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Evaluating and Assessing Radon Testing in Housing with multifamily federal financing (The EARTH Study)

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Table of Contents

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Abstract

To determine if radon mitigation is needed to protect occupants of multifamily housing, reliable testing procedures are needed. Yet, protocols on how many ground-contact housing units should be tested for radon vary widely, ranging from 10% to 25% to 100%. Inadequate testing could place occupants of unmeasured units at an increased health risk. This study examined the probability of failing to identify a unit containing elevated radon when all ground-contact units are not tested. Testing data was obtained from 29 US states for 7892 ground-contact units in 687 multifamily buildings of various sizes (primarily 5-20 units per building). Each building had radon results for all (or nearly all) ground-contact residential units. Overall, about 15% of the units had radon ≥4 pCi/L (the EPA action level), and 59 units had radon levels ≥20 pCi/L, with a maximum of 96 pCi/L. The likelihood of failing was modeled to identify unmeasured ground-contact units using hypergeometric and Monte Carlo statistical methods. Based on measurement data for various building sizes, the testing frequency that is necessary to assure the absence of units with radon ≥4 pCi/L was determined for various confidence levels. For building sizes of 5-20 ground-contact units, the 2018 federal testing protocols that currently require testing of 10% and 25% of ground contact units in each building failed to identify 47-69% and 32-46% of the units, respectively, with the range dependent on building size. Measurement of at least 90% of the ground contact units in buildings with 5-20 ground-contact units would result in <4% of the units with elevated radon being missed. A higher testing rate would eliminate the chance of missing units with elevated radon. To achieve 95% confidence that no units in the building have radon ≥4 pCi/L in buildings up to 20 units, 100% sampling is required. For the vast majority of multifamily building sizes, all ground floor units in multifamily buildings should be tested for radon.

Introduction

Radon is a radioactive Group 1 carcinogen that is responsible for approximately 21,000, or 15% of the total, lung-cancer deaths annually (BEIR 1999) in the United States (US). Comprehensive scientific reports on radon health effects have concluded that lung cancer rates increase with increasing cumulative radon exposure (Lubin 1997; Krewski 2006) at the concentrations observed in homes. The current EPA action level for radon in the US, established in 1986, is 4 pCi/L (148 Bq/m^3), while the World Health Organization (WHO) established a reference level of 2.7 pCi/L (100 Bq/m^3) in 2009. WHO reported (Zeeb 2011) that the Population Attributable Fraction of lung cancer from radon was between 2-12%, and thereby annually afflicts, for example, at least 1,234 in France and 1,896 people in Germany.

Elevated radon levels in a multifamily structure are dependent on several variables including 1) the strength of the radon source in the soil under the building, 2) negative pressure differentials within units that continuously draw radon gas from the soil into the building, 3) thermal bypasses that allow uncontrolled entry and circulation of radon in the building, and 4) the rate of fresh-air exchange. These variables often differ markedly in each unit of a multifamily building, resulting in broad distributions of radon and other indoor air-quality metrics. [N*ote: All references to 'units' pertain only to 'ground contact units' in this report.]*

Radon measurement protocols for multifamily housing programs and professional organizations have differed vastly in terms of the percentage of units in multifamily housing to be tested to characterize the radon potential for the building. Radon testing guidelines for loans from two US government-sponsored enterprises (GSEs), Federal National Mortgage Association (known as Fannie Mae) and Federal Home Loan Mortgage Corporation (known as Freddie Mac) allows measurement through partial testing of "a minimum of 10 percent of the units, or one unit per building [for] units on the lowest habitable contact." Prior to a December 2020 policy change to require 100% testing (HUD-MAP 2020), the US Department of Housing and Urban Development's Office of Multifamily Housing required testing 25% of ground level units in each building under FHA multifamily housing loan programs subject to the Multifamily Accelerated Processing (MAP) Guide, the Residential Care Facilities program, and the Rental Assistance Demonstration Program. Currently, no other HUD programs have a radon testing requirement.

In contrast, the testing protocol of the American National Standards Institute-American Association of Radon Scientists and Technologists (ANSI-AARST 2017) requires measurements in 100% of the ground contact units. Most of the states (14 of 19) that regulate radon testing require 100% ground-contact unit testing, while 31 US states do not have the testing requirement. Measurement professionals certified by the National Radon Proficiency Program must conduct 100% ground-contact unit testing. When federal and federally-regulated loan programs authorize measurement of fewer ground contact units, the lender has no incentive to pay for 100% testing, causing a financial conundrum for the radon professionals who must follow the standard's protocols and thereby lose business to others willing to not adhere to the standard. Table 1 summarizes the diverse prescribed testing percentages in the ground contact units of multifamily buildings for radon.

Table 1. Radon testing procedures for multifamily buildings in 2018.

Regulating Authority	**Radon testing protocol**
Federal National Mortgage Assoc. (known as Fannie Mae)	10% of ground contact units
Federal Home Loan Mortgage Corp. (known as Freddie Mac)	10% of ground contact units
U.S. Department of Housing and Urban Development (HUD) Federal Housing Administration (FHA)*	25% of ground contact units
ANSI-AARST MAMF-2017 Multifamily Measurement	100% of ground contact units

** HUD-FHA requires compliance with ANSI-AARST MAMF except 100% ground-contact unit testing*

Ideally, a multifamily radon testing protocol should minimize the chances of failing to identify units with elevated radon levels to protect public health, and avoid needless testing. This requires knowledge of the actual distribution of radon levels in such buildings. To our knowledge, this is the first national study of field data to examine the efficacy of multifamily testing protocols.

Guidance developed (HUD 2012) regarding lead-based paint inspections in multifamily housing include a Table 7.3 and Appendix 12 that details the statistical rationale used to develop sample sizes for testing in multifamily housing that relied on a hypergeometric distribution. The sample size estimates are based on the number of units to be tested to be 95% confident that <5% (for pre-1960) or <10% (for 1960-1978) of all units in the building are out of compliance with lead standards. This hypergeometric approach was applied (Neri 2019) to calculate probabilities for detecting various percentages of units with radon (e.g., ≥4 pCi/L) in multifamily housing units. Wilson (2020) used a similar approach to calculate estimates for multifamily housing of 4-plex and 6-plex buildings.

Although earlier approaches applied hypothetical and small-building data, real probabilities can best be established using actual measurements to develop an evidence-based statistically-sound testing protocol for multifamily housing that is sufficiently protective for the occupants without being overly burdensome to property owners. It permits measurement professionals to follow a single standardized testing protocol to produce validated findings. This paper describes an evaluation of various percentage-based radon testing recommendations using measurement data from one of the largest multifamily housing radon-testing databases ever assembled.

Methods

Prior to data collection, a uniform data-reporting template (Appendix A) was developed for distribution to measurement professionals who participated in the study. This provided a consistent format that could be directly used by the study. The template included "error traps" to assure entries were not non-sensical and were of sufficient quality. Each template was password-protected to shield the privacy of tenants and owners. Table 2 lists the variables provided by the measurement professionals, although some parameters (e.g., Loan Type) were not available for some properties.

Table 2. Parameters collected for measured buildings using study template.

• Unit Number	• Device Manufacturer
• Result (pCi/L)	• Crawlspace vent (Y/N) and Vent Status
• Test Type (single, duplicate, blank)	• Address, City, State, Zip
• Corner or End Unit (Y/N)	• EPA Zone
• Entry Opens to Outside (Y/N)	• Stories in Building
• Testing Location (e.g., basement)	• Type of HVAC
• Description of Room use	• Is Property Subsidized (Y/N)
• Start and End Dates	• Was Testing Lender- Initiated (Y/N)
• Device Used (AC, AT, EL, LS)*	• Loan Type (e.g., HUD-FHA, other)

**AC (activated charcoal), AT (alpha track), EL (electret), LS (liquid scintillation vial)*

All radon results were received from radon professionals certified by either the National Radon Proficiency Program (NRPP) or the National Radon Safety Board (NRSB), and (when applicable) certified and/or licensed by state radon programs. Participation and contributions were voluntary, and preference was not given to data from any state. While data were received from many professionals, a significant portion was supplied by Protect Environmental, LLC (KY), A-Z Solutions, Inc. (OH), Radon Detection Specialists, Inc. (IL) and DuPage Radon Testing, Inc. (IL), due to the volume of multifamily buildings tested by these companies.

All data used in this study employed a 100% testing protocol. Although testing all residential ground-contact units in a building was a goal, occasionally access to a unit to deploy or retrieve a detector was problematic. In order to be included in this study's database, a minimum of 90% completion was deemed acceptable for buildings with 10 or more units. Buildings with 5-9 units were acceptable provided at most one unit was incomplete. No measured units had a radon mitigation system. Upon receipt, all data were reviewed for compliance with quality assurance protocols (Appendix B) and then forwarded to the statistician for further review prior to inclusion in the data set.

Measurements were conducted about equally by calendar quarter, with the exception of nearly 40% more during the third quarter. Nearly all (88%) radon measurements were conducted using activated charcoal detectors, followed by alpha track, electret, and liquid-scintillation vial detectors.

S*tudy limitations and areas of potential bias*

It was not the intent of this study, nor do the authors suggest, that the radon prevalence found in this study is nationally representative of radon at US multifamily properties. Radon measurements included only ground-contact units of multistory buildings, thus this study does not represent radon throughout all multifamily buildings, but rather prevalence in the ground contact units of the multifamily buildings studied.

As the number of each building size was obtained, preference was given to obtaining data for other buildings in the range of 5-20 ground-contact housing units per building. When necessary to develop statistical power, building sizes were grouped (e.g., 5-6 units, 7-8 units, etc.). Preference was ~~also~~ given to obtaining data that included buildings with one or more units with elevated radon, since a central study question was to ascertain the likelihood of missing a unit with elevated radon. However, a sensitivity analysis was conducted to assess how the total error probability would change if the percentage of buildings with any units ≥4pCi/L were 50% lower or 50% higher than the observed value.

The data are not a geographically or regionally representative sample as might be found in a national survey with randomized selection. As shown in Table 3, data for 18 states are based on 3 or fewer properties and, thus, unlikely to be representative of the state. However, less than 5% of the properties are located in counties classified by EPA as Zone 3, which is consistent with the fact that less radon testing occurs in areas labeled low-risk.

Note that, while indoor radon levels may fluctuate both daily and seasonally, most measurements in the study database were only 2-3 days in duration.

Nevertheless, this study's database constitutes one of the nation's largest and enables a sound examination of various testing protocols in multifamily housing.

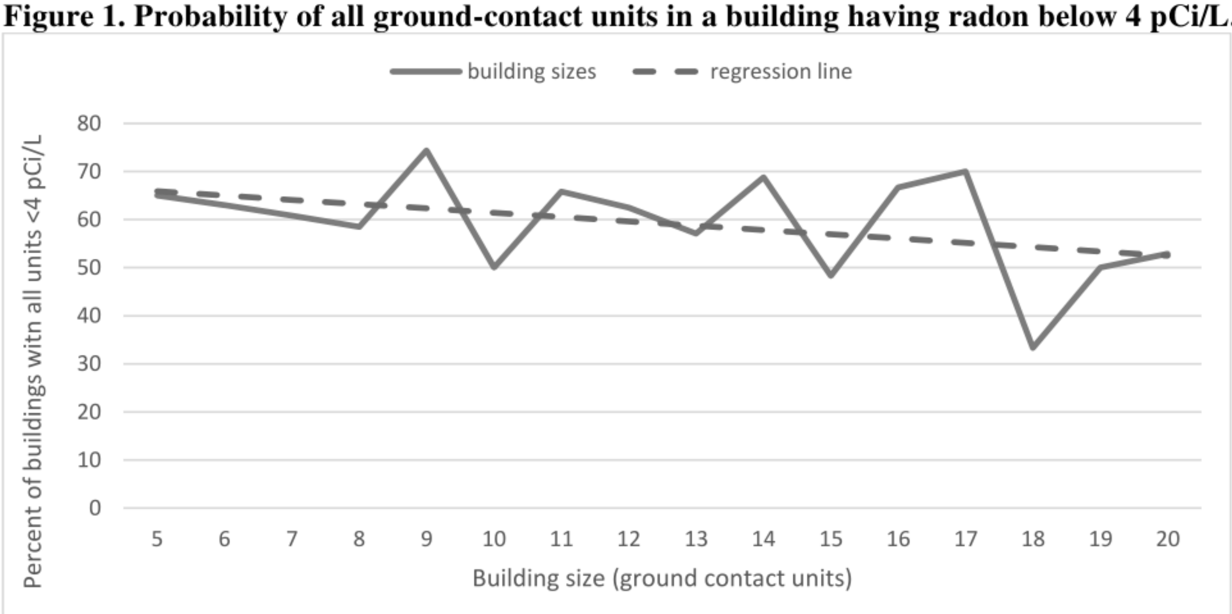
Results and Discussion

Ground-contact radon levels in multifamily buildings were obtained from 687 buildings located on 152 properties in 29 US states (Table 3). One third of the buildings were in locations (e.g., IL and OH) where State radon licensure programs require 100% testing of multifamily ground-contact units. The total number of units tested in states ranged from 24 (MT) to 1705 (OH). Overall, 93% of the buildings were three or fewer stories and 43% of the buildings were assisted living facilities. The frequency of units with elevated radon levels exceeded the average of 1-in-7 units in nine states.

Of the 7892 measured residential units, nearly 15% contained radon levels ≥4 pCi/L which is significantly greater than the 6% estimate for national prevalence reported by the EPA (NRRS 1986). Over 25% of the radon results exceeded the WHO action level of 2.7 pCi/L. The arithmetic mean of 2.36 pCi/L was also greater than the EPA average of 1.25 pCi/L. Of the 687 buildings, 42% had elevated radon in at least one unit, therefore 398 buildings had no units ≥4 pCi/L of radon.

The probability of a building having all units with radon below 4 pCi/L generally decreased as the number of units within a given building increased (Figure 1), dropping from 66% to 52% for 5 to 20 units per building, respectively.

Figure 1. Probability of all ground-contact units in a building having radon below 4 pCi/L.



The distribution of units that contained radon ≥4 pCi/L is shown in Figure 2. The frequency distribution of the study's buildings may reflect actual housing stock, as most multifamily buildings are located in urban and suburban areas where real estate costs dictate smaller building footprints (fewer ground-contact units). Buildings with a larger footprint (>20 units) comprised only 7% of the total submitted by measurers. This skewed distribution is reflected in the total number of units for each building size (Figure 3) even though a single 15-unit building has triple the units of a 5-unit building. Several building sizes have radon measurements from over 500 units.

Table 3. Locations of and radon prevalence in measured buildings.

	Property		Building		Unit	
State	**Number of Properties**	**Percent of properties with ≥4 pCi/L**	**Number of Buildings**	**Percent of buildings with ≥4 pCi/L**	**Number of Units**	**Percent of units with ≥4 pCi/L**
AL	1	100	24	67	202	19
AZ	3	100	14	71	302	22
CT	8	50	56	18	547	4
FL	9	89	34	82	438	41
IL	31	58	98	40	992	12
IN	3	100	24	50	195	18
KS	3	67	13	23	182	3
KY	11	55	30	53	435	31
MA	6	67	17	35	173	14
MI	1	100	26	19	237	4
MN	3	33	10	20	145	5
MT	1	0	1	0	24	0
NC	4	75	15	60	151	32
NJ	2	0	20	0	198	0
NV	2	100	8	75	102	16
NY	3	67	6	67	68	10
OH	23	70	139	50	1705	15
OR	2	50	7	14	64	2
PA	8	88	29	52	380	22
RI	1	100	9	11	104	1
SC	2	100	3	67	78	5
TN	5	60	28	39	264	20
TX	1	100	1	100	77	10
UT	1	100	19	37	124	9
VA	5	80	14	57	152	11
WA	2	0	5	0	57	0
WI	7	57	24	33	324	5
WV	3	0	8	0	114	0
WY	1	0	5	0	58	0
Total	152	65	687	42	7892	15

For buildings with 5-20 ground-contact units, the average radon levels varied significantly according to the number of units with radon ≥4 pCi/L. As shown in Table 4, 59% of the units were in buildings that had no units with radon ≥4 pCi/L and their radon levels averaged 1.02 pCi/L. However, the building radon level doubled when a single unit in the building had ≥4 pCi/L, and quintupled when more than one unit in the building contained radon ≥4 pCi/L.

Figure 2. Distribution of buildings sizes with one or more units containing radon ≥4 pCi/L.

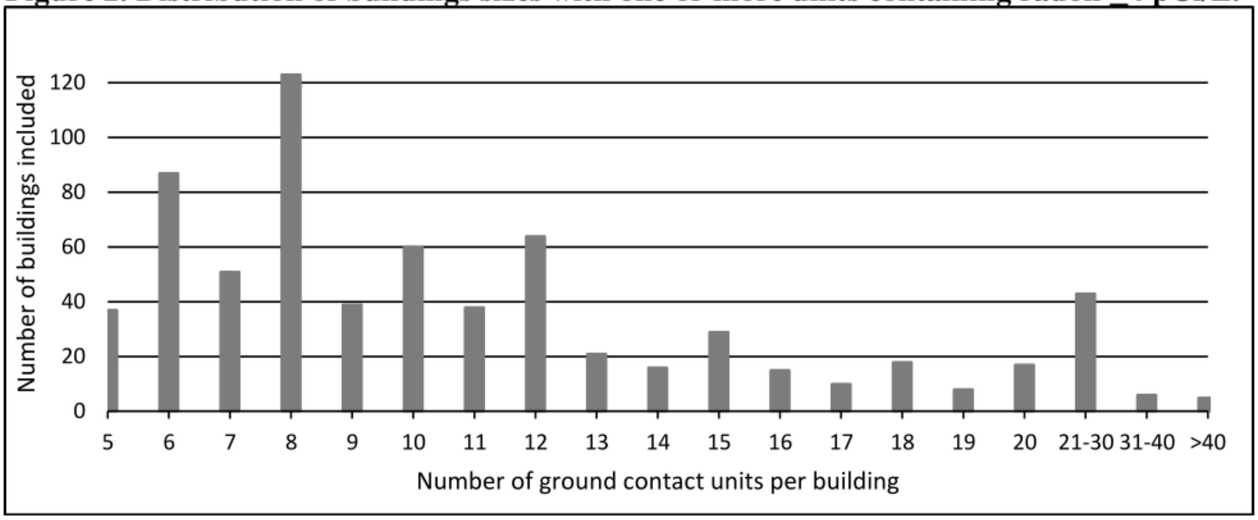


Figure 3. Distribution of ground contact units containing radon ≥4 pCi/L by building size.

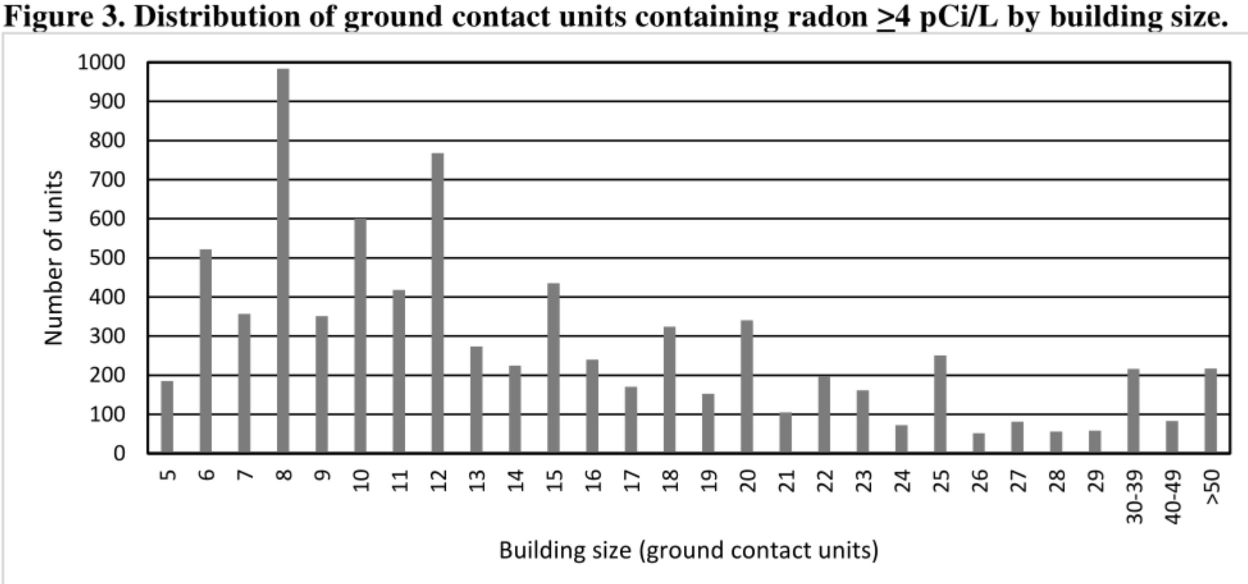
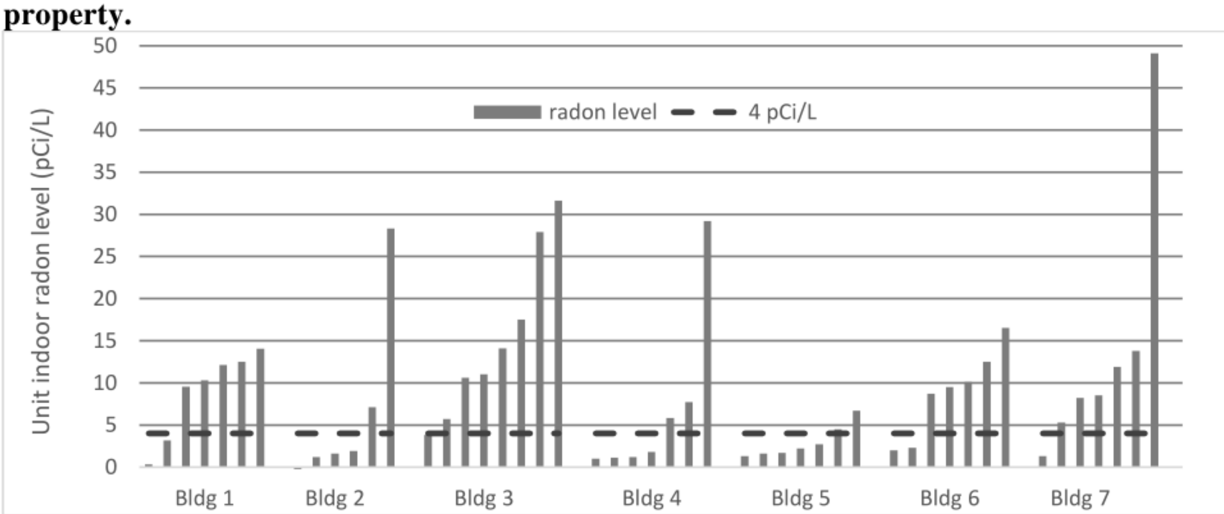


Table 4. Average radon levels in buildings vary with number of units with elevated radon.

Number of units in building ≥4 pCi/L	Number of buildings	Number of units	Arithmetic Mean (pCi/L)	95% confidence interval for AM (pCi/L)	Geometric Mean (pCi/L)	95% confidence interval for GM (pCi/L)
0	379	3,722	1.02	0.99-1.04	0.71	0.69-0.73
1	70	747	2.13	2.01-2.25	1.59	1.49-1.69
2 or more	184	1,874	5.15	4.89-5.41	3.48	3.34-3.63

Buildings that contained 10 or fewer units comprised 58% of the total (Figure 2). Under current federal GSE mortgage (Fannie Mae; Freddie Mac) testing procedures, only one unit would need to be measured in these buildings (Table 1). Such testing procedures are likely problematic, as the radon level in a particular unit is dependent on the radon content of the underlying soil and the differential pressure that continuously draws radon into the unit. These two variables alone can produce a wide range of radon levels, even within a small building. For example, all buildings in a seven-building complex that had at least one unit with radon below 4 pCi/L in each building (Figure 4) would misrepresent the buildings as having no radon problem if (although unlikely) those were the units measured. Yet, over 60% of the unmeasured units did in fact contain elevated radon. Thus, testing a small number (or percentage) of the units could easily mischaracterize the true radon risk associated with a large number of units. Even the HUD FHA 25% sampling procedure (2 units tested) would have missed units with elevated radon in five of the seven buildings.

Figure 4. Example of radon level variation by unit and building in a seven-building property.



Study information collected included whether the main entry of a measured unit opened to the outdoors (Table 5). Of the 3944 units that had an inside main entry, 17% of the units contained ≥4 pCi/L, while only 6% of the 1583 units with outdoor main entries had elevated radon levels, presumably due to increased dilution with outdoor air. Inside entry units had statistically significantly higher geometric mean (GM) radon levels compared to outside entry units ($p<0.001$).

Table 5. Radon levels based on unit main entry.

Main entry to unit	Number of units	Units ≥4 pCi/L	Geometric Mean Radon (pCi/L)
Outside entry	3,944	6%	1.11
Inside entry	1,583	17%	1.39

Reported measurement locations (Table 6) were primarily (83%) "above slab" (e.g., slab on grade) and this foundation type had the highest percentage of units with elevated radon.

Table 6. Radon prevalence in measurement locations.

Measurement Location	Number of units	Percent of units ≥4 pCi/L
Above crawl space	31	10
Above basement	344	3
Above slab	6,626	16
In basement	824	14
Other	67	1.5

In 1993, the EPA developed county-level radon potential maps and assigned each to a "zone", with zone 1 containing homes with the greatest likelihood of indoor radon levels ≥4 pCi/L and zone 3 having the least likelihood. These zone designations are in common use throughout the US. Buildings in this study were assigned EPA zones based on their locations. Although data were obtained from 29 states, nearly all (97%) measured buildings (Table 7) were in the higher radon-potential zones 1 and 2. The percentages of buildings and units with radon ≥4 pCi/L were equivalent for the two zones.

Table 7. Radon zone locations for study measurements.

	Buildings			Units	
EPA Zone	Number of Buildings	Percent of any unit ≥4 pCi/L		Number of Units	Percent of a unit with ≥4 pCi/L
1	383	43		4,333	14
2	283	44		3,289	17
3	21	5		270	3

Although 58% of all study buildings had no units with radon levels ≥4 pCi/L, the results for the units with elevated radon (Table 8) drop off quickly with 77% below 10 pCi/L and 95% below 20 pCi/L. However, 59 units had radon levels ≥20 pCi/L, ranging up to a maximum of 96 pCi/L.

Several states with over 15% of units containing radon ≥4 pCi/L (Figure 5) were located in temperate and hot climates. Generally, the EPA radon map equates these climates with having moderate radon potential, but due to cooling costs the demand for "tight" housing likely results in low fresh-air exchange in these units and a greater probability for elevated radon levels.

Table 8. Distribution of measurements ≥4 pCi/L.

Indoor radon level (pCi/L)	Number of units	Percentage
4 to <6	574	49
6 to <8	224	19
8 to <10	106	9
10 to <15	144	12
15 to <20	56	5
20 or more	59	5

Figure 5. Percent of multifamily units with radon ≥4 pCi/L in US states with 4 or more measured properties.

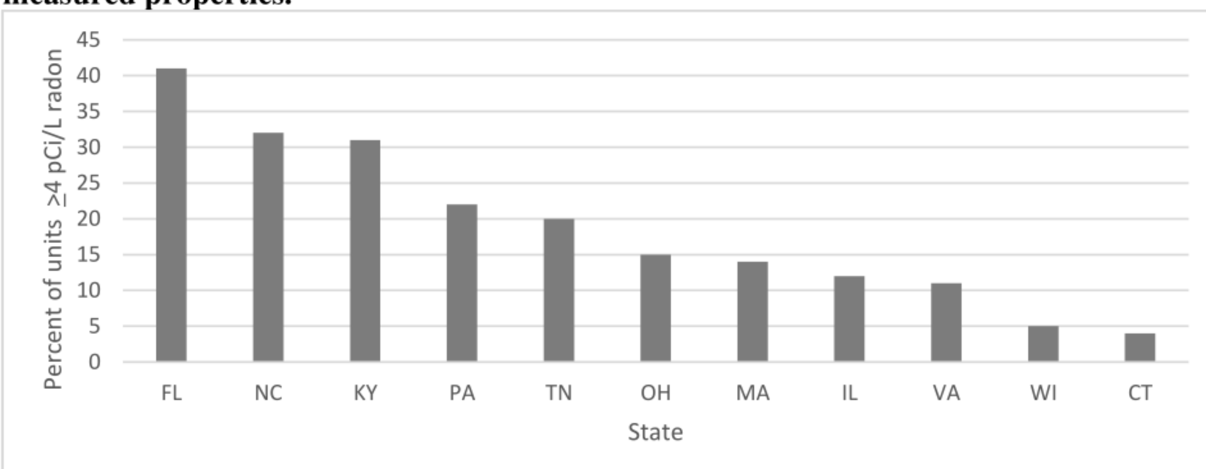


Table 9. Radon prevalence by IECC climate zone.

IECC Climate zone		Number of units	Percent of units ≥4 pCi/L
1-A	Very Hot - Humid	392	41
2-A	Hot- Humid	46	44
2-B	Hot - Dry	302	22
3-A	Warm - Humid	478	11
4-A	Mixed - Dry	1,664	20
4-C	Mixed - Marine	85	1
5-A	Cool - Humid	4,112	12
5-B	Cool - Dry	262	10
6-A	Cold - Humid	469	5
6-B	Cold - Dry	82	0

To further examine climatic influence, building locations were categorized based on International Energy Conservation Code zones (IECC 2020). “Hot” climate zones contained the largest percentage of units ≥4 pCi/L (Table 9) with units in the cooler climates having less radon ≥4 pCi/L. The high percentage of units with ≥4 pCi/L contrasts with EPA low-radon Zone 3 (FL and NC) and Zone 2 (AZ and KY) designations.

Statistical Methods and Results

Statistical significance is traditionally defined as an observed significance level (p-value) less than 0.05. For analysis of radon levels, measurement data were natural log-transformed. If the radon result was below the limit of detection it was replaced by the limit of detection divided by the square root of two. SAS version 9.4 was used for all analysis (SAS Statistical Software, Cary, NC).

There are two primary reasons to focus on log-transformed radon and geometric means rather than non-log-transformed radon and arithmetic means. First, researchers have found the distribution of residential radon concentrations to be satisfactorily represented by a lognormal distribution (Marcinowski 1994; Nero 1986). Second, factors affecting radon levels are multiplicative, not additive (Miles 1994; Daraktchieva 2010).

Many analyses presented here are based on whether the radon threshold of 4 pCi/L (yes/no) is exceeded. Other analyses are based on actual radon concentrations. For buildings with a specified number of ground contact units exceeding a threshold, the hypergeometric probability distribution describes the probabilities of drawing a specific number of units exceeding the threshold and is used for many calculations in this report. A strength of that hypergeometric analysis is that assumptions regarding the number of units exceeding a threshold are easy to make. However, such analysis does not distinguish between a radon level of 4.1 and 41.1 pCi/L.

Table 10 presents a summary of the radon found in the study units. Forty-two percent of buildings have at least one unit with radon ≥4 pCi/L.

Table 7.3 of the HUD Guidelines for the Evaluation and Control of Lead-Based Paint Hazards presents the number of multifamily units that must be tested for lead. If all sampled units are compliant for lead, there is at least 95% confidence that less than 5% of the pre-1960 or less than 10% of the 1960-1978 units in the building do not meet the compliance requirements for lead. The same approach can be applied to radon. This study uses the more stringent approach to be 95% confident that no units in the building are out of compliance (i.e., radon ≥4 pCi/L).

Statistically, this is equivalent to determining the number of units to test so that, in a building with **at least one unit** with radon ≥4 pCi/L, the probability of the testing not including any units ≥4 pCi/L is less than 95%. A difficulty with this approach is that the probability cannot be calculated when the number of units with radon ≥4 pCi/L in the building is not explicitly known. Therefore, the probability of testing no units with radon ≥4 pCi/L in a building of the specified size with **exactly one** unit with radon ≥4 pCi/L is less than the probability when there is at **least one** unit with radon ≥4 pCi/L. Hence the estimates in Table 11 are based on the worse case that is most difficult to detect (that only one unit in the building has radon ≥4 pCi/L). Table 11 presents the percent testing requirements to achieve 95% confidence that the specified thresholds for units ≥4 pCi/L are met based on the hypergeometric distribution. The data obtained for this study is not needed to perform this calculation. In up to 20-unit buildings, all units must be tested to obtain 95% confidence that <5% or no units have radon ≥4 pCi/L.

All subsequent analyses in this report use the hypergeometric distribution and actual study data.

Table 10. Summary of radon ≥4pCi/L in buildings and units.

Building size (GC units)	Number of Buildings	Percent of buildings with at least one unit ≥4pCi/L	Number of buildings with at least one unit ≥4 pCi/L	Number of units	Percent of units ≥4 pCi/L
05-06	124	36	45	707	15
07-08	174	41	71	1,341	18
09-10	99	40	40	951	15
11-12	102	36	37	1,186	11
13-14	37	38	14	497	13
15-16	44	45	20	675	18
17-18	28	54	15	494	12
19-20	25	48	12	492	9
21-26	36	61	22	838	16
27-77	18	72	13	711	15
All	687	42	289	7,892	15

Table 11. Number of units to test and percent testing requirements to achieve 95% confidence that the specified thresholds are met.

	Threshold		
Number of Ground contact units	<10% units have radon ≥4pCi/L	<5% units have radon ≥4pCi/L	No units have radon ≥4 pCi/L
5	5 (100%)	5 (100%)	5 (100%)
10	10 (100%)	10 (100%)	10 (100%)
15	11 (73%)	15 (100%)	15 (100%)
20	15 (75%)	20 (100%)	20 (100%)
25	15 (60%)	20 (80%)	24 (96%)
30	18 (60%)	23 (77%)	29 (97%)
40	18 (45%)	23 (58%)	39 (98%)