Revisiting the Building Design Attributes and Indoor Radon: A Survey of 36 Homes in the Commonwealth of Kentucky

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Abstract

Radon is an odorless radioactive gas that exists in the soil underneath buildings in areas that is rich in Radium and Uranium. It seeps from the soil and accumulates in the indoor environment. In 2009, radon gas has been classified by the International Agency for Research on Cancer as being carcinogenic to humans. According to the US Environmental Protection Agency (EPA), indoor radon is the second leading cause of lung cancer after smoking in the United States. EPA recommends homeowners mitigate their houses against radon if the indoor radon concentration exceeds 4 pCi/L. Building new healthy homes while developing affordable building renovation strategies is one of the key solutions to mitigate the impacts of such environmental hazards. This research explores the relationship between building design attributes and radon gas in areas prone to higher concentrations of indoor radon. 36 homes with different age, design features, and construction materials were tested in Bowling green Kentucky, an area classified as zone 1 by the Environmental Protection Agency (EPA). Zone 1 is defined by the EPA as an area where the predicted indoor radon average is greater than 4 pCi/L. The survey also collected data about the architectural design, construction materials, structure systems, HVAC systems, and building envelope design of each house that participated in the study. The purpose is to feedback to the construction industry with potential improvements to help with the current indoor radon mitigation efforts. The results open the doors for further research needed to enhance the current building design and construction methods in areas prone to a higher concentration of indoor radon.

Keywords: Indoor radon; Design attributes; Home; Kentucky

1 Introduction

Radon gas exists in the soil of areas rich in radioactive substances such as Radium and Uranium (Dieu Souffit et al., 2022; Missimer et al., 2019). It seeps from the soil to indoor environment and accumulates to higher levels during the winter months. One of the adverse health effects of indoor radon is being one of the primary causes of lung cancer for non-smokers (Cheng et al., 2021; Riudavets et al., 2022; Su et al., 2022; Vogeltanz-Holm & Schwartz, 2018). EPA set 4 pCi/L indoor radon concentration as a threshold for homeowners to mitigate their houses. The current study investigates various design attributes and potential impacts on indoor radon in Warren County, Kentucky. The average indoor radon in this area is higher than 4 pCi/L.

A previous geological research was done to study the fact that Bowling Green is a city built on Karst landscape is subjecting homes to environmental issues such as high indoor radon (Webster, 1990). The study found indoor radon concentration average of 25 pCi/L with 47% of the homes in the area above the 4.0 pci/L limit. The EPA reported in 2020 that the average indoor radon is 14.0 pci/L in Bowling Green Kentucky homes (EPA). However, the geological research did not include building design attributes regarding indoor radon in such areas.

2 Building Design Attributes

There are many design attributes that contribute to indoor radon. The attributes include building structure, foundation type, building envelope design, construction materials, heating and cooling systems, building location, and cost of construction. Homeowner's requirements or needs are the main driver to the building design attributes (Barros-Dios et al., 2007; Li & Hopke, 1991; Lu et al., 2019; Mansour, 2021; Stabile et al., 2016; Webster, 1990). However, homeowners are not fully aware of such important design attributes. According to the realtor association of US only 5-10% of home buyers are aware of indoor radon issue who ask to get the house tested before signing the contract (Momin et al., 2018). Homeowner's choice of home location is mostly based on their work location (Manaugh et al., 2010). Also, according to The National Association of Home Builders (NAHB) analysis of the Census Bureau's Survey of Construction (SOC), Custom homes accounted for only 17.6% of new single-family homes started in 2021. This indicates that most of home design attributes are not a result of feedback from the current homeowners or building users. For instance, homeowners might have a preference in the foundation type but most of the time they buy a house with certain type of foundation based on the availability in the area they want to live in. they don't choose the construction details, they just choose from what is available and already built by the contractors.

Homeowners find wood frame structure as a first and dominant choice when buying a house in the United States. They only have a few choices for building envelope style and materials, either exterior wood frame wall covered with vinyl siding, or covered with brick veneer. They also don't have various choices for heating and cooling systems. For example, in Bowling Green Kentucky with its humid subtropical climate, all new construction homes are mechanically ventilated with forced air HVAC system, A combination of a furnace for heating in winter and a heat pump for cooling in summer. The authors surveyed various factors that could attribute to the indoor radon concentration, however, only 4 attributes were examined in the current study; foundation type, ventilation type, building envelope materials, and availability of mitigation systems in the tested homes, Figure 1 shows the building design attributes considered in the current study.

Fig. 1: Building design attributes considered in the study

3 Method

Most of the research into indoor radon involves measurements of radon averages in the indoor environment using one of two ways (Yarmoshenko et al., 2016). Short-term testing using passive devices or active devices that usually take between 2 and 90 days. The passive devices include Alpha track detectors, charcoal canisters, or charcoal liquid scintillation detectors. After using passive devices for testing, they are usually sent to a laboratory for analysis. On the other hand, active devices require power to operate. Continuous monitors and Alpha trackers are commonly used for long-term testing (George, 2008). A long-term test gives a reading that is more likely to reflect the building's year-round average radon level than a short-term test (Barros et al., 2014). In the present study, active digital Alpha trackers were used to offer more precise readings for greater potential for generalization.

Professional digital radon monitors were used to identify the average indoor radon concentrations in thirty-six houses, each house was tested for at least 72 hours. Some houses were tested for longer term up to three months period because they were part of another experiment. Each monitor has a passive diffusion chamber and uses Alpha spectrometry to calculate the average indoor radon. Table 1 shows the sample characteristics such as age, mitigation status, foundation type, building envelope materials, ventilation type, and average indoor radon in pCi/L. Figure 2 shows the sample clustered based on building design attributes.

Table 1: Building characteristics aligned with the indoor radon averages

House number	Time it was built	Mitigation status (Mitigated/ non-mitigated)	Foundation type	Building Envelop materials	Naturally/ Mechanically Ventilated	Average indoor radon concentration pCi/L
1	1970	Mitigated	Crawlspace	Brick	Mechanically	5.3
2	1999	Mitigated	Crawlspace	Vinyl siding	Mechanically	5.1
3	1920	Mitigated	Slab	Brick	Mechanically	8.9
4	2006	Mitigated	Crawlspace	Brick	Mechanically	2.5
5	1924	Mitigated	Slab	Brick	Mechanically	6.4
6	1993	Mitigated	Crawlspace	Vinyl siding	Mechanically	5.4
7	2004	None	Crawlspace	Brick	Mechanically	4.1
8	1981	Mitigated	Basement	Brick	Mechanically	1.4
9	2005	None	Crawlspace	Brick	Mechanically	2.0
10	1951	None	Crawlspace	Vinyl siding	Mechanically	8.1
11	2021	None	Crawlspace	Vinyl siding	Mechanically	13.2
12	2017	None	Crawlspace	Vinyl siding	Mechanically	2.9
13	2010	Mitigated	Crawlspace	Brick	Mechanically	1.8
14	1974	Mitigated	Slab	Brick	Mechanically	8.4
15	2018	None	Crawlspace	Vinyl siding	Mechanically	5.9
16	2018	None	Crawlspace	Vinyl siding	Mechanically	7.6
17	2019	None	Crawlspace	Vinyl siding	Mechanically	9.2
18	2019	None	Slab	Vinyl siding	Mechanically	4.3
19	2019	None	Crawlspace	Vinyl siding	Mechanically	13.1
20	2020	None	Crawlspace	Vinyl siding	Mechanically	7.6
21	2020	None	Crawlspace	Vinyl siding	Naturally	0.7
22	2020	None	Crawlspace	Vinyl siding	Mechanically	5.5
23	2020	None	Crawlspace	Vinyl siding	Mechanically	8.9
24	1938	None	Basement	Vinyl siding	Mechanically	2.9
25	1950	None	Crawlspace	Brick	Mechanically	54.5
26	1950	None	Crawlspace	Stone	Mechanically	4.0

House number	Time it was built	Mitigation status (Mitigated/ non-mitigated)	Foundation type	Building Envelop materials	Naturally/ Mechanically Ventilated	Average indoor radon concentration pCi/L
27	1972	None	Crawlspace	Vinyl siding	Mechanically	13.8
28	1971	None	Crawlspace	Brick	Mechanically	26.0
29	1972	None	Crawlspace	Brick	Mechanically	21.8
30	1973	None	Crawlspace	Brick	Mechanically	25.8
31	1971	None	Crawlspace	Brick	Mechanically	25.3
32	1936	None	Basement	Stone	Mechanically	16.8
33	1936	None	Crawlspace	Brick	Mechanically	5.5
34	1978	None	Crawlspace	Brick	Mechanically	22.0
35	1992	None	Crawlspace	Brick	Mechanically	26.4
36	1993	None	Crawlspace	Vinyl siding	Mechanically	14.1

The radon data was analysed to find out whether is there a corelation between building age and indoor radon, to identify the mean and median of indoor radon in the 36 houses, the mean and median of indoor radon in each foundation type, the mean and median of each building envelope type, and compare these averages. The purpose is to explore a potential impact of such building design attributes on indoor radon concentration in Bowling Green KY an area classified as zone 1 by the EPA.

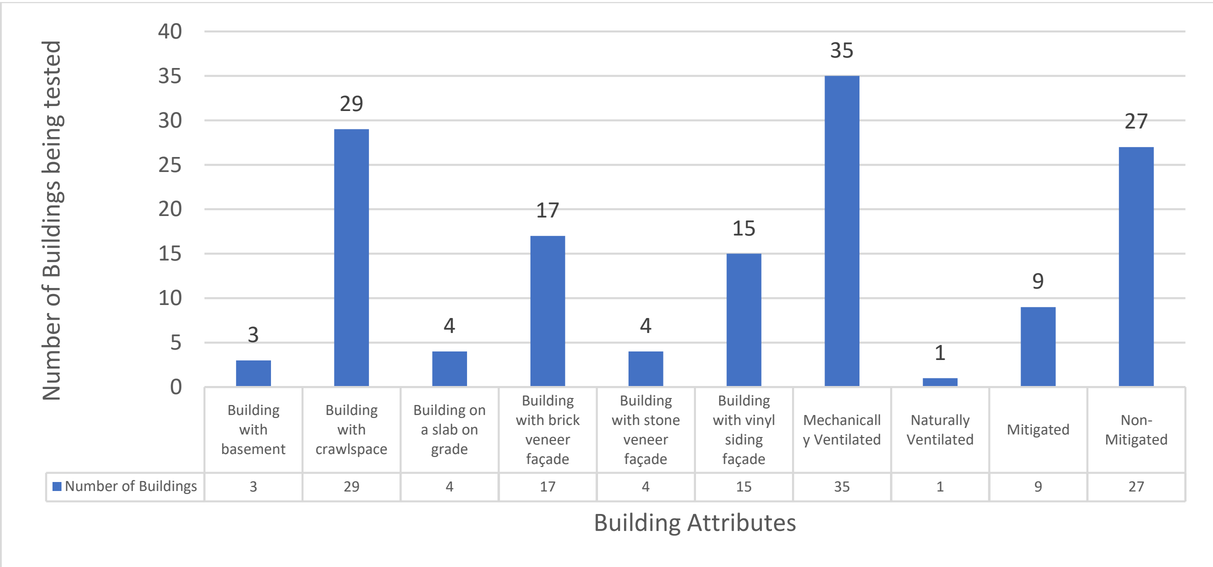

Fig. 2: Buildings included in the study clustered based on the design attributes

4 Results

The indoor radon readings range between 2 to 54.4 pCi/L in the 36 houses with average of 11.03 pCi/L and median 7.6 pCi/L. The indoor radon concentration average in the 36 houses exceeds the limit set by the EPA 4 pCi/L (the mitigation threshold set by the EPA). This result updates the work of Webster (Webster, 1990) that showed the average of indoor radon in 113 homes in Bowling Green Kentucky in 1990 to be 25 pCi/L. in the current study, only 3 (8.3%) of the 36 houses have indoor radon concentration less than 4pCi/L. 9 (25%) of the 36 houses have radon mitigation systems installed, however, it has been found that only 2 of the 9 mitigated houses have indoor radon concentration less than 4pCi/L.

Figure 3 shows the radon readings with the indoor air temperature, relative humidity, and atmospheric pressure in one of the houses. This house was tested for long term indoor radon. The readings were collected around the clock for five months, the average indoor radon concentration was found 14.1 pCi/L.

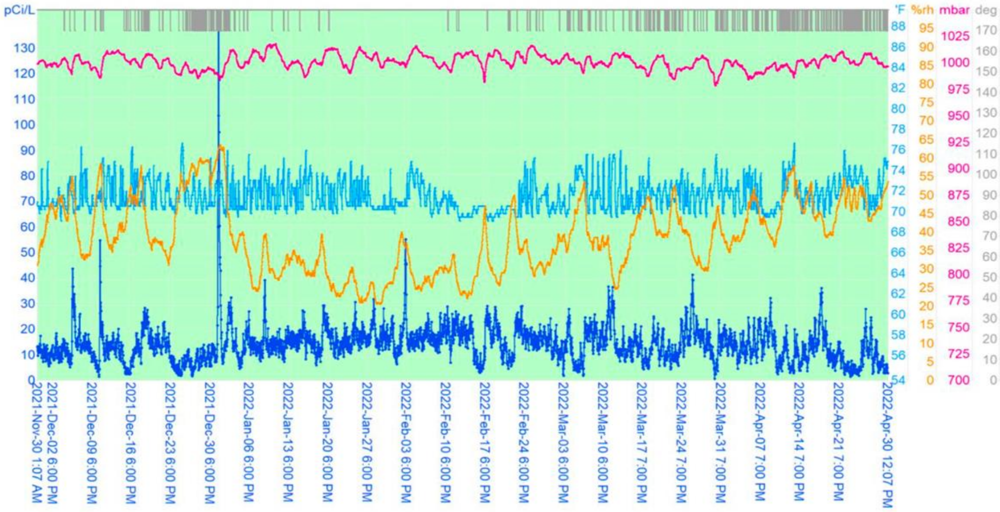

Fig. 3: Indoor radon readings pCi/L aligned with indoor air temperature, relative humidity, and atmospheric pressure in one of the houses included in the study

Figure 3 shows the relationship between the house age and the averages of indoor radon. The analysis shows that there is a weak or almost no correlation between building age and indoor radon averages in the 36 houses. The correlation coefficient is 0.2718. This result contradicts with the authors previous pilot study on mitigated houses in Bowling Green Kentucky (Mansour, 2021)

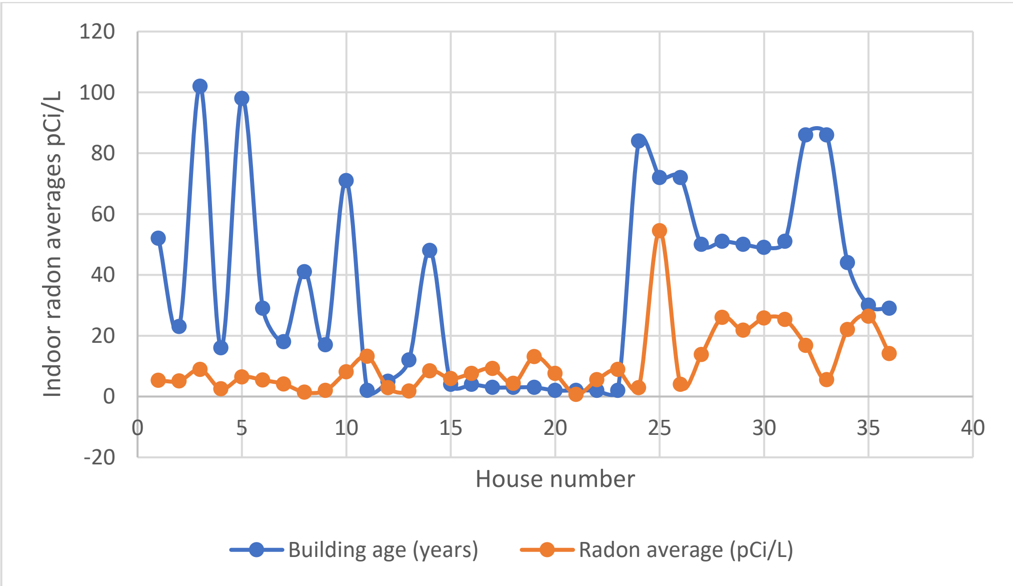

Fig. 4: The correlation between house age and radon averages in the 36 houses

Figure 5 shows the relationship between the mean and median of indoor radon in pCi/L of the 3 different types of foundation included in the study. The foundation type that was associated with the least indoor radon averages was slab-on-grade. The average indoor radon concentration in the houses built on concrete slabs is 7 pCi/L while the median value is 7.4 pCi/L. in the houses with basement the mean value is 7.03 pCi/L while the median value is 2.9 pCi/L. In the houses built on crawlspace, the mean value is 12 pCi/L while the median value is 7.6 pCi/L.

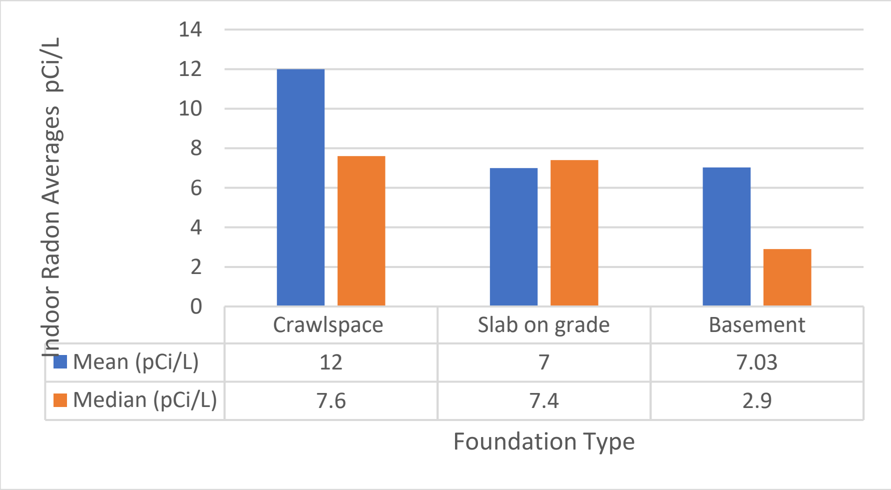

Fig. 5: The Mean and Median of indoor radon averages associated with the three different foundation types found in the 36 houses

Figure 6 shows the relationship between the mean and median of indoor radon in pCi/L of the 3 different types of building envelop materials included in the study. The building envelope type that was associated with the least indoor radon averages was wood frame covered with vinyl siding. The average indoor radon concentration in the houses with vinyl siding is 6.69 pCi/L while the median value is 5.9 pCi/L. In the houses with stone veneer, the mean value is 12,18 pCi/L while the median value is 13.95 pCi/L. In the houses with wood frame and brick veneer facads, the mean value is 14.59 pCi/L while the median value is 8.4 pCi/L.

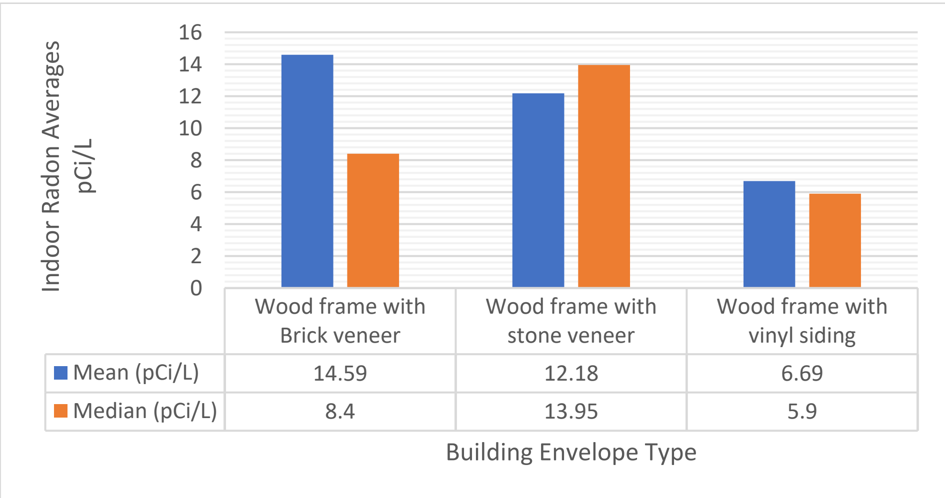

Fig. 6: The Mean and Median of indoor radon averages associated with the three different building envelope types found in the 36 houses

5 Conclusion

In the present study, 36 random homes were tested for indoor radon in Warren County, Kentucky. The average of indoor radon in this area is higher than 4 pCi/L. The objective is to investigate weather building design attributes impact or correlate with the indoor radon concentration average in these homes. This research builds on a previous study done in 1990 to investigate the impact of the Karst landscape on indoor radon in Bowling Green single family houses (Webster, 1990).

Digital radon monitors were used to measure the indoor radon concentration in each house. The indoor radon concentration was measured through monitoring the Alpha particles in the indoor environment around the clock. The test period ranges from short term testing for 72 hours in some buildings to long term testing for 5 months in other buildings. The study focusses on building age, construction type, building materials, foundation type, and ventilation system type as building design attributes that could impact the concentration of indoor radon.

The measurements indicate that there is a weak or almost no correlation between the building age and indoor radon averages in the 36 houses. The indoor radon concentration ranges between 2 to 54.4 pCi/L in the 36 houses with average of 11.03 pCi/L and median 7.6 pCi/L. The radon average exceeds the limit set by EPA 4 pCi/L. only 13% of the sample had indoor radon concentration less than 4 pCi/L. Houses built on a slab on grade had indoor radon concentration lower than houses with crawlspace. Houses with facades covered with vinyl siding had indoor radon averages lower than houses with brick or sone veneer building envelope.

The results show a novel perspective for the relationship between building design attributes and indoor radon in areas classified as zone 1 by the EPA. It also, helps homeowners to better understand the importance of mitigating their homes against such environmental hazards. The authors suggest that radon mitigation should be regulated in areas classified as zone one by EPA. Further investigation in more houses is currently underway to generalize the conclusion of the current study.

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