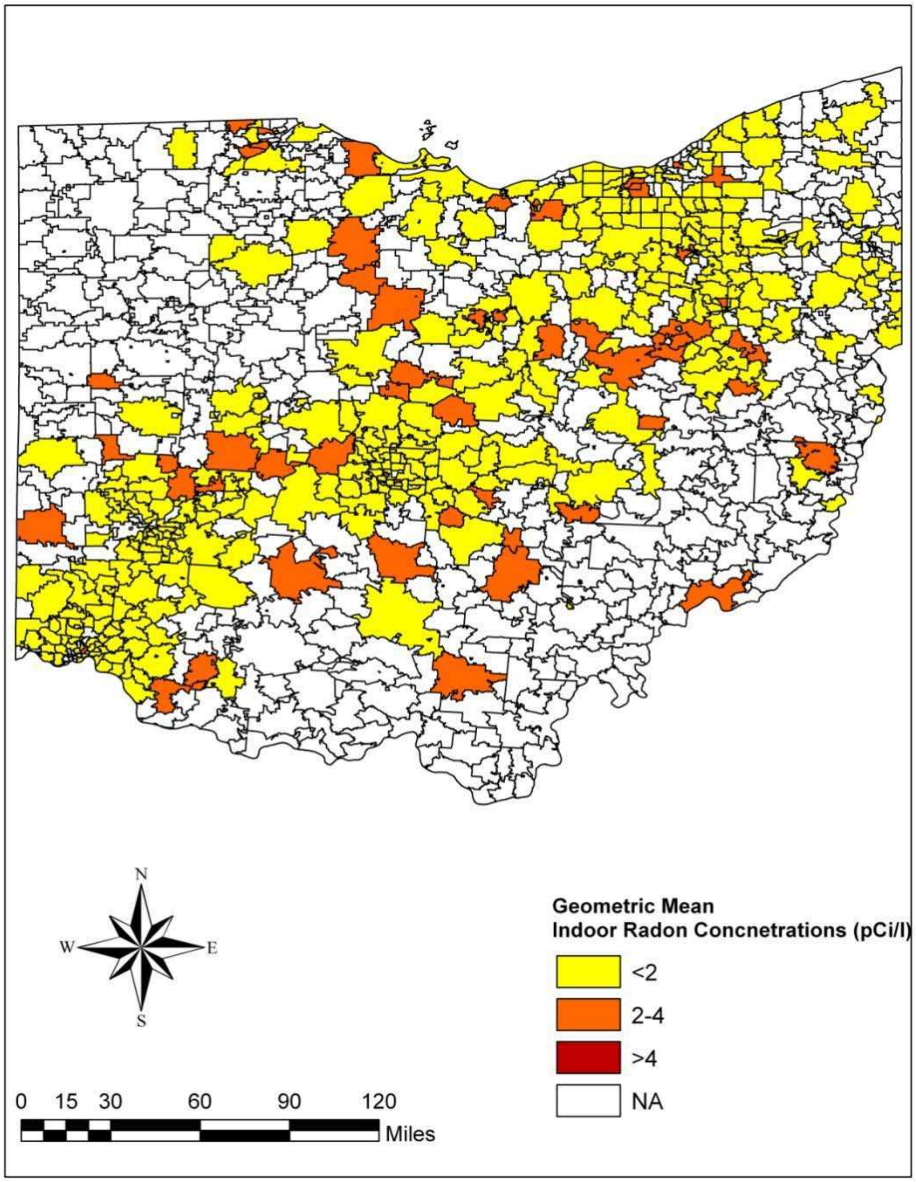


Figure 1 shows pre-mitigation radon levels in Ohio zip codes which were chosen for the SSD mitigation systems from 2008 - 2010. The 'NA' indicates zip codes where SSD systems have not been installed. Figure 2 shows radon levels for various zip codes after the installation of the SSD systems. It can be observed that with the exception of a few zip codes, all the zip codes where the SSD was installed were below the US EPA recommended level of 4 pCi/l. These maps clearly show the effectiveness of implementing the SSD mitigation systems for removal of radon. Moreover, it can be observed that the SSD systems are the most commonly used mitigation system in the state of Ohio (Table 5).

Figure 2. Radon levels in Ohio Zip-Codes after installing the SSD system.



The variation in the average percent removal efficiency with respect to pre-mitigation and post-mitigation radon levels is shown in Figure 3 and Figure 4. Figure 3 indicates an average removal efficiency of 76.85% in the pre-mitigation range of 4 pCi/l – 8 pCi/l. Moreover, it was found that the average percent removal efficiency increased as the pre-mitigation radon levels increased in the tested homes. On the other hand, observation from Figure 4 shows that the average percent removal efficiency decreases with an increase in the post-mitigation radon level. It can be noticed that the average percent removal efficiency of 91.14% was observed to achieve post-mitigation radon levels between 0 pCi/l and 1 pCi/l, based on Figure 4. Hence these graphs will be helpful in choosing a mitigation system.

Figure 3. Variation of average % removal efficiency with pre-mitigation level for the best performing system for year 2010.

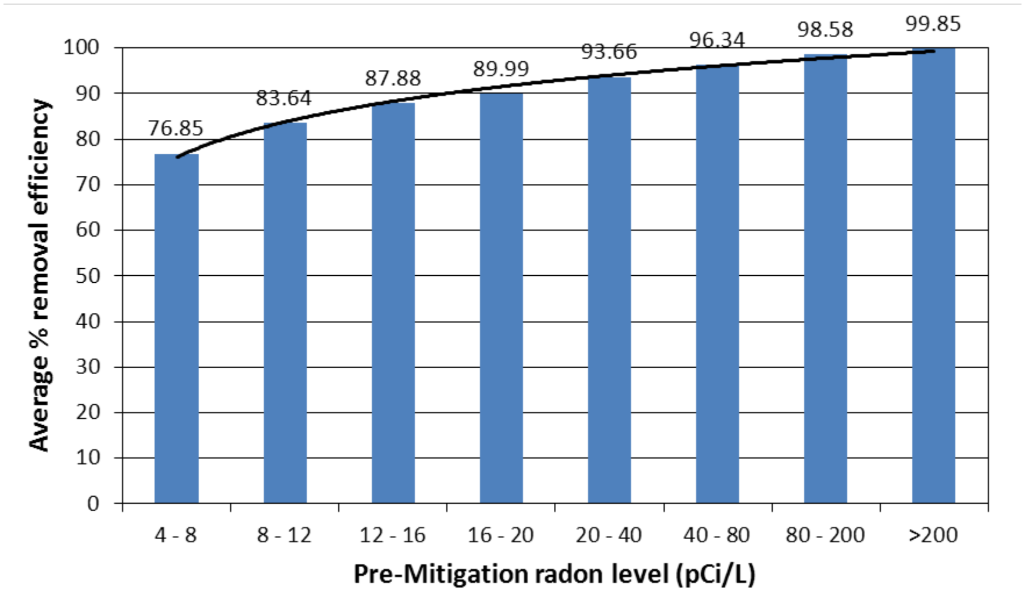
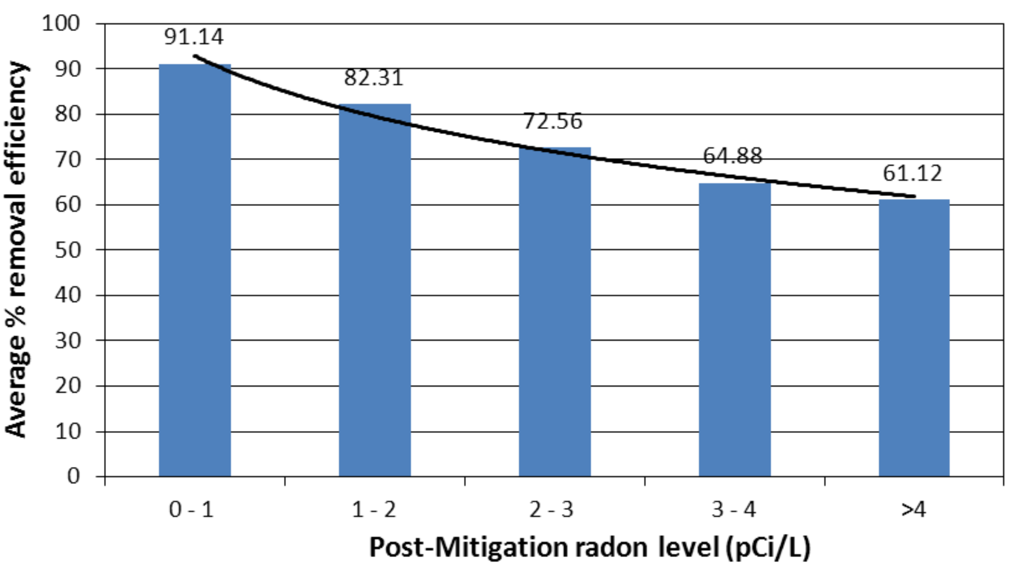


Figure 4. Variation of average % removal efficiency with post-mitigation level for the best performing system for year 2010.



SUMMARY

A total of 14,431 mitigation systems were reported by the mitigation contractors from 2008 to 2010 in the state of Ohio. Among those, 93% of the records were complete. A statistical analysis of each mitigation system was performed, by evaluating its average removal efficiency in terms of standard errors of the mean. It was found that the sub slab depressurization system (SSD) and the sump/drain tilt depressurization system (SUMP/DTD) had overall better removal efficiency among all the other mitigation systems used for the years 2008 - 2010. Moreover, it was found that the SSD system is the most commonly used mitigation system in the state of Ohio. These results were found to be consistent with Kumar et.al [13]. The analysis of mitigation data clearly shows the effectiveness of the mitigation systems used in the state of Ohio.

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KEYWORDS

Radon, mitigation systems, statistical analysis, Ohio Department of Health (ODH), radon database, sub slab depressurization system (SSD).