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ABSTRACT

The Environmental Protection Agency's (EPA's) Radon Mitigation Branch (RMB) conducts research and development on the reduction of indoor radon levels. Finding that there was no comprehensive database on the physical characteristics of the nations's school buildings (with information specific to radon-mitigation research), the RMB conducted a study that measured radon levels in a subsample of 100 schools from the Environmental Protection Agency's (EPA's) National School Radon Survey (NSRS). The schools were visited to obtain information on building structure and age, location of utility lines, and the type of heating, ventilating, and air-conditioning (HVAC) system. Building-characteristic profile sheets for all schools were then compiled. Information from each school was entered into a database to determine the relative proportions of physical characteristics of America's school-building population. This paper describes the sample-selection process, preliminary findings from the profile sheets, and the statistical limitations of the study. The results will be used by the EPA to guide further radon-mitigation research in schools. The building characteristics will also be correlated with school radon levels to identify any relationships between the physical characteristics and radon levels. Six figures and five tables are included. (LMI)

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CHARACTERISTICS OF SCHOOL BUILDINGS IN THE U.S.

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ABSTRACT

A subsample of 100 schools from the Environmental Protection Agency's (EPA's) National School Radon Survey were visited to obtain information on building structure, location of utility lines, and the type of heating, ventilating, and air-conditioning system. Information for each school was entered into a database to determine the relative proportions of physical characteristics of the U.S. school building population. The results will be used by EPA to guide future radon mitigation research in schools. The building characteristics will also be correlated with school radon levels to identify any relationships between the physical characteristics and radon levels.

This paper has been reviewed in accordance with EPA's peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

The Environmental Protection Agency's (EPA's) Radon Mitigation Branch (RMB) conducts research and development on reduction of indoor radon levels. To help guide future radon research in schools and better focus technical guidance documents, RMB conducted a literature search to find information that quantifies the physical characteristics of U.S. school buildings. Information specific to radon mitigation research in schools was not found in any existing reports or databases. In fact, according to a 1989 publication by the Education Writers Association (1), "Nationally, not even a marginally adequate data base about school facilities exists.... Several national groups have conducted surveys of school facilities, but these tend to be either outdated or incomplete." As a result, RMB chose to characterize the U.S. school building population using a sample of schools from EPA's National School Radon Survey (NSRS).

The schools are a nationally representative random sample selected for the NSRS by EPA's Office of Radiation Programs (ORP). To record the necessary information, a building characteristic profile sheet was completed for each of a sample of the schools by RMB staff engineers and selected contractors during 1991 and 1992.

This paper discusses the random sample selection procedures, describes the information collected on the building characteristic profile sheets, summarizes some of the results recorded on the school profile sheets, compares the results with those observed in RMB's research schools, and presents the statistical limitations of this study. All analyses from this project will ultimately be summarized in an EPA report.

SAMPLE SELECTION PROCEDURES

The NSRS consists of two independent samples: (1) a large sample of approximately 1,000 schools where all-ground contact rooms were measured with charcoal canisters, and (2) a smaller sample of 101 schools where all occupied rooms were measured with both alpha track detectors (ATDs) and charcoal canisters. This smaller sample was selected independently of the larger sample. The schools were drawn randomly from lists of schools in 25 geographical areas called Primary Sampling Units (PSUs). These 25 PSUs were randomly selected for the NSRS from the 125 PSUs used previously by EPA for the National Residential Radon Survey. ORP's use of these residential PSUs in selection of schools for the NSRS is intended to permit comparison of residential and school building radon concentrations in these PSUs.

The 125 PSUs used for the Residential Survey were selected from a list of counties or county-equivalents covering the entire U. S., except for portions of Alaska and all territories and possessions. This list was partitioned in 22 strata, developed to guarantee proportioned sample sizes in each of the 10 EPA regions. Within each region, counties were assigned to one of three radon potential categories: High, Medium, or Low. The assignment of states and substate areas to radon potential categories is summarized for each region in Table 1. The number of residential PSUs selected for the Residential Survey is shown in the far right column.

Within each of the 25 NSRS PSUs selected randomly from Table 1, approximately 5 public schools were randomly selected for inclusion in the NSRS ATD/canister sample, resulting in a total of 125 schools. This small sample of schools represents a random sample of the 78,715 U. S. public school population in 1988 (2).

For the NSRS, radon was measured (using both ATDs and charcoal canisters) in 101 of the 125 schools in the sample. The remaining schools either refused to participate or were unable to decide to participate within the time frame allotted for placement of the ATDs. One of the 101 schools did not participate in the profile, resulting in a sample of 100 schools for our study. The locations of the 100 participating schools are shown in Table 2.

DESCRIPTION OF PROFILE SHEETS AND DATA ENTRY

A three-page profile sheet was developed for this project for on-site characterization of the structure, utility penetrations, types of heating, ventilating, and air-conditioning (HVAC) equipment, and other building features pertinent to radon diagnostics and mitigation. Because many schools have several contiguous structures often constructed at different times and each with its own unique characteristics, the profile sheet was completed separately for each structure. In a few cases, where the structures are not contiguous but are campus-style school complexes, profile sheets were completed for each distinct structure in the school, unless all were of the same vintage and construction type.

Where available, building plans were examined to determine structure and HVAC system information that is not always available through on-site observation. Following inspection of the building plans, the school was visited to verify information on the plans and to collect any additional profile sheet information that was not on the plans. Complete sets of construction plans were available for only 40% of the structures. When the plans were not available, the profile sheet was completed based on discussions with school personnel and the judgement of the researchers.

Distribution of the profile sheet responses into the categories used for data analysis required reducing detailed responses to shorter, categorical responses for many of the profile sheet questions. The original responses for each school were entered into a DBase IV file along with the shorter categorical responses used for the statistical analyses.

Because many of the schools have a number of distinct structures, it is difficult to generally describe the entire school for a given characteristic, except rarely when all structures have the same characteristic. For example, in a school with two additions to the original building, two of the three buildings might be slab-on-grade and the third building a basement. Each of the individual buildings would be treated separately on the profile sheet. Therefore, no attempt is made to calculate percentage distributions based on the number of <u>schools</u> in each category. Instead, distributions are calculated both in terms of the number of sample <u>structures</u> and in terms of structure <u>area</u>.

A sample of the results is discussed in the following section. Statistical limitations of the study are contained in the final section. Detailed results of the complete analysis for this project will be included in a final project report.

PRELIMINARY RESULTS OF SCHOOL BUILDING PROFILE

The sample of schools selected for this profile are nationally representative. However, due to the small sample size, extrapolation of estimates based on the sample statistics to the national population of schools involves some degree of sampling error. The standard deviations due to sampling errors for reported percentages range from 2.5 to 5.5 percentage points for population estimates of 5% and 50%, respectively. The 95% confidence intervals for these estimated population percentages thus range from +/- 5% points to +/- 11%. Due to the large confidence intervals, small differences (less than 10 percentage points) in reported population percentages may not be significant at the commonly used 95% level of significance. These statistical limitations are discussed in detail in the next section.

The results presented in this paper are the actual proportions of the school characteristics for the nationally representative sample of 100 schools. For most of the characteristics, the results are presented both in terms of the percentage of the number of structures and in terms of area. The discussion is grouped into structural characteristics and HVAC system characteristics.

Where available, comparisons from RMB's 47 research schools are presented. Although the RMB research schools do represent a biased sample in that they are located in radon prone areas, comparisons of these two samples are helpful in observing trends.

Structural Characteristics

The schools used for this study typically contain two or three unique structures. The distribution of structures by year of construction is shown in Figure 1. Nearly half of the school structures were built between 1950 and 1969, with about 20% built before and 30% built after. This distribution is consistent with the survey conducted by the Education Writer's Association that found that more than 50% of the schools in use today were constructed during the 1950s and 1960s (1). By comparison, 46% of the schools in our profile were constructed during this period.

Over 90% of these school structures have a conventional classroom design, with a corridor that has classrooms on either side. Approximately 5% have a campus-type design, with a number of individual buildings.

The distribution of school structures in terms of total area is shown in Figure 2. Approximately 45% of these structures are less than 10,000 square feet*, probably because many of the older buildings have had additions to the original building. Approximately one out of eight structures (12.3%) have more than 50,000 square feet, ranging to over 600,000 square feet in one school structure.

For radon reduction research, the substructure of a school is of interest. As seen in Figure 3, slab-on-grade substructures are most prevalent, accounting for 72.6% by structure and 51.6% by area. Crawl spaces and basements account for 10.3% and 6.7% of the structures, respectively. These results are consistent with RMB's research schools which are 70% slab-on-

* 1 square foot = 0.093 square meter

grade (3). Figure 3 also shows that about 10% are combination substructures, such as slab-on-grade and crawl space in the same structure. Comparing the percentage by number of structures with the percentage by area, there is a tendency for a crawl space to be constructed in conjunction with either a slab-on-grade or a basement. These two categories account for approximately 8% of the number of structures, but almost 35% of the area. More than two-thirds of all school structures consist of only one floor.

Location of subslab footings and the presence of subslab aggregate are very important in designing a subslab depressurization (SSD) system for radon mitigation. As seen in Figure 4, gravel (which improves the SSD system effectiveness) was indicated on the plans for about 45% of the structures with information available. Many of the structures did not indicate the subslab material on the plans or the plans were not available. The remaining structures indicated fine-grained material (such as sand or earth) under the slab. The location and number of subslab footings is also important in determining subslab barriers for SSD systems. Figure 5 shows that over half of the structures have no internal footings (typically post-and-beam construction, facilitating SSD). However, 24% have footings between classrooms and along the corridor, complicating a SSD system installation.

Location of utility lines is also important since utility lines located under the slab or in a subslab tunnel can serve as a major radon entry route. The data in Figure 6 show that about a third of the structures (and area) have overhead utility lines. However, a third (a quarter by area) also have utility lines in either a tunnel or subslab. Utility tunnels were present in one-third of RMB's research schools (3), and tended to be more prevalent in certain school districts than others.

HVAC System Characteristics

Research on the use of HVAC systems for radon reduction includes a large portion of both RMB's and ORP's radon research in schools. As a result, it is important to quantify the various types of HVAC systems found in existing U.S. school buildings.

The distribution of types of HVAC equipment in the sample schools is shown in Table 3. The categories in this table are mutually exclusive. Only one-third of all schools have a single type of equipment in all structures. Most often, this is a central HVAC system. Radiant heat only (6%) or fan coils only (8%) or both (2%) are present in 16% of the surveyed schools, indicating that the other 84% of schools have either central HVAC or unit ventilators capable of delivering conditioned outdoor air. The remainder of the schools have various combinations of central HVAC, unit ventilators (UVs), fan coils (FCs), and radiant heat (RAD). In some schools, other radiant heat systems have been abandoned (RAD-NU) for heating, but their presence must be considered from a radon perspective.

In Table 4, the distribution of the four basic types of HVAC systems is tabulated by number of schools, count of structures, and structural area. These categories are not mutually exclusive, due to the occurrence of combinations of HVAC systems within a school structure. Central HVAC is the predominant system, occurring in 71% of the schools and 52% of the structures, either alone or in combination with other equipment. Radiant heat, including abandoned systems, is the second most common system, when counted by schools (56%) or by structures (44%). In terms of structural area, radiant heat systems are as prevalent as central HVAC systems. Unit ventilators and fan coil systems (with no ventilation capability) are less common than central HVAC and radiant heat systems, each occurring in approximately 30% of all structures and 40% of all schools.

Considering the combinations of HVAC systems within a given school, 45% of RMB's research schools have central air handling systems; 43% have unit ventilators; 30% have radiant heat; and 11% have fan-coil units (3). Only radiant heat (11%) or only fan-coil units (6%) are present in 17% of the research schools, indicating that the other 83% have some type of installed HVAC system that can deliver conditioned outdoor air.

The school profile sheets contain more detailed information concerning the location of air supply and return ducts, the location of unit ventilators and fan coils, and the types of radiant heating systems. The most common location of air supply and return ducts in structures with central HVAC systems is in the ceiling or suspended overhead. However, ducts located in corridors, basements, or tunnels occur more often in larger structures.

The most common location of unit ventilators and fan coils is along the outside wall. Radiators are used in most structures, but baseboard systems amount for more structural area.

STATISTICAL LIMITATIONS

Because of the random selection of NSRS ATD/canister schools within the 25 selected residential PSUs, the sample of profiled schools is nationally representative. However, extrapolation of the survey estimates to the national population of schools must reflect the magnitude of sampling errors expected for a survey of this size. Sampling errors should also be considered when the relative proportions of two response categories are compared.

Clustering of the sample schools within the residential PSUs results in some loss of sampling efficiency compared to a truly random sample of schools for this survey. An additional loss of sampling efficiency arises due to non-response adjustments to the sampling weights, which will be made when the final weights are provided by ORP. At this time, the sampling weights for the NSRS ATD/canister sample have not been determined.

The loss in sampling efficiency can be explained in terms of a design factor (DF) for the survey, defined as:

$$DF = \frac{N}{n}$$

where N represents the actual sample size (100) and n represents the reduced effective sample size for this design. The effective sample size is defined as the required size for a truly random sample to generate the same sampling errors. Because of the random selection of residential PSUs and the random selection of schools within these PSUs, we estimate that a worst case DF would not exceed 1.25. For this assumption, the effective sample size is approximately 80.

The standard error (SE) of an estimated population percentage (P) is given by:

$$SE = \sqrt{\frac{P(1-P)}{n}}$$

$$n = \frac{N}{DF} = \textit{effective sample size}$$

Knowledge of the standard errors of the estimated percentages permits determination of approximate 95% confidence intervals (CIs) for the reported estimates. An estimated population percentage P has a 95% CI extending approximately two standard errors on either side of the estimate. Thus, the approximate 95% CI for a population percentage estimate P would be the interval (P - 1.96SE, P + 1.96SE).

The estimated 95% CIs for various estimated population percentages are reported in Table 5 for the specified effective sample size. The 95% CI for an estimate of 5% extends approximately from 0 to 10%. For a population percentage of 20%, the 95% CI extends approximately from 10 to 30%. Similarly, an estimate of 80% has a 95% CI ranging approximately from 70 to 90%.

The 95% CIs reported in Table 5 are relatively large, due to the small effective sample size of approximately 80. The size of these CIs should be considered when comparisons are made between the reported population proportions for two different response categories. For example, if outcome "a" is observed in A% of the 100 schools, and outcome "b" in B% of the schools, then A + B <= 100% with the inequality applying if more than two outcomes are possible. To determine if A is significantly less (or greater) than B, the standard error of the difference (A - B) is determined by:

$$SE(A - B) = \sqrt{\frac{A + B - (A - B)^2}{n}}$$

To test the hypothesis that A is greater than B (or A is less than B), the difference between A and B should be significantly greater (less) than 0. Hence, the quantity (A - B) should be more than two standard errors away from 0, indicating that the difference is significantly positive (A greater than B) or significantly negative (A less than B). Regions where A is significantly greater (or less) than B are shown in Table 6. In this table, the symbol << denotes that A is significantly less than B, and >> denotes that A is significantly greater than B (at the 95% significance level) as determined by:

$$|A - B| > 1.96\ SE(A - B)$$

For example, an estimate of 8% is significantly less than an estimate of 20%, but it is not significantly less than an estimate of 16% because the SE of the difference between estimates of 8 and 16% is about 5 percentage points. Thus the difference of 8 percentage points is less than 1.96 SE, and the difference is not considered significant at the 95% significance level.

CONCLUSIONS

The school profile sheets contain many significant findings concerning the distribution of school building characteristics. The profile sheets provide evidence of the variety of building structures and HVAC equipment found in typical schools. The age of a school, number and size of different structures, type of substructure, location of utility lines, and types of HVAC equipment vary widely in the sample schools.

The substructure of a school has important implications for radon diagnostics and mitigation. Determination of substructure detail depends on locating building plans, which were available for only half of the structures. Where identified, subslab materials were almost evenly divided between gravel and fine-grained material such as earth or sand. Internal footings are found in half of the structures, with footings under both corridor and classroom walls in one-quarter of the structures. Utility lines may enter the building at a wide variety of locations, including tunnels, subslab penetrations, and overhead. In a few schools, older unused radiant heating systems may provide additional radon entry routes.

Commonly encountered structural characteristics include slab-on-grade with a conventional school building design with a single floor. Central HVAC is common, but often combined with other HVAC systems within a single school. Where applicable, central HVAC ductwork is usually located in the ceiling or suspended overhead. Radiant heat, using baseboard or radiator systems, is the second most common HVAC system. Unit ventilators and fan coils also present in many of the schools are most often located along outside walls, but may be in the ceiling, suspended overhead, along an inside wall, or on the roof.

REFERENCES

1. Education Writers Association, Wolves at the Schoolhouse Door. Washington, DC, 1989.

2. Quality Educational Data (QED), Inc., Denver, CO, 1988.

3. Leovic, K.W., A.B. Craig, and D.B. Harris, Update on Radon Mitigation Research in Schools. Presented at the 1991 AARST Conference, Rockville, MD, October 1991.

TABLE 1. ASSIGNMENT OF RADON POTENTIAL CATEGORIES FOR RESIDENTIAL SURVEY

EPA Region	Radon Potential Category	State/Substate Area	No. of PSUs Selected
1	High	ME, NH, VT	3
	Medium	MA, CT, RI	5
	Low	None	0
2	High	Northern NJ	4
	Medium	NY	8
	Low	Southern NJ	2
3	High	PA, Western MD, WV, Western VA	15
	Medium	None	0
	Low	DE, Central and Eastern VA, Eastern MD, DC	2
4	High	Western NC, Western SC, Northern GA, Northern AL, Eastern TN	7
	Medium	KY, Western and Central TN	3
	Low	Central and Eastern NC, Eastern SC, Southern GA, Southern AL, MS, FL	7
5	High	MN, WI, IL, IN, OH	30
	Medium	None	0
	Low	MI	2
6	High	NM	2
	Medium	OK, Western and Central TX, Northern AR	5
	Low	LA, Southern AR, Southeastern TX	3
7	High	NE, IA	4
	Medium	KS, MO	3
	Low	None	0
8	High	MT, WY, UT, CO, ND, SD	6
	Medium	None	0
	Low	None	0
9	High	NV	2
	Medium	None	0
	Low	CA, AZ, HI	8
10	High	AK, ID	2
	Medium	None	0
	Low	WA, OR	2
		Total	125

TABLE 2. LOCATION AND CHARACTERISTICS OF PARTICIPATING SCHOOLS IN THE SCHOOL PROFILE SAMPLE

EPA Region	State	No. of Schools	Type of Schools*
1	Massachusetts	3	K-6, K-6, K-6
2	New Jersey New York	5 7	K-6, 7-12, K-6, K-6, K-8 7-9, K-6, K-6, P-3, K-6, K-6, K-6
3	Virginia West Virginia	5 5	6-8, 6-8, K-6, K-6, K-6 K-6, K-6, 7-12, K-6, 7-12
4	Mississippi Tennessee	7 5	6-8, P-K 10-12, 6-8, K-6. K-6, K-6 6-8, K-8, K-6, K-6, SP-ED
5	Illinois Ohio	4 4	K-8, K-8, K-6, 9-12 SP-ED, 6-8, 7-9, K-6
6	New Mexico Oklahoma Texas	4 5 11	K-6, K-6, K-6, 6-8 K-6, 7-12, K-6, 6-8, 9-12 9-12, K-6, 6-8, K-6, K-6, 6-8, K-6, K-6, K-8, 9-12, K-6
7	Kansas Nebraska	5 4	9-12, 7-12, K-6, 7-12, K-6 7-12, 6-8, K-6, K-6
8	Utah	5	K-6, K-6, 6-8, K-6, 9-12
9	Arizona California	4 13	9-12, K-6, K-6, 6-8 K-6, K-6, K-6, 7-9, K-6, K-6, P-K, K-6, 6-8, K-6, 9-12, K-6, K-6
10	Washington	4	K-6, K-6, K-6, 6-8
Total		100	

* K = Kindergarten
P = Primary
SP-ED = Special Education

TABLE 3. DISTRIBUTION OF TYPES OF HVAC SYSTEMS BY SCHOOL

Type of System:		No. Schools
Central HVAC only	(HVAC)	13
Unit ventilators only	(UV)	7
Fan coils only	(FC)	8
Radiant heat only	(RAD)	6
UV/RAD-NU[a]		1
HVAC/UV/RAD-NU		1
HVAC/UV/FC/RAD		3
HVAC/UV/FC/RAD-NU		1
HVAC/UV/RAD		16
HVAC/FC		7
HVAC/RAD		8
HVAC/FC/RAD		12
HVAC/UV		7
HVAC/FC/RAD-NU		2
UV/FC		1
FC/RAD		2
UV/RAD		4
HVAC/UV/FC		1
Total Number of Schools		100

[a] NU = not used

TABLE 4. TYPE OF HVAC EQUIPMENT BY NUMBER OF SCHOOLS, NUMBER OF STRUCTURES, AND STRUCTURAL AREA

Type of System	Count by Schools	Percentage	Count by Structures	Percentage	Count by Structural Area (square feet)	Percentage
Central HVAC	72	71.3	120	51.5	3643604	67.1
Radiant heat	57	56.4	103	44.2	3659727	67.4
Unit ventilators	43	42.6	70	30.0	1734323	31.9
Fan coils	38	37.6	61	26.2	1883987	34.7

Note: [a] Unknown types are not included in analysis.
[b] Percents add to more than 100% due to the possibility or more than one system for a structure.

TABLE 5. APPROXIMATE 95% CONFIDENCE INTERVALS FOR ESTIMATES

Estimated Population Percentage	Expected 95% Confidence Interval[a]
P = 5% or P = 95%	(P - 4.8%, P + 4.8%)
P = 10% or P = 90%	(P - 6.6%, P + 6.6%)
P = 20% or P = 80%	(P - 8.8%, P + 8.8%)
P = 50%	(P - 11.2%, P + 11.2%)

[a] The actual confidence intervals surrounding the estimates will not be symmetric except for the case P = 50%.

TABLE 6. REGIONS OF SIGNIFICANT DIFFERENCE BETWEEN TWO POPULATION PERCENTAGE ESTIMATES, A AND B.

PERCENTAGE B

PERCENTAGE A	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88	92	96
4	.	.	.	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<
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16	>>	.	.	.	.	.	.	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<	<<			
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24	>>	>>	.	.	.	.	.	.	.	.	<<	<<	<<	<<	<<	<<	<<	<<	<<					
28	>>	>>	>>	.	.	.	.	.	.	.	.	<<	<<	<<	<<	<<	<<	<<						
32	>>	>>	>>	>>	.	.	.	.	.	.	.	.	<<	<<	<<	<<	<<							
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44	>>	>>	>>	>>	>>	>>	.	.	.	.	.	.	.	.										
48	>>	>>	>>	>>	>>	>>	>>	.	.	.	.	.	.											
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56	>>	>>	>>	>>	>>	>>	>>	>>	.	.	.													
60	>>	>>	>>	>>	>>	>>	>>	>>	>>	.														
64	>>	>>	>>	>>	>>	>>	>>	>>	>>															
68	>>	>>	>>	>>	>>	>>	>>	>>																
72	>>	>>	>>	>>	>>	>>	>>																	
76	>>	>>	>>	>>	>>	>>																		
80	>>	>>	>>	>>	>>																			
84	>>	>>	>>	>>																				
88	>>	>>	>>																					
92	>>	>>																						
96	>>																							

NOTE: The symbol ">>" denotes that percentage A is significantly greater than percentage B at the 95% significance level; the symbol "<<" denotes that A is significantly less than B; and the symbol "." denotes that A and B are not significantly different at the 95% significance level.

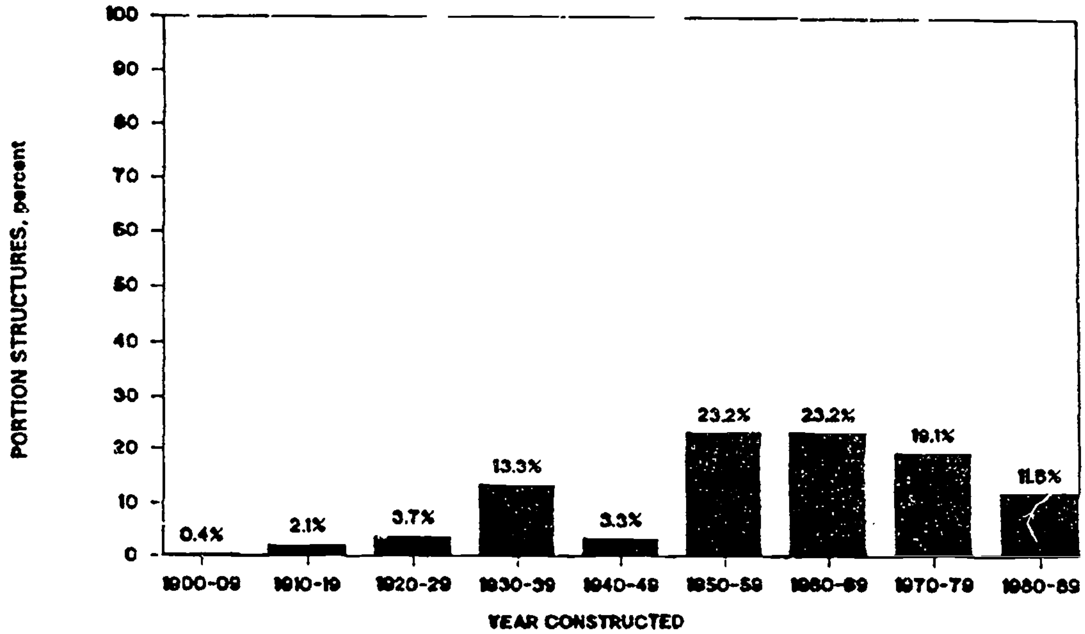


Figure 1. Distribution of structures by year constructed.

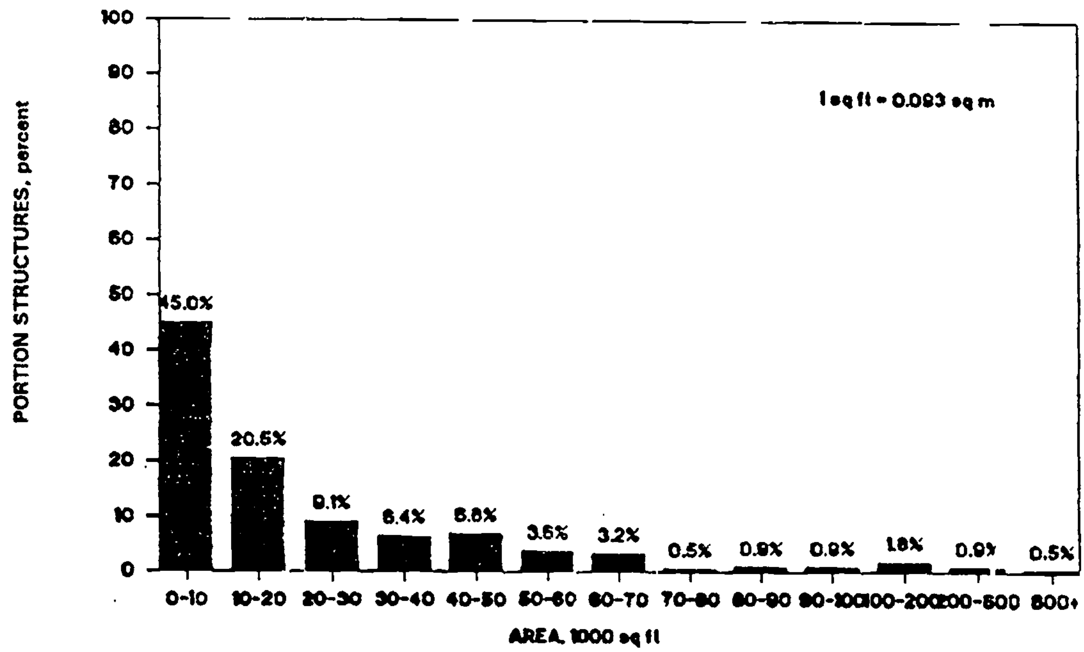


Figure 2. Distribution of structures by area.

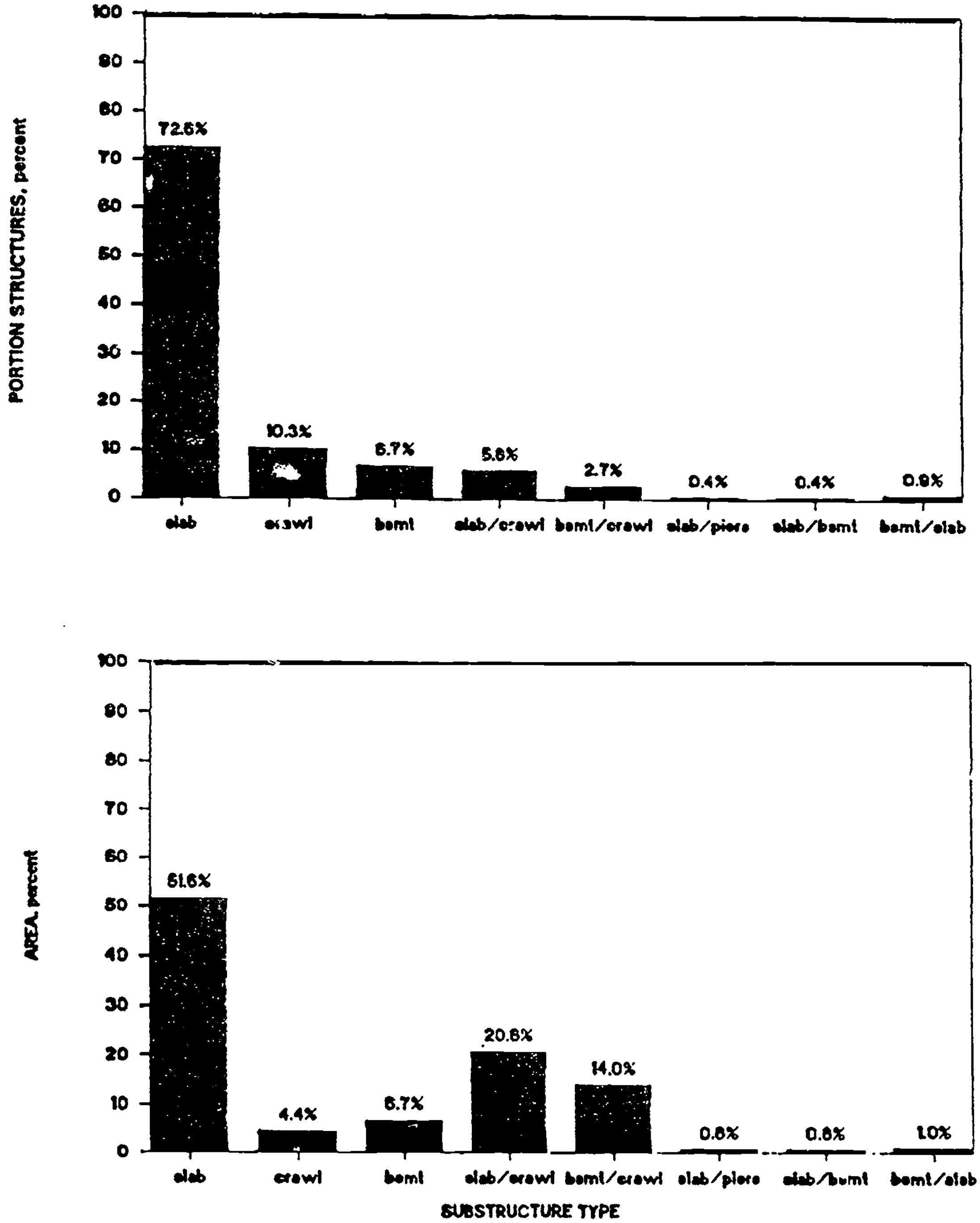
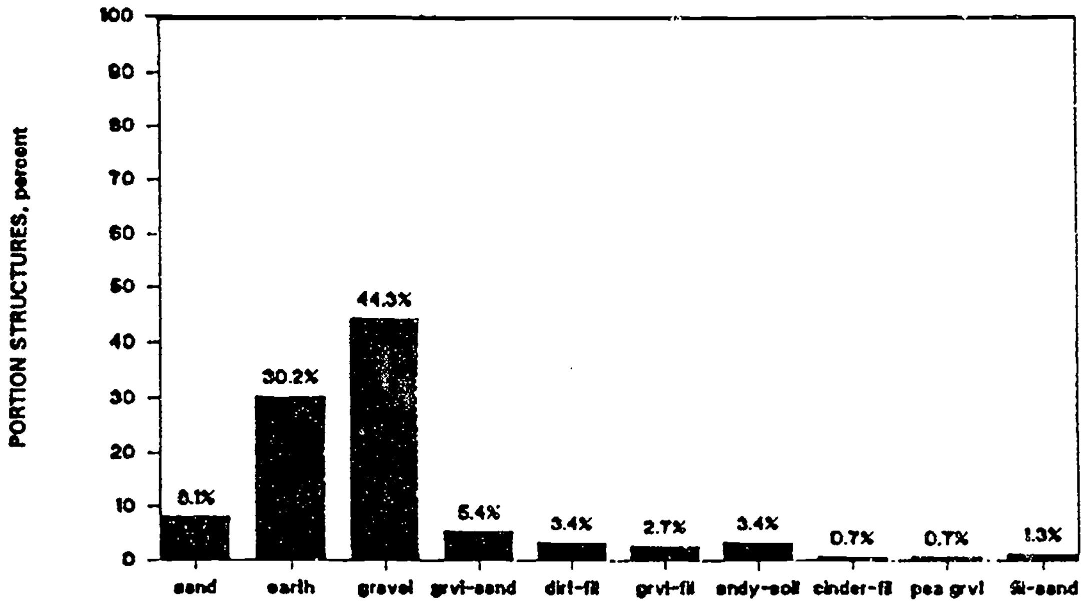


Figure 3. Distribution by substructure type (top % by number of structures; bottom % by area).



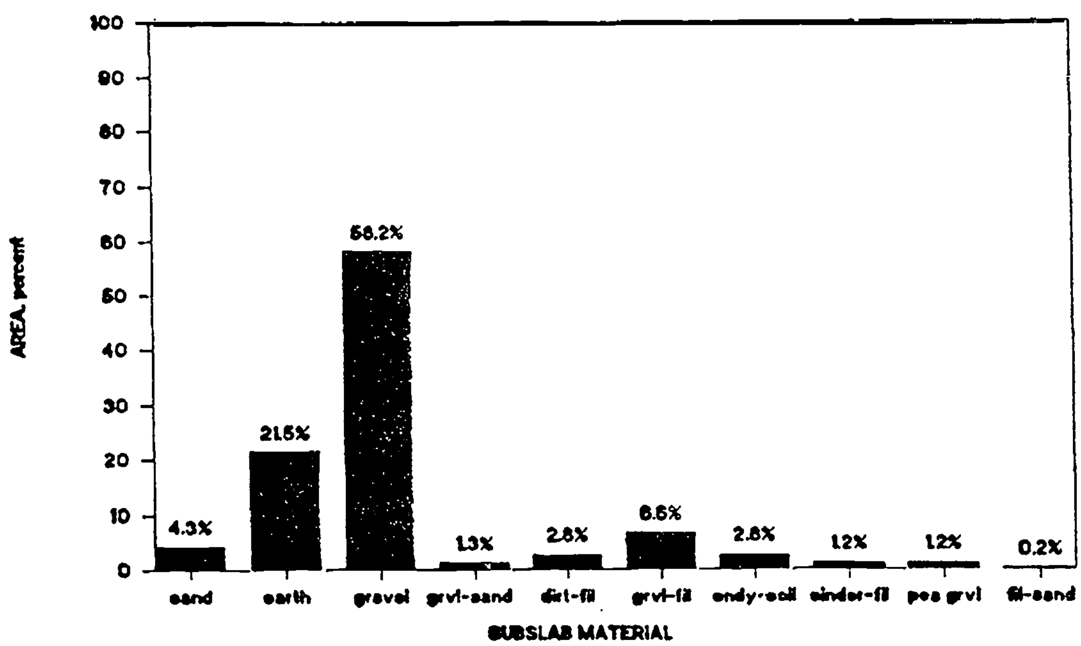


Figure 4. Distribution of subslab material (top % by number of structures; bottom % by area).

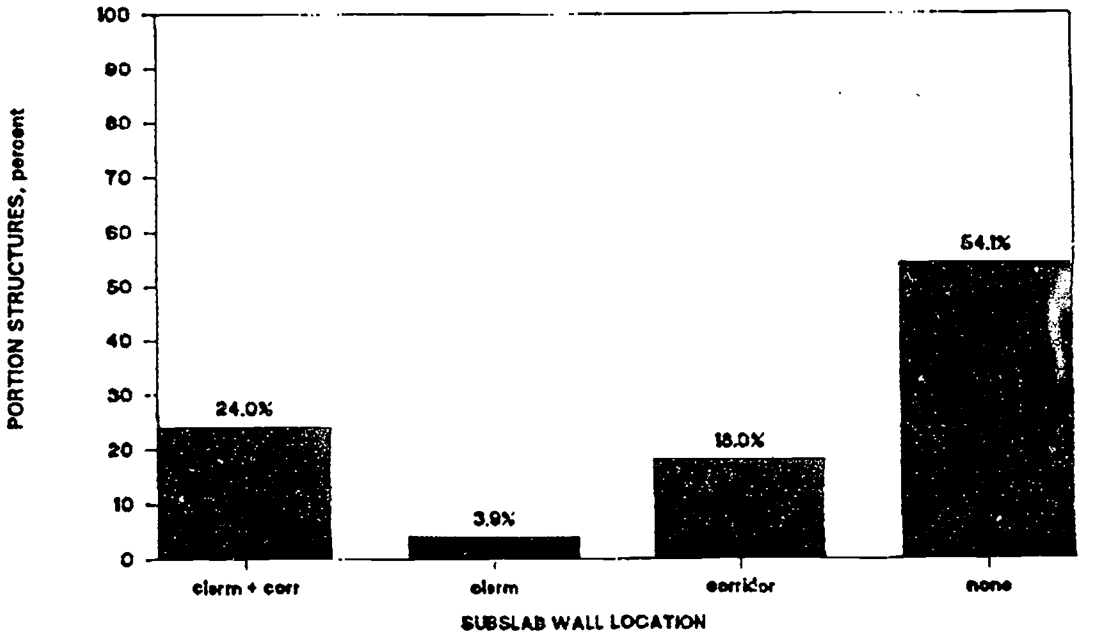
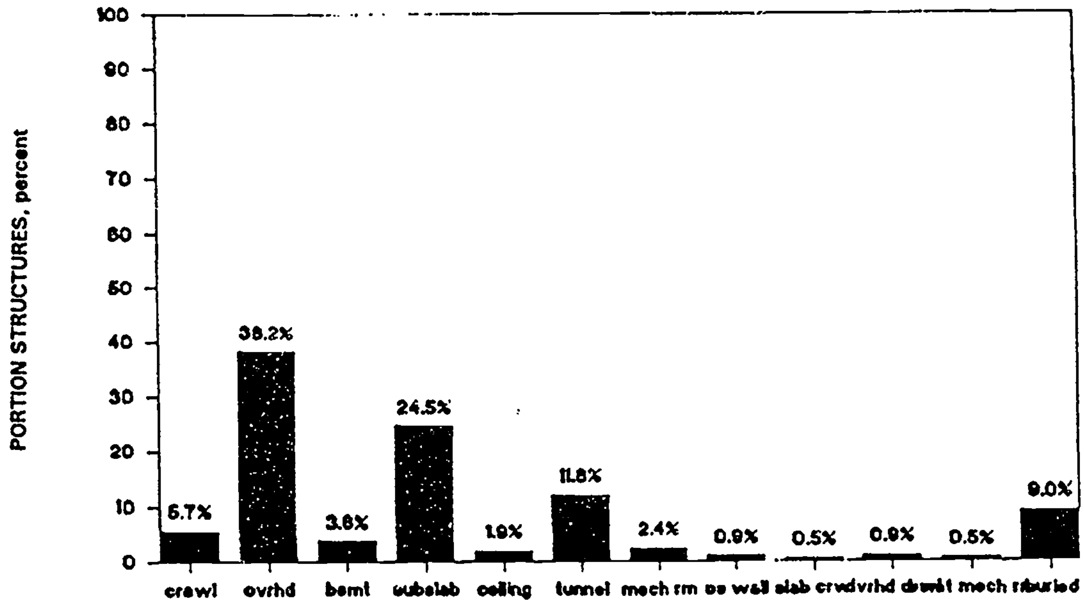


Figure 5. Distribution of subslab wall locations.



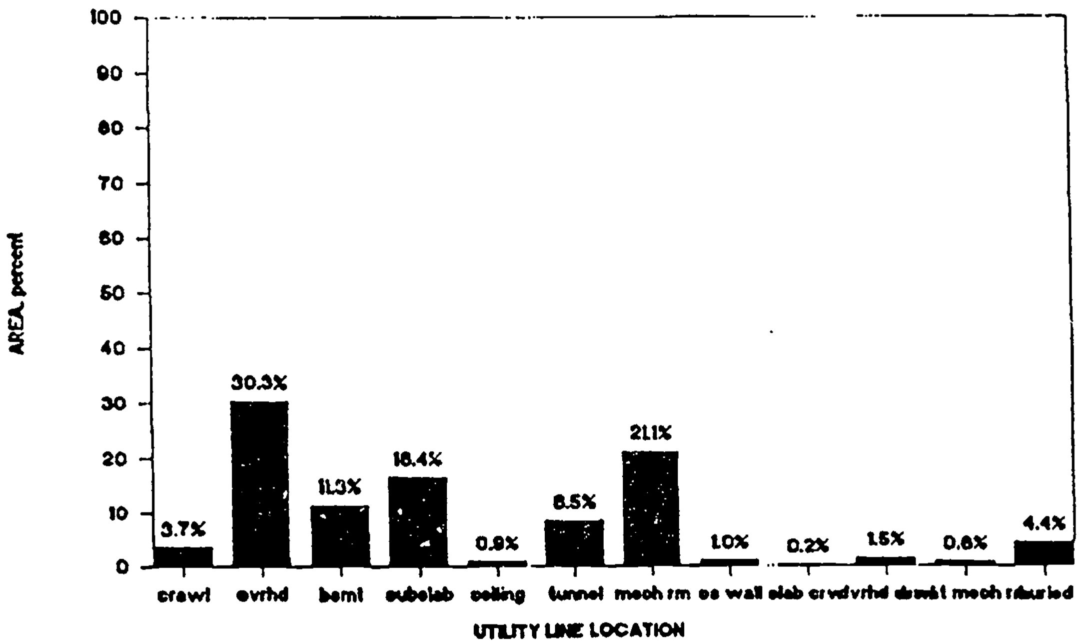


Figure 6. Distribution of utility line locations (top % by number of structures; bottom % by area).