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Radon in child care centers: An examination of state laws and regulations in the United States

Benjamin Poku ^{1,*} and Sayed Hussaini ²

¹ *Disaster Preparedness and Emergency Management (DPEM) – Arkansas State University, United State.*

² *Master of Public Health (MPH)-Eastern Washington University, United State.*

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Abstract

Radon is the second leading cause of lung cancer after smoking in the United States (US); however, there is a lack of state policies and regulations to address radon gas exposure. This study aimed to explain if state radon legislation for child care centers is associated with the percent of counties within the state in radon zone 1 (above 4 pCi/L). The research method was secondary analysis. Data were obtained from EPA radon website, journal resources, state laws and regulations, and official state government websites. The existing radon laws were assessed based on the EPA radon zones. Then, independent T-Test with a significant level of $P < 0.05$ was used. The finding of this study indicated 39 US states have at least one county or more in radon zone 1, and 11 states have no counties in radon zone 1. Eleven states have legislation associated with child care centers, and 39 states have no such regulation in place. Twenty eight percent (28%) ($n=39$) of states with at least one county or more in radon zone 1 have radon regulations for child care facilities. The findings reveal that states located in EPA radon zone 1, partially or completely, were Eighty eight percent (88%) likely to not have different regulations requiring the radon testing in child care centers than states that are not in zone 1. In other words, the association between state radon legislation for child care centers and the percent of counties in radon zone 1 is remarkable but not significant (p -value = 0.12).

Keywords: Radon; Radon requirement; Child care centers; State policies; EPA radon zone map

1. Introduction

Radon has been classified as a known human lung carcinogen (25). Radon is a radioactive gas. It is measured in picocuries per liter of air (pCi/L), a measurement of radioactivity and is an odorless, invisible gas that results from the natural decay of uranium and thorium in soil and rock. The gas enters homes through cracks in the foundation where it can be trapped inside, especially during winter months when homes are sealed. Because it is water soluble, well-water can be a source of residential radon however, most of the exposure of the general population is via soil gases (36). In the United States (US), radon is currently the second leading cause of lung cancer after smoking, and it is the number one cause of lung cancer in non-smokers. Especially important, radon causes about 20,000 cases of lung cancer each year in the United States (Centers for Disease Control and Prevention, 2015). The Environmental Protection Agency (EPA) estimates that radon causes approximately 15,000 lung cancer deaths per year (16). The average indoor and outdoor radon levels in the United States are about 1.3 pCi/L and 0.4 pCi/L, respectively (Environmental Protection Agency, 2016). The US Surgeon General and EPA recommend fixing homes and buildings with radon levels at or above 4 pCi/L. Additionally, EPA recommends that people should fix their properties for radon levels between 2 pCi/L and 4 pCi/L, because there is no known threshold below which radon exposure carries no risk (World Health Organization, 2016).

* Corresponding author: Benjamin Poku
Disaster Preparedness and Emergency Management (DPEM) – Arkansas State University, United State.

The Environmental Protection Agency has developed radon potential maps, available to the public as an online tool. Indoor radon potential is characterized by EPA into three categories (Foster & Everett Jones, 2016). Zone 1, or red zone, designates areas having predicted average indoor levels above the action level (>4 pCi/L), zone 2, or orange zone, has predicted average indoor radon between 2 and 4 pCi/L, and zone 3, or yellow zone, has the lowest predicted average indoor radon (<2 pCi/L). Based on these EPA radon potential maps, 34 percent of all US counties have the potential for indoor radon levels above or equal to the action level (4 pCi/L) (Kumar & Kadiyala, 2015).

Children's bodies are still developing making them more susceptible to hazardous substances from environmental exposures, including radon (Foster & Everett Jones, 2016). As such, children are vulnerable to environmental exposures at child care facilities because of the many hours they spend in these centers. Other studies show most exposure to radon, for both adults and children, comes from being indoors in homes, offices, schools – including child care facilities, and other buildings (D'Mello, 2019; Rabi & Oufni, 2016). The potential risk of radon exposure for children attending child care facilities is significantly remarkable. From a public health perspective, children are one of the most vulnerable groups in a society. By spending their time in centers with elevated radon levels (higher than 4 pCi/L), they would have long-term exposure to this gas. In fact, they are exposed to radon during a biologically susceptible time of life. EPA estimates that more than 70,000 school classrooms in use as of 2018 have high radon levels. Based on the EPA radon map, 41 states in the United States have at least one county or more located in EPA radon zone 1 (Environmental Protection Agency, 2019). This means these counties have a predicted average indoor radon screening level greater than the 4 pCi/L (Action Level); however, the majority of these states do not have radon testing nor radon mitigation policies associated with child care facilities (Environmental Law Institute, 2019).

This study sought to address the following research question: Is state radon legislation for child care centers associated with the percent of counties within the state in radon zone 1?

The hypothesis tested is that state radon legislation for child care centers is not associated with the percent of counties within the state in radon zone 1. Data for this study were collected from EPA website, journal resources, state laws and regulations, and official state government websites. Ultimately, the purpose of this study was to review radon laws and regulations associated with child care centers at state levels in the United States. The findings also provided additional facts to support the idea that states should have a comprehensive radon policy for child care centers located in elevated radon areas.

2. Literature Review

Being exposed to radon for a long period of time can lead to lung cancer. In 1988, the International Agency for Research on Cancer (IARC) determined that radon was a cause of human lung cancer, based on studies of underground miners historically exposed to high levels of the gas (International Agency for Research on Cancer, 1988). Mandated by the US Congress via the Indoor Radon Abatement Act of 1988, the EPA took the responsibility of identifying areas of the United States with potentially elevated indoor radon levels (Foster & Everett Jones, 2016). The EPA Radon Map was developed by the EPA using information from a combination of geologic, aerial radioactivity, soil characteristic measures, indoor radon measurements, and building foundation type. The radon map classifies counties into one of three zones depending upon the levels of predicted average indoor radon level. Based on EPA Radon Map, three states (Iowa (IA), North Dakota (ND), and Ohio (OH)) are fully located in radon zone 1, and they have the potential for indoor radon levels above or equal to the action level (4 pCi/L) (Environmental Protection Agency, 2019). Additionally, 38 states have at least one or more counties in zone 1, and 12 states (Alaska (AK), Arizona (AZ), Arkansas (AR), Delaware (DE), Florida (FL), Hawaii (HI), Louisiana (LA), Mississippi (MS), Oklahoma (OK), Oregon (OR), Texas (TX), and Vermont (VT)) are estimated to have radon levels below the action level. Radon is also the single largest source of radiation for almost everyone in Washington (Washington State Department of Health, n.d.). According to the EPA Map of Radon Zones, seven counties in Washington State are predicted to have high levels of radon (above 4 pCi/L) (Environmental Protection Agency, 2019) and are considered Zone 1 (red). In other words, these seven counties have a predicted average indoor radon level greater than the 4 pCi/L. To summarize, this EPA online tool is available for public, and it allows viewing radon test data for communities as well as radon risk map.

Children at childcare centers are one of the most vulnerable groups, and they are at higher risk of radon gas exposure in the red zone areas. Due to lung shape and size differences, children have higher estimated radiation doses than adults. Risk of lung cancer in children resulting from exposure to radon may be almost twice as high as the risk to adults exposed to the same amount of radon (Agency for Toxic Substances and Disease Registry, 2012). Children's lungs are smaller than those of adults and they have higher breathing rates potentially exposing them to higher doses of radiation. In many states, even those located in the EPA Radon Zone 1 (red zone), radon testing is not required in child care centers where children spend many hours of their daily life (Environmental Law Institute, 2019).

People who are living in the areas of higher radon levels have a higher risk of lung cancer if the radon exposure is not managed properly. Over the past decade, more attention has focused on the provision of geographical residential radon concentrations. A cancer prevention study in the United States estimated long-term ecological residential radon concentrations in large population samples. In this study, average county-level radon measurements were linked to study participants' zip codes to estimate radon exposure. The results of the study demonstrated a positive relationship between residential radon and lung cancer mortality. A 15% increase in the risk of lung cancer mortality was observed per 100 Bq/m³ (1 pCi/L= 37 Bq/m³) increase in radon across the United States (Turner, et al., 2011). In a similar study in Canada, lung cancer risk associated with living in areas with different geographic variation in radon was examined (Hystad, et al., 2014). The researchers used a population-based case-control study of 2,390 lung cancer cases and 3,507 controls collected from 1994-1997 in eight Canadian provinces. They found a 50 Bq/m³ increase of radon level in the area was associated with a 7% increase in the odds of lung cancer. For every 10 years that individuals lived in high radon geological areas, the odds of lung cancer increased by 11%. The aforementioned studies clearly state that geographical area is an important risk factor for lung cancer associated with radon gas exposure; the higher the radon concentration in a geographical area, the higher the risk of lung cancer. These findings further support the higher risk of long-term radon exposure for those who are living in EPA radon zone 1 (above 4 pCi/L) if the exposure to this gas is properly managed.

Child care centers are significant sources of radon exposure for young children. A nationwide survey estimates that almost one in five schools has at least one classroom with a radon level above 4 pCi/L (Environmental Protection Agency b, 2018). EPA also estimates that more than 70,000 classrooms in use as of 2018 have high radon levels. This study proves radon exposure in schools is a serious problem nationwide. So far; however, there has been less discussion about radon in child care centers. If schools, including child care centers, are plagued by elevated levels of radon gas, students and children are more likely to have long-term exposure to radon gas, thus their risk for lung cancer will be significantly higher. Some states have passed laws requiring schools and child care centers to be tested for radon levels. As of 2018, thirteen states' statutes clearly state radon issues in schools (Gordon, et al., 2018). These states are CO, CT, FL, IL, IA, MN, NJ, NY, OR, RI, TN, VA, WV. Radon testing in schools is mandatory only in nine states including CO, CT, FL, NJ, NY, OR, RI, VA, WV. Six of these states (Connecticut (CT), Minnesota (MN), New York (NY), Rhode Island (RI), Virginia (VA), West Virginia (WV) require radon mitigation in schools if the test results are above 4 pCi/L. In Washington State radon testing in schools and child care centers is not required. As mentioned, 34 percent of all the counties in the United States have the potential for indoor radon exposure (Kumar & Kadiyala, 2015), however, radon testing and mitigation requirements in most states are different and often are not enforced.

Radon is a serious problem not only in the United States, but also globally. According to new estimates published in Environmental Health Perspectives, radon exposure itself may be responsible for 14–17% of lung cancer cases and 3% of all cancer mortality in the 66 nations for which national data on radon exposure are available (Seltenrich, 2019). Radon has had the highest estimated impact in Armenia, leading to 29–30% of all lung cancer cases and approximately 6% of all cancer deaths. Among other countries, these estimates were about 12–16% and 4% for lung cancer and all cancer deaths, respectively, for China; 13–17% and 3% for Russia; and 9–13% and 3% for the United States. These studies acknowledge that radon is a serious concern worldwide, and it is considered a significant hazard associated with lung cancer.

2.1. Design and Population Methods

The research method for this study was secondary analysis. This study was accomplished by reviewing scholarly articles as well as collecting radon laws in child care centers adopted by the states. Data were obtained from scholarly articles, journal resources, state laws and regulations, and official state government websites. In the second stage of this study, existing radon laws were assessed based on the EPA radon zones. This study was conducted between November 2019 and February 2020.

2.2. Sampling Methods

In this study, radon regulations and statutes in child care centers in each US state were reviewed for public health implications. Search terms such as “radon”, “radon exposure”, “child care”, “radon requirement”, “mitigation”, “certification”, “licensing”, “state policy”, and “EPA radon zone” were used to search current radon laws and requirements from official state government websites and scholarly article databases for related regulatory and statutory requirements concerning radon in child care centers. This study highlighted the features and discrepancies of state laws and regulations concerning radon in child care centers.

Resources from the state legislature’s websites and regulations from official state government were featured alongside those from other relevant databases including Science Direct, PubMed, ProQuest, EBSCOhost, and EPA radon website were used as primary tools to facilitate the review.

One state-level variable was derived to approximate radon potential using the EPA county map, percent in EPA zone 1. Percent EPA zone 1 was defined as the proportion of counties within each state designated as zone1 by the EPA map. This is a basic indicator of total geographic area related to the risk of radon exposure. For instance, Maryland has 8 counties on the EPA map and 24 (33%) are zone 1. Finally, the state radon laws and regulations associated with radon in child care centers were assessed based on EPA radon zones. Independent T-Test with a significant level of $P < 0.05$ was used in this research.

2.3. Findings

Information collected from reviewing US state regulations associated with radon gas in child care centers and the EPA radon map was analyzed. For this study, data were used from EPA radon map, journal resources, state laws and regulations, and official state government websites. EPA radon map was used because it is the most current data available to evaluate state radon situations. The collected secondary data were analyzed using Excel 2016 software. Summaries of US states’ statutes addressing radon issues in child care centers were reviewed focusing on states’ radon situations based on the EPA radon map. It should be noted that two state radon maps (Colorado and Florida) were used in addition to the EPA radon map. In the following section, the states’ regulations and their radon situations are combined to visualize the data and communicate the findings in constructive ways.

The findings of this study indicate 35% ($n = 3144$) of all US counties have the potential for indoor radon levels above or equal to the action level (4 pCi/L). Based on the EPA radon map, 34 states in the US have at least 10% or more of their counties located in radon zone 1 while only eleven states have radon regulations associated with child care facilities (Table 1). Moreover, 78% of US states (39 states) are located partially or completely located in radon zone 1. In other words, these states have at least one or more counties in radon zone 1. On the other side, 22% of US states (11 states) have no counties in radon zone 1. A summary of their regulations and how the states are located in radon zone are shown in the following paragraphs.

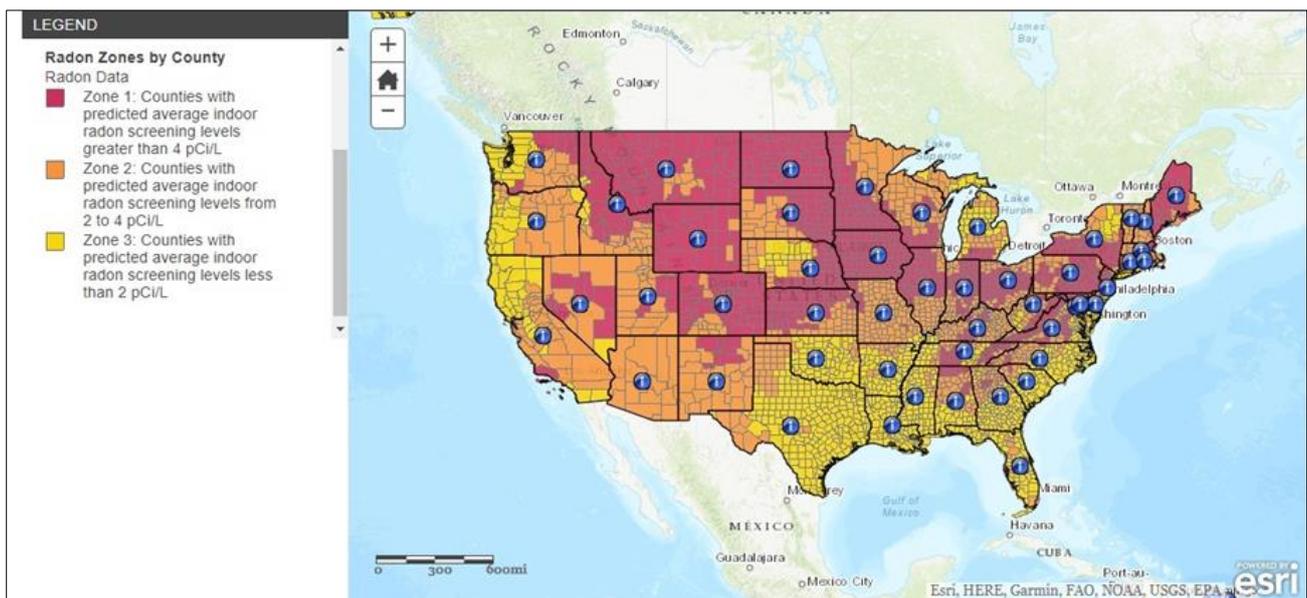


Figure 1 EPA Radon Map. [S. Hussaini, 2020; Source: EPA 2019]

Based on EPA Radon Zone Map, 52 counties in Colorado State have radon level 4 pCi/L or higher, while Colorado official web portal (Colorado Department of Public Health and Environment a, 2020) indicates all 64 counties in this state are in radon zone 1 (above 4 pCi/L). In Colorado, new child care facilities opening after 1/14/2016 must complete radon tests within six months of occupancy (6 Code of Colorado Regulations 1010-7, 2016). The regulations also required existing child care facilities to conduct radon testing by May 1, 2017.

Table 1 States' Statutes and Percent of Counties in EPA Radon Zone 1

State	Radon Testing in Child Care Centers	Percent of counties in EPA radon zone 1
CO	Required	100
CT	Required	50
FL	Required	6
ID	Required	43
IL	Required	55
IA	Required	100
MD	Required	33
MI	Required in Child Care Home	11
NJ	Required	33
NY	Required	55
RI	Required	40

S. Hussaini, 2020; Sources: EPA 2019, US States Official Web Sites

In Connecticut, regulations publicized under Connecticut Administrative Code 19a-79-7a, Section e17 require if the child day care center or group day care home uses the basement level or the first floor of a building, at least one radon test must be conducted during the months of November through April (Connecticut Administrative Code 19a-79-7a, Section e17, 2015). Furthermore, the results must be posted with the license, and then the department and the local director of health must be notified of the results. Regulations require radon mitigation by a service provider who meets state qualifications if radon levels are 4pCi/L or greater. In this state, 50% of its counties (n=8) have radon level of 4 pCi/L or higher.

In Florida, the State Statute 404.056 requires all state-licensed day care centers for children or minors which are located in counties designated as "Intermediate" or "Elevated Radon Potential" must be tested to determine the level of indoor radon (Florida Statute 404.056 , 2011). In this state 6% (n= 67) of their counties are located in radon zone 1.

Idaho State administrative code of IDAPA 16.06.02. 726 requires child care buildings must be free from hazardous materials and toxins (IDAPA 16.06.02. 726, 2015). An organization must provide documentation of testing for radon gas, materials containing asbestos, and lead paint. Documentation must be maintained at the facility confirming any hazardous material or toxins have been removed or do not pose a threat to the children served. Hazardous materials or toxins are not limited to lead paint, asbestos, and radon. There are 19 counties out of 44 counties (%43) in EPA radon zone 1 (above 4 pCi/L).

Fifty five percent (n=102) of counties in the State of Illinois are located in EPA red zone map (above 4 pCi/L). Per State of Illinois regulation, 225 ILCS 10/5.8, this state requires licensed day care centers, day care homes, and group day care homes to test for radon at least once every three years, in accordance with state rules (225 Illinois Compiled Statutes 10/5.8, 2013). This was effective since January 1, 2013.

The Iowa Department of Human Services adopted rules setting minimum standards for the operation and maintenance of child care centers. Per state regulations, within one year of being issued an initial or renewal license, the child care centers operating at ground level, in basement areas, or with a basement beneath the program area must have radon testing in accordance with state law governing radon certification (Iowa Administrative Code 441-109.11 (7), 2019). Radon testing is required if test kits are available from the local health department or the Iowa Radon Coalition. Moreover, the centers must be retested at least every two years from the date of the initial test if test kits are available from the local health department or the Iowa Radon Coalition. If testing reveals radon levels over 4.0 pCi/L, a mitigation plan must be approved by the state prior to full licensing of the facility. In Iowa state, 100% (n=99) of counties are located in radon zone 1.

Maryland has 24 counties, and 33% of these counties are in elevated radon level above 4 pCi/L. This state is authorized to establish regulations for the licensing of residential child care programs. State regulations require licensees of residential child care programs to maintain evidence that the buildings have been tested for, and found to be free of, hazards from lead paint, asbestos, and radon (Code of Maryland Regulations 14.31.06.07, 2015).

In Michigan 11% (n=83) of counties are in the red zone. Regulations adopted under Michigan Administrative Code established a radon standard for family or group child care homes (Michigan Administrative Code R 400.1934, 2009). The code states the lowest level of the child care homes must have radon levels of less than 4 pCi/L. It also requires that documentation of radon test results be kept on file in the home. Those homes registered or licensed before the effective date of these rules must have six months from the effective date of these rules to comply.

New York has a guidance document, Environmental Hazard Guidance Sheet, that requires license applicants for child day care in EPA radon zone 1 areas who have not already tested for radon to complete testing (New York State Office of Children and Family Services, 2019). Further, they must resolve any identified problems before registration and licensing is completed. In this state, 55% (n= 62) of their counties are in radon zone 1 with radon level of 4 pCi/L or higher.

New Jersey requires that child care centers be tested for the presence of radon gas in each classroom on the lowest floor level used by children at least every five years (New Jersey Administrative Code 3A:52-5.3, 2017). It also requires posting of the test results in a prominent location in all buildings. In this state 33% (n=21) of their counties are located in EPA radon zone 1 (above 4 pCi/L).

Rhode Island regulations establish radon standards, measurement and mitigation protocols, and requirements for testing, mitigation and notification of radon levels above 4 pCi/L in high priority buildings such as public buildings, schools, and child care facilities (216- Rhode Island Code of Regulations 50-15-2, 2014). The owner of public or high priority buildings must submit a radon testing schedule to the Department of Health identifying the dates of initial radon testing scheduled for each building. Testing schedules must be designed to ensure that child occupied buildings are completed first. The owners are required to report all test results to the Department of Health within thirty days of receipt of the test results. Additionally, any area which has initial test results of 4 pCi/L or greater must be re-tested per state requirements. Mitigation system installations are also required within one year, six month, and sixty days for test results greater than 4 pCi/L but less than 20 pCi/L, greater than 20 pCi/L but less than 100 pCi/L, and above 100 pCi/L, respectively. This state has five counties, and 2 of them (40%) are in radon zone 1.

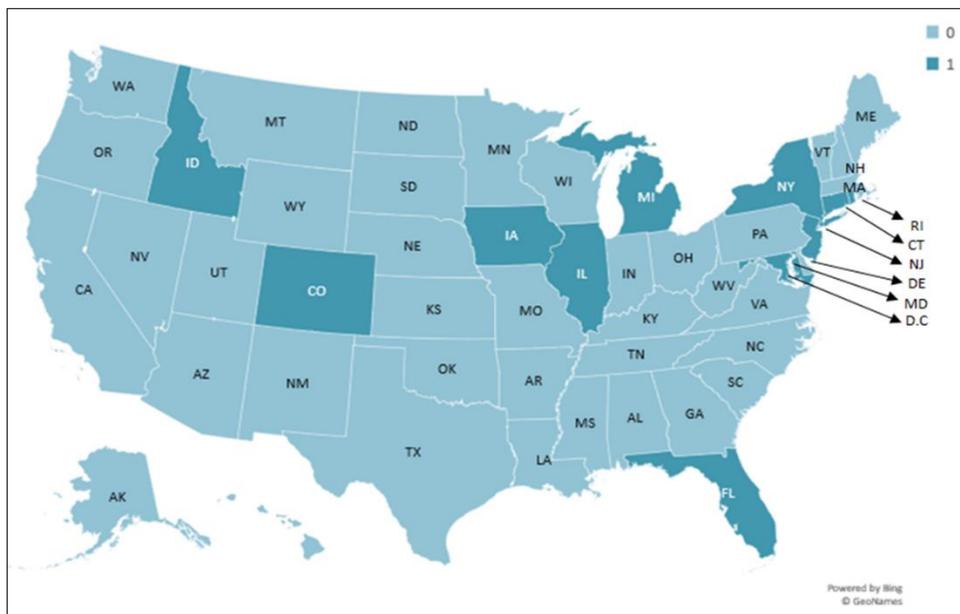


Figure 2 States with Radon Regulations for child care center
[S. Hussaini, 2020; Source: EPA 2019]

Figure 2 (below) illustrates that eleven states have radon regulations associated with child care centers. In other words, 22% of US states have this legislation. The rest (78%), including District of Columbia (DC), have no regulations for radon gas in these centers.

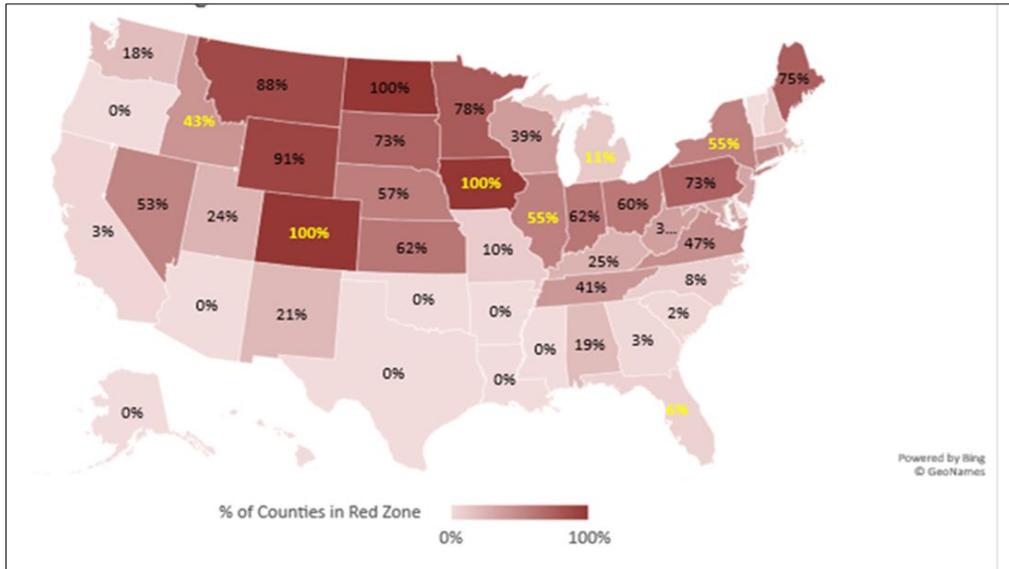


Figure 3 Percent of counties in Radon Zone 1 [S. Hussaini, 2020]

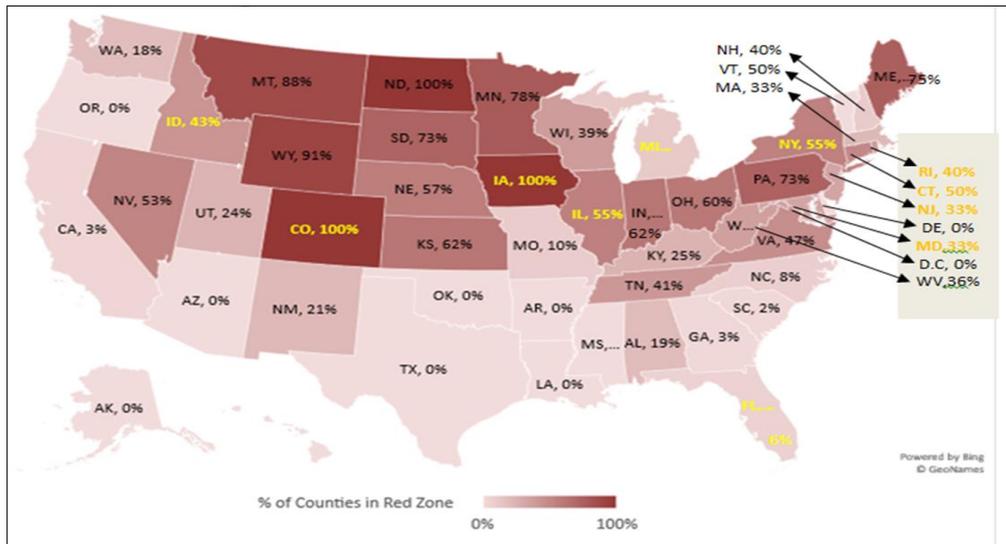


Figure 4 Percent of counties in Radon Zone 1 [S. Hussaini, 2020]

The maps above (Figures 3 and 4) show states with the percentage of their counties located in radon zone 1. Those in yellow are states with regulations that require child day care centers and group day care homes be tested for radon gas. It is apparent from this map that eleven states have established radon testing requirements for child care facilities. A comparison of the two results reveals 29% of states with 10% or more of their counties in radon zone 1 established regulations for radon gas in these high priority centers. The rest, 71% of US states with 10% or more of their counties in radon zone 1, currently have no regulations in this regard. As mentioned earlier, 78% of states (39 states) are located partially or completely in radon zone 1, while 22% of states (11 states) have radon legislation for radon in child care centers. Figure 5 is the same data discussed above in a chart format.

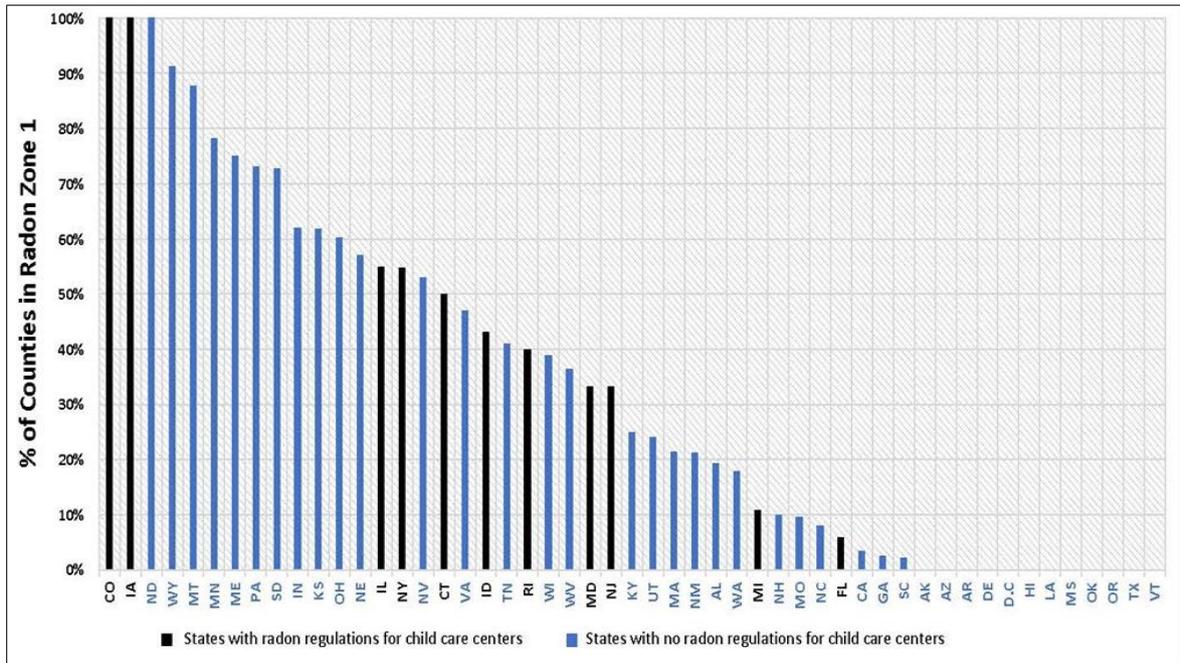


Figure 5 US states' statutes and percent of counties in radon zone 1 (> 4pCi/L)

[S. Hussaini, 2020; Source: EPA 2019]

Table 2 compares an overview of state's laws and their radon situations obtained from this research. It also indicates the state code of regulation associated with radon issues in child care centers.

Table 2 Summary of state's laws and state's radon situations

State	Total Counties	% of Counties in Red Zone	Radon Reg. for Child Care*	State Code
Alabama	67	19	0	
Alaska	27	0	0	
Arizona	15	0	0	
Arkansas	75	0	0	
California	58	3	0	
Colorado	64	100	1	6 CCR 1010-7
Connecticut	8	50	1	CT Admin. Code 19a-79-7a, Section e17
Delaware	3	0	0	
District of Columbia	1	0	0	
Florida	67	6	0	Florida Statute 404.056
Georgia	159	3	0	
Hawaii	5	0	0	
Idaho	44	43	1	IDAPA 16.06.02. 726
Illinois	102	55	1	IL Compiled Statutes Ch. 225 § 10/5.8
Indiana	92	62	0	
Iowa	99	100	1	IA Admin. Code 441-109.11 (7)

Kansas	105	62	0	
Kentucky	120	25	0	
Louisiana	64	0	0	
Maine	16	75	0	
Maryland	24	33	1	Code of MD Regulations 14.31.06.07
Massachusetts	14	21	0	
Michigan	83	11	1	Michigan Adm. R 400.1934
Minnesota	87	78	0	
Mississippi	82	0	0	
Missouri	115	10	0	
Montana	57	88	0	
Nebraska	93	57	0	
Nevada	17	53	0	
New Hampshire**	10	10	0	NH Administrative Code He-C 4002.14
New Jersey	21	33	1	New Jersey Admin. Code 3A:52-5.3
New Mexico	33	21	0	
New York	62	55	1	NY Environmental Hazard Guidance
North Carolina	100	8	0	
North Dakota	53	100	0	
Ohio	88	60	0	
Oklahoma	77	0	0	
Oregon	36	0	0	
Pennsylvania	67	73	0	
Rhode Island	5	40	1	216- RICR 50-15-2
South Carolina	46	2	0	
South Dakota	66	73	0	
Tennessee	95	41	0	
Texas	254	0	0	
Utah	29	24	0	
Vermont	14	0	0	
Virginia	136	47	0	
Washington	39	18	0	
West Virginia	55	36	0	
Wisconsin	72	39	0	
Wyoming	23	91	0	

* Number 1 indicates the state has regulation, and number 0 indicates the state has no regulation associated with radon in child care facilities.

**New Hampshire has regulation for radon mitigation in child care centres, but it does not address radon testing, so it is excluded from the finding of this study.

As mentioned in previous section, sampling methods, Independent T-Test with a significant level of $P < 0.05$ was used in this research. Figure 6 indicates the result, and it represents that the association between state radon legislation for child care centers and the percent of counties in radon zone 1 is remarkable but not significant (p -value = 0.12).

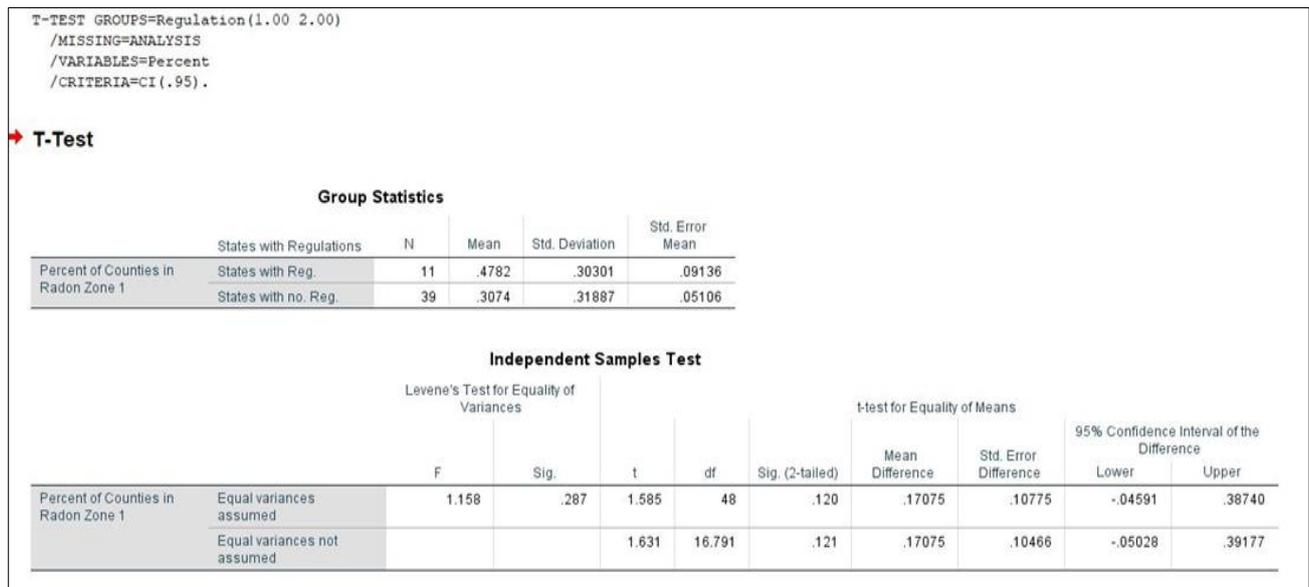


Figure 6 T-Test Results [IBM SPSS Analysis]

3. Discussion

The finding of this study shows 35% ($n = 3144$) of all US counties have the potential for indoor radon levels above or equal to the action level (4 pCi/L). This is 1% higher than what Kumar and Kadiyala found in their research (Kumar & Kadiyala, 2015). However, the EPA tool used in this research does not provide data regarding exactly how high the radon levels are in zone 1 (above 4 pCi/L). It was assumed that child care centers in EPA zone 1, with the highest potential for elevated indoor radon levels, were likely to have policies requiring child care facilities be tested for radon. The findings represent that almost 72% ($n = 39$) of US states located in radon zone 1 lacked radon testing regulations. Only 28% of them have radon legislation for child care centers. Furthermore, none of the states located outside of radon zone 1 have radon policy for child care centers. Regardless of zone, EPA recommends all schools, including child care centers, should be tested for radon because public buildings outside of high zones can have elevated indoor radon levels (Environmental Protection Agency, 2016).

Per the EPA radon map, 38 states have at least one or more counties in zone 1, and 12 states (AK, AZ, AR, DE, FL, HI, LA, MS, OK, OR, TX, and VT) are estimated to have radon level below the action level (Environmental Protection Agency, 2019). This differs from the finding of this study. According to Florida Health Department, this state has 4 counties in zone 1 (Florida Department of Health, n.d) whereas the EPA maps indicates there is no county in Florida in radon zone 1. This study demonstrated 39 states in the US, including Florida, have at least one or more counties in radon zone 1.

As of today, eleven states' regulations clearly address radon issues in child care centers. Radon testing in child care centers is mandatory in these eleven states. Even among these eleven states, regulations on radon testing in child care centers vary considerably. The states may address radon in the licensing process based on other regulatory provisions. For instance, New York requires child care facilities in high radon potential zones to test for, and resolve, any radon problems as part of the licensing process. While some of the radon laws and regulations apply to all types of licensed facilities, some of the states have radon requirements that apply specifically to child care centers, or in one case, in Michigan, only to home-based facilities (Environmental Law Institute, 2019). In Iowa, per child care regulations, radon testing is required "if test kits are available from the local health department or the Iowa Radon Coalition (Iowa Administrative Code 441-109.11 (7), 2019).

Radon testing in child care centers is not mandatory in North Dakota, Wyoming, and Montana where 100%, 92%, and 88% of their counties, respectively, have elevated radon concentrations (above 4 pCi/L). Nine more states including Indiana, Kansas, Maine, Minnesota, Nebraska, Nevada, Ohio, Oklahoma, Pennsylvania, and North Dakota all have more

than 50% of their counties in zone 1 while they do not have radon statutes for child care centers. These findings acknowledge that there is lack of radon legislation at state levels in the US.

Six percent of US states (n=16) with less than 10% of their counties in radon zone 1 have radon policy for child care centers, and the rest, 94%, do not have. The most interesting finding was that Florida has radon regulations for child care centers despite having 4 counties, 6% of their total counties (n=67), in an elevated radon zone (above 4 pCi/L). It should be noted, the EPA radon zone map indicates this state has no counties in zone 1, but the state radon map shows 4 counties in Florida are located in radon zone 1. As far as District of Columbia County, it is shown in the charts and maps in previous chapter, but it is excluded from the interpretations in this study.

Regarding radon testing protocols, some of these eleven states that require radon testing also established testing procedures for radon measurement. In some states such as Rhode Island, Florida, and Illinois, the radon testing procedures are clearly referenced in the regulations (Environmental Law Institute, 2019). In Connecticut, Iowa, and New Jersey the regulations do not establish or require detailed testing procedures, but the states have developed guidance to meet the radon testing requirements under the state's child care regulations.

The finding of this study represents that state radon legislation for child care centers is strongly associated, although not significant, with the percent of counties in radon zone 1 (p-value = 0.12) (see figure 6). US states located in EPA radon zone 1 (> 4 pCi/L), partially or completely, were 88% likely to not have different regulations requiring the radon testing in child care centers than states that are not in zone 1. As mentioned earlier, only 28% (n=39) of the states with at least one county or more in radon zone 1 have such regulations in place, and 72% do not have radon regulations associated with child care facilities.

Limitations

The most obvious limitation in this study was the complete reliance on previously published data from EPA radon map. Based on EPA radon map, the state of Colorado 83% (n=64) of their counties are located in radon zone 1 while the state's official website indicates it has 100% of their counties in zone 1 (Colorado Department of Public Health and Environment a, 2020). Along the same line, the EPA map shows State of Florida has no counties in red zone, but Florida Health Department has an online radon map indicating 4 counties in zone 1 (Florida Department of Health, n.d). Another major source of uncertainty was data exported from the EPA website and the EPA radon map. Some of the data did not match the website and the online map. In order to overcome these problems additional resources such as the state official websites were reviewed to ensure the data is correct.

Second, some states may be addressing radon in ways not reflected in testing requirements directly. For example, New Hampshire requires when there is information indicating that child care centers may contain radon hazards, the program owner must submit evidence that the building has been inspected, and is free of radon hazards (New Hampshire Administrative Code He-C 4002.14, 2017). In fact, they must have their mitigation plan to reduce the radon level in those centers. This code does not explain the radon testing as a requirement, and it jumps to the next step which is radon mitigation. Per EPA, the only way to determine if a problem exists is to test for it (Environmental Protection Agency b, 2018), but the New Hampshire state code does not address radon testing requirements which is a fundamental step to identify if a radon problem exists. The similar states codes are excluded from the finding of this study.

Another limitation in this study was the reliance on the previously published EPA radon zone map. Currently, the only national resource for radon data is the EPA Radon Zone map (Gallaway, Berens, Puckett, & Foster, 2019). More recently, state radon programs have begun collecting, analyzing, and publishing radon testing result information by county. However, these data are state specific, and the data collection methods vary by state.

4. Conclusion

Radon gas exposure is a major public health concern that affects many Americans and is the second leading cause of lung cancer after smoking. The U.S. Environmental Protection Agency (EPA) has estimated that as many as 20,000 deaths are caused each year by radon. Nearly 70,000 school classrooms, including child care centers, have high radon levels. Child care facilities present a special case, being a living environment for children. In fact, children spend most of their time in child care environments than in any other indoor environment besides their home (Branco, M, Martins, & Sousa, 2014). This group of age are also significantly more sensitive to radon gas exposure than adults (Kleinerman, 2006) even at low concentrations. Moreover, the risks of radon exposure are distributed across the United States, but they can be minimized if properly managed through government legislation.

The current research explored the provisions that US states developed in regard to radon in child care centers. The EPA radon map was used to determine the potential radon levels in each state. According to EPA radon map as well as states official radon maps, 35% (n= 3144) of all US counties have the potential for indoor radon levels above or equal to the action level (4 pCi/L). Thirty-nine US states have at least one county or more in radon zone 1, and eleven states have no counties in radon zone 1. As it was expected, none of the states located in radon zones other than zone 1 (e.g. zone 2 or 3) have radon policy for child care centers. On the other side, 28% (n=39) of states with at least one county or more in elevated radon areas (zone 1) have radon regulations associated with child care facilities and 72% do not have such regulations in place. Overall, the finding of this study represents that US states located in EPA radon zone 1 (above 4 pCi/L), partially or completely, were 88% likely to not have different regulations requiring the radon testing in child care centers than states that are not in zone 1. In other words, the association between state radon legislation for child care centers and the percent of counties in radon zone 1 is remarkable but not significant (p-value = 0.12).

Recommendations

The issue of radon in child care centers has received little attention by researchers as well as local, state, and federal agencies. Although some states have already legislated radon testing requirements for these centers, it is not clear enough how their programs effectively reduce radon exposure on a population level. It is also discussable how the radon policies are effective. Thus, state-level legislation should continue to be monitored for effect and adoption considered by all states if appropriate. Equally important, states that are completely or partially located in the EPA Radon Zone 1 should develop a comprehensive radon policy at least for child care centers located in elevated radon areas. The regulations should clearly address the radon testing in child care centers. More federal and state funds should be available as well for assessing radon risk in these centers and other public buildings, where people may spend their time. States may then work on their plans to offer radon exposure training for child care centers to increase the radon health risk awareness among these groups. Additionally, future studies may focus on state radon zone maps, but the EPA map can be supplemented with any available local data in order to further understand and predict the radon potential for each state.

Compliance with ethical standards

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Disclosure of conflict of interest

This study has not been duplicate publication and the authors declare that they have no conflict of interest to the publication of this article.

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