AN EXAMINATION OF TWO CASE STUDIES OF INDOOR RESIDENTIAL RADON RELATED TO RADON POLICY AT THE STATE AND LOCAL LEVELS

by

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A REPORT

Submitted in Partial Fulfillment of

Requirements for the Degree

MASTER OF ARTS

Department of Landscape Architecture/ Regional and Community Planning
College of Architecture, Planning and Design

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2003

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ABSTRACT

The 1986 Indoor Radon Abatement Act passed by the United States Congress provided a non-binding mandate to the individual states to design and operate programs designed to educate the public about the potential hazards of exposure to elevated indoor radon gas levels and to provide some measure of technical assistance to individuals whose homes exhibit elevated radon. Kansas is currently in the fourteenth year of operating such a program financed through the US Environmental Protection Agency (EPA) State Indoor Radon Grant (SIRG) program. As part of its operations, the program performs a certain amount of research designed to facilitate planning issues related to radon in Kansas. The current paper discusses two such research activities. The Kansas Radon Program maintains a large database of residential radon test results that are used to generate maps of exhibited radon. The first study performed a more in-depth analysis of the database using geographical information system (GIS) tools to evaluate statewide testing patterns and to examine the reliability of the data. The Kansas Radon Program also recently performed a series of efficiency testing of homes built with code-mandated radon resistant new construction (RRNC). The second study examines the results of that study and the apparent effectiveness of building techniques at reducing elevated indoor radon gas levels.

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Acknowledgements

There were several people and organizations that made this project possible. I wish to express thanks to Bruce Snead for his assistance and well-advised comments on the results. Thanks also to Kim Steves and KDHE for access to the Kansas radon database, and for the permission to perform the current study. And an especial thanks goes to Bob Dye and the EPA for the financial support across the years that has led to the development of a comprehensive database. The aid offered by my advisory committee in the Landscape Architecture/ Regional and Community Planning Department (Professors Lawhon, Keithley and Keller) is also of note. And finally, special thanks to my wife Amy, for putting up with odd hours and listening patiently to all the difficulties.

Chapter 1

ELEVATED INDOOR RADON AS A PLANNING ISSUE

Introduction

Among a number of indoor air quality (IAQ) issues, exposure to elevated levels of indoor radon gas poses a significant health risk, while also offering to be one of the simplest indoor environmental hazards to remediate. Radiation released by the radioactive decay of radon can cause lung tissue damage, thereby increasing the risk of an individual developing lung cancer. However, simple methods exist that reliably reduce the amount of radon gas in a home, thereby reducing the risk.

Radon is a chemically inert, naturally occurring, radioactive gas [1](U.S. EPA 1992b). The two primary sources of radon are the radioactive elements thorium and uranium, both of which undergo radioactive decay into radium. Radium undergoes radioactive decay into radon gas. Radioactivity is measured in curies, where 1 curie equals 37 billion elemental disintegrations per second. Radon gas is measured in picocuries per liter (pCi/L), or one-trillionth of a curie per liter of air. The danger presented by radon is primarily related to its radioactive decay products. The radon decay products have very short half-lives (less than 30 minutes) and are the source for most of the radioactivity caused by radon. These decay products are polonium-218, lead-214, bismuth-214, and polonium-214; polonium-218 and polonium-214 pose the greatest health risk as they both emit an alpha particle during their decay process. The alpha particle is the particle that causes damage to lung tissue.

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[1] Appendix B of the Technical Support Document for the 1992 Citizens Guide to Radon, both published by the EPA, provides a comprehensive review of the properties of radon.

Radon is found virtually everywhere as its predecessors (uranium and radium) are found in all rock and soil types (U.S. EPA 1992a). Outdoor air concentrations of radon are generally less than 1.0 pCi/L but have been measured as high as 1.11 pCi/L. Indoor radon gas concentrations can vary from as little as 0.5 pCi/L to as high as 2000 pCi/L. The EPA has set an action level of 4.0 pCi/L indoor radon; levels equal to or greater than this level are recommended to be lowered. The National Residential Radon Survey indicates that 1 in 15 homes (or approximately 6%) will have radon gas levels above 4.0 pCi/L. Iowa has the highest risk of elevated indoor radon levels at 7 in 10 homes (approximately 77%). Hawaii has the lowest exhibited risk at less than 1 in 100 homes (less than 1%). The state of Kansas has a risk factor of approximately 1 in 4 homes (25%) that will exhibit elevated indoor radon (U.S. EPA 1993a).

Based on numerous studies of lung cancer in radon-exposed underground miners, radon has been classified as a human carcinogen (IARC 1988). As such radon is the second leading cause of lung cancer death behind tobacco smoking, according to the United States Surgeon General's Office (U.S. EPA 1993c). The current official estimate of lung cancer deaths attributed to radon is 15,000-22,000 per year (U.S. EPA 2002). Epidemiological estimates however raise that number and might actually exceed 38,000 lung cancer deaths per year (Field, Smith, Steck and Lynch 2002).

The most current federal review of radon risk potential was the Sixth Committee on Biological Effects of Ionizing Radiations (BEIR VI) (NRC 1999). In order to determine the mechanistic effect of radon carcinogenesis, a review of the available molecular studies indicated that a single alpha particle impact on lung epithelial tissue could cause significant genomic damage in cells that are not killed by the incurred damage. This effect led to the adoption of a linear relationship between alpha particle dose and cancer risk. Alpha particles which are generated by airborne radon decay (and subsequently inhaled) and by radon decay within the lungs are used to determine overall equivalent dose (Kendall and Smith 2002). Radon was ranked as a high cancer and non-cancer health risk using the EPA's four risk types (cancer, non-cancer health effects, ecologic effects and welfare effects) for 31 environmental problems and placed among 12 assessed environmental risks including indoor air pollutants other than radon, accidental releases of toxic materials, and exposure to hazardous consumer products (Johnson 2000).

The EPA measures progress with radon issues across four major categories: (1) awareness of the general public about radon, (2) the number of homes tested for radon contamination, (3) the number of homes that exhibit elevated levels of radon that have been mitigated and (4) the number of new homes built with radon resistant new construction (RRNC) (Gregory and Jalbert 2002). A study of surveys conducted by the EPA between 1993 and 1999 provided baseline successes across those four categories. By 1999, 68% of survey respondents were aware of radon and aware of the primary health threat; that being increased risk of lung cancer. Testing of homes for radon hit a peak number of tests in 1999 of approximately 1.5 million homes. Since the mid-1980's, it is estimated that 18 million homes total have been tested. This number is difficult to truly estimate as the EPA does not require that tests be reported either to it or to the relevant state health or environmental offices. Mitigation of homes with elevated radon has steadily increased since 1993, reaching a peak of more than 50,000 homes in 1999. It is estimated that 500,000 homes have been mitigated since the mid-1980. The last category, homes built with RRNC techniques, has remained relatively level since 1990, with an estimated 1.8 million homes having been built with RRNC systems since the early 1990's.

The primary source of exposure to radon for the general public is the home (Field 2002). The major sources of indoor radon are: (1) soil gas emanations from soils and rocks, (2) release of radon from water systems, (3) building materials and (4) outdoor air. Soil gas is the predominant source. Four primary testing methods exist for measuring indoor radon gas concentrations: (1) activated charcoal adsorption detectors, (2) alpha track detectors, (3) electret ion chamber detectors and 4) continuous radon monitoring devices (U.S EPA1992b). These methods are designed to perform either short-term radon tests (tests for radon that take less than 90 days to complete), long-term radon tests (tests for radon that take at least 90 days to complete) or both. Activated charcoal tests are typically deployed for 2-7 days, and allow continual adsorption and desorption of radon across the exposure time. This device yields a single average radon value for the exposure period. Alpha track detectors are designed for long-term deployments and function by measuring the number of alpha particle strikes on a plastic strip or film across the exposure period. This device also yields a single average radon concentration. Electret ion chamber devices can be deployed for either short-term or long-term periods. Ion chamber radon measurements are obtained by measuring the difference in ion charge across a Teflon plate, caused by ionizing radiation released by radon as it decays. Electret devices yield a single average concentration across the deployment period. Continuous radon monitors record radon levels every hour and provide a point-by-point graph of radon levels as well as generating an average value for the testing period.

In order to assess the national potential for radon generation and indoor radon elevation potential, the EPA and the United States Geological Service (USGS) performed a national survey of all 50 states between 1987-1989 (U.S. EPA 1993a). This survey was designed to set a threat potential for all 3141 counties in the United States (U.S. EPA 1993b). Three threat potential zones were used to describe each county's radon potential: (1) Zone 1 counties have a predicted average indoor radon screening level greater than 4 pCi/L, (2) Zone 2 counties have a predicted average indoor radon screening level of 2.0 to 4.0 pCi/L and (3) Zone 3 counties have a predicted average indoor radon screening level of less than 2.0 pCi/L. Graphical representations of the country and of each state were generated once the county threat potentials were designated. Figure 1 represents the United States as a whole and Figure 2 represents the state of Kansas.

It needs to be noted that these maps are not designed to predict the radon level of individual homes (U.S. EPA 1993a). The county designations are designed to predict regional radon potential. Information used to develop the county designations included indoor radon measurements, geology, aerial radioactivity, soil permeability and foundation type (U.S. EPA 1993b). It is possible to have elevated indoor radon even in Zone 2 and Zone 3 counties; even with Hawaii's low potential, a home has been found to have indoor radon more than 20 times the EPA recommended action level of 4.0 pCi/L.

Radon as a Kansas Planning Issue

The purpose of the current paper is to examine case studies related to radon in Kansas and how those studies could impact state and local planning issues related to radon. The first case study performs an extensive review of the Kansas Radon Database through the use of geographical information system (GIS) applications. The second case

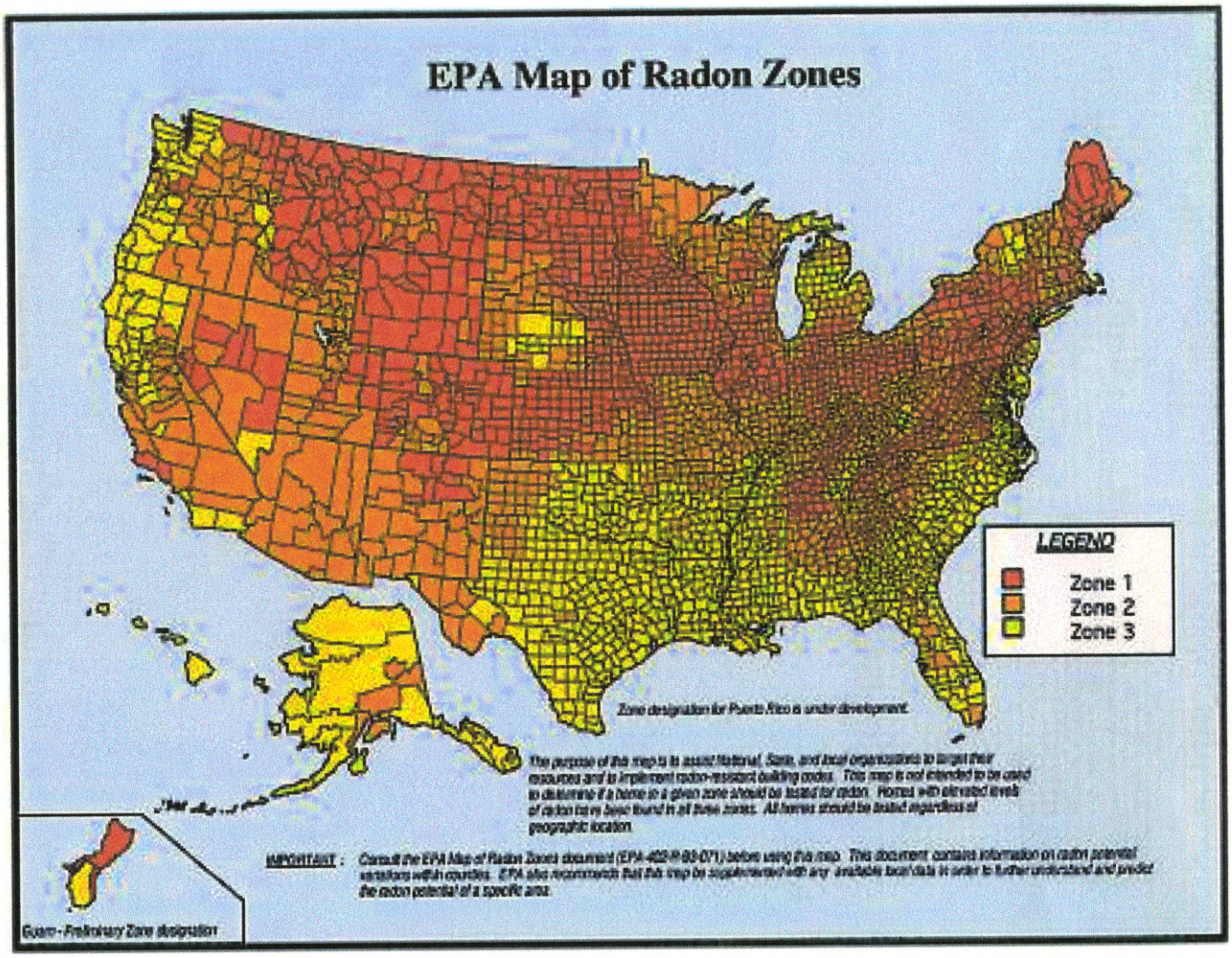


Figure 1. The EPA/USGS county designation map of the United States. Zone 1 counties are colored in red and have the highest risk of elevated indoor radon. Zone 2 counties are colored in orange and have a moderate risk of elevated indoor radon. Zone 3 counties are colored in yellow and have the lowest risk of elevated indoor radon.
Source: EPA 1993a (color version from www.epa.gov)

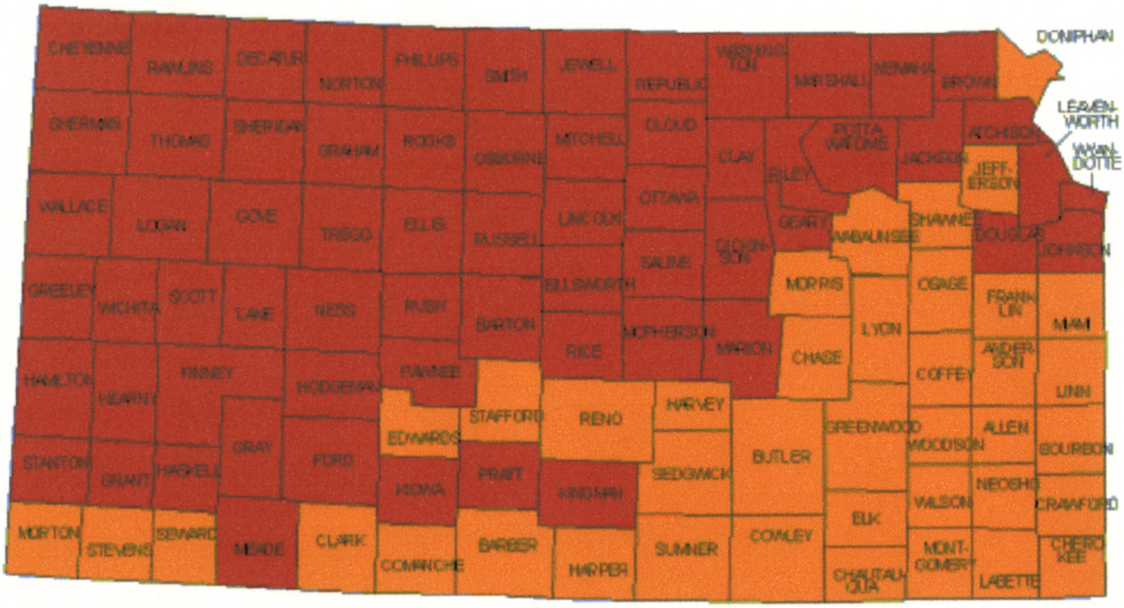


Figure 2. The EPA/USGS Zone designation listed for Kansas counties. The southeast area of the state is classified Zone 2 (Orange), or having a moderate risk for elevated indoor radon. The northwest and central portions of the state are classified Zone 1 (Red), or having the highest risk of elevated indoor radon. Zone 3 (Yellow) counties exhibit the lowest potential for elevated indoor radon (not shown in Kansas)
Source: EPA 1993a (color version from www.epa.gov)

study examines the results of an efficiency testing study performed on radon resistant new construction (RRNC) homes built in Manhattan, Kansas. The two case studies provide insight into tasks state and local planners should be focusing efforts at reducing elevated indoor radon within the state and offers first-hand observations on the effectiveness of one local program to mitigate the potential for elevated indoor radon.

The two case studies look at two different planning-related issues. The GIS study is a metanalysis of the aggregated statewide residential indoor radon testing performed over the last 16 years (1987-present). The purpose of the metanalysis was to look for trends across the state in regards to residential radon testing and to determine the degree of reliability of the data. While the state has been using the data to generate county-by-county maps of radon potential for some time, little thought has been given in the past as to whether or not the data is adequately modeling radon occurrence in Kansas as compared to the potential for the state noted by the 1987-1988 EPA/USGS analysis. If the data is providing an adequate model for the state, are state resources for education and technical assistance to the public being focused in the most at-risk areas of the state?

The RRNC study was an analysis of the effectiveness of a local attempt to reduce the possibility of the occurrence of elevated residential indoor radon in new homes. The EPA has published a technical document detailing how to install passive radon gas control systems in homes. The municipal government of Manhattan, Kansas, has adopted those technical standards as part of the municipal building code for new single- and two-family housing. The study attempted to evaluate the effectiveness of those systems using the EPA's efficiency testing protocols for RRNC homes. The results of the study offer evidence that modifying local residential building codes to include radon resistant construction techniques can, and do, reduce the level of indoor radon gas. However, as will be discussed below, enough problems were found (primarily related to the installation of the passive radon control systems) to warrant the discussion of the overall usefulness of radon resistant new construction.

Together, the two studies offer some insight into how state and local planning officials and regulatory agencies can advise Kansas municipalities in regards to this particular health-related issue. With an estimated 25% of homes in Kansas expected to have radon levels in the home above the EPA's recommended action level lends as much as a quarter of the state's population to high radon exposure. As such, the first step in reducing the possible health threat posed by radon is to educate the individuals who set the policies for the state and local governments.

Chapter 2

ANALYSIS OF THE KANSAS RESIDENTIAL RADON DATABASE

Introduction

Geographical information system (GIS) data analysis tools have been effectively utilized to identify, track and pinpoint radon potential in many states. However, additional GIS analysis for radon potential beyond that performed by the nationwide EPA/USGS study of 1987-88 by the states has been haphazard. Ohio and Pennsylvania have created limited, single-county GIS databases designed primarily to describe geographic patterns of indoor radon (Harnapp, Dollwet and Rong 1997; Geiger and Barnes 1994). Connecticut developed a state-wide GIS database, using 5000 indoor radon results and 700 ground water well results (Siniscalchi, Tibbetts, Beakes, Soto, Thomas-Margaret, McHone and Rydell, 1996). Internationally, Sweden has attempted to develop a GIS model for the country based on the national census register and standard global positioning system (GPS) technology to identify the potential radon exposure for most of the country's population (Kohli, Sahlen, Lofman, Siverturn, Foldevi, Trell and Wigertz 1997). This project in Sweden is currently the most ambitious modeling project for radon yet attempted.

The Kansas database of indoor radon results is organized at the zip code level. To date, the database has been used to create maps of each county in Kansas identifying the average radon value for each zip code within a given county (see Figure 3). This organization therefore has allowed for the creation of maps that have finer regional definition of exhibited indoor radon. The primary fallacy inherent within these maps

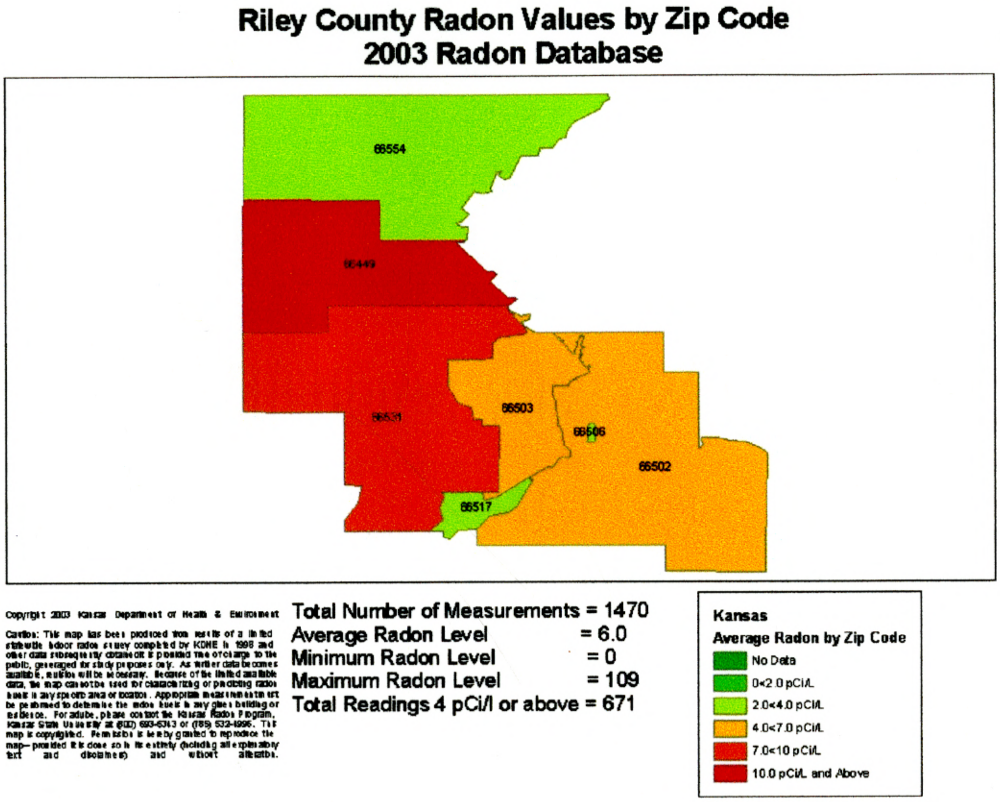


Figure 3. A typical map generated using the Kansas radon database. Maps include information on total number of test results for each county, the average indoor radon level across all associated zip codes, the minimum and maximum radon values for each county, and the total number of results equal to or greater than 4.0 pCi/L.

however is that the maps are generated with unequal number of test results across the zip codes used in each map. Zip codes with n test results of 2 count equally towards the county's overall average, as do zip codes with n test results of 1000.

The purpose of the current study is to expand on the geographical analysis of radon potential for Kansas. The study will attempt to do three things. The first is to compare current state indoor radon testing data with the original EPA/USGS county zone designations. This analysis is expected to conform in nature to the original graphical representation for Kansas. The second is to identify regions of Kansas that show limited or zero indoor radon testing. The purpose of this analysis is to identify areas of the state that may have been underserved by state and federal radon programs. Also, this analysis is expected to identify areas of the state where unequal number of test results are unduly affecting local county average radon values. The third is to compare regional clusters with high numbers of radon tests for internal consistency of average radon results. This analysis is expected to show that clustered regions with high n-values of radon tests will yield similar average radon results, which would provide better definition of radon potential in such regions.

Materials and Methods

Participants

The participating homes which have had radon gas tests performed and that have been recorded in the Kansas Radon database are collected from one of three primary sources. One source is the voluntary testing of homes by homeowners that have purchased either state-subsidized test kits or test kits from retail outlets (such as home improvement stores). Subsidized kits are distributed throughout the state by the Kansas

State University Research and Extension Service and by a limited number of county health departments. A second source is tests performed by professional radon testing labs, most notably RTCA and Alpha Energy Labs, whose services are retained by the homeowner. Results from these companies are turned over to the Kansas Department of Health and Environment (KDHE). The third primary source of residential test results is the KDHE laboratory made available from tests performed as part of whole-home inspections for environmental contamination.

It should be noted that the database does not receive the results of radon tests performed by home inspectors as part of a real estate transaction unless those tests are performed using equipment from testing labs, which submit their results to KDHE. This omission is important as real estate-derived radon tests generate the second highest number of tests performed each year behind the purchase of do-it-yourself radon kits from either the state radon program distribution system or home improvement outlets.

Apparatus

A Dell Dimension desktop computer, utilizing the Microsoft Windows 2000 operating system was used to perform the analyses below. The Kansas Radon Program database is maintained in Microsoft Access format. The graphical information system (GIS) used to analyze the database is ESRI Arc Info 8.2. Microsoft Word was used to write the report contained herein.

Procedure

The Kansas Radon Program database is organized by the statewide zip code system. Radon test results generated by the sources described above are reported to the state with the origin of the test being identified by its zip code. In all test result cases, the zip code and the radon value are entered. When available, additional information, such as the type of test equipment and the location of the test, is also entered. Data is available starting from January 1, 1987 and updated through December 1, 2002. A total of 22,148 test results were available for analysis.

Arc Info 8.2 is capable of integrating information maintained in Microsoft Access format. In order to collate the database into a format suitable for import into Arc Info 8.2, a summary file of the Kansas Radon Program database was generated using Microsoft Access. The summary file contained entries for the following: (1) each zip code for which radon gas data was available, (2) the average radon gas level of the available data for each zip code, (3) the minimum radon value for each zip code, (4) the maximum radon value for each zip code and (5) the total number of test results for each zip code. It should be noted that not all Kansas zip codes have data associated with them. This situation is caused by the volunteer nature of residential radon testing in Kansas and is examined in detail below.

The database summary file was imported into Arc Info 8.2 using a "join" procedure. This procedure appends a data file to an Arc Info 8.2 shape file using a data element common to the two files; in this case the common element was the zip code numbers for Kansas. The shape file used for this analysis was the zip code shape file delineating each Kansas zip code district from the ESRI data CD-ROM for the western United States (as distributed by ESRI in Arc View 8.0).

The joined data file provided a graphical representation of Kansas as delineated by each zip code district's boundaries. This representation was used to perform a number of analyses, using the tools available in Arc Info 8.2. The first analysis generated a map of Kansas using the EPA/USGS three radon risk zones plus one zone used to indicate zip code districts for which no test results are available. The second analysis generated a data density plot for all zip code districts for which data was available, as well as creating a highlight map of Kansas identifying zip code districts for which no data is currently available. The third analysis generated a map identifying specific counts of radon tests per zip code. This map was used to identify three areas in Kansas with zip code clusters with relatively high number of radon samples (greater than 25 samples in a zip code district); those areas are Shawnee County, Sedgwick County and the Kansas City Metropolitan area (including Wyandotte County, Leavenworth County, Johnson County and Douglas County).

Results

Analysis 1: EPA/ Kansas Database Risk Comparison

The first GIS analysis was a comparison of the original EPA/USGS radon potential designation to the results of the ongoing data compilation in Kansas. The EPA/USGS analysis performed across the country during the 1987-1989 time period set three classes of radon threat, broken out by each county within a state. Zone (1) counties have the highest potential for elevated indoor radon levels of 4.0 pCi/L or higher. Zone (2) counties average indoor radon levels of 2.0 to 4.0 pCi/L concentrations. Zone (3) counties expect average indoor radon levels of less than 2.0 pCi/L concentrations. Kansas exhibits a majority of counties as Zone (1), with the southern and eastern counties ranking as Zone (2) (see Figure 4).

A comparison of the data collected in the Kansas database, using the same zone criteria as EPA/USGS, identifies a similar trend (see Figure 5). While the individual zip

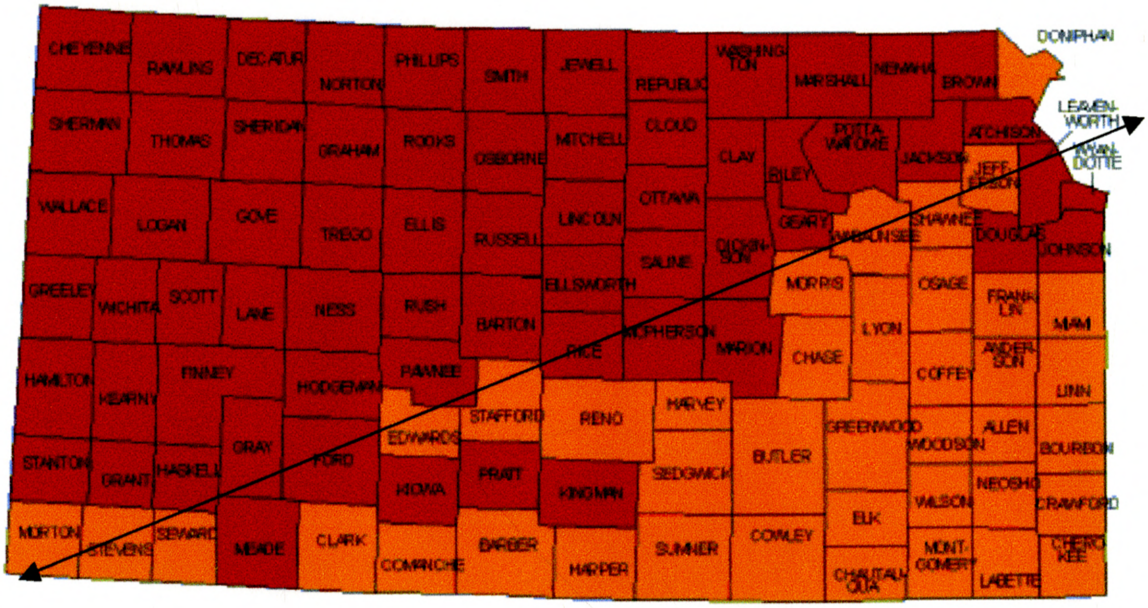


Figure 4. The EPA/USGS Zone designation listed for Kansas counties. The southeast area of the state is classified Zone (2) (orange counties) while the northwest and central portions of the state are classified Zone (1) (red counties).

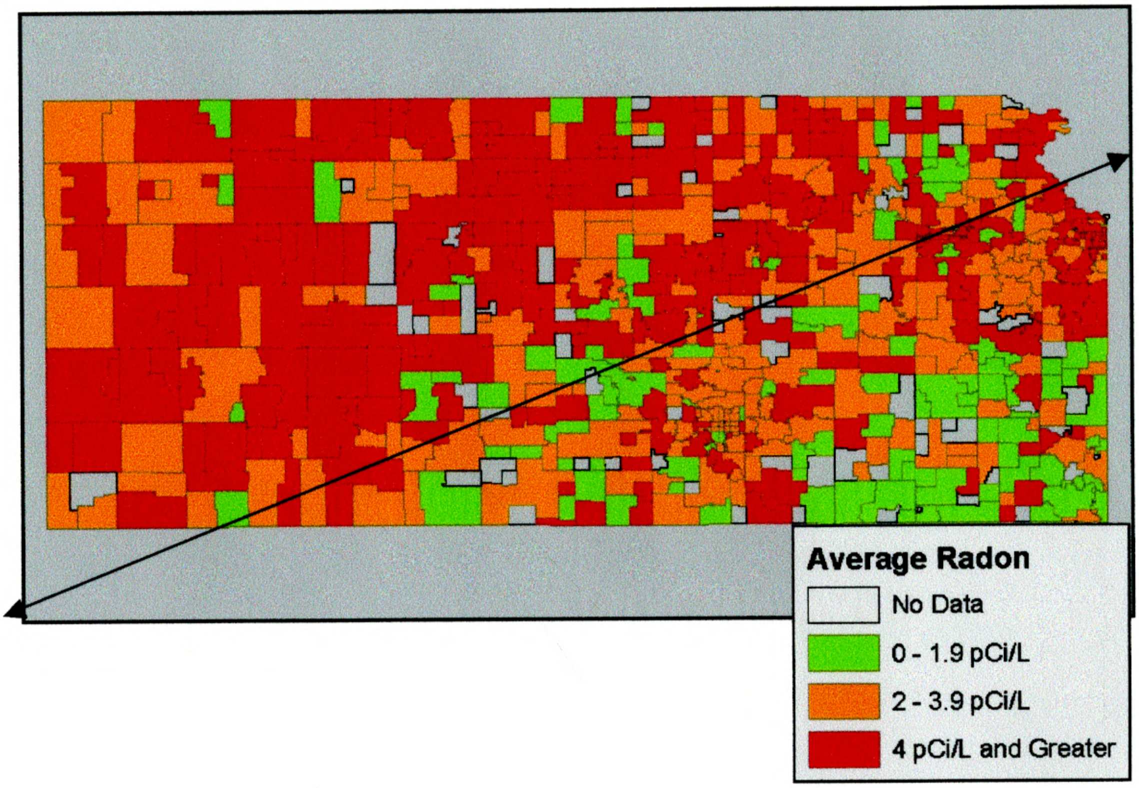


Figure 5. A map of Kansas zip code districts. Each zip code district is ranked as per the EPA/USGS zone categories. Zip codes for which no data has been collected are colored gray.

codes do not necessarily exhibit the same average indoor radon concentrations as expected by the EPA/USGS county analysis, the identified trends of higher average indoor radon levels in the northwest and central portions of Kansas and lower average indoor radon levels in the southeast region of the state are confirmed.

Analysis 2: Data Density Analysis of Radon Testing in Kansas

As noted above in Figure 5, the database is lacking in data for a number of zip code districts in Kansas. This lack of data is a result of the voluntary nature of residential radon testing in Kansas. An analysis of testing density indicates that the zip codes with the highest number of recorded test results occur in areas with the highest population densities (see Figure 6). The map clearly indicates that the metropolitan areas of Kansas City, Topeka and Wichita have recorded the greatest number of radon tests. The regions surrounding Hutchinson, Manhattan, and Salina exhibit the next tier of testing densities.

Analysis 3: Radon Variability in Zip Code Clusters with Large N Values

A direct examination of total number of radon tests in Kansas revealed that the Kansas City, Topeka and Wichita areas had the highest densities of recorded tests. These three areas exhibited clusters of zip codes with relatively high n-values, equal to or exceeding 25 radon tests per zip code as seen in the total test result count map in Figure 7. Shawnee County and the Topeka area exhibited a cluster of 18 such zip codes, the fewest of the three metropolitan areas. Sedgwick County and the Wichita area exhibited 20 zip codes with 25 or more test results each. The Kansas City Metropolitan area, including Johnson County, Wyandotte County, Leavenworth County and Douglas County, exhibited 42 zip code districts with at least 25 test results.

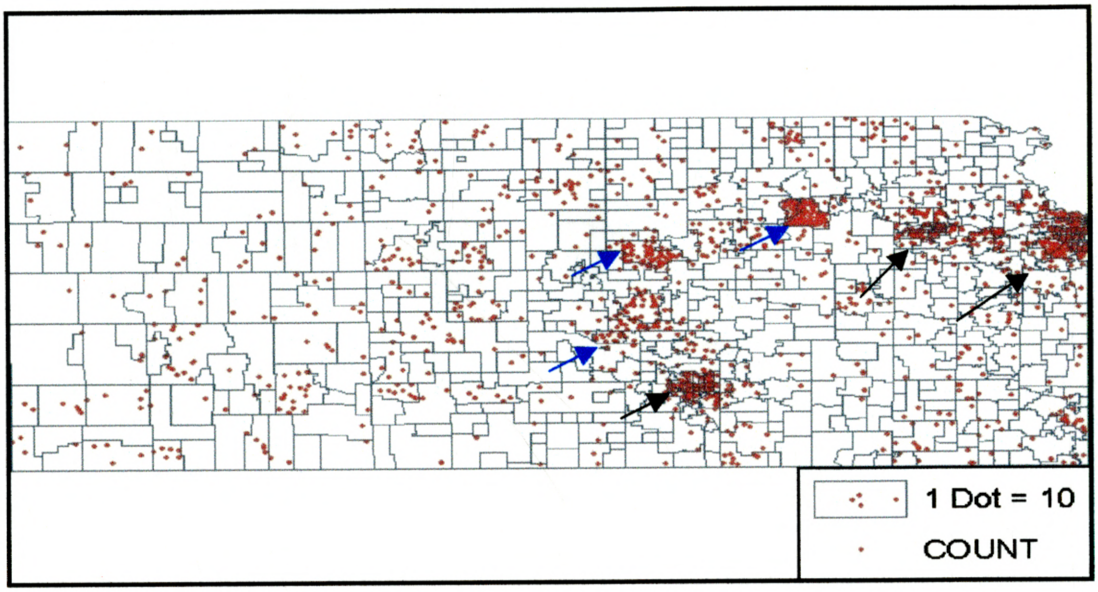


Figure 6. This map is a data density plot of the total number of radon test results taken in Kansas from January 1, 1987 through December 1, 2002, or a grand total of 22,148 tests.

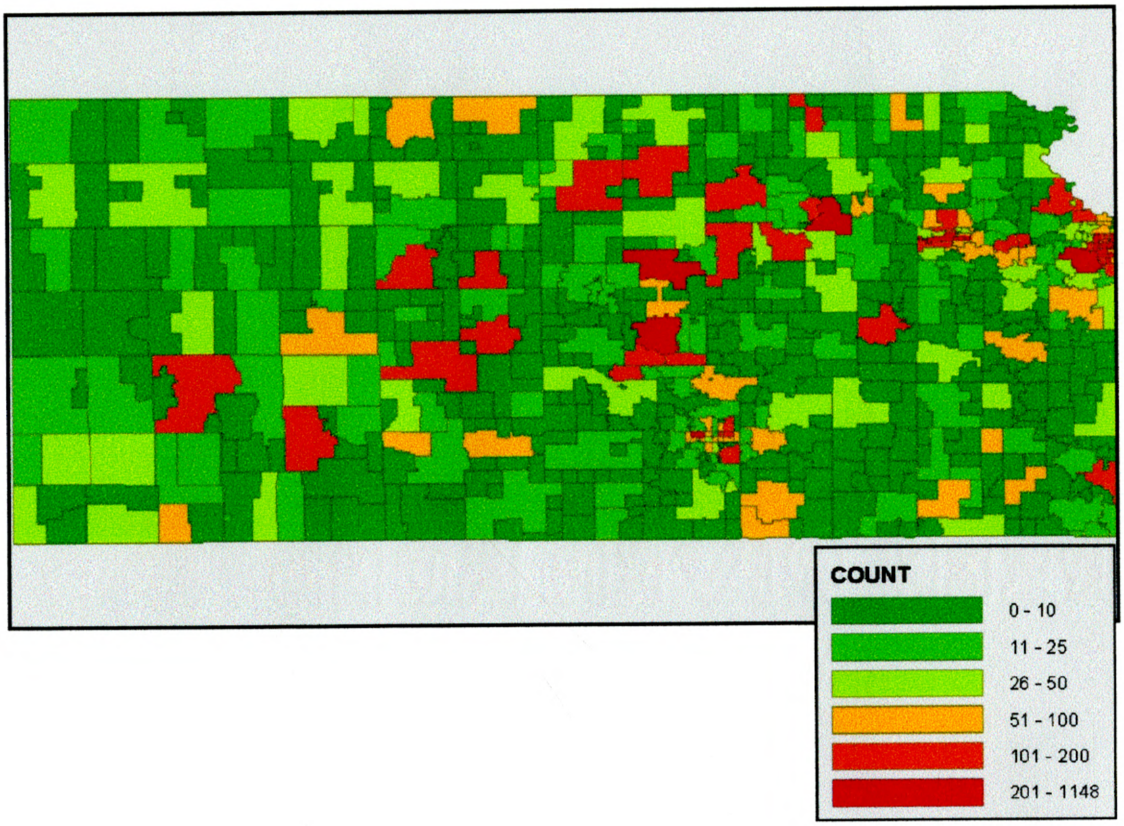


Figure 7. Kansas zip code districts examined by total number of recorded radon tests.

Each of these three regions was examined for variability of average radon values across the zip code clusters. For each region, the results of all the zip code radon averages were graphed. The region-wide analysis was followed by an analysis of zip code districts with 25 or more radon test results. The 25 or more analysis was followed by an analysis of zip code districts with 50 or more radon test results. The 50 or more analysis was followed by an analysis of zip code districts with 100 or more radon test results. Each graph shows the complete range of average radon values for the zip code districts involved and a graphical representation of the zip code districts present (i.e. the first graph for each of the three regions includes all possible zip code districts, with each successful graph indicating the remaining zip code districts meeting the analysis criteria). The dotted blue lines on each graph indicate the range of one standard deviation in difference between the average values for each chart. The solid red line indicates the EPA's recommended action level of 4.0 pCi/L indoor radon concentrations. The error bars for each individual zip code denote standard calculated error. The inset pictorial of the region being examined is colored as to the average radon value for each zip code, following the EPA's radon zones described above.

1) Sedgwick County

A decreasing trend in the variation between average radon values across zip codes is apparent in relation to increasing number of test results. Total radon test counts for Sedgwick County's zip codes are listed in Figure 8. If the graph in Figure 9 is examined, Sedgwick County as a whole exhibits a range of radon averages from about 1.0 pCi/L to slightly more than 8.0 pCi/L. If the analysis is limited to zip codes with 25 or more test

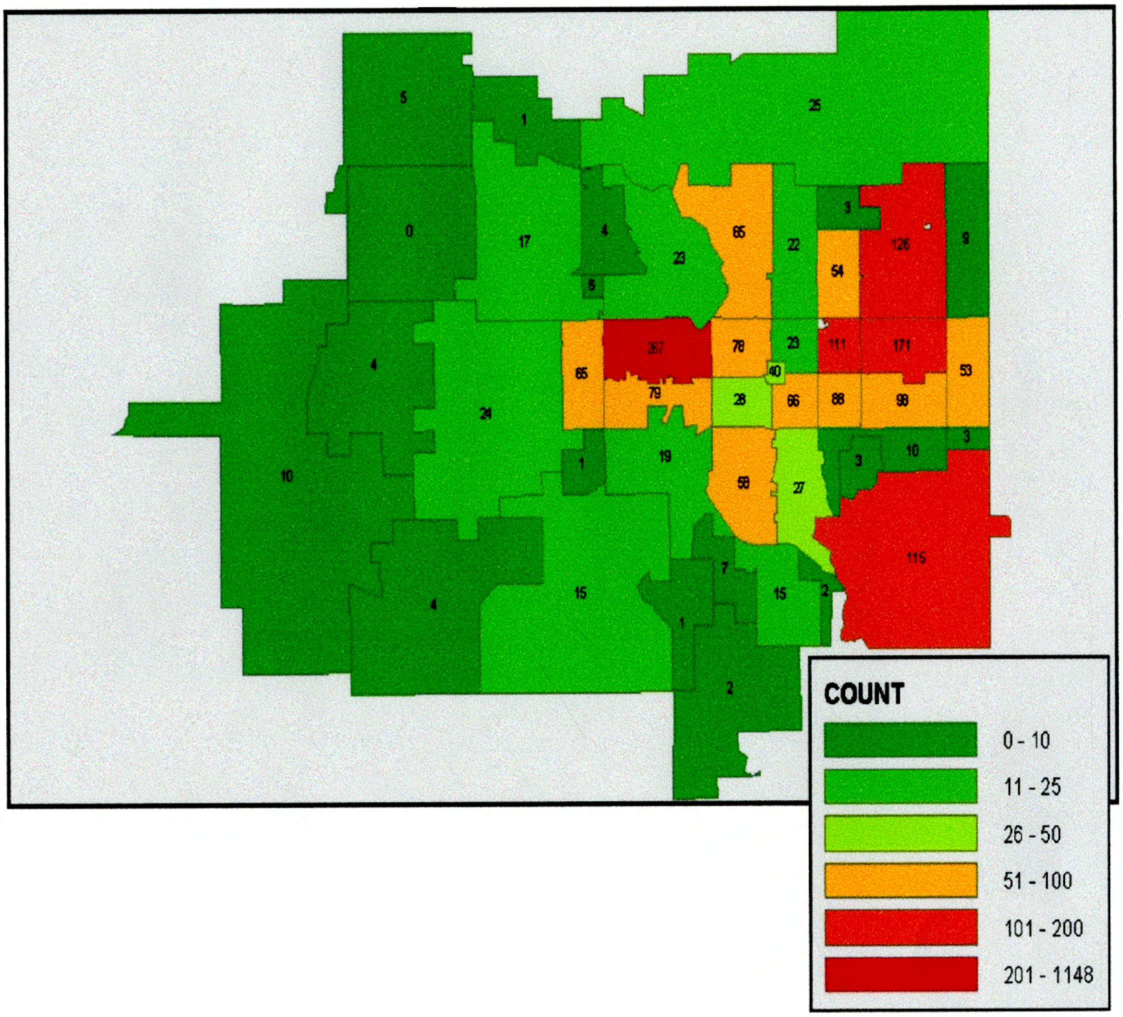


Figure 8. Sedgwick County and the Wichita Metropolitan area zip code districts listed by their total n-value of radon tests.

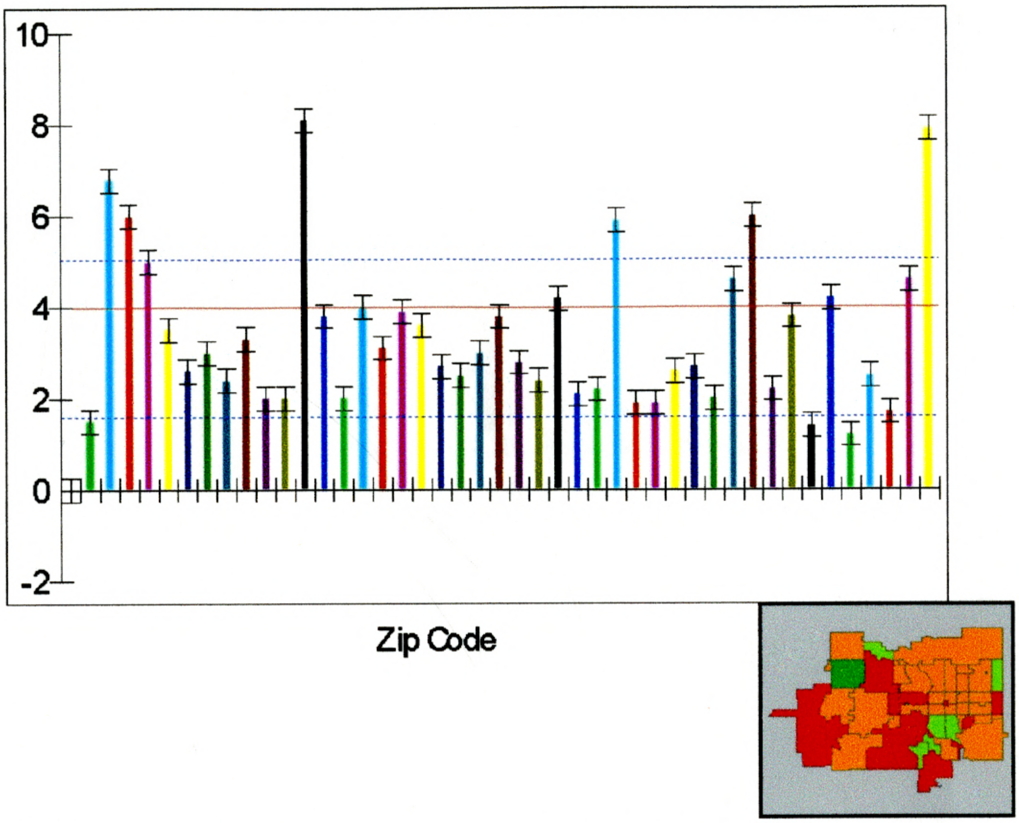


Figure 9. Sedgwick County and the Wichita Metropolitan area by average radon value (all zip codes). Light green zip codes average less than 2.0 pCi/L indoor radon concentrations. Orange zip codes average between 2.0 and 4.0 pCi/L indoor radon concentrations. Red zip codes average 4.0 pCi/L or higher indoor radon concentrations. Dark green zip codes have no data collected. The solid red line is the EPA's recommended action level for reducing indoor radon levels (4.0 pCi/L). The blue dotted lines indicate the range of one standard deviation.

results, the range of radon averages decreases to slightly less than 2.0 pCi/L to 4.5 pCi/L (see Figure 10). Further limiting of zip codes to 50 or more test results does not significantly alter the exhibited range of 2.0 pCi/L to 4.5 pCi/L (see Figure11). In zip codes with 100 or more test results the range of average radon values reduces to 2.5 pCi/L to 3.7 pCi/L (see Figure 12); however, only five such zip codes are available for Sedgwick County.

One problem with the Sedgwick County analysis is that almost the entire western half of the county is excluded after the initial analysis due to low numbers of test results (as seen when Figure 9 and Figure 10 above). This exclusion places all zip code districts in the successive analyses for Sedgwick County within the Wichita metropolitan core. As such, it is difficult to impossible to extrapolate these results to the areas outside of the Wichita core to the rest of the county. The EPA (1993a) has designated Sedgwick County as a Zone 2 county (having a moderate risk of elevated indoor radon). Of the 1806 tests in the Kansas data base for Sedgwick County, 493 (27%) equal or exceed 4.0 pCi/L. This percentage is on par for the statewide value of an expected 25% of test results meeting or exceeding 4.0 pCi/L.

2) Shawnee County

A decreasing trend in the variation between average radon values across zip codes is apparent in relation to increasing number of test results. Total radon test counts for Shawnee County's zip codes are shown below in Figure 13. If the graph in Figure 14 is examined, Shawnee County as a whole exhibits a range of radon averages from about 1.5 pCi/L to about 6.0 pCi/L. If the analysis is limited to zip codes with between 25 and 99 test results, the range of radon averages remains similar to that of the entire county (1.5

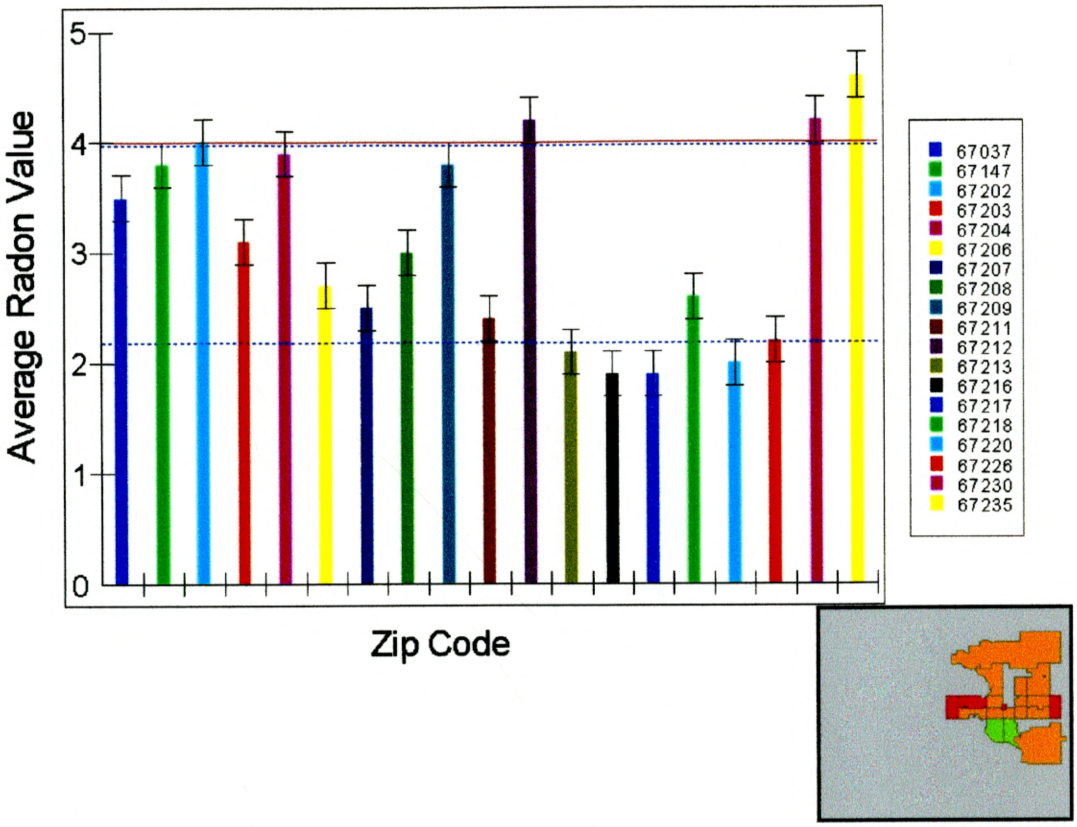


Figure 10. Sedgwick County and the Wichita Metropolitan area by average radon value (25 or more test results). Zip code districts with 25 or more tests are listed. Light green zip codes average less than 2.0 pCi/L indoor radon concentrations. Orange zip codes average between 2.0 and 4.0 pCi/L indoor radon concentrations. Red zip codes average 4.0 pCi/L indoor radon concentrations. Dark green zip codes have no data collected. The solid red line is the EPA's recommended action level for reducing indoor radon levels (4.0 pCi/L). The blue dotted lines indicate the range of one standard deviation.

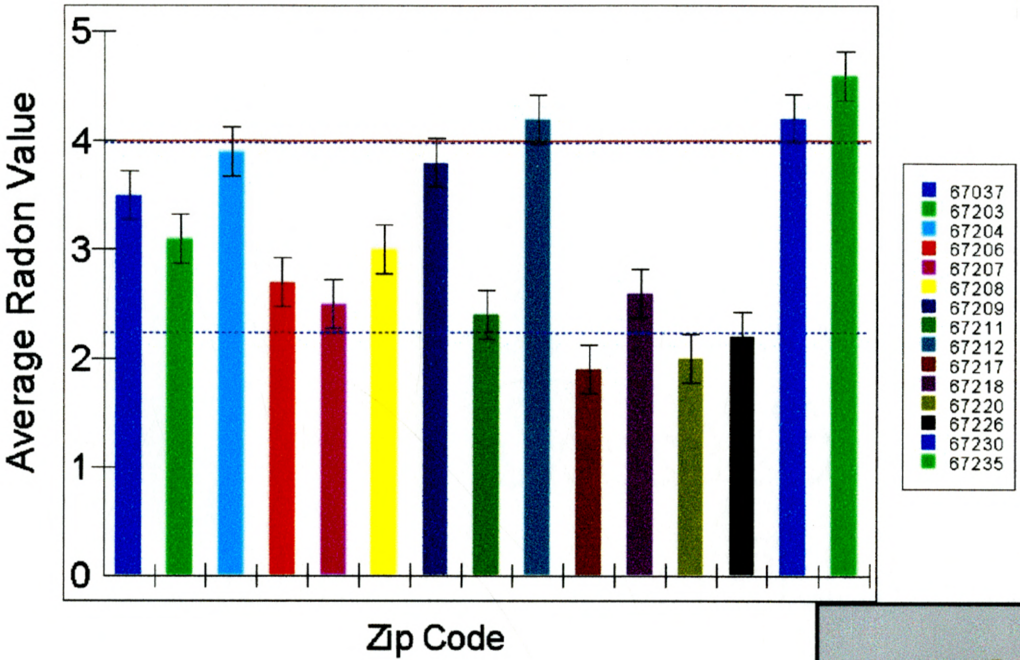


Figure 11. Sedgwick County and the Wichita Metropolitan area by average radon value (50 or more test results). Zip code districts with 50 or more tests are listed. Light green zip codes average less than 2.0 pCi/L indoor radon concentrations. Orange zip codes average between 2.0 and 4.0 pCi/L indoor radon concentrations. Red zip codes average 4.0 pCi/L indoor radon concentrations. Dark green zip codes have no data collected. The solid red line is the EPA's recommended action level for reducing indoor radon levels (4.0 pCi/L). The blue dotted lines indicate the range of one standard deviation.

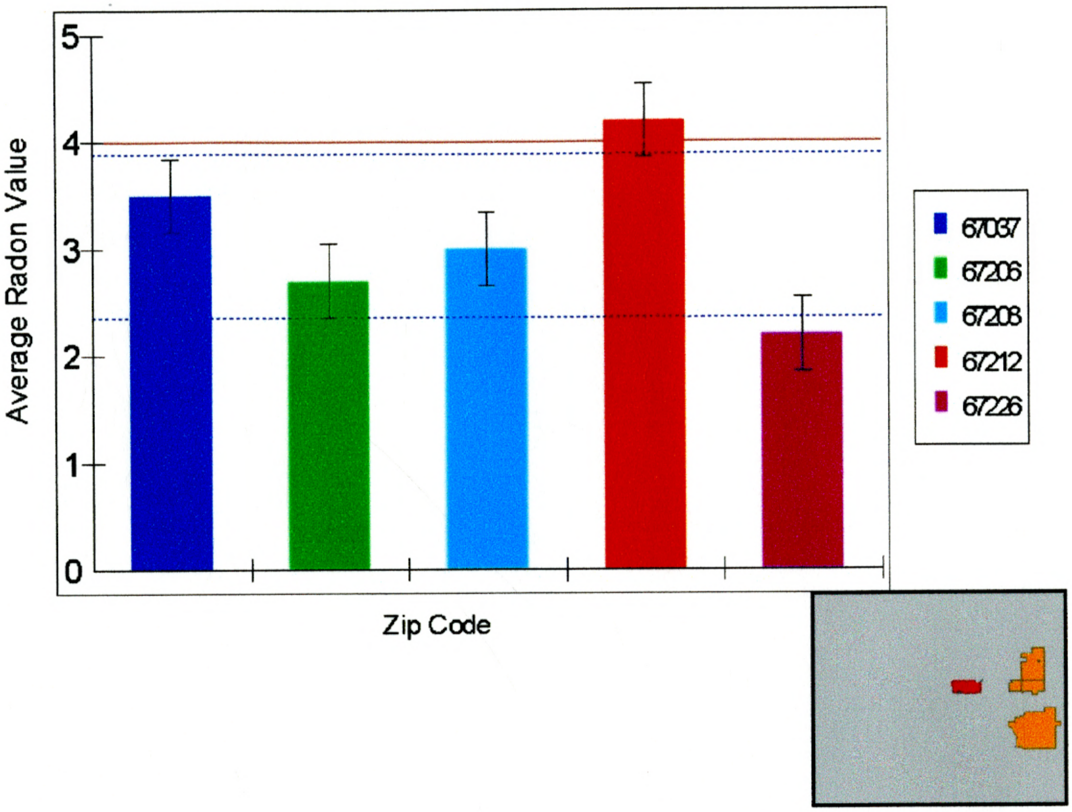


Figure 12. Sedgwick County and the Wichita Metropolitan area by average radon value (100 or more test results). Zip code districts with 100 or more tests are listed. Light green zip codes average less than 2.0 pCi/L indoor radon concentrations. Orange zip codes average between 2.0 and 4.0 pCi/L indoor radon concentrations. Red zip codes average 4.0 pCi/L indoor radon concentrations. Dark green zip codes have no data collected. The solid red line is the EPA's recommended action level for reducing indoor radon levels (4.0 pCi/L). The blue dotted lines indicate the range of one standard deviation.

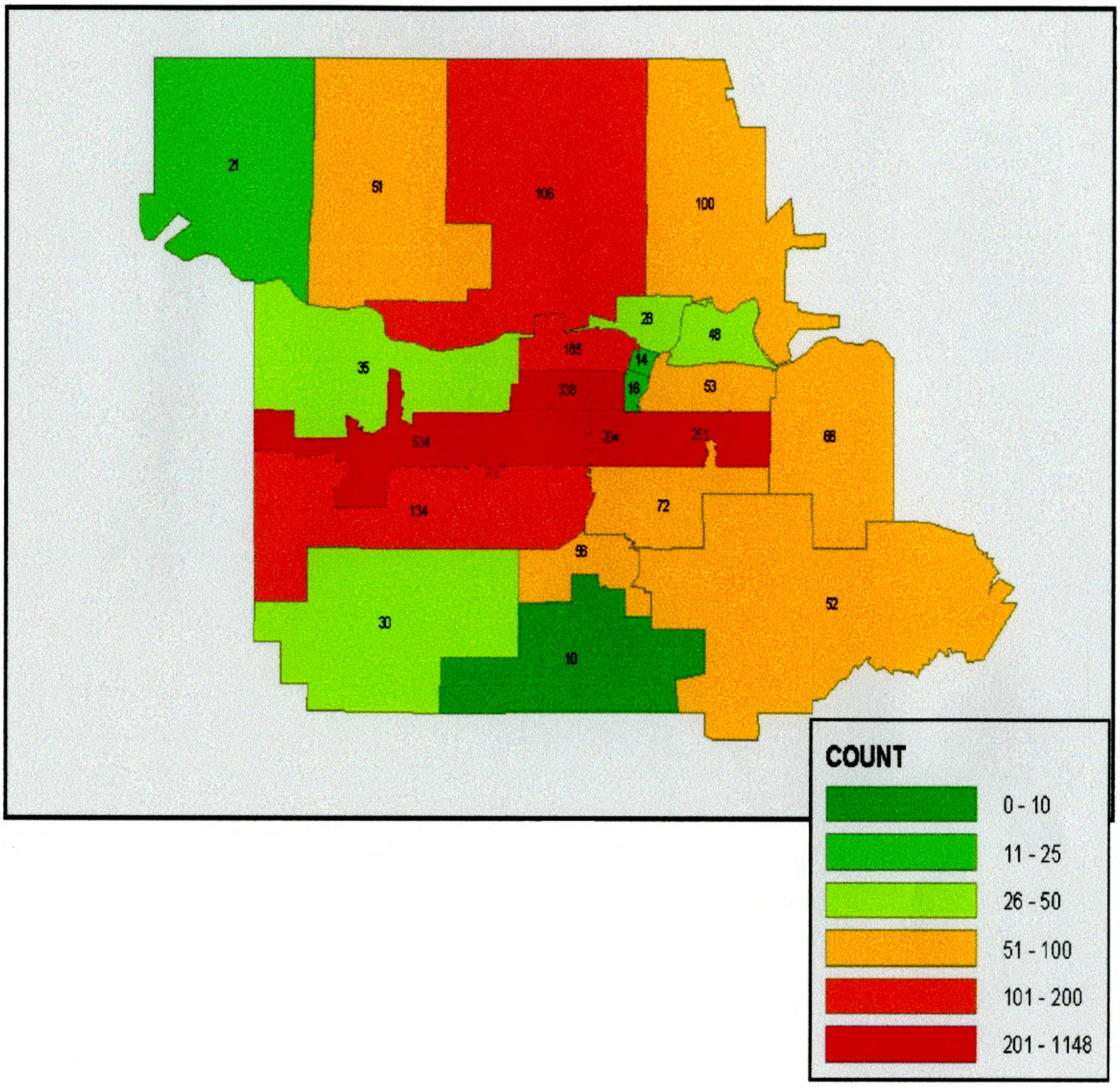
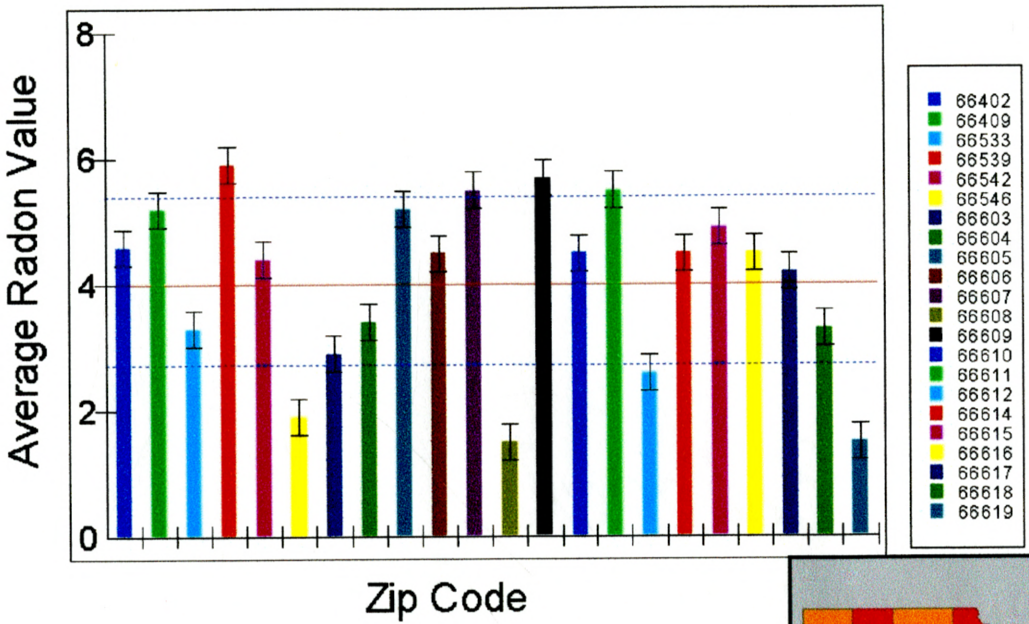


Figure 13. Shawnee County and the Topeka Metropolitan area zip code districts listed by their total n-value of radon tests.



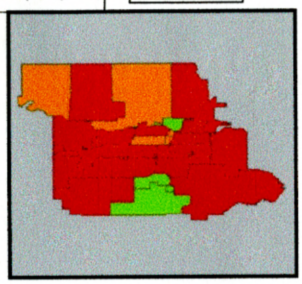


Figure 14. Shawnee County and the Topeka Metropolitan area by average radon value. Light green zip codes average less than 2.0 pCi/L indoor radon concentrations. Orange zip codes average between 2.0 and 4.0 pCi/L indoor radon concentrations. Red zip codes average 4.0 pCi/L indoor radon concentrations. Dark green zip codes have no data collected.

pCi/L to about 6.0 pCi/L), but the number of outlier points beyond a single standard deviation decreases (see Figures 15 and 16 below). However, in zip codes with 100 or more test results the range of average radon values decreases to 3.5 pCi/L to 5.7 pCi/L (see Figure 17); however, only eight such zip codes are available for Shawnee County.

Shawnee County has a distribution of zip codes in relation to high numbers of test results similar to that of Sedgwick County. Again, the zip codes with lower number of test results are collected in the western half of the county (mostly rural area), pushing the zip codes with the highest number of tests back into the Topeka metro core. Shawnee County is also designated a Zone 2 county by the EPA (1993a). Of the 2617 test results for the county, 1011 (39%) of the test results meet or exceed EPA's 4.0 pCi/L action level. The high number of elevated radon tests in comparison to the expected 25% of statewide test results may indicated that the radon potential for Shawnee County was misjudged and that the county should have been designated a Zone 1 county by the EPA (counties with the highest potential for elevated indoor radon).

3) Kansas City Metropolitan Area

A decreasing trend in the variation between average radon values across zip codes is apparent in relation to increasing number of test results. Total radon test counts for the Kansas City metropolitan area zip codes are listed in Figure 18. If the graph in Figure 19 is examined, the metropolitan area as a whole exhibits a range of radon averages from about 1.0 pCi/L to slightly more than 6.5 pCi/L. If the analysis is limited to zip codes with 25 or more test results, the range of radon averages decreases to slightly less than 2.5 pCi/L to 6.5 pCi/L (see Figure 20). Further limiting of zip codes to 50 or more test results does not significantly alter the exhibited range of 3.5 pCi/L to 6.5 pCi/L (see

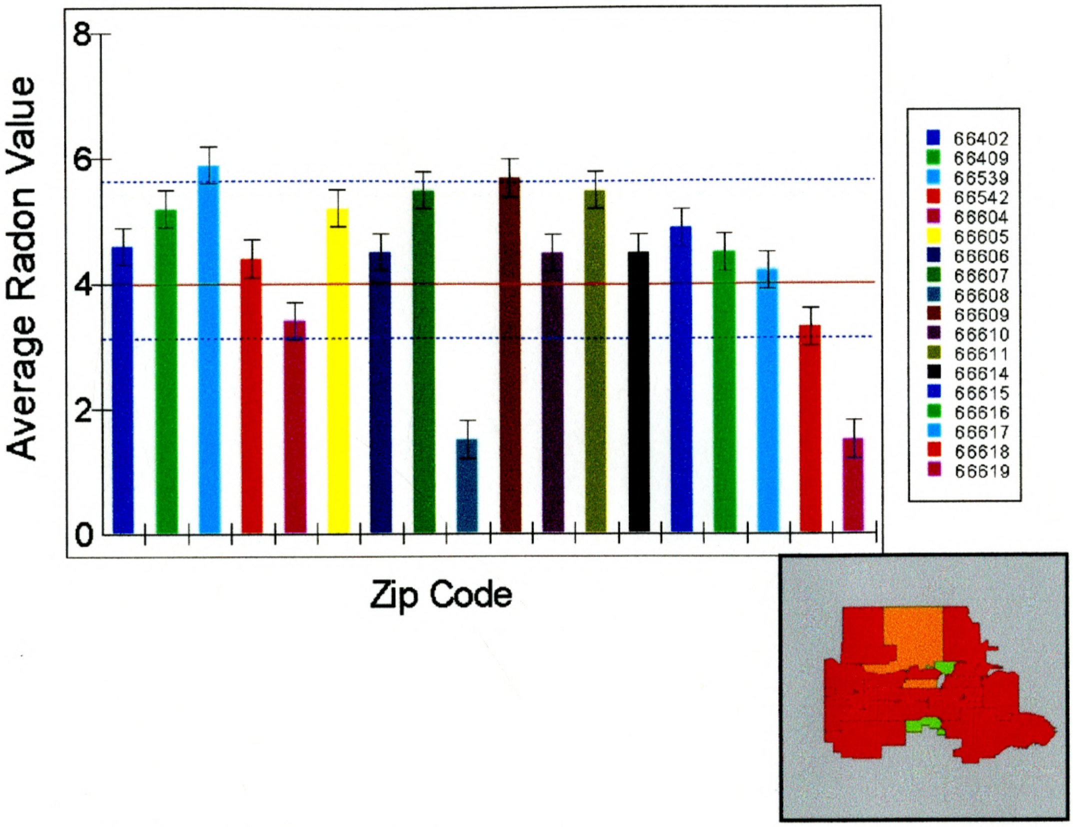


Figure 15. Shawnee County and the Topeka Metropolitan area by average radon value (25 or more test results). Zip code districts with 25 or more tests are listed. Light green zip codes average less than 2.0 pCi/L indoor radon concentrations. Orange zip codes average between 2.0 and 4.0 pCi/L indoor radon concentrations. Red zip codes average 4.0 pCi/L indoor radon concentrations. Dark green zip codes have no data collected.

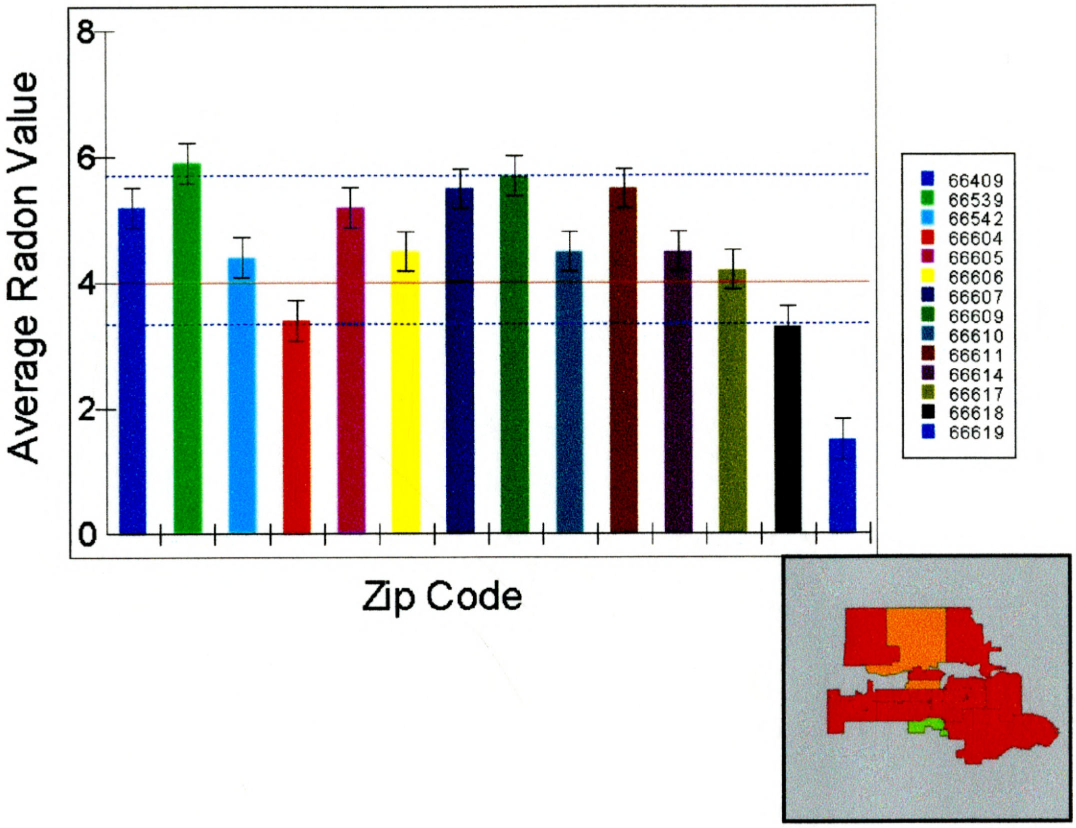


Figure16. Shawnee County and the Topeka Metropolitan area by average radon value (50 or more test results). Zip code districts with 50 or more tests are listed. Light green zip codes average less than 2.0 pCi/L indoor radon concentrations. Orange zip codes average between 2.0 and 4.0 pCi/L indoor radon concentrations. Red zip codes average 4.0 pCi/L indoor radon concentrations. Dark green zip codes have no data collected.

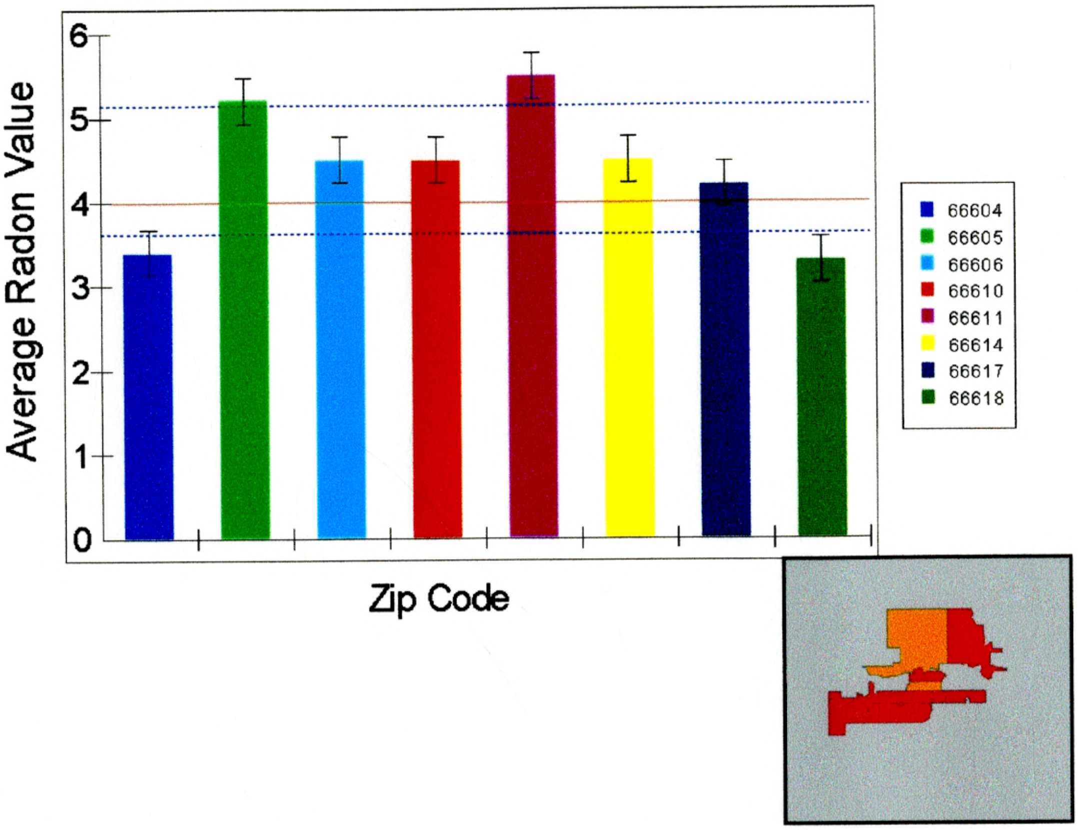


Figure 17. Shawnee County and the Topeka Metropolitan area by average radon value (100 or more test results). Zip code districts with 100 or more tests are listed. Light green zip codes average less than 2.0 pCi/L indoor radon concentrations. Orange zip codes average between 2.0 and 4.0 pCi/L indoor radon concentrations. Red zip codes average 4.0 pCi/L indoor radon concentrations. Dark green zip codes have no data collected.

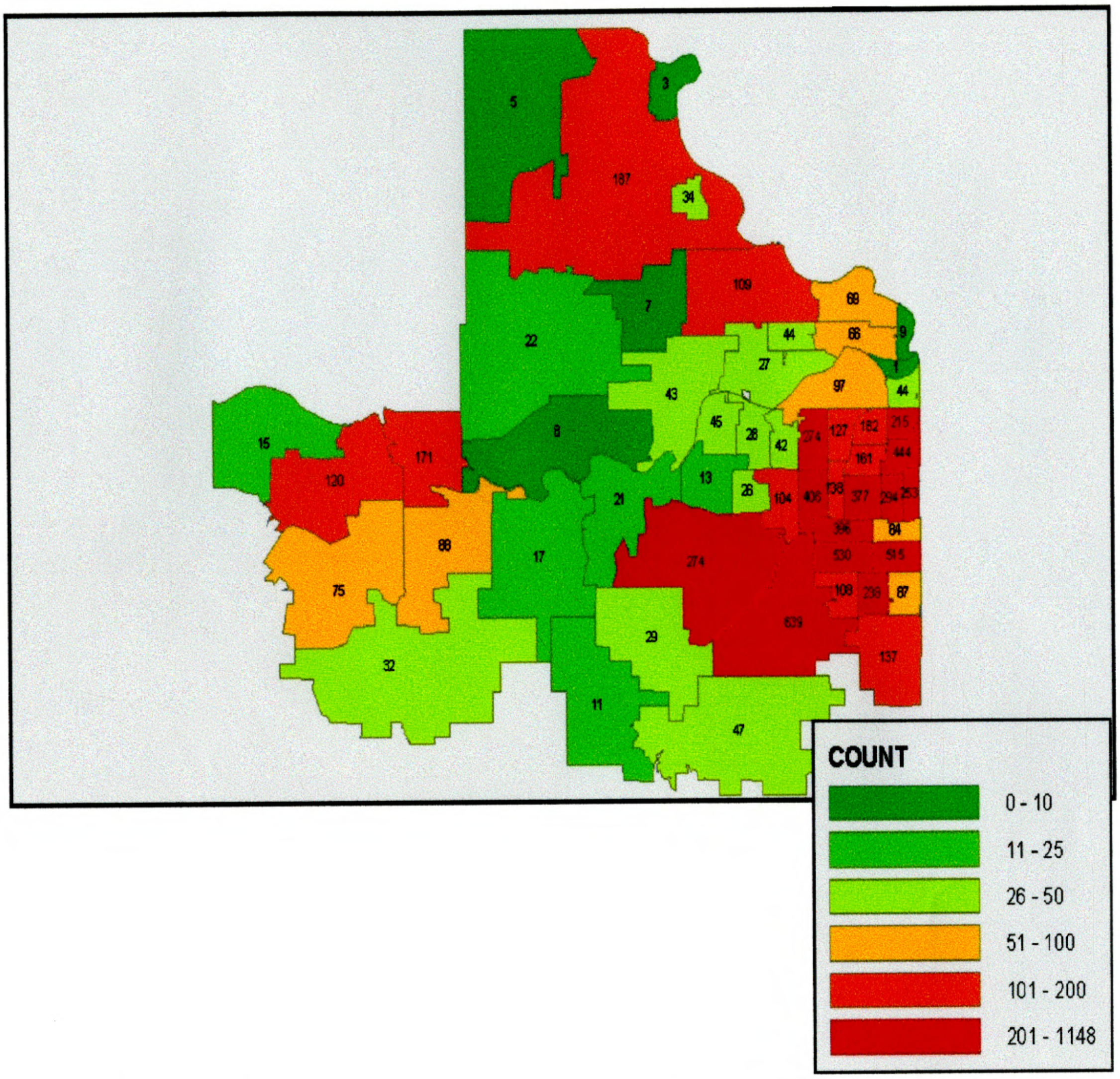
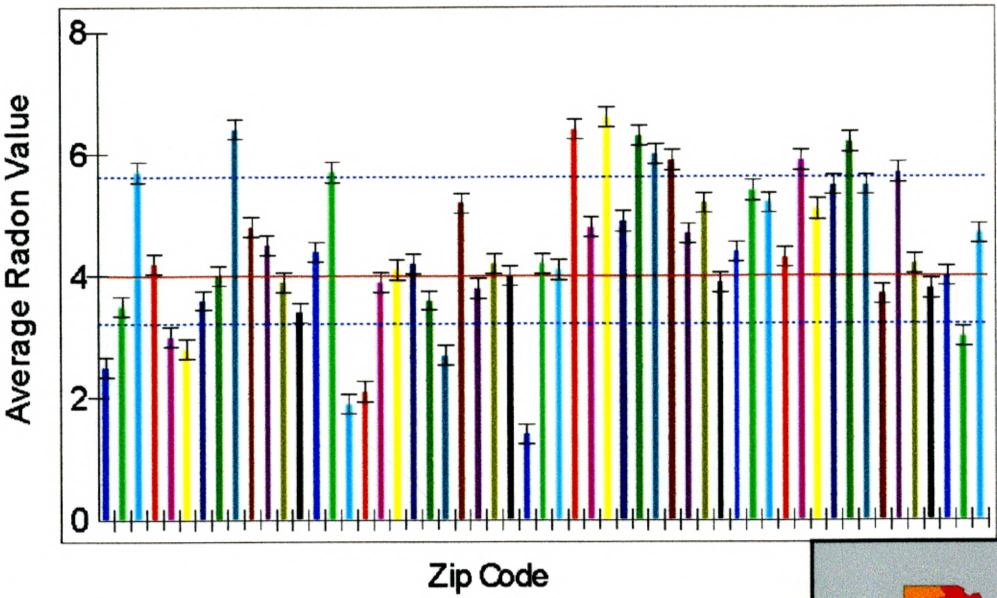


Figure 18. The Kansas City Metropolitan area (including Johnson, Douglas and Wyandotte counties) zip code districts listed by their total n-value of radon tests.



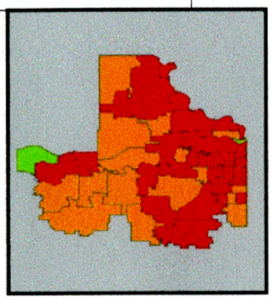


Figure 19. Kansas City Metropolitan area (including Johnson, Douglas, Leavenworth and Wyandotte counties) listed by average radon value. Light green zip codes average less than 2.0 pCi/L indoor radon concentrations. Orange zip codes average between 2.0 and 4.0 pCi/L indoor radon concentrations. Red zip codes average 4.0 pCi/L indoor radon concentrations. Dark green zip codes have no data collected.

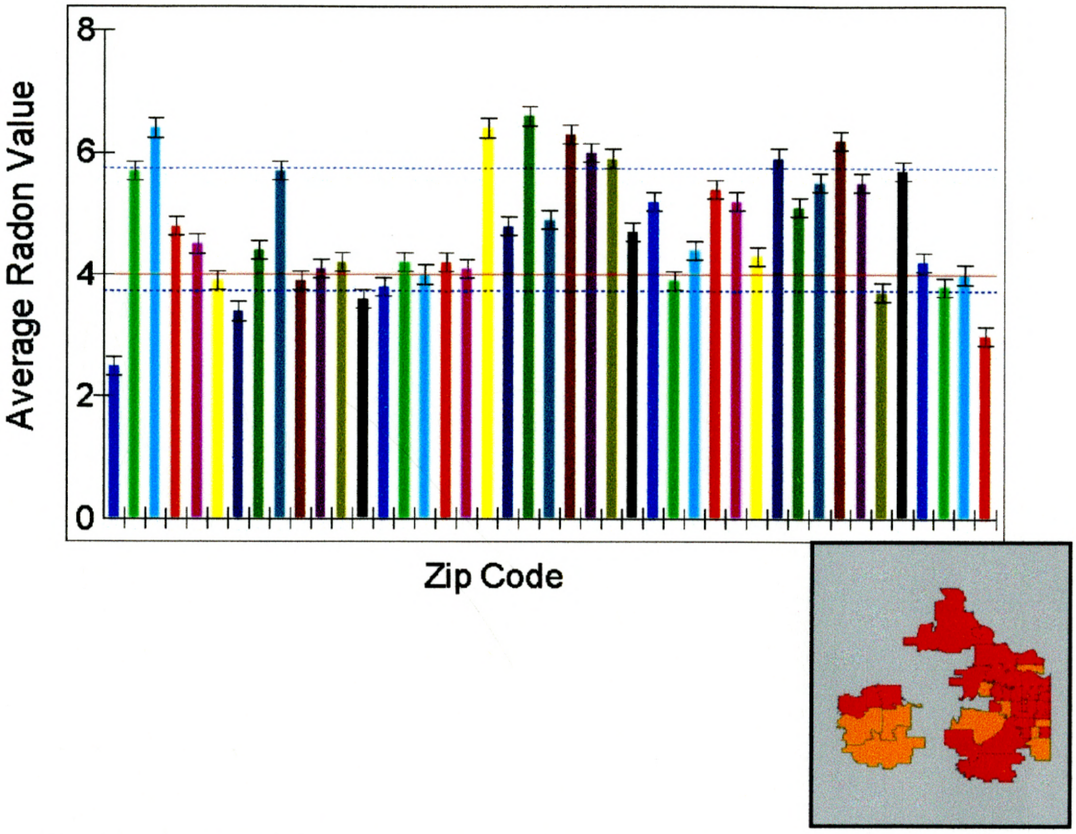


Figure 20. Kansas City Metropolitan area (including Johnson, Douglas, Leavenworth and Wyandotte counties) by average radon value (25 ore more test results). Zip code districts with 25 or greater test results are listed. Light green zip codes average less than 2.0 pCi/L indoor radon concentrations. Orange zip codes average between 2.0 and 4.0 pCi/L indoor radon concentrations. Red zip codes average 4.0 pCi/L indoor radon concentrations. Dark green zip codes have no data collected.

Figure 21). In zip codes with 100 or more test results the range of average radon values changes to about 3.7 pCi/L to 6.5 pCi/L (see Figure 22.)

The Kansas City metropolitan area includes Johnson, Wyandotte, Leavenworth and Douglas Counties and includes the cities of Kansas City (plus its primary suburb communities) Leavenworth and Lansing (a continuous municipal group), and Lawrence. The high urban density of the region has assisted in producing some of the most widespread radon testing in Kansas. The high test density also provides the best illustration of the tendency towards lower variability of average radon values in adjacent zip codes. Across the four counties, the database has records of 7800 radon tests with 3191 tests (40%) meeting or exceeding the 4.0 pCi/L guideline. All four counties in this portion of the analysis are designated as Zone 1 counties (counties with the highest possibility for elevated radon) by the EPA (1993a).

Conclusion

Geographical analysis of observed Kansas indoor radon test results provides information valuable to the state radon control program. The data reaffirms the original EPA/USGS radon potential map. The analysis of the test count distribution clearly identifies regions of Kansas that require greater testing attention. The data also indicates that regions with high numbers of test results generate coherent and consistent average radon values.

It should be restated that GIS analysis of radon results by region are not designed to predict the indoor radon level of any given house. That having been said, the current study has provided the Kansas Radon Program with several pieces of useful information. First, the study reiterated the statewide potential for radon using considerably more

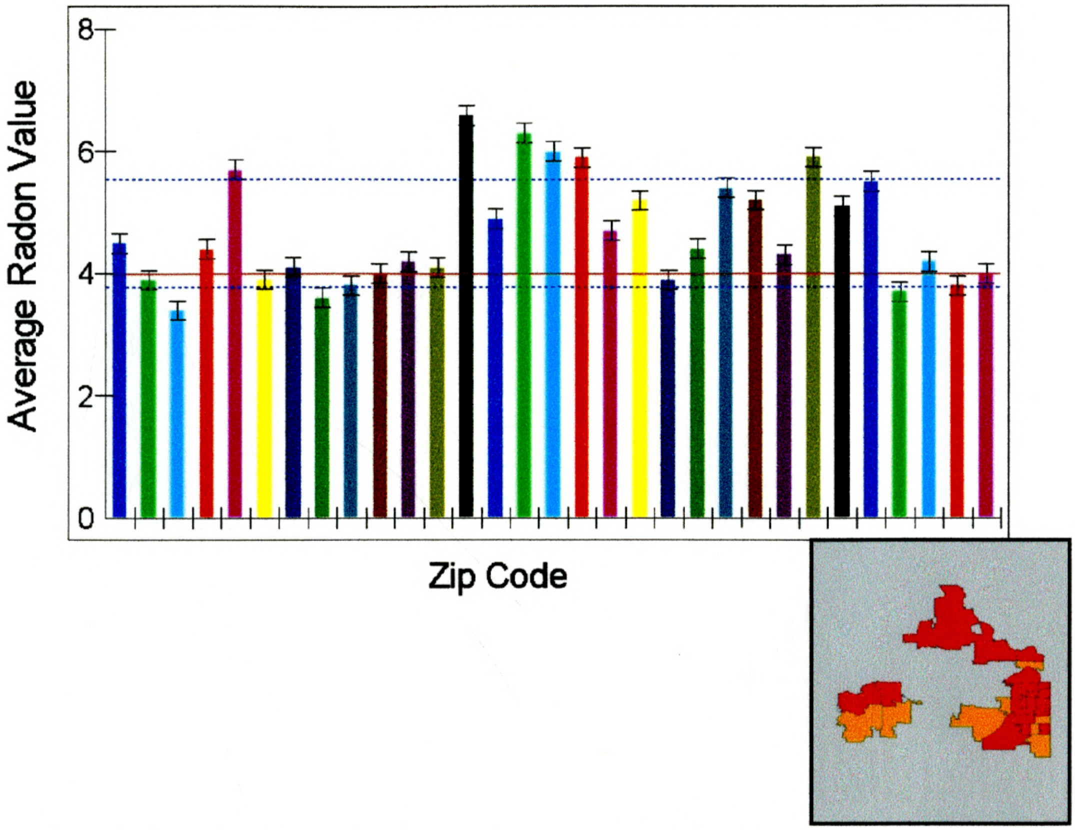


Figure 21. Kansas City Metropolitan area (including Johnson, Douglas, Leavenworth and Wyandotte counties) by average radon value (50 or more test results). Zip code districts with 50 or greater test results are listed. Light green zip codes average less than 2.0 pCi/L indoor radon concentrations. Orange zip codes average between 2.0 and 4.0 pCi/L indoor radon concentrations. Red zip codes average 4.0 pCi/L indoor radon concentrations. Dark green zip codes have no data collected.

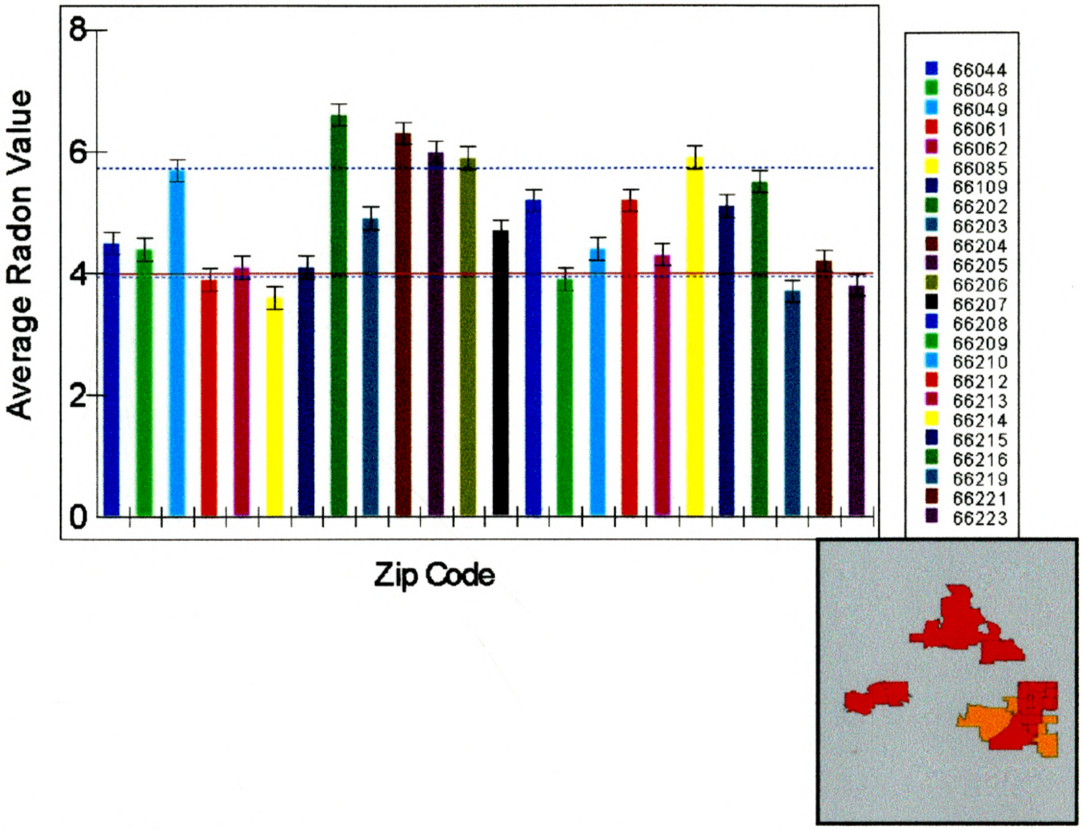


Figure 22. Kansas City Metropolitan area (including Johnson, Douglas, Leavenworth and Wyandotte counties) by average radon value (100 or more test results). Zip code districts with 100 or greater test results are listed. Light green zip codes average less than 2.0 pCi/L indoor radon concentrations. Orange zip codes average between 2.0 and 4.0 pCi/L indoor radon concentrations. Red zip codes average 4.0 pCi/L indoor radon concentrations. Dark green zip codes have no data collected.

indoor radon data than the 1987-88 survey, which included 2009 household samples (U.S. EPA 1993a). The current Kansas database contains in excess of 22,000 indoor radon samples as of December 2002. A comparison of the EPA radon potential map for Kansas (see Figure 4 above) to a map using current results and identical range categories (see Figure 5 above) indicates a strong pattern similarity. Differences in boundaries between the maps are due to the use of zip code borders in Figure 5 versus county borders in Figure 4. The primary value in this result is the additional confidence the current results give the original EPA zone designations for Kansas. One of the EPA's primary goals in relation to radon is to encourage the use of radon resistant new construction (RRNC) in new single and two-family housing in Zone 1 counties. The current study provides additional information when working with state and local planning officials in relation to radon.

Second, the analysis clearly identifies regions of Kansas for which there are few to zero radon test results available as noted above in Figure 5. Taking into account the low population density of many rural Kansas counties (as seen above in Figure 6), this information indicates areas, which may be being underserved by state and federal radon programs. Given the relatively high chance (25%) of any given home in Kansas to exhibit elevated radon, the identification of these areas offer substantial information in relation to where to focus available resources. In terms of the Kansas Radon Program, this equates both to educational opportunities and to the distribution of available grant funds that can be used to subsidize non-commercial residential testing.

Third, the study indicates that where substantial radon testing has occurred, that data can be used to create maps for Kansas counties with greater apparent resolution than the standard EPA Kansas map. This resolution is possible because of the ability to separate data into smaller regions (limited to zip code by the nature of the database organization). As such, the results of the current study indicate that when zip codes accumulate relatively high n-values of test results the resulting map of averages across those zip codes exhibit fairly low variation. The reduced variation further enhances the ability of the Kansas Radon Program to isolate regions of particularly high radon activity. The study also sets an obvious goal of at least 50 test results per zip code, with an ideal zip code sample being greater than 100 tests. Examining the results of the most heavily sampled area (the Kansas City Metropolitan area), the variation between the 50+ (Figure 21) and 100+ (Figure 22) n-value zip codes is relatively minor.

The current study shows the value of adopting GIS techniques to study state-wide trends in radon potential. These trends provide insight that can be used to further the debate on the use of radon resistant new construction (RRNC) building systems in regions with high-observed radon potential. The trends offer information on potentially underserved regions of the state in regards to radon education and testing. And the trends allow state and local personnel to benefit from regional maps with greater resolution than those available from the EPA/USGS study. As ongoing data is included, the database will become ever more useful. The identification of regions with little to no testing can be examined specifically and those discrepancies can be reduced.

Implications for state and local planning are dependent upon governmental official's abilities to disseminate and interpret the data presented. Given the importance of radon from a health risk assessment, it is hoped that this study, along with additional and ongoing similar research, will be of use in setting realistic governmental policy for adequate control of radon as an indoor air quality (IAQ) issue.

Chapter 3

EVALUATING RADON RESISTANT HOMES IN MANHATTAN, KANSAS

Introduction

The EPA recommends the use of radon resistant new construction (RRNC) in all single and two family homes built in zone 1 designated counties. In Kansas, 65 of the 104 counties are designated zone 1. However, few homes built in Kansas incorporate RRNC building standards. The primary reason for this has been the resistance of local governments (at both the municipal and county level) to incorporate RRNC techniques into the required building codes.

Three primary elements exist with RRNC construction. First, a porous fill is used to level the future foundation of the house. Gravel fill is ideal, as it provides the least resistance to airflow. Sand fill can be used as long as corrugated drain tile is looped through the fill under the concrete foundation. Second, a polyvinyl sheet is used to separate the fill from the concrete. The polyvinyl sheet acts as a barrier to radon gas, which aids in keeping the radon from penetrating the concrete foundation. Third, a polyvinyl vent stack is run from the fill, through the foundation, and up through the roof of the house. The vent stack provides a means of escape for the radon from under the foundation and the polyvinyl sheet and acts to vent the radon into the atmosphere. However, since RRNC techniques are designed to be inherently passive means of radon control (i.e. the system does not require any additional energy input other than natural heating of the home), there is no guarantee that indoor radon levels will be maintained below the 4.0 pCi/L action level. Passive radon control systems can be made active by the installation of a radon suction fan in the attic of homes with RRNC construction. The suction fans are low wattage (usually below 100 watts) and are relatively economical to operate; active radon control systems will reduce radon levels below 4.0 pCi/L in most homes.

Manhattan Kansas is one of only a few municipalities in Kansas that has incorporated RRNC building standards into their residential building code. Manhattan is the only municipality of 10,000 or more residents to adopt the standards. As of February 2001, all new single-family and two-family homes in Manhattan, Kansas, have been required to be built with radon-resistant new construction (RRNC) building techniques, due to the city's adoption of the RRNC appendix to the International Building Code (IBC). The goal of RRNC construction is to control indoor radon concentrations, with the stated concentrations to be maintained below 4.0 pCi/L, which is the EPA's recommended action level.

In order to examine the efficiency of RRNC construction, National Environmental Health Association (NEHA) and the EPA partnered to provide funds to municipalities to test homes built to RRNC specifications. The city of Manhattan, Kansas, in conjunction with the Kansas State University Research and Extension Service, was one of the award grantees. The Kansas Radon Program performed the field assessments of the homes involved in the study.

Materials and Methods

Participants

Approximately 60 homes had been built in Manhattan incorporating RRNC building techniques at the time that the Kansas Radon Program became involved with the project. The Kansas Radon Program had been contacted by the Manhattan Fire and Code

Services department and requested to perform the home evaluations and radon testing. All 60 homes received a letter detailing the project and requesting up to 50 participants. All participants would receive $50.00 as a stipend for participation. Additionally, homes (if any identified) that tested at 4.0 pCi/L or higher would receive consultation and possible financial assistance to activate the RRNC system by the installation of a radon suction fan, thereby correcting the inability of the passive system to maintain radon levels within the home below 4.0 pCi/L. Twenty-six homeowners agreed to participate, but only 24 homes were eventually scheduled for assessment; two homes failed to return correspondence related to the assessment scheduling. Of those 24 homes, only nine agreed to participate in the entire study.

Apparatus

All homes were tested for indoor radon concentrations using two simultaneously deployed electret ion chamber detector radon test kits. Electret ion chamber kits function by measurement of the voltage potential across a charged membrane before placement and after testing. The voltage difference in addition to the time of exposure is used to calculate the indoor radon concentration. Concentrations were calculated using the Win-Sper 2.0 software.

Procedure

The evaluation procedure was performed in two parts, with some of the homeowners only agreeing to participate in the first. The first portion of the evaluation consisted of performing simultaneous electret ion chamber device testing for indoor radon concentrations. The homes were tested for an average of 163 hours under closed house conditions. Closed house conditions consist of having all exterior openings to the home (primarily windows and doors) closed during the testing period. Exterior doors could be opened long enough to allow the entrance or exit of individuals from the home. Heating and cooling systems can be run throughout closed house testing periods. The two radon concentration values yielded by the paired electret ion chamber devices were averaged.

The second portion of the evaluation consisted of an in-depth visual assessment of the home and the accessible portions of the RRNC radon control system. The second evaluation also consisted of an efficiency test of the RRNC to determine the estimated amount of reduction exhibited by the passive radon control system. The efficiency testing consisted of testing the radon concentrations inside the home first while the RRNC system is operating normally and second while the RRNC system has been temporarily taken out of service. The systems were taken out of service by capping the exhaust pipe on the home's roof. The efficiency testing was performed using the EPA (1999) protocols for evaluation of RRNC homes.

Results

Results for the initial radon tests are listed below in Table 1 and Figure 23. All homes were tested with simultaneously deployed electret ion chamber test devices using short-term electret plates, with an average testing period of 163 hours. Homes were kept in closed-house conditions throughout the testing period. Test results for each home were averaged. Of the 24 homes, 13 exhibited average radon values above 4.0 pCi/L.

Table 1. Preliminary Home Testing. Thirteen of twenty-four homes tested at or above the EPA's recommended radon reduction level of 4.0 pCi/L.

#	Zip Code	Kit 1	Kit 2	Kit Average
1	66502	1.0	0.2	0.6
2	66503	1.1	1.1	1.1
3	66502	1.3	1.3	1.3
4	66503	1.7	1.7	1.7
5	66502	2.2	1.2	1.7
6	66502	1.9	1.8	1.9
7	66502	2.4	1.8	2.1
8	66502	2.0	2.4	2.2
9	66502	2.6	2.4	2.5
10	66502	2.6	2.4	2.5
11	66502	3.5	3.7	3.6
12	66502	**4.4**	3.8	**4.1**
13	66502	**4.4**	**4.1**	**4.3**
14	66502	**4.4**	**4.3**	**4.4**
15	66502	**5.4**	**4.9**	**5.2**
16	66502	**4.9**	**5.4**	**5.2**
17	66502	**5.4**	**5.0**	**5.2**
18	66502	**6.1**	**6.0**	**6.1**
19	66502	**6.0**	**6.2**	**6.1**
20	66502	**5.5**	**6.7**	**6.1**
21	66502	**6.0**	**6.7**	**6.4**
22	66502	**8.7**	**8.7**	**8.7**
23	66502	**10.1**	**9.5**	**9.8**
24	66502	**10.3**	**10.4**	**10.4**

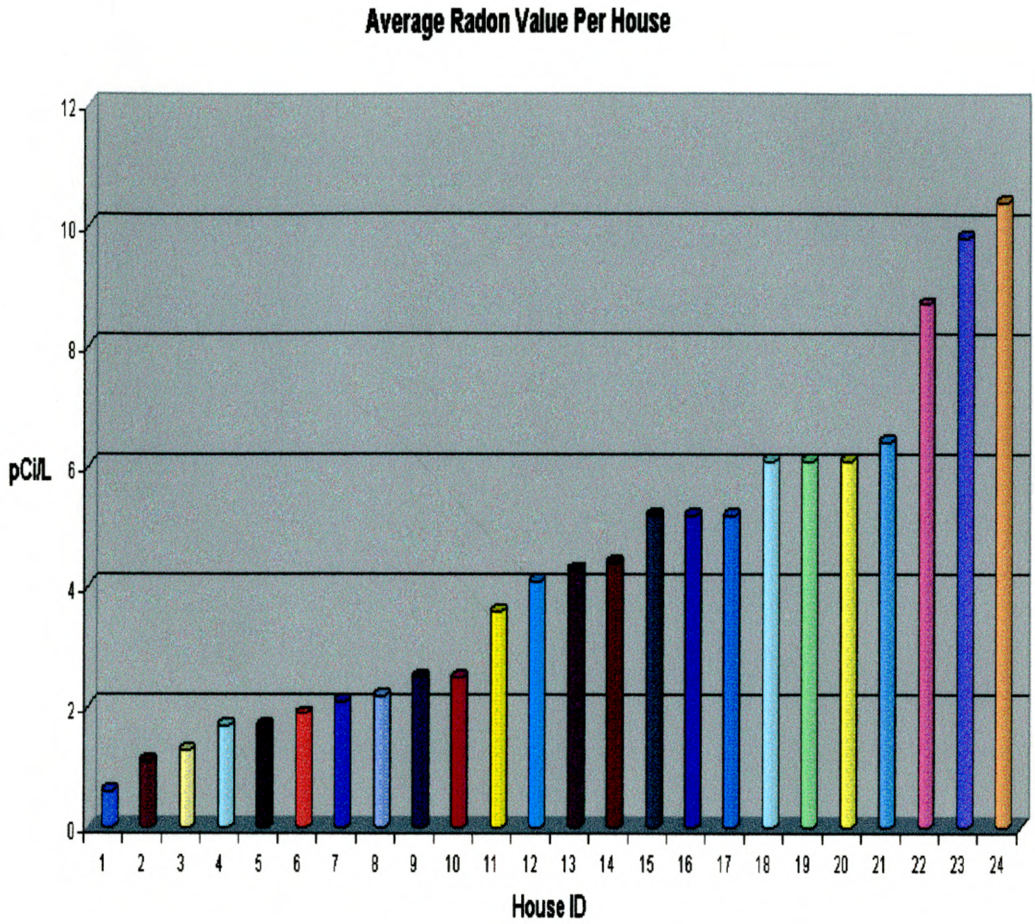


Figure 23. Graph of the indoor radon concentration results for the initial testing of the 24 homes. Indoor radon concentrations ranged from 0.6 pCi/L to 10.4 pCi/L.

Following conclusion of the initial testing, volunteers were requested from the 24 homes to conduct further testing using the EPA RRNC testing protocol. This protocol consists of three periods: (1) a five-day simultaneous test with the RRNC passive system uncapped and functional, (2) a seven-day period through which the RRNC passive system vent is capped (making the system temporarily non-operational) and followed by (3) a second five day simultaneous test with the system capped and non-functional.

Nine homes agreed to the additional testing procedure. One of the nine homes was eliminated from testing due to construction features of the roof, which would have made the capping/uncapping process unnecessarily dangerous. A second of the nine homes was disqualified when additional examination of the RRNC vent stack revealed that it had been exited through the side of the house at ground level rather than vented through the roof as required by the RRNC protocol. Seven homes were tested using the EPA RRNC efficiency protocol, results of which are listed below in Table 2 and Figure 24.

Five of the seven homes tested exhibited a drop in radon levels when the RRNC system was operational (i.e. the vent stack was uncapped) versus the system being non-operational (i.e. the vent stack was capped), with the average radon reduction being approximately 31%. However, two homes were disqualified from the efficiency testing due to a loss of closed house conditions during the second testing period. House #1 indicated that a window in an upstairs bedroom had inadvertently been opened. House #7 indicated that the HVAC system for the house had been turned off and that there was one evening during the testing period where two windows were inadvertently opened on the upper floor but not in the basement where the test kits were located.

Table 2. Participants listed here took part in the RRNC efficiency testing protocol as described by the EPA (1999). Average percent reduction across the five homes was 31%.

#	Zip Code	Preliminary Test	House Operational	House Non-operational	Percent Reduction
1	66502	2.3	2.4	1.9	N/A
2	66502	4.4	3.8	4.6	**17.4%**
3	66502	5.2	4.1	7.0	**41.4%**
4	66502	5.2	4.8	5.7	**15.8%**
5	66502	6.1	4.8	7.9	**39.2%**
6	66502	6.1	6.1	11.1	**45.0%**
7	66502	10.1	12.1	7.7	N/A

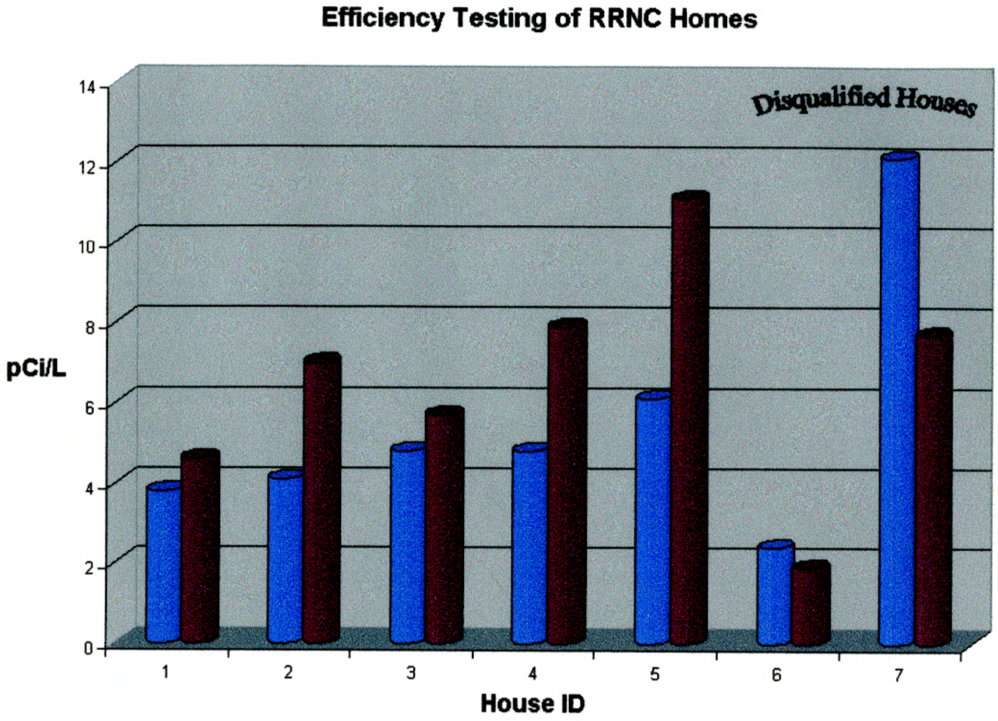


Figure 24. Results of the efficiency testing period. The average percent reduction exhibited in the five successfully tested homes was 31%.

A statistical examination of the results (see Table 3 below) indicated an average radon value of 5.4 pCi/L with RRNC systems operational and 6.6 pCi/L with the systems non-operational. A Student's T-Test indicates that there is no significant difference between the operational and non-operational sample sets ($t=0.4$, $p<0.05$). This result indicates that the absolute radon values between the two sample sets are not statistically different. However, the observed average percent reduction of 31% in radon between the sample sets is a better indicator of system efficiency, due to the low n-value of homes used in the statistical evaluation.

Table 3. Statistical results based on a Students T-Test of the homes tested using the EPA (1999) RRNC efficiency protocol.

	House Operational	House Non-operational
Mean	5.4	6.6
Standard Deviation	3.1	2.9
Student's T-Test		**0.4**

Conclusion

The current study examined the efficiency of RRNC construction techniques for the control of indoor radon concentrations, with the state goal being to maintain radon concentrations below the EPA's action level of 4.0 pCi/L. Of the homes tested in Manhattan, Kansas, all were two years of age or less.

The initial test results indicated that 54% of the 24 homes tested exhibited an average indoor radon value of 4.0 pCi/L or higher during winter testing (November-December 2002). Seven homes were subsequently tested using the EPA's protocol for RRNC efficiency testing. Statistical evaluation of the samples during operational and non-operational phases indicated no significant difference in radon reduction. However, an examination of the percent reduction indicated an average 31% radon reduction across the houses between operational and non-operational phases. This observed reduction indicates that while the RRNC passive systems are not meeting the 4.0 pCi/L goal, the systems are reducing indoor radon concentrations.

Bruce Snead, mitigation specialist and radon program trainer for the Kansas Industrial Extension Service, identified several construction flaws or mistakes in the passive radon control systems during the examination of the houses. Several of those flaws were as follows: (1) in homes containing basement sump pump pits, only one home examined had the pit covered with an airtight seal; (2) horizontal runs of the vent pipe within the conditioned space of the homes were excessive in two homes examined when compared to the vertical heights required to reach the roof exit point; (3) one house examined had the vertical exit run piped through the unheated garage; (4) one house had the exit run piped horizontally through the side of the home at ground level, rather than vertically through the home's roof.

These construction flaws contribute to the loss of radon reduction value from the RRNC construction. Long horizontal runs reduce the vent stack's ability to draw radon through it by increasing airflow resistance. Garage-mounted vent stacks have reduced pulling ability by losing the heat provided to the vent stack when embedded in interior walls. It is the natural heating of the pipe when located within the conditioned space of the home that provides the vacuum effect that removes the radon from under the foundation. Non-sealed sump pits provide areas of escape for radon gas from the vent stack itself. The failure to provide for a roof exit point in the case of the sidewall-exited system severely incapacitates the passive movement of radon through the system.

Two items need to be noted concerning results of this study. One, RRNC construction techniques do reduce the amount of indoor radon gas. As noted above, the average percent reduction of radon gas across the five houses was approximately 31%. Given the possible lung cancer risk factors associated with long-term radon exposure, any reduction in the radon concentration is desirable. Two, errors in following the protocols for installation of RRNC passive control systems deteriorate the overall efficiency of those systems. However, there is no blame to be given in the observed construction faults. There is a learning curve associated with any new technique, and it is the purpose of this type of research to identify flaws and offer recommendations on corrective measures. Once identified, a design fault can be corrected, and the information gained here will assist in correcting those faults in the future.

Chapter 4

APPLICATIONS OF STUDY INFORMATION TO PLANNING

The case studies reviewed herein provide information valuable to both the regulator at the state level and the planner at the local level. The analysis of the Kansas radon database provides distinct information related to the potential occurrence of radon across the state. The efficiency testing and evaluation of radon resistant new construction (RRNC) homes provides information on both the usefulness of RRNC techniques in controlling radon infiltration of homes and the usefulness of proper supervision of builders by local code enforcement agencies. A summary of both studies along with general comments follows.

The geographical information system (GIS) analysis of the accumulated indoor residential radon testing provided several pieces of information that taken as a whole offer a coherent picture of the radon issue in Kansas. First, it is obvious that the original United States Geological Service (USGS)/Environmental Protection Agency (U.S. EPA) survey of indoor radon potential for the state was accurate. The estimate from that survey indicated that statewide 25% of homes would test for elevated indoor radon levels, with some areas of the state exhibiting as high as 40% of the homes testing high (U.S. EPA 1993a). The Kansas City metropolitan area (all Zone 1 or high potential counties) is currently exhibiting 40% of all reported results as high (4.0 pCi/L or greater). Sedgwick County (Wichita, Kansas), a Zone 2 or moderate potential county, is currently exhibiting 27% of reported radon tests as high. The overlay map using the Kansas database (see Figure 5 above) clearly follows the same trends identified by the USGS/EPA in 1987-1988 (see Figure 4 above). This information is of use to state regulators and educational consultants in determining what areas of the state should receive the majority of the state's available resources. The information is of use to local planners and code adoption authorities when making decisions regarding EPA recommendations on RRNC single and two-family housing standards.

Second, the GIS analysis also clearly indicated where the majority of statewide radon testing is occurring, with that activity being primarily focused in the larger municipal areas. The test density analysis indicated a strong relationship to population density to the density of indoor radon evaluation. The overlay map indicating the gross number of reported tests per zip code further defines the state areas that show relatively high order testing levels. The most telling aspect of the test county map and the associated maps for the data consistency analysis is that even in zip codes with high rates of testing and a dense population (both Sedgwick and Shawnee counties), the rural portions of the counties with high metropolitan populations still exhibit a relatively low order of radon testing when compared to the metropolitan core areas. This information is of use to local educational outlets (such as the Extension Service) when designing programs for their constituents, particularly potential populations that have been under-serviced by past outreach activities. The information is also of value to state regulators and educational consultants again in assisting with the decision as to resource allocation. The data does raise the question as to whether the overall ratio of population density to test result density is the same or whether it differs across urban and rural areas. If the test density ratios are similar, then it could be concluded that both the rural and urban populations are receiving equivalent access to radon services and information. If the ratios differ, then it could be concluded that service and informational access is not being equally met between rural and urban districts of the state.

Third, the GIS analysis indicated that areas with relatively high levels of testing imply greater overall consistency of average radon results than areas with disparate testing levels. The analysis of Sedgwick county, Shawnee county, and the Kansas City metropolitan area showed that when adjacent zip codes had high numbers of indoor residential radon tests, the average radon values exhibited across those zip codes were similar. All three areas had at least one zip code on average falling within each of the three EPA zone ranges (Zone 1 or highest potential for elevated indoor radon, Zone 2 or moderate potential, and Zone 3 low potential). In all areas, when zip codes were limited to districts with a minimum of 25 test results, all, or an overwhelming majority, of remaining zip codes fell within only two of the three Zones. When zip codes were limited to those with a minimum of 50 tests, one of the three zones became the majority. This information is useful to state regulators and local planners in that it gives greater resolution to an area's potential for elevated indoor radon than do the maps currently available from the EPA. It would be of interest to take the three areas of Kansas used for this portion of the GIS analysis and perform an exhaustive set of testing in the zip codes for each area that lack the minimum 25 test results. A subsequent analysis compared to the current analysis would either verify the tentative conclusions reached above or provide enough additional information to generate new conclusions related to the data's validity and worth.

The second case study steps away from the statewide approach to the radon issue in Kansas, to a direct look at one aspect of local attempts to proactively mitigate a region's indoor radon problem through local ordinance and code enforcement. The EPA recommends the use of radon resistant new construction (RRNC) in all single and two family homes built in Zone 1 counties (U.S. EPA 2001). Manhattan, Kansas, adopted the RRNC amendment to the International Building Code (IBC), which became effective in February 2001. The efficiency study conducted in Manhattan was part of a national survey of RRNC homes undertaken by the EPA and the National Environmental Health Association (NEHA).

The estimates of RRNC technique effectiveness by the EPA were based on test homes built and evaluated by EPA contract (U.S. EPA 2001). The predicted effectiveness of RRNC homes for reduction of indoor radon below 4.0 pCi/L were 75-80%; conversely the estimate for the failure rate for RRNC homes to maintain radon concentrations below 4.0 pCi/L were between 10-15%. The initial screening in Manhattan indicated a failure rate of greater than 50% of the homes evaluated (54% or 13 of 24 homes).

An in-depth evaluation of each of the homes involved in the efficiency testing portion of the study and the subsequent work performed under contract with a local radon mitigation specialist hired to activate the systems of the homes with radon concentrations of 4.0 pCi/L, indicated a high rate of construction error in nearly all examined RRNC systems. Following is a brief list of identified construction errors: (1) failure to run the vent stack pipe within the heated envelope of the house; (2) failure to adequately seal sump pump pit foundation penetrations, (3) failure to exist the vent stack pipe through the roof of the home, (4) failure to adequately label vent stack pipes involved with the RRNC system, (5) excessive horizontal pipe runs, used either to run the vent stack to a plumbing run to the attic or within the attic itself, (6) failure to adequately connect vent stack pipe at pipe joints. Each one of these construction errors will contribute to the loss of efficiency of the RRNC system.

What is of more importance to the local planner regarding this study is the obvious failure of the code inspection service to identify and correct the construction errors. RRNC home building properly implemented in areas of the United States with demonstrated potential for elevated indoor radon could greatly reduce the number of new housing units being added to the housing market with significant radon problems. One issue that the Manhattan City Commission did not take into consideration when it adopted the IBC RRNC code amendment was that the amendment does not require that RRNC systems be installed by professionals trained in RRNC building techniques; the code amendment simply details the required elements for such systems. This oversight has led to the building of well over 100 homes in the Manhattan area that could have significant problems built into the RRNC systems.

The information gathered by the current study had been made available to the Manhattan Fire and Code Service department. Education of the code inspectors has been implemented to ensure that the errors identified in the evaluation homes are corrected in ongoing housing construction. However, it seems likely that there was a failure to properly educate both the code inspection unit and the area builders on the proper installation and testing of RRNC systems at the time of the code adoption. That educational failure might possibly have been a result of the planning officials failure to adequately research problems with RRNC code adoptions in other municipalities. However, as Manhattan was the first large municipality in Kansas to make such an adoption, it might be argued that the individuals evaluating the code amendments simply did not have available, a comparable program in the area with which to discuss implementation problems.

The case studies reviewed in this paper cover two important topics related to radon and radon-related planning issues. The first is the adequate evaluation of a given region's potential for elevated indoor residential radon. The second is an evaluation of a local planning attempt to mitigate potential radon problems in new homes through the requirement of installation of passive radon control systems in new housing. The target audience for both case studies is very inclusive. The data garnered from the GIS analysis can be used from the federal level and the EPA down to the local Kansas municipal planner. Likewise, the evaluation of the RRNC system effectiveness is of use to the EPA, state regulators, local planners, and the building industry. The difficulty lies in proper dissemination of the information. Portions of the GIS analysis are available for public consumption through the Kansas Radon Program website. The efficiency testing of the RRNC homes in Manhattan, Kansas was presented at the 2003 International Radon Symposium by the author to both the state and federal program officials and to the professionals of the radon industry. However, greater outlets for the information are needed within Kansas if the information reviewed herein is to be of substantial use in identifying and correcting the residential radon issue within the state.

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