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BASEMENT OCCUPANCY AND ACTIVITY PATTERNS OF RESIDENTS IN NEW ULM, MINNESOTA

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ABSTRACT

This study investigates occupancy of basements in the cold-climate plains region of the United States of America, where houses are typically built on basements, to assess the relationships between family usage, structural characteristics and radon concentrations measured in the house. One representative house in each residential block of New Ulm, Minnesota was selected for a complete energy analysis, including a furnace audit and measurements of air-leakage and radon concentrations. A survey of residents yielded occupancy and activity data. The combined data sets were analyzed by multiple regression.

Nearly five percent of individuals spent over 80 hours/week in basements, and 20 percent of families averaged 20 hours/week there. Radon measured over 4.0 pCi/L in approximately 50% of the cases. These data show the importance of evaluating regional housing practices in formulating risk assessments and measurement protocols for household pollutants, such as radon.

INTRODUCTION

Residents of Minnesota and other cold-climate plains regions have responded to the demands of their climate by evolving structural characteristics and occupancy patterns in their houses that set them apart from housing in other regions of the United States. One of the characteristics of Minnesota housing is the almost universal practice of building upon a basement foundation (National Association of Homebuilders, 1981). Some of these basements have been or are being adapted to provide finished space for a variety of family needs. These differences in site, structure, and occupancy may influence the influx of radon and its effect on the occupant.

National housing occupancy studies currently available do not fully examine regional aspects of basement design and use, and reliable data do not exist that indicate the degree to which Minnesotans live in their basements. Hence, current occupancy data that form the basis for health risk assessments from exposure to pollutants such as radon may not fully represent these regional variations of basement occupancy patterns. The purpose of this study is to investigate the relationships of these factors in a sample of New Ulm, Minnesota houses. This information can be compared to other housing studies to ascertain whether additional study is warranted.

Health risk to housing occupants from indoor air pollution includes an assessment of resident exposure to the types and concentrations of typical pollutants, such as radon, measured in various areas of typical houses (National Research Council, 1981). The assessment of risk includes assumptions about the frequency and length of time people spend in those areas of their houses (National Research Council, 1983). Assumptions about occupancy in the various areas of the house are derived from the investigations of housing occupancy now available, such as

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those done in California by Wiley and colleagues (1991). Measurement and mitigation protocol, and various other public policy issues are decided, based on those risk assessments. The assertion has been made that residents of houses in the United States spend a negligible percentage of their time in basements where radon is typically highest, and that radon measurement in basements is unnecessary and/or improper[1]. For these reasons, and because characteristics of Minnesota houses differ from those of the nation as a whole, a study of basement occupancy in this region is appropriate.

Setting of the Study

To promote local health and safety, the New Ulm Energy Advisory Board and the Minnesota Extension Service, Brown County conducted an ongoing information campaign in New Ulm, Minnesota, encouraging introduction of outdoor air to combustion heating equipment, and monitoring combustion exhaust flues for effluent spillage. In conjunction with that campaign, in 1990 they sponsored a program of year-long radon measurement and energy analysis in a sample of houses in the city of New Ulm, Minnesota. They aimed at identifying conditions in these houses that would allow them to forecast probable radon levels in neighboring houses. This investigation reports on 1) secondary analysis of data from their records of expert observations about structural characteristics and equipment in New Ulm houses, including measurements of radon concentrations, and 2) the responses from a survey asking the residents of the same houses the amount of time they spend in their basements, and the activities they engage in there.

MATERIALS AND METHODS

Sample Characteristics

Residents volunteered their units for the study, and from these volunteered units the New Ulm Energy Coordinator selected one housing unit representative of the dwellings on each residential or mixed-residential block. Twelve are rental units; the rest are owner-occupied. The audit files listed 209 single-family detached houses, six townhouses or duplexes, three houses with auxiliary apartments (one a basement unit), one converted store-front, and one not characterized.

The New Ulm Energy Analyst placed alpha radon measurement devices and the survey questionnaires in these 220 New Ulm housing units, along with a packet of information explaining the study to the residents. The devices were to remain for one year, when they were to be removed by the analyst. Radon was measured on the lowest liveable level of the house, as judged in observation by the energy analyst when he placed the detectors. The questionnaires were to be returned by the respondent in the self-addressed, stamped envelope included in the packet. Radon measurements were obtained in 95.5% of the cases (see Table 1). Survey questionnaires were returned in 80.9% of the cases (see Table 1). Only one of the 12 renters failed to return the questionnaire.

Data from the survey questionnaires listed, for each member of the family: age, gender, highest educational level, length of tenure, typical length of time spent in the basement, and the activities conducted there. The data also includes a list of any activities ever performed in that household's basement. Respondents also replied to an extensive list of basement structural, finish and content characteristics.

The ages of household residents ranged from a few months to 91 years, with a mean of 34.8 years. There were 164 females and 150 males, a total of 314 persons in 108 households (M=2.899,SD 1.33). The number of households, their size and composition are approximately comparable to the total New Ulm city population. The city of New Ulm has a somewhat higher percentage of single-person households and a slightly higher percentage of dual-person households that may be housed in multi-family units, not included in this study. Percentages of households with more than two members were similarly represented in the sample and the city populations.

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[1] Nero, A. V. (December 10, 1991) Letter, and attachments, to the Radon Program Review Panel, Environmental Protection Agency, 401 M Street, SW, Washington, DC 20460.

Educational achievement was the socio-economic measure.

Table 1. Responses to components of New Ulm Basement Study

Total Households Contacted = 220	Radon Test	Survey	Audit	Furnace Test
Radon Test	210	169	202	156
Survey	170	178	173	108
Audit		173	212	155
Furnace Test			155	155
Study Sample				108

The Energy Coordinator aimed at conducting energy audits on each unit in the study, including blower door tests for envelope tightness, and appropriate furnace efficiency tests. Furnace burner diagnostics, including efficiency and chimney temperature, were conducted using a Combustion Efficiency Computer[2]. A moderately positive increase of temperature in the chimney temperature gives a buoyancy effect to the combustion gases, so it is important that the chimney is within reasonable boundaries of temperature (Fugler, 1989). Blower door tests were conducted using the Minneapolis Blower Door[3]. Results of the furnace and blower door tests were calculated by the energy analyst and recorded in each house audit file. In fact, 96.4% of the units in the study had total or partial energy audits during the study, or had previously been audited (see Table 1). In all audits, reports were sent to the residents and/or owners, including recommendations for lowering energy use and maintaining health and safety in the dwelling. The number of audits that included a furnace analysis was limited by availability of testing equipment and by the characteristics of some furnaces, themselves. Fourteen furnaces in the sample had forced drafts or were sealed combustion units, eliminating the possibility of complete analysis, but, in theory, reducing the need for it. In six of the 32 boiler units, the burners were not accessible. Audits with complete furnace measurements were obtained in 156 cases.

RESULTS

In the furnace evaluations, the chimney temperature ranged 420 degrees F, from 243 degrees F. to 663 degrees F (M=457.6, SD=80.6). Efficiency of the furnaces ranged from 59.6% to 82.0% (M=75.9, SD=7.2). The burner in each furnace that produced the most carbon monoxide ranged 1991 ppm, from 9 ppm to 2000 ppm or more (M=111.8, SD=304.4). Air exchanges per hour (ACH) at 50 pascals pressure differential were calculated from the blower door data. The ACH range from 2.27 to 15.39 (M=5.84, SD=2.27). Computations also yielded the number of cubic feet per minute (cfm) of exhaust air flow (EAF) that would produce negative pressure adequate to backdraft the combustion appliances. The EAF range was 1365 cfm, from 120 to 1485 cfm (M=418.4, SD=225.7). The mean is somewhat disturbing, considering that many kitchen exhaust fans promise 400 cfm exhaust capacity, whether or not they can actually produce that volume.

Radon occurrence and sources

Radon (M=4.5, SD=3.4) was measured at or above the EPA action level of 4.0 pico Curie per liter (pCi/L) on the lowest livable level in nearly 50% of these houses. In 7.4% of the cases radon measured at or above 10.0 pCi/L, and in one house in the study above 20.0 pCi/L. (See Table 2 and Figure 1)

[2] Model 942-XP, Energy Efficiency Systems, Inc., Westbury, NY.

[3] The Energy Conservatory, 5158 Bloomington Ave. S., Minneapolis, MN 55417.

Table 2. Summary of radon concentrations of sample houses in New Ulm, Minnesota

	Radon =<3.9 pCi/L	Radon =>4.0 pCi/L	Total categories
Basement measurement			
Number of cases	29	47	76
Mean	2.5	7.0	5.3
Standard Deviation	1.0	3.5	3.6
Main floor measurement			
Number of cases	27	5	32
Mean	2.1	6.1	2.7
Standard Deviation	0.9	2.6	2.0
Total house			
Number of cases	56	52	108
Mean	2.3	6.9	4.5
Standard Deviation	1.0	3.4	3.4

Multiple regression of radon measurements upon data retrieved from the cases in the analyst's audits (including those without survey data, excluding one outlying case) identified only four significant predictors of elevated radon in these housing units: 1) high carbon dioxide in burner jet, 2) dirt in the floor of the basement, 3) low temperature rise in the chimney, and 4) presence of a fireplace in the house. These predictors can only account for approximately 25% of the variation of radon in these houses (See Table 3).

Table 3. Radon concentrations regressed upon New Ulm housing and equipment characteristics

R Square .266

Adjusted R Square .246

Standard Error 3.460

F = 13.05894 Signif F = .0000

---------- Variables in the Equation ----------

Variable	Beta	T	Sig T
Carbon dioxide in burner jet one	.404	5.636	.0000
Fireplace observed in basement	.1727	2.406	.0174
Dirt floor observed in basement	.2067	2.882	.0046
Temperature rise in chimney at jet one	-.2069	-1.870	.0047
(Constant)		3.291	.0013

Several materials used in construction of these basements have been identified as friendly to radon and moisture from exterior sources, because they can infiltrate through cracks or structural breaks. These materials include 1) improperly sealed concrete block, 2) stone, 3) wood, and 4) hollow structural tile. Material the analyst observed in basement structural walls included concrete block in 67 cases, stone in 11 cases, wood in four cases, hollow tile in one, and poured concrete in 33 cases, but none were significant in the regression. Respondents reported slab perimeter (french) drains in two cases, pump heads in three cases, and cracks over one-half inch in width in four cases. These are expected sources of soil moisture and possible sources of radon. Open sumps in 22 houses may be radon infiltration sources under conditions of negative pressure.

When gas-fired equipment uses interior air for combustion the basement may be depressurized so that radon can move in more readily. Minnesota building codes in place since 1978 require a supply of outdoor air to these appliances for their use in the combustion process. Nevertheless, the furnace audits identified 101 gas furnaces without a combustion air supply. Many furnaces needed to be cleaned and adjusted to burn efficiently.

Basement occupancy

Respondents were asked to estimate the time per week during the year each household member spent in the basement. Those data are summarized in Table 4, and categorized more completely in Tables 5 and 6.

Table 4. Percent of New Ulm households in which time is spent in basement, by time categories

	Number of hours spent in basement					
	0-9	10-19	20-39	40-59	60-79	80 +
Household average, percent	66.1	13.7	15.6	2.8	1.8	0.0
Most individual hours, percent	49.1	21.3	13.9	3.7	7.4	4.6

Average basement time

The survey respondents reported from zero to 215 hours per week per household spent in their basements (M=34.8, SD=45.3). The average time (per person per household) spent in the basement per week ranged from zero to 61.67 hours (M=10, SD=12.5). Sixty-six percent of the households averaged less than 10 hours per person per week in the basement. About 14% of households reported an average time in the basement between 10 and 20 hours per week. In 20% of the households persons averaged 20 or more hours per week in the basement. Nearly five percent of the households averaged 40 hours per week or more in the basement -- a time period equal to or greater than full-time employment (see Table 6).

Individual basement time

The time of the individual in each surveyed family who spent the most time in the basement ranged from zero to 100 hours per week (M=18.6, SD=23.8). Nearly 50% spent less than 10 hours per week, and 21% spent 10 to 19 hours per week in their basements. Nearly 30% of the individuals spent at least 20 hours a week in their basement -- equivalent to or exceeding occupational half-time. The individual in each family with the most hours in their basement spent 40 hours per week or more there in about 16% of the households. Over 12% of those individuals spent 60 or more hours per week, and nearly five percent spent 80 hours or more per week in their basement (see Table 7).

The time the average family spends in the basement can be related to physical characteristics of that space, such as the types of rooms that have been finished, and the type of finish materials. Amenities such as a fireplace, tiled bathrooms, and materials locally regarded as appropriate for middle-class furnishings are indicators of the amount of time the family spends in the basement. These types of housing and occupancy variables account for over 70% of the time these New Ulm families reported spending in their basements (See Table 8).

The longest basement occupancy duration of an individual in the family can be accounted for, in part, by these same characteristics. In addition, the number of household members indicates a specific need for additional private space that is filled by retiring to the basement. Cooking or canning in the basement may be a hold-over from more rural patterns of their German-American heritage. The five variables found to be significant in the regression account for 71% of the individual's reported time in the basement (See Table 9).

Table 6. Average time per week all family members spend in basement

	Up to 19.9 hours		20 to 39.9 Hours		40 to 100 Hours	
	Rn=<3.9	Rn=>4.0	Rn=<3.9	Rn=>4.0	Rn=<3.9	Rn=>4.0
Measure Rn in Basement	Cases=20 Rn M=2.5, SD=1.0	Cases=36 Rn M=7.1, SD=3.6	Cases= 6 Rn M=3.0, SD=0.6	Cases= 9 Rn M=7.1, SD=3.4	Cases= 3 Rn M=1.9, SD=0.8	Cases= 2 Rn M=4.4, SD=0.1
Measure Rn on First Floor	Cases=26 Rn M=2.1, SD=0.9	Cases= 5 Rn M=6.1, SD=2.6	Cases= 1 Rn M=2.4 ____	Cases= 0 ____ ____	Cases= 0 ____ ____	Cases= 0 ____ ____
Measure Rn on Either Floor	Cases=87 Rn M=4.5, SD=3.4		Cases=16 Rn M=5.3, SD=3.3		Cases= 5 Rn M=2.9, SD=1.5	
Total	Average family time: Cases=108; Mean of average family time=10.7, SD=12.5					

Table 7. Most hours one individual in family spends in basement

	Up to 19.9 hours		20 to 39.9 Hours		40 to 100 Hours	
	Rn=<3.9	Rn=>4.0	Rn=<3.9	Rn=>4.0	Rn=<3.9	Rn=>4.0
Measure Rn in Basement	Cases=17 Rn M=2.3, SD=1.0	Cases=29 Rn M=6.9, SD=2.2	Cases= 6 Rn M=3.2, SD=0.6	Cases= 7 Rn M=9.1, SD=7.1	Cases= 6 Rn M=2.5, SD=0.9	Cases=11 Rn M=5.6, SD=2.2
Measure Rn on First Floor	Cases=25 Rn M=2.1, SD=1.0	Cases= 5 Rn M=6.1, SD=2.6	Cases= 2 Rn M=2.3, SD=0.2	Cases= 0 ____ ____	Cases= 0 ____ ____	Cases= 0 ____ ____
Measure Rn on Either Floor	Cases=76 Rn M=4.2, SD=2.8		Cases=15 Rn M=6.1, SD=5.8		Cases=17 Rn M=4.5, SD=2.4	
Total	Total individual hours: Cases=108, Mean of individual hours=10.7, SD=12.5					

Table 8. Average time family spends in basement regressed upon New Ulm survey variables

R Square .713

Adjusted R Square .693

Standard Error 6.913

F = 35.44514 Signif F = .0000

---------- Variables in the Equation ----------

Variable	Beta	T	Sig T
Wooden outside wall	.217	3.983	.0001
Fireplace in basement	.1408	2.482	.0147
Tile outside wall	-.2608	-3.310	.0013
Gypsumboard interior wall finish	.2396	4.158	.0001
Sleeping 3 or less nights per month	.3985	5.127	.0000
Sleeping 4 or more nights per month	.5292	9.299	.0000
Sitting, TV, reading	.1965	3.523	.0006
(Constant)		3.724	.0003

Table 9. Most individual hours in basement regressed upon New Ulm survey variables

R Square .710

Adjusted R Square .696

Standard Error 13.097

F = 50.03133 Signif F = .0000

---------- Variables in the Equation ----------

Variable	Beta	T	Sig T
Fireplace in basement	.154	2.863	.0051
Gypsumboard in wall finish	.209	3.716	.0003
Sleeping 4 or more nights/month	.647	10.921	.0000
Cooking or canning	.1165	2.110	.0096
Total persons in household	.1480	2.639	.0096
(Constant)	3.291	3.291	.0013

The health risk from radon is influenced by a number of characteristics of the individual occupant, such as age, breathing rate, and other influences on the metabolic processes of the occupant. The types of activities, as well as the time spent in the basement, were investigated in this study. Respondents in the New Ulm study responded to a question that asked them to mark on an extensive list of potential activities those that were ever performed by their household members in their basements. The purpose of the question was to identify activities that might contribute to depressurization of the basement, to contribute to other indoor pollutants, or to influence breathing rates of the occupants (See Table 10).

Table 10. Activities residents report performing in their New Ulm, Minnesota basements

Activity	Number reporting	Percentage
Laundry & clothing care	94	87.0
Dry cleaning using vacuum cleaner, broom	84	77.8
Utility, such as storage, freezer	60	55.6
Sitting, TV, or reading	60	55.6
Bathing or showering	59	54.6
Fitness activity with equipment	39	36.1
Active play by or with children	36	33.3
Quiet play by or with children	36	33.3
Cleaning with water and/or solvents	34	31.5
Sewing with machine	29	26.9
Hobbies, crafts using solvents, paint	26	24.1
Hobbies, crafts creating dust	26	24.1
Wrapping gifts, storing giftwrap	25	23.2
Recycle, sort, store paper and cans	20	18.5
Records, school or officework without computer	19	17.6
Sleeping more than 4 nights per month	17	15.7
Records, school or officework with computer	15	13.9
Sleeping 3 nights or less per month	8	7.4
Cooking or canning	8	7.4
Plant potting or flower arranging	8	7.4
Other activities not listed	6	5.6
Workshop, repairing	5	4.6
Meals, entertaining, card parties	3	2.8
Weaving with loom, quilting with frame	2	1.9
Pet care	1	0.9
Sauna or hot tub	1	0.9

DISCUSSION

In this analysis the activities are coded 1 for the activity taking place, and 0 if the activity does not take place, in order to avoid the regression analysis being contaminated by the time involved in particular activities, such as sleeping. Some activities require physical adaptation that cannot be identified in the available data in any other way. Hence, these variables could also may be regarded as surrogates for finished spaces, such as hobby or family rooms or bedrooms.

Radon was not predictable in New Ulm neighborhoods by use of these physical structural variables. New Ulm has a variety of soil types in the neighborhoods, and these may have made a significant contribution to the source strength. That type of data should be used in any expanded study in the city.

CONCLUSIONS

A limitation of this study was the lack of a radon measurement on each floor, so that false positives and false negatives cannot be derived from the data. It would be necessary to have concurrent measurements on both basement and ground level floors to determine the most appropriate site. Future studies should also seek more specific data about 1) the relationships between basement activities and ages of the participants, 2) the types of finished basement spaces, such as bathrooms and bedrooms, and 3) the relationships between combustion and air-exhaust equipment usage in order to adequately assess risk from radon and other indoor pollutants.

This study clearly indicates that New Ulm residents do spend a significant portion of their time in their basement, conducting a variety of activities. Because the United States has a variety of cultural patterns manifested in their housing usage, a regional study of bi-level housing occupancy and concurrent bi-level radon measurements may be necessary in order to determine the most appropriate housing level upon which to measure radon in regions where houses are typically built with basements.

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Fig. 1 Percentage of Radon Concentrations in New Ulm Houses