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Temporal Variation in Indoor Radon Concentrations Using Environmental Public Health Tracking Data

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Abstract

Indoor radon is the second leading cause of lung cancer in the United States (US) after smoking and the number one for lung cancer in non-smokers. Understanding how indoor radon varies during the year reveals the best time to test to avoid underestimating exposure. This study looks at the temporal variation in 13 years of radon concentrations in buildings located in 46 US states and the District of Columbia (DC). In the dataset, radon concentration varies from 3.7 Bq m^{-3} (Becquerels per cubic meter) to 52,958.1 Bq m^{-3}, with an overall mean of 181.4 Bq m^{-3}. About 35.4% of tests have a radon concentration level equal to or greater than the US Environmental Protection Agency (US EPA) action level 4.0 pCi L^{-1} (148 Bq m^{-3}).[3] Temporal variation in radon concentrations was assessed using the overall monthly mean radon concentration. The highest concentrations were found in January (203.8 Bq m^{-3}) and the lowest in July (129.5 Bq m^{-3}). Higher monthly mean indoor radon concentrations were found in January, February, and October, and lower in July, August, and June. This result is consistent with findings from other studies and suggests continuing to encourage radon testing throughout the year with an emphasis on testing during the colder months. Health Phys. 000(00):000–000; 2023

Keywords

operational topics; cancer; ^{222}Rn; radon

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[3] Note that the radon concentration units are given here in pCi L-l (called traditional units) because that is the unit used by the US Environmental Protection Agency. However, the Health Physics Society has adopted the SI (International System) of units and this is given in parentheses

The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

INTRODUCTION

Radon is a naturally occurring radioactive gas that is created during the radioactive decay of uranium. Radon can accumulate in buildings and pose a health risk to those living or working in those structures (CDC 2021a). The International Agency for Research on Cancer (IARC) classified radon as a carcinogen in 1988 (IARC 2012).

The US Environmental Protection Agency (US EPA) estimates around 21,000 lung cancer deaths per year attributed to radon exposure (US EPA 2021b). Of those, the majority are those who smoke and are exposed to radon, but 2,900 cases of lung cancer occur in people who have never smoked (US EPA 2021b). People who smoke and are exposed to radon are at much higher risk for lung cancer than people who do not smoke (US EPA 2021b; Copes and Scott 2007). Exposure to radon is the number one cause of lung cancer in people who do not smoke (US EPA 2021b; Copes and Scott 2007).

Radon gas that is created during radioactive decay of uranium is released into the surrounding soil. This gas is released from the soil into the surrounding environment. If the soil is beneath a building radon gas can accumulate in an indoor environment because modern, airtight buildings are designed to be energy efficient to retain heat or conditioned air (US EPA 2016). Radon can also be released into indoor air from building materials that contain radium (US EPA 2021a). Background levels of radon in outdoor air are generally quite low, but radon levels can vary based on location and soil geology. Indoor levels of radon are generally higher than outdoor levels (CDC 2012). The primary exposure to radon is through inhalation of air inside buildings. Radon can also be found in drinking water; 30 to 1,800 deaths per year are attributed to radon from household water (US EPA 2016; CDC 2021b). The exposure threat from radon in water is not from drinking but rather from the release of radon gas into the air during showering, washing dishes, laundering, and other uses of water (CDC 2021b).

A review of the literature found that the few studies conducted in the US that look at temporal variation in indoor radon concentrations were limited because they were not nationally representative (Kellenbenz and Shakya 2021; Mose et al. 2010). In Pennsylvania, winter and fall had significantly higher indoor radon concentrations than summer and spring (Kellenbenz and Shakya 2021). Another study conducted in Virginia was one of the few studies showing a reversal in the general pattern of seasonal variation influenced by unusual patterns of rainfall. Summer concentrations were higher in buildings tested in Virginia during a summer of above normal rainfall than the prior winter of below normal rainfall (Mose et al. 2010). Other studies, that were conducted outside of the U.S. had a dataset limited in size and years. In Brazil, higher concentrations of indoor radon were found during the winter dry season (E Silva et al. 2020). In Korea, indoor radon concentrations were higher in the winter and lowest in the summer (Park et al. 2018). In Germany, a study of radon emission from soil found higher rates of radon emission in the winter and spring compared to the summer and fall (Yang et al. 2017).

Another study conducted in gulf countries looking at indoor radon concentration variation in a desert climate found that seasonal variation was dependent on the presence of a basement in the building tested (Al-Khateeb et al. 2017). Homes with basements showed significant seasonal variation with higher values in the winter, while those buildings without a basement showed very little variation, and summer and winter values were similar (Al-Khateeb et al. 2017).

People are advised to test their homes for indoor radon in the winter because that is the time when people spend the most time indoors. Knowing the temporal variation of indoor radon concentrations identifies the best time to test to avoid underestimating the risk of radon exposure. The results of this investigation can confirm when radon measurements in homes are the highest; however, one must still consider when people spend the most time indoors.

This study looked at the temporal variation in radon concentrations in air measured in buildings throughout the United States. Using a large dataset submitted to CDC by national radon testing laboratories, monthly highs and lows were determined from 13 years of data and presented below. State-to-state and year-by-year temporal variation was also examined.

MATERIALS AND METHODS

Data source description

We assessed the temporal variation in indoor radon concentrations using the national radon testing laboratories data (lab data) from the CDC's National Environmental Public Health Tracking Network (Tracking Network). The lab data is a dataset collected by the CDC Tracking Program in collaboration with national radon testing laboratories, facilitated by the American Association of Radon Scientists and Technologists (AARST). The dataset provides results from radon in indoor air testing from six private radon testing laboratories: AccuStar (2 Saber Way, Ward Hill, MA 01835), Air Chek (1936 Butler Bridge Road, Mills River, NC 28759), Alpha Energy (2501 Mayes Road, Ste 100, Carrollton, TX 75006), EMSL Environmental Molecular Sciences Laboratory (5950 Fairbanks N Houston Road, Houston, TX 77040), Radalink (5599 Peachtree Road, Atlanta, GA 30341), and RAL Inspection Services (160 W Carmel Drive, Ste 214, Carmel, IN 46032), which includes test results from 49 US states (excluding New Jersey) and DC.

The data source consisted of 2,671,242 records of indoor radon test results from 1,712,465 buildings tested in the period 2005 through 2019. Test results in the dataset were characterized with the test start and end dates, the measured value of the indoor radon concentration, the building purpose (residential, commercial, school, day care center, or other), and the type of the test [pre-mitigation, post-mitigation, or not collected (when the type of the test was not provided by the laboratory where the tests were analyzed)]. Other information, such as the floor level tested, the reason for the test, the test device location, and the building type, were considered optional for data submission and were not readily available.

Analytical methods

Microsoft Power BI desktop version: 2.88.1682.0 64-bit (One Microsoft Way, 157th Avenue NE, Redmond, WA 98052–7329) was used for data processing and analysis. For data processing and to ensure that the indoor radon concentrations used for the study were those measured before any radon mitigation was conducted, radon tests designated as post-mitigation were removed from the study data. Radon data for the years 2018 and 2019 and from Hawaii and Mississippi were removed because the number of test records was very sparse and were too few to be representative for the state. Kansas data were not included in the study at the state's request. Five radon test measurement outliers were identified using boxplots and removed from the dataset (291,534.1 Bq m^{-3}; 177,600 Bq m^{-3}; 152,255 Bq m^{-3}; 118,400 Bq m^{-3}; 84,989 Bq m^{-3}) to avoid skewing the data. For indoor radon concentrations that were less than the limit of detection, the measure was replaced with half the corresponding laboratory detection limits, which were 14.8 Bq m^{-3} for AccuStar, 11.1 Bq m^{-3} for AirChek, 7.4 Bq m^{-3} for Alpha Energy, 11.1 Bq m^{-3} for EMSL, 18.5 Bq m^{-3} for Radalink, and 7.4 Bq m^{-3} for RAL. The final study dataset included 2,405,006 indoor radon concentration test results from 1,560,025 buildings tested from 2005 through 2017 located in 46 US states and DC.

For the analysis, the test end date was used as the reference date for the test results. First, the data from the 13 years of indoor radon concentrations for the 46 states and DC were grouped by month of the test end date. The monthly mean radon concentrations were then estimated, and the results were displayed on an area chart for analysis. Temporal variation in indoor radon concentrations was assessed using the overall monthly mean radon concentration. Next, the 13 years of radon data were grouped by year and by month. The monthly mean radon concentrations for each year were estimated and a graph of each monthly mean radon concentration was displayed on an area chart to determine if there was a consistent pattern for the 46 states and DC for each year. Finally, the 13 years of indoor radon data were grouped by state and by month, and the monthly mean radon concentration for each state was estimated. A graph of each state monthly mean radon concentration was displayed on an area chart to determine if the pattern found for the 46 states and DC was consistent across states for that same timeframe.

RESULTS AND DISCUSSION

Characteristics of the study dataset

In the dataset, indoor radon concentration varied from 3.7 Bq m^{-3} to 52,958.1 Bq m^{-3} with an overall mean of 181.4 Bq m^{-3}. The greatest number of indoor radon tests performed were in January (12.08%), February (11.94%), March (11.94%), and April (10.02%) (Fig. 1). This pattern may be attributed to Radon Action Month, a national communications and outreach campaign held annually in January bringing awareness, promoting radon testing, and offering free or low-cost radon test kits. These campaigns have likely contributed to increase the number of people becoming aware and testing their homes or businesses for radon. Although there were more tests in January, February, March there were sufficient tests in all the other months to establish the monthly pattern. Additionally, about 35.4% of tests had a radon concentration level equal to or greater than the US EPA action level of 4.0 pCi L^{-1} (148 Bq m^{-3}). The CDC Tracking Program (https://ephtracking.cdc.gov/) has created county-level maps to display radon data on the Tracking Data Explorer and provides information on radon analysis, collection, and data dissemination to accompany the data (CDC 2022a and b). State and local health departments have access to these data and are engaged in the effort to communicate the risks of exposure to radon to the public (CDC 2022a). The National Radon Action Plan, a collaborative effort of federal agencies and non-governmental agencies to which CDC is a partner, outlines a long-range plan to address and eliminate radon-induced lung cancer in the United States (RadonLeaders 2022). The annual communication campaigns, National Radon Action Month and CDC's Radon Awareness Week, are aimed at educating the public to test their homes and to mitigate if the radon concentration in their homes is at or above 148 Bq m^{-3} (US EPA 2021c; CDC 2022c).

Temporal variation of indoor radon concentration data in all 46 states and the District of Columbia (13 years)

Overall, the monthly mean indoor radon concentrations from 2005–2017 exhibited a temporal variation, with the highest concentrations in January (203.8 Bq m^{-3}) and the lowest concentrations in July (129.5 Bq m^{-3}) (Fig. 2). Concentrations gradually decreased from January to May (203.8 Bq m^{-3} to 172.1 Bq m^{-3}), then show a steeper decrease from May to July (172.1 Bq m^{-3} to 129.5 Bq m^{-3}) followed by a steep increase until October (199.5 Bq m^{-3}) where they reach another peak. From there, concentrations start decreasing slowly again to reach a level of 191.8 Bq m^{-3} in December. Higher monthly mean indoor radon concentrations were found in January, February, October, November, March, and December, and lower monthly mean indoor radon concentrations were found in July, August, June, May, September, and April. This result is consistent with findings from other studies (Senitkova and Kraus 2019) and with the assumption that concentration levels are higher in the winter months due to homes being more closed up during colder climates allowing greater accumulation of radon in indoor air. Kellenbenz and Shakya found that winter and fall had significantly higher indoor radon concentrations than summer and spring (Kellenbenz and Shakya 2021). Overall, monthly mean indoor radon concentrations using the 13 years of data were at or above the US EPA action level of 148 Bq m^{-3} for all months except for tests done in June, July, and August.

Temporal variation of indoor radon concentration data in all 46 states and the District of Columbia by year

The trend of the monthly mean indoor radon concentrations for most of the years individually was similar to the trend for the 13-y time period (Fig. 3). July had the lowest mean radon levels for most of the years (11 or 84.6%) followed by August (2 or 15.4%) and February had the highest mean radon levels for most of the years (4 or 30.8%), followed by January (3 or 23.1%) and October (3 or 23.1%).

Temporal variation of indoor radon concentration data in each of the 46 states and the District of Columbia (13 years)

While there was some slight variation, the trend of the monthly mean indoor radon concentrations for most of the states for the 13-y period (Fig. 4) was similar to the overall trend for the 13-y period using the combined 46 states and DC data. Thirty-three (70 %) of the 46 states and DC (Alabama, California, Colorado, Connecticut, Georgia, Illinois, Indiana, Iowa, Kentucky, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, Nevada, New Hampshire, New York, North Dakota, Ohio, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin, Wyoming) had their lowest mean indoor radon concentrations in July (Fig. 5). The highest mean indoor radon concentrations for 13 states (28%) (Connecticut, Delaware, Illinois, Indiana, Kentucky, Maine, Massachusetts, Nevada, New Hampshire, New York, Ohio, Virginia, West Virginia) were seen in October; eight states (17%) had the highest concentrations in January; seven states (15%) in November; six states (13%) in March; five states (11%) in December, five states (11%) in February; one state and DC in July, and the remaining one state in May (Fig. 6).

CONCLUSION

Analysis of the radon laboratories data on the Tracking Network for 46 states and DC from 2005 through 2017 shows temporal variation in indoor radon concentrations consistent with other studies conducted in the US and other countries (e.g., Brazil, Korea, and Germany). The lowest concentrations are seen in July for most of the states and the years. The highest concentrations of radon are found in the fall and winter months from October to February, with no single month consistently higher than the next.

The greatest number of radon tests are conducted in January through April, tapering off from there. Radon Action Month, which takes place in January, likely plays an important role in increased radon testing in buildings. 35.4% of the radon tests used in this study had a concentration level equal to or greater than the U.S. EPA action level of 4.0 pCi L^{-1} (148 Bq m^{-3}). Based on this analysis, we suggest continuing to encourage radon testing throughout the year, emphasizing testing during the colder months, particularly October through February for the US.

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Biography

Sidoine Lafleur Kamgang is a bilingual (French and English) and experienced Health Informatics Specialist She currently works as a Pediatric Health Information System Analyst (Data Management and Reporting) at Children’s Healthcare of Atlanta. Prior to Joining Children’s, Sidoine worked for seven years at CDC with the Asthma and Climate Health Branch, then the Environmental Public Health Tracking Section providing guidance in using information technology to develop and improve tools and processes for data collection, data quality checks, data analysis, visualization, reporting and information system evaluation. Sidoine deployed to multiple locations for Covid 19 outbreak responses. Prior to CDC, Sidoine worked as Software Developer/IT Business Analyst for private organizations. Sidoine has a Master’s degree in Computer Science and a Master’s degree in Management of Information Systems from Georgia State University, US, and the University of Picardie Jules Verne, France. Her email is masidoine@yahoo.com.

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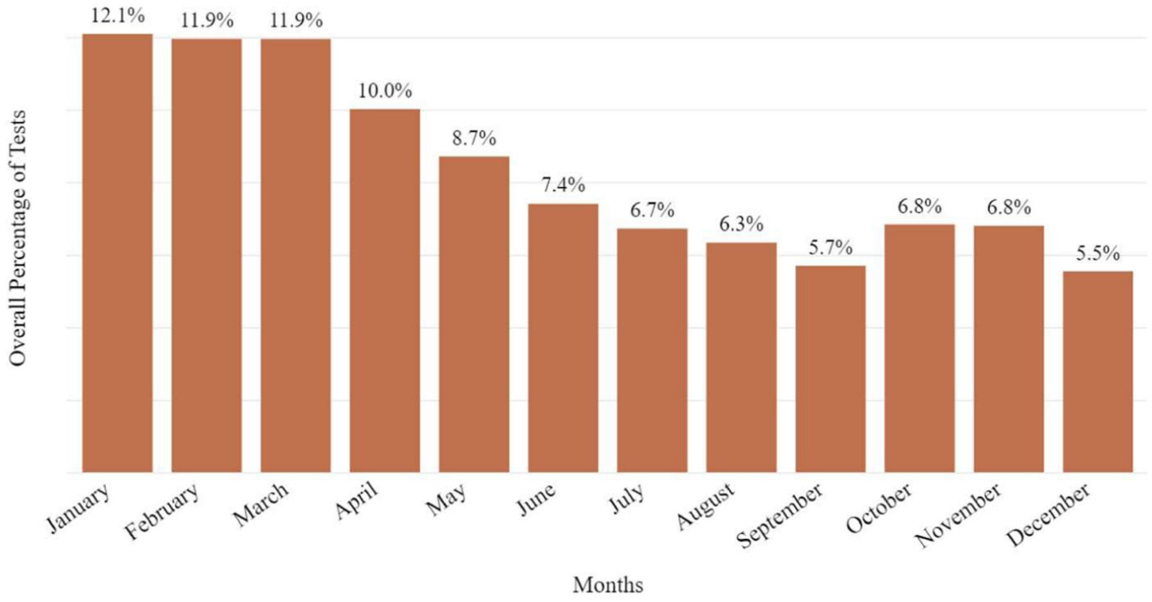

FIG. 1.

Percentage of indoor radon tests per month for 46 US states and the District of Columbia (2005–2017) excluding New Jersey, Hawaii, Kansas, and Mississippi, CDC Environmental Public Health Tracking Network (EPHTN) National Radon Testing Laboratories Data.

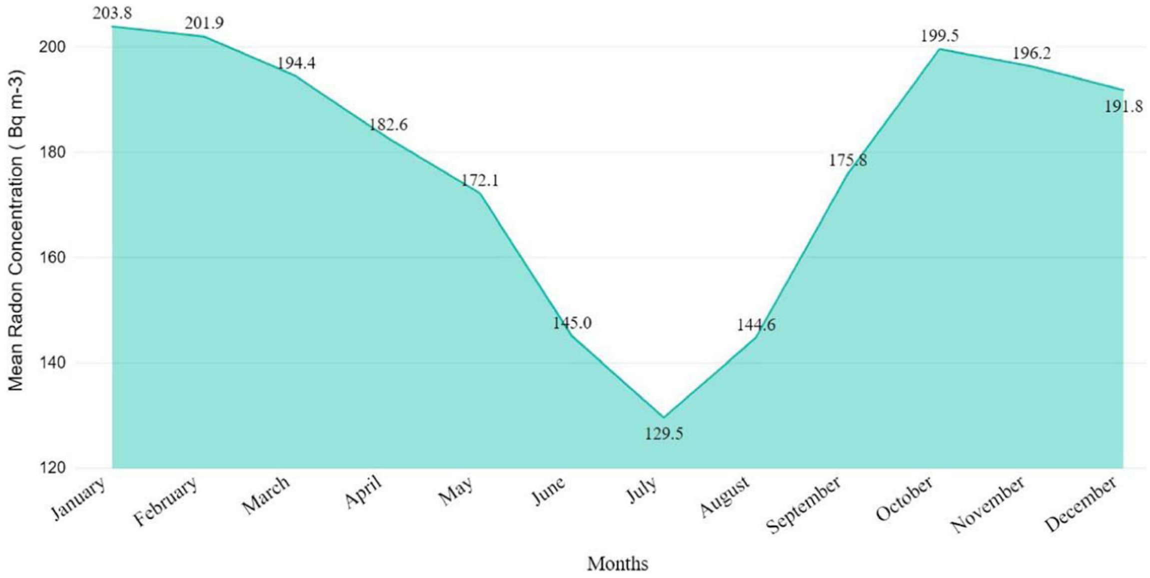

FIG. 2.

"Mean" monthly temporal variation of indoor radon concentrations for 46 US states and the District of Columbia for 13 years (2005–2017) excluding New Jersey, Hawaii, Kansas, and Mississippi, CDC Environmental Public Health Tracking Network (EPHTN) National Radon Testing Laboratories Data.

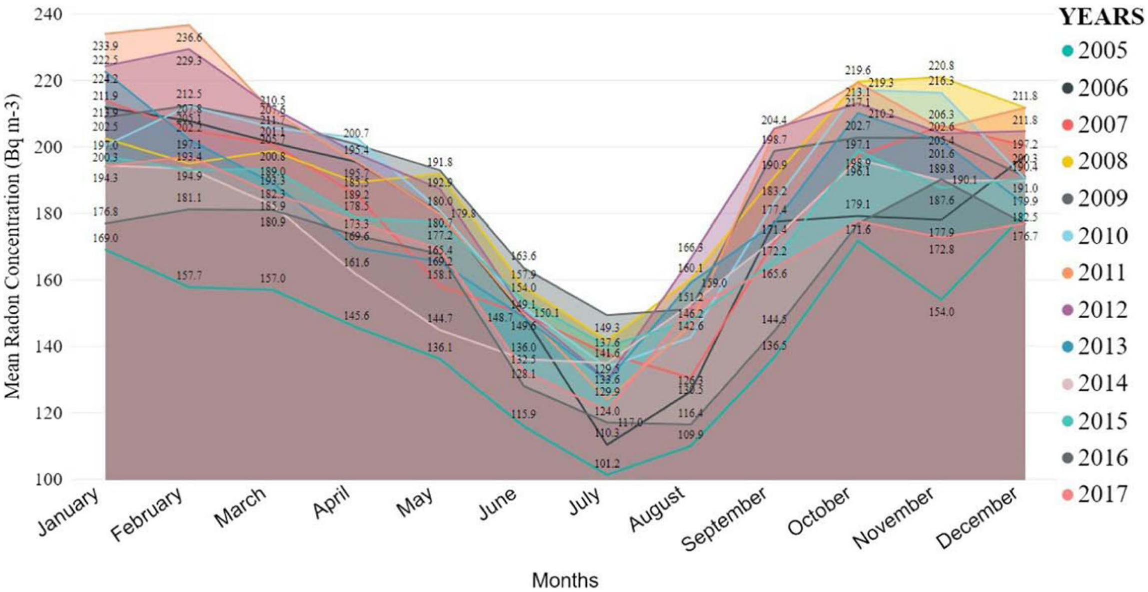

FIG. 3.

“Mean” monthly temporal variation of indoor radon concentrations for 46 US states and the District of Columbia per year (2005–2017) excluding New Jersey, Hawaii, Kansas, and Mississippi, CDC Environmental Public Health Tracking Network (EPHTN) National Radon Testing Laboratories Data.

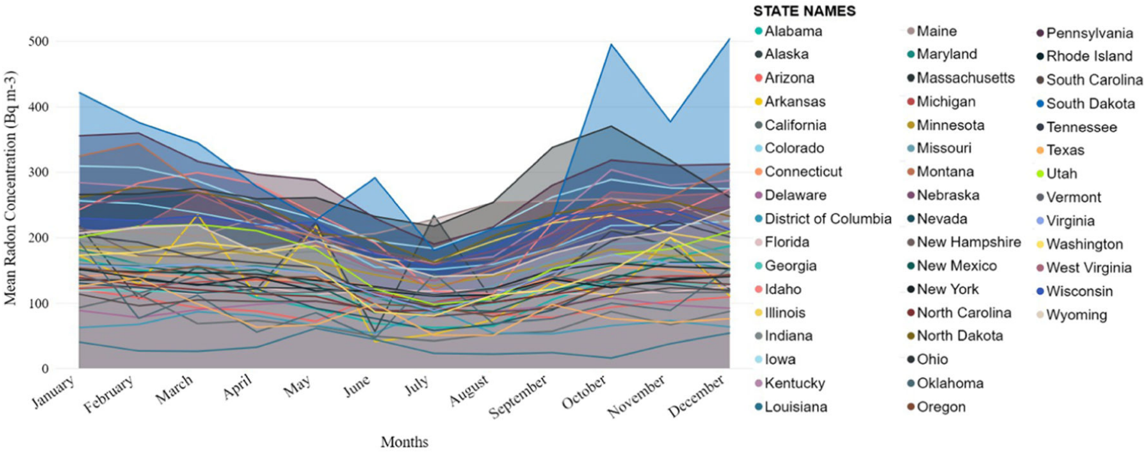

FIG. 4.

"Mean" monthly temporal variation of indoor radon concentrations for each of the 46 U. states and the District of Columbia for the 13 years (2005–2017) excluding New Jersey, Hawaii, Kansas, and Mississippi, CDC Environmental Public Health Tracking Network (EPHTN) National Radon Testing Laboratories Data.

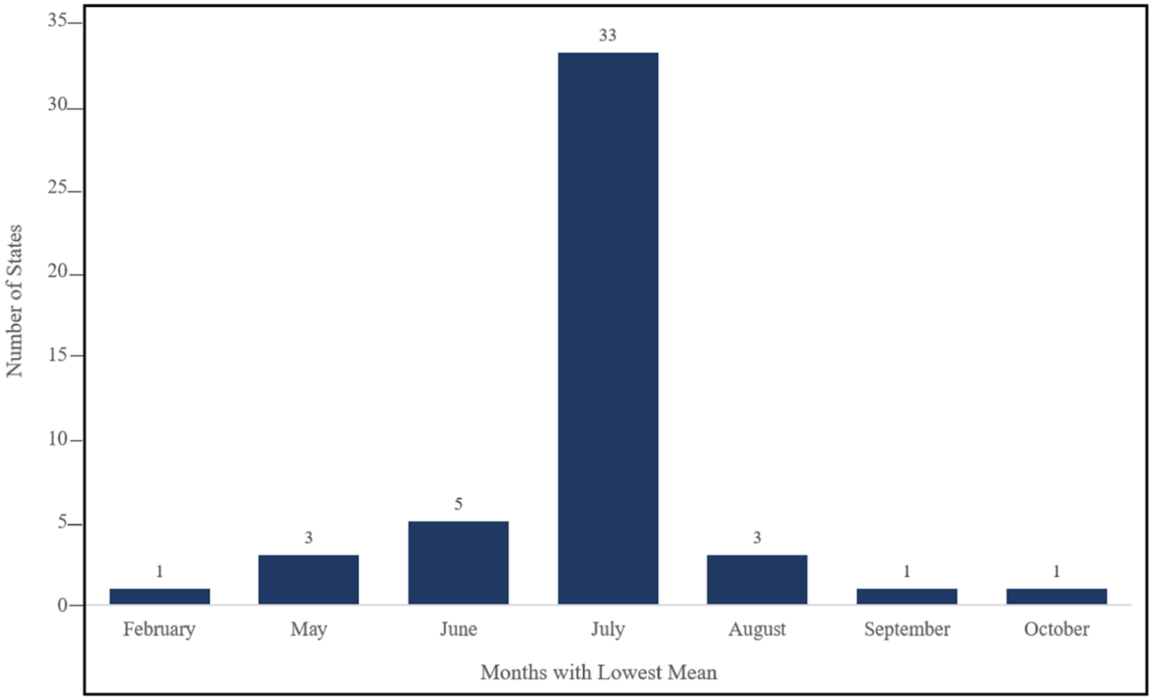

FIG. 5.

Number of states per month with lowest mean radon concentration for the 46 US states and the District of Columbia during the 13 years (2005–2017) excluding New Jersey, Hawaii, Kansas, and Mississippi, CDC Environmental Public Health Tracking Network (EPHTN) National Radon Testing Laboratories Data.

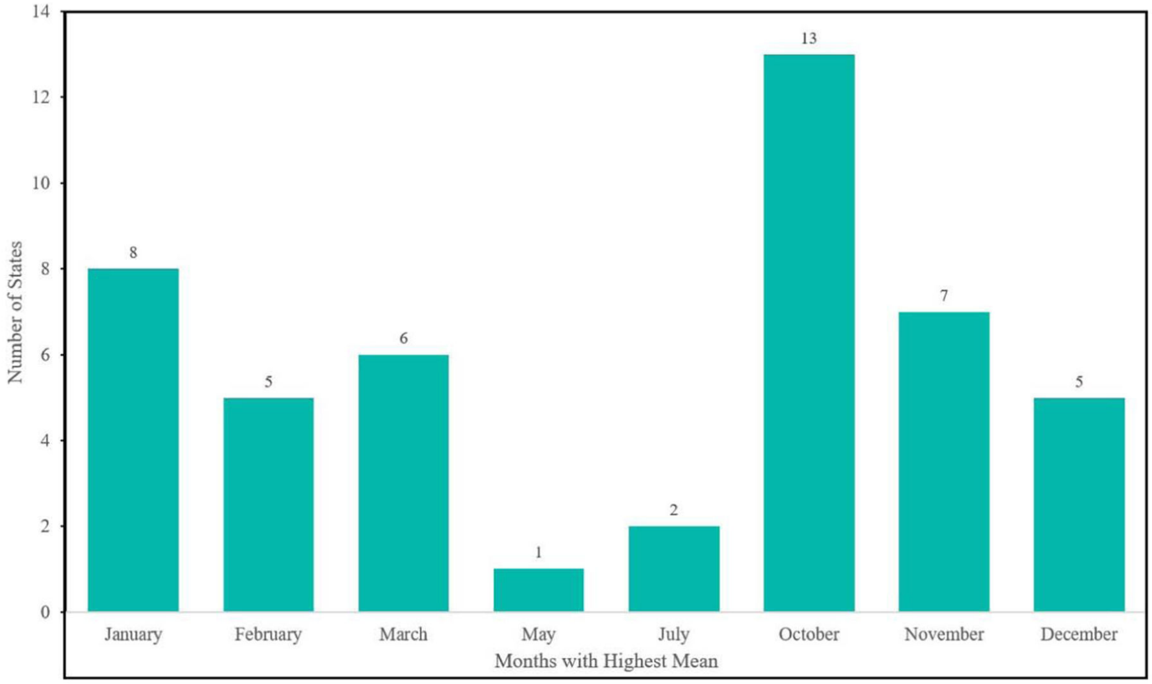

FIG. 6.

Number of states per month with the highest mean radon concentration for the 46 US states and the District of Columbia during the 13 years (2005–2017) excluding New Jersey, Hawaii, Kansas, and Mississippi, CDC Environmental Public Health Tracking Network (EPHTN) National Radon Testing Laboratories Data.