#5507

PRELIMINARY RESULTS OF HVAC SYSTEM MODIFICATIONS TO CONTROL INDOOR RADON CONCENTRATIONS

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ABSTRACT

Designing and building houses that control radon in the course of their normal operation is a desirable goal. A project was undertaken by the Environmental Protection Agency to assess the feasibility of modifying the heating, ventilating, and air conditioning (HVAC) system in a newly constructed tract house, so that radon entry is prevented, the risk of moisture condensing in the building shell is reduced, and minimum ventilation recommendations are met.

A house has been selected, and the HVAC system has been modified to slightly pressurize the basement while slightly depressurizing the upper floors. Basement and first floor radon concentrations, and first floor and basement to outdoor air pressure differentials have been monitored.

The initial results from one cooling season show that this method can be as effective as active soil depressurization at controlling indoor radon levels, with comparable power consumption.

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

TECHNICAL APPROACH

The purpose of this work was to evaluate whether a typical residential furnace unit (air handler) could be easily modified to pressurize the basement of a tract house to prevent the entry of radon-laden soil gas. In order to accomplish this goal, the air pressure relationships between the upper floors and the basement, and each of those zones and the outdoor air, must be controlled. This is accomplished by using the air handler of the central heating and cooling plant, and the existing conditioned air distribution system, to pressurize the basement and slightly depressurize the upper floors. The basic idea is illustrated in Figure 1.

The house chosen for the study is located in a subdivision in the Allentown, Pennsylvania, area. It is a two story colonial house with a basement under all but the living room. The living room is on a slab, on-grade. The house, when originally constructed, was built with the knowledge that other houses in the area contained high indoor radon concentrations. The builder therefore incorporated several radon resistant techniques during its construction. During construction, attention was paid to building a foundation that prevented soil air from entering. This effort included poured concrete walls and floor, all concrete joints sealed with caulk, and a polyethylene vapor barrier under the slab. In addition, an active soil depressurization system was installed in the building, with a 4 in.* layer of DOT #2 stone, an interior perimeter loop of 4 in. drain pipe, a 4 in. PVC pipe routed through the building and out the roof, and an in-line centrifugal blower.

Air pressure relationships were measured between the inside and outside of the building, and between zones within the building. HVAC system airflows and power consumption were measured for the three HVAC blower operating speeds. These were quite close to the manufacturer's specifications. Investigations of the extent of air leakage, in what appeared to be carefully installed ductwork, revealed that the ductwork was still surprisingly leaky. This was particularly true of the return system. An indication of the effects of this leakage was that, when the air handler was operated on low speed, several pascals negative pressure was produced in the basement relative to outdoor air. Extensive sealing of the return air ductwork was required to bring the basement into neutral pressure with the outdoor air. See the later section on air leakage patterns for details.

The air handler that heats and cools the first floor of the house is located in the basement. All supply and return ductwork is also located in the basement. The basement was pressurized simply by sealing the leaks in the return air ductwork and cutting an opening in the supply ductwork main trunk. This modification resulted in the pressurization of the basement, with respect to outdoors, of 4 Pa. This modification also resulted in greater infiltration in the upstairs living area to make up the air lost through the basement.

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*Readers more familiar with metric units may use the factors at the end of this paper to convert to that system.

AIR HANDLER DESCRIPTION AND OPERATING CHARACTERISTICS

Effects of HVAC system operation on radon levels

The effects of system operation on indoor radon were studied by monitoring radon continuously in the basement and the kitchen with the air handler off, with the air handler on low speed continuously, and with the air handler on high speed only when cooling was called for. The results are summarized in Table 1, and illustrated in Figures 2, 3, and 4. Figure 2 shows that, while the air handler is on, there is about a 4 Pa positive air pressure difference between the basement and outdoor air, and the indoor radon averages 1.2 pCi/L in the basement and kitchen (a sign of good mixing with the air handler on). This level compares well with the active soil depressurization results from the previous year of 1.1 pCi/L[1]. However, with the air handler off, the basement air pressure quickly drops, and there are radon spikes each time the basement goes negative relative to outdoor air. This pattern has been observed in many buildings before[2],[3],[4]. The average radon concentration with the system off is around 14 pCi/L in the basement and 2 pCi/L in the kitchen. Later system off measurements in July (see Table 1) show the same levels in the basement, and a slightly higher kitchen average of 3.3 pCi/L. Figure 3 shows typical data for the system operating continuously, on a scale that allows better detail. The results are the same as the June measurements in Figure 2, and it is clear that radon is being controlled in both the upstairs and basement, with 50% and 90% reductions, respectively. Figure 4 shows a detail of system performance when the air handler runs only in response to cooling demand. While the radon is lowered by a factor of around 3, it is still above the action guideline of 4 pCi/L, averaging 7 pCi/L for the cooling operation test period. It is also clear from the pressure data that the fractional on time of the air handler was large during the test period. The radon levels in this building will be very sensitive to fractional on time.

Description

The house is heated and cooled using a York heat pump with a three-speed air handler. Table 2 lists the design airflows for this unit at low, medium and high speeds for two static pressures.

Airflows through ductwork with the air handler on low speed

Airflows were measured at the supply and return grills, and in the main trunk of the supply ductwork, with the intentional opening used to pressurize the basement open and closed. The results of these measurements are given in Tables 3 and 4. The total measured supply, measured in the supply trunk close to the air handler, was 952 ± 90 cfm. This compares well with the manufacturer's specifications of 1160 to 1185 cfm for the air handler on low speed. From the measurements made, the leakage through the supply ductwork was calculated to be around 230 cfm, and through the return ductwork was around 450 cfm. This means that, with the unit as installed, the basement was under negative pressure of several pascals whenever the air handler was on. The supply ductwork was foil faced ductboard. The return ductwork was made by sealing ductboard to the bottom of floor joists. It is thought that the excessive leakage in the return system, to a great extent, is due to leakage in the floor and wall components that form the return ductwork. In fact, careful sealing of the return system reduced the return air duct leakage to about 200 cfm.

The results of measurements and calculations with the ductwork sealed, and the basement pressurization opening open and closed are presented on Tables 3 and 4.

<u>Sealing the return ductwork</u>

The return system in the basement was carefully sealed using duct tape and caulk. The indoor-outdoor pressure differential was monitored before and after the sealing. With the air handler running and the pressure opening closed, the basement was several pascals negative before the sealing, and neutral after. Sealing the return air ducts reduced leakage to approximately 200 cfm. At this point supply leakage, excluding the intentional opening used to pressurize the basement, approximately equaled return leakage. It is estimated that the additional cost of sealing ductwork and making wiring modifications to the air handler is $200 to $300.

AIR LEAKAGE PATTERNS CAUSED BY OPERATION OF THE BASEMENT PRESSURIZATION MODE

In order to understand the dynamics of operating the air handler to pressurize the basement and slightly depressurize the upstairs, interzonal and indoor to outdoor pressure differentials, and the leakage areas of interest were measured. From these data, the amount of outdoor air drawn into the building could be estimated. This can then be compared to the ASHRAE ventilation guidelines [5] and the estimated stack effect infiltration that would occur in this house normally.

Operating the air handler induces a 4 Pa pressure differential between the basement air and the outdoor air and a 4.5 Pa pressure differential between the upstairs and the basement. This implies a 0.5 Pa pressure differential between the upstairs air and the outdoors.

By combining this air pressure distribution data with measured building leakage area data, airflows between the two zones and outdoors can be estimated. The leakage areas were measured using a fan door technique, involving the use of two fan doors. Measurements were made on each zone individually, and then simultaneously. Details of the method are presented elsewhere [6]. The results of the measurements and analysis are found on Figure 5.

ENERGY AND VENTILATION ISSUES

Changing the air pressure relationships in a building to control soil gas entry will have an impact on other dynamics in the building. Specifically it is expected that this will impact on the ventilation pattern, the energy costs associated with ventilation, and the risk of moisture condensation in the building shell. No data are available to judge the effects of moisture in the building shell. However, the data collected can be used to estimate the impact on the amount and pattern of infiltrating air. This is accomplished by first estimating the amount of air that would flow through the building as a result of ordinary stack effect and then comparing to the airflows induced by pressurizing the basement

The results of these estimates can be used to calculate the power consumption for controlling radon with basement pressurization and with active soil depressurization.

Impact of basement pressurization on infiltration

A fan door test of the entire building shell revealed that it has 5 air changes per hour (ACH) at a 50 Pa pressure differential. This is two to three times tighter than the average house built between 1945 and 1980, but is more typical of houses built in the northeast United States since 1980. This translates to about 0.25 ACH under natural conditions.

The infiltration due to stack effect alone has been calculated using four air infiltration models: the Lawrence Berkeley Laboratory model, the Kronval model, the Shaw model, and a modified Shaw model [7]. The results of these four models are plotted on Figure 6. Excluding the Shaw model, the mean values range from 0.13 to 0.17 ACH. This corresponds well to the 0.25 ACH combined wind and stack estimate made from dividing the ACH at 50 Pa by 20 [7]. By using the monthly ACH data the average volume of airflow through the building operating under average stack conditions can be calculated. This has been done in Table 5.

The amount of outdoor air drawn through the building by operating the air handler in the basement pressurization mode was estimated to be between 53 and 87 cfm. If any, there should be only a small energy penalty added by operating in this manner, amounting at most to an additional 35 cfm of outdoor air. This would add 3.3 x 10^6 Btu to the normally operating stack effect load of 4.6 x 10^6 Btu. This amounts to around $33 of oil at $1.10/gal. or $79 of electric resistance heat at $0.08/kW-hr. It would actually be less than this because of the superior efficiency of the heat pump in the swing seasons [coefficient of performance (COP) of 2.2].

However, it is unlikely that this will be the case because the direction of airflow is opposite that of the stack effect. The power of the fan will be competing with the power of the stack effect. They should just about cancel each other out in the coldest parts of the year resulting in lowered infiltration for the building during the winter months. This, however, is not an accurate model because the system is acting a lot more like two separate zones with the air handler powering the exchange, rather than with the stack effect powering it. A distributed resistance simulation could approximate the final situation.

It is likely that the infiltration due to stack effect will about equal the infiltration due to pressurizing the basement. The difference is that, with basement pressurization, the infiltration will be greatest in the summer and least in the winter, the opposite of stack effect. Either will provide an average of about 40 cfm. This is over half the recommended ASHRAE guideline of 15 cfm/person and the ASHRAE recommended ventilation rate of 0.35 ACH for residential buildings [5].

POWER CONSUMPTION COMPARISON OF NORMAL HVAC OPERATION AND ACTIVE SUB-SLAB SUCTION VS. USING THE HVAC ON LOW SPEED TO PRESSURIZE THE BASEMENT

The total power consumption of radon control and operation of the heat pump air handler for soil depressurization and basement pressurization must be compared.

The amount of electricity used to power the soil depressurization system is 90 W continuously for a year. This amounts to 788 kWh. The power consumption for the normal air handler operation is estimated to be 671 kWh/yr (223.6 W for 3000 hr a year). This gives a total power consumption of 1459 kWh/yr for the active soil depressurization system.

The amount of power needed to pressurize the basement for the year is estimated as follows. The amount of power used to operate the air handler on high speed for normal operation and low speed for the remaining time is 1673 kWh/yr (174 W for 5760 hr on low speed and 249 W for 3000 hr on high speed).

It is estimated that basement pressurization will use 214 kWh/yr more than soil depressurization or about $18 a year for electricity at $0.085/kWh.

CONCLUSIONS

The basic idea of using the interaction of the air handler, conditioned air distribution system, and the building shell to control air pressure relationships has been demonstrated in a newly constructed house. It has also been demonstrated that this control can prevent radon entry with minimal additional power consumption for equal performance when compared to active soil depressurization. There is insufficient data to determine whether or not the minimum ASHRAE guidelines for ventilation have been met or whether the risk of moisture condensation in the building shell has been reduced. Further research will be required to answer these questions.

The effort required to modify the HVAC system was not great. However, the measurements and understanding it took, while involving only trivial physics, are not part of the ordinary experience or training of builders, mechanical contractors, or mechanical engineers. Further complicating this procedure is the fact that the work needed to make the modifications cuts across traditional trade jurisdictions. It is likely that most of the work falls into the jurisdiction of the mechanical contractor. However, general contractors must be able to request the work and judge the performance.

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CONVERSION FACTORS

Readers more familiar with metric units may use the following to convert to that system.

Non-metric	Multiplied by	Yields Metric
Btu	1.055	kJ
cfm	0.00047	m^3/s
gal.	0.0038	m^3
in.	2.54	cm
in. WC	249	Pa
$in.^2$	0.00065	m^2

TABLE 1 EFFECTS OF AIR HANDLER OPERATION ON INDOOR RADON

Date (mm/dd/yy)	Location	Average Rn (pCi/L)	Average ΔP (Pa)	HVAC Status
06/07-15/90	basement	1.2 ± 0.3	4.0 ± 1.3	on
06/07-15/90	1st floor	1.1 ± 0.4		on
06/16/90-07/04/90	basement	14.3 ± 5.1	0.8 ± 1.8	off
06/16/90-07/04/90	1st floor	2.1 ± 1.4		off
07/07-23/90	basement	14.2*	0.5 ± 1.6	off
07/07-23/90	1st floor	3.3 ± 1.7		off
07/25/90-08/05/90	basement	1.4 ± 0.3	4.2 ± 0.8	on
07/25/90-08/05/90	1st floor	1.2 ± 0.4		on
08/14/90-09/11/90	basement	1.4 ± 0.3	4.2 ± 0.8	cooling
08/14/90-09/11/90	1st floor	1.2 ± 0.4		cooling

* This measurement taken with a Honeywell At-ease Monitor.

TABLE 2 MANUFACTURER'S SPECIFICATIONS FOR FAN UNIT

Speed	Airflow @ 0.2 in. WC (cfm)	Airflow @ 0.3 in. WC (cfm)
high	1625	1550
medium	1355	1310
low	1185	1160

TABLE 3 OPERATING CHARACTERISTICS WITH BASEMENT PRESSURIZATION

Total measured supply at diffusers = 567 ± 60 cfm

Total measured supply = 952 ± 90 cfm

Total supply leakage* = 385 ± 40 cfm
(including flow through the intentional opening pressurizing the basement)

Total measured return = 496 ± 50 cfm

Total return ductwork leakage* = 456 ± 46 cfm

* calculated values

TABLE 4 OPERATING CHARACTERISTICS WITHOUT BASEMENT PRESSURIZATION

Total measured supply at diffusers = 719 ±72 cfm

Total supply ductwork leakage* = 232 ± 23 cfm

Intentional opening to pressurize the basement* = 153 ± 15 cfm

* calculated values

TABLE 5 STACK EFFECT AIRFLOWS FOR AVERAGE TEMPERATURES

Month	Stack (cfm)
Jan	73
Feb	71
Mar	64
Apr	51
May	36
Jun	0
Jul	0
Aug	0
Sep	25
Oct	28
Nov	60
Dec	71

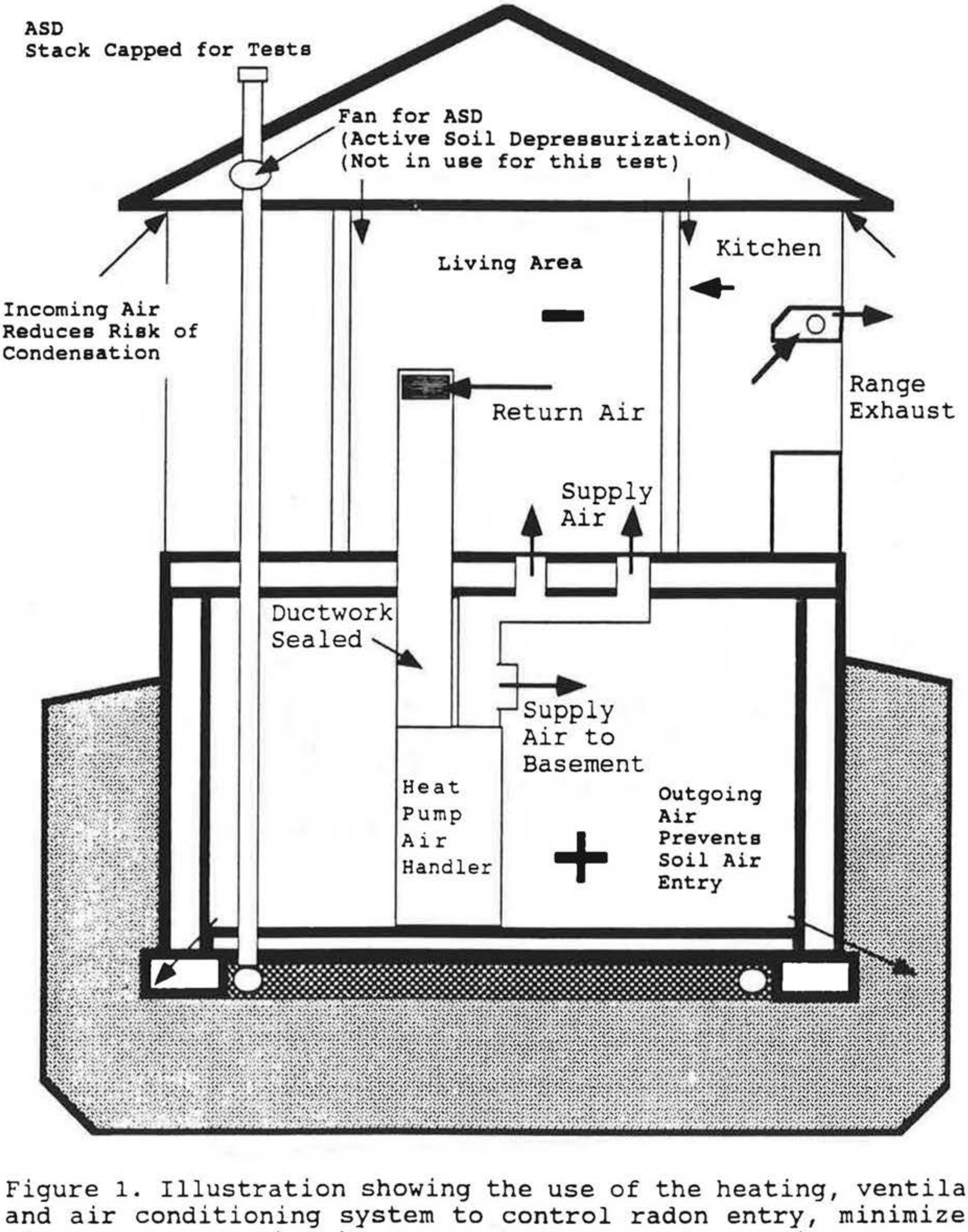


Figure 1. Illustration showing the use of the heating, ventilating and air conditioning system to control radon entry, minimize the risk of condensation in the upper floors, and provide recommended ventilation rates.

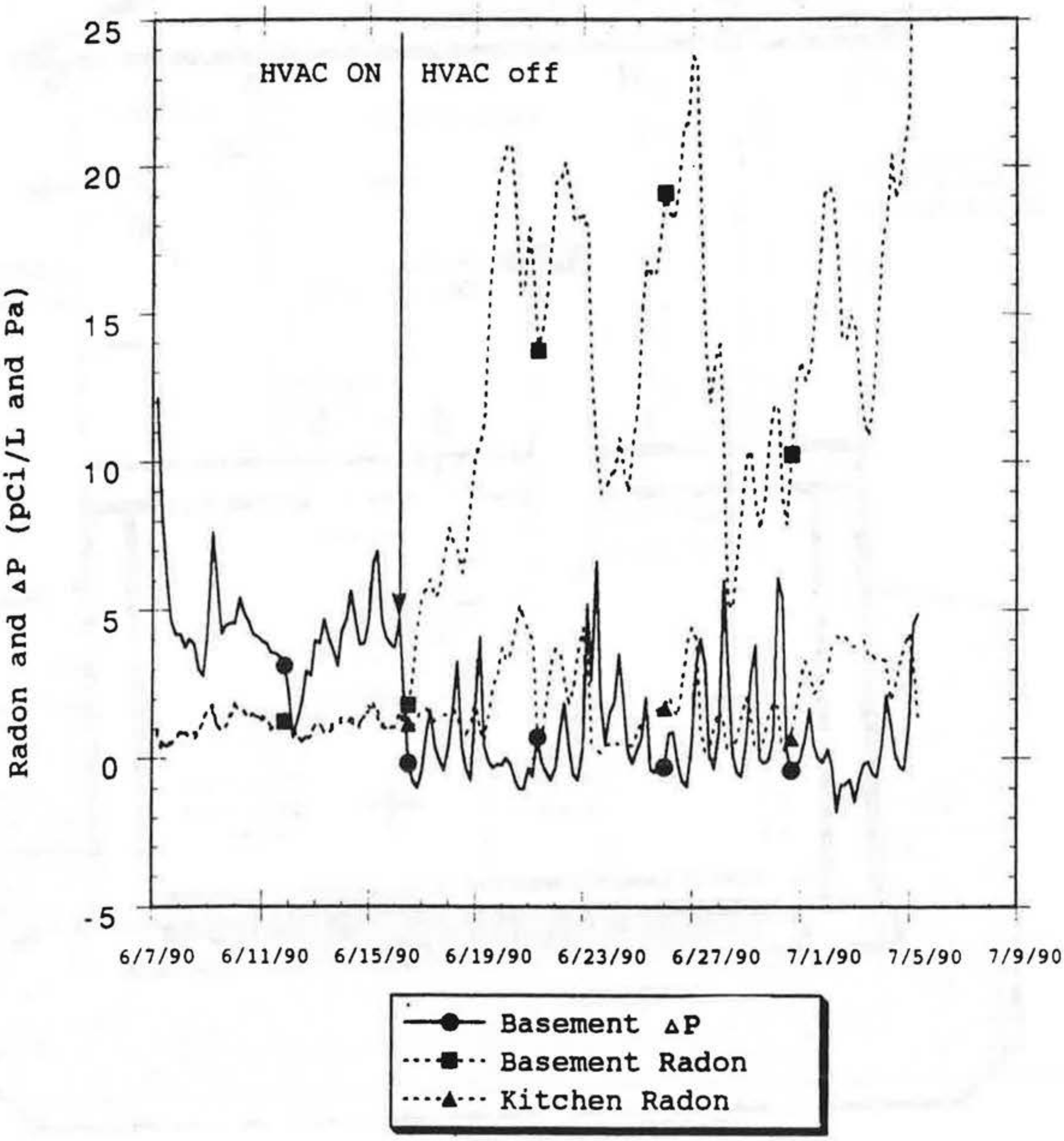


Figure 2. Radon levels and differential pressures with air handler on and off.

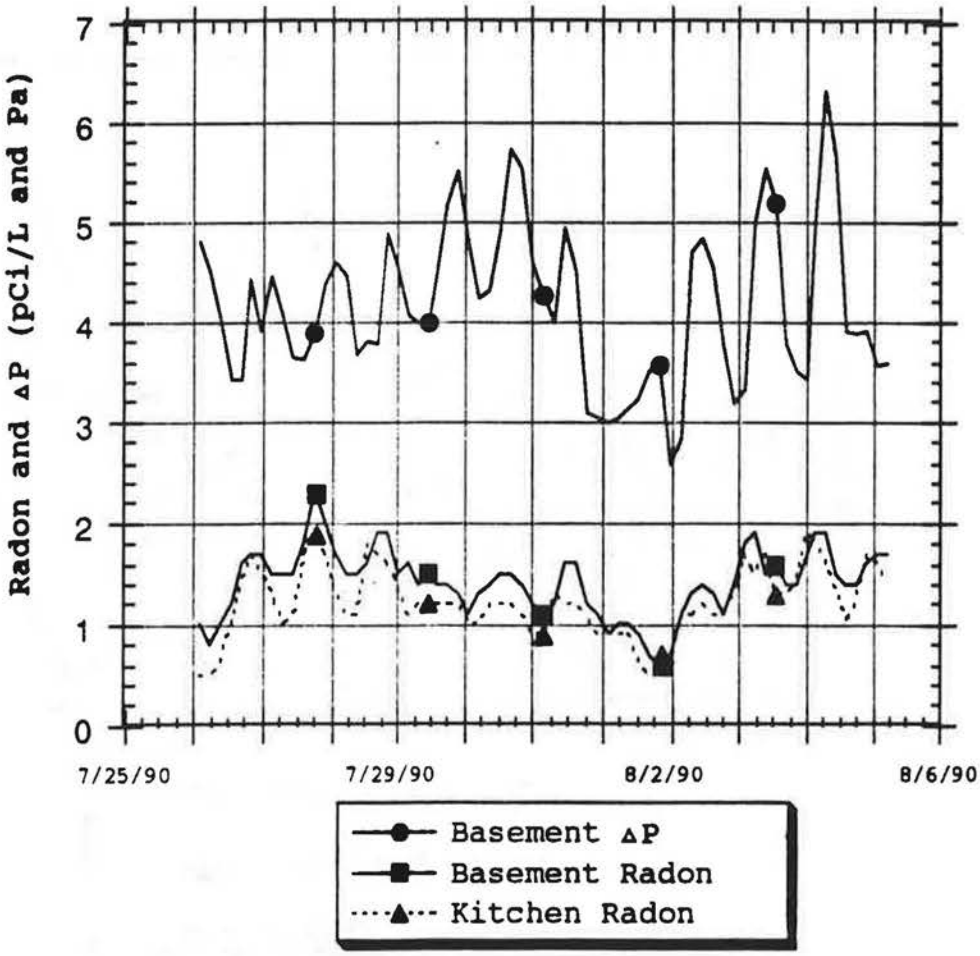


Figure 3. Radon levels and differential pressures with the air handler on continuously

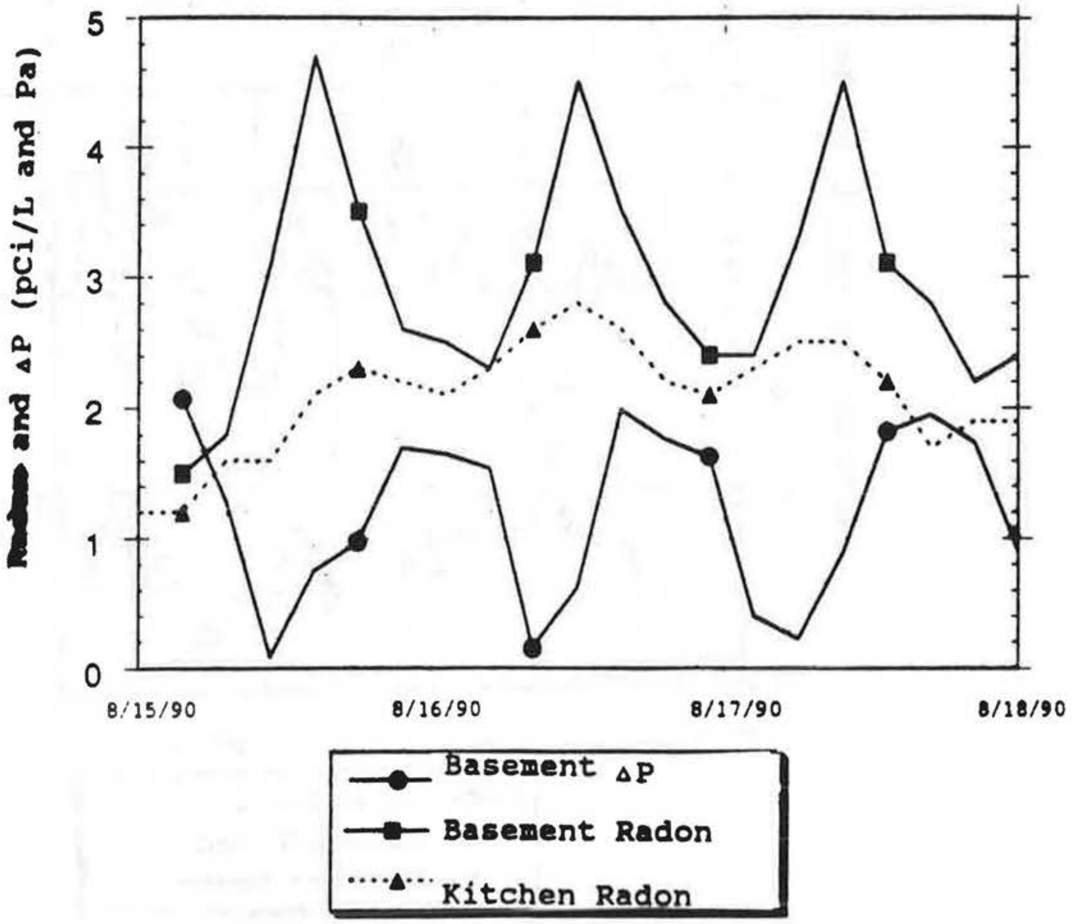
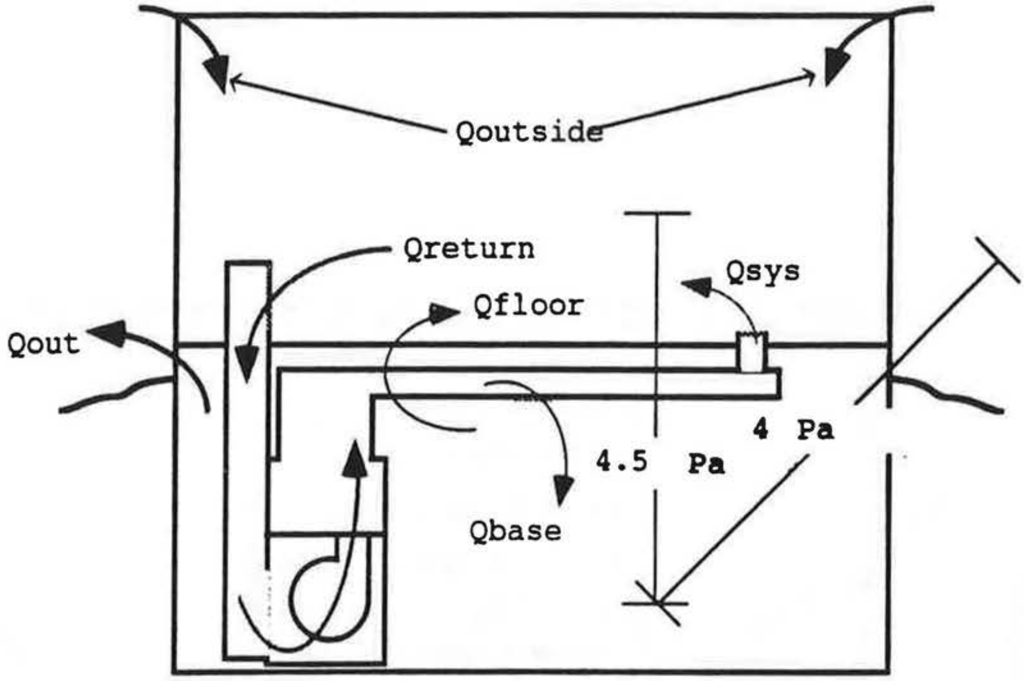


Figure 4. Radon levels and differential pressures with the air handler operating in normal cooling mode



Measured Effective Leakage Area (ELA)

ELA House less floor = 69 sq in.

ELA Basement less floor = 40 sq in.

ELA floor = 35 sq in.

Calculated directly from pressure - ELA data using airflow through a sharp edged orifice

Qfloor = 83 cfm ± 25 cfm
Qout = 87 cfm
Qoutside = 53 cfm ± 20 cfm

Qoutside should equal Qout. Although 53 does not equal 87 the difference is within the experimental error of the measurements.

Assuming that the return leaks equal the supply leaks
Qbase = Qoutside + Qfloor

Resulting in Qbase estimates of

Qbase = 136 - 170 cfm

This compares well with Qbase estimated from the ductwork airflow measurements of 138 cfm.

Figure 5. Airflows and pressure patterns with the air handler on low speed

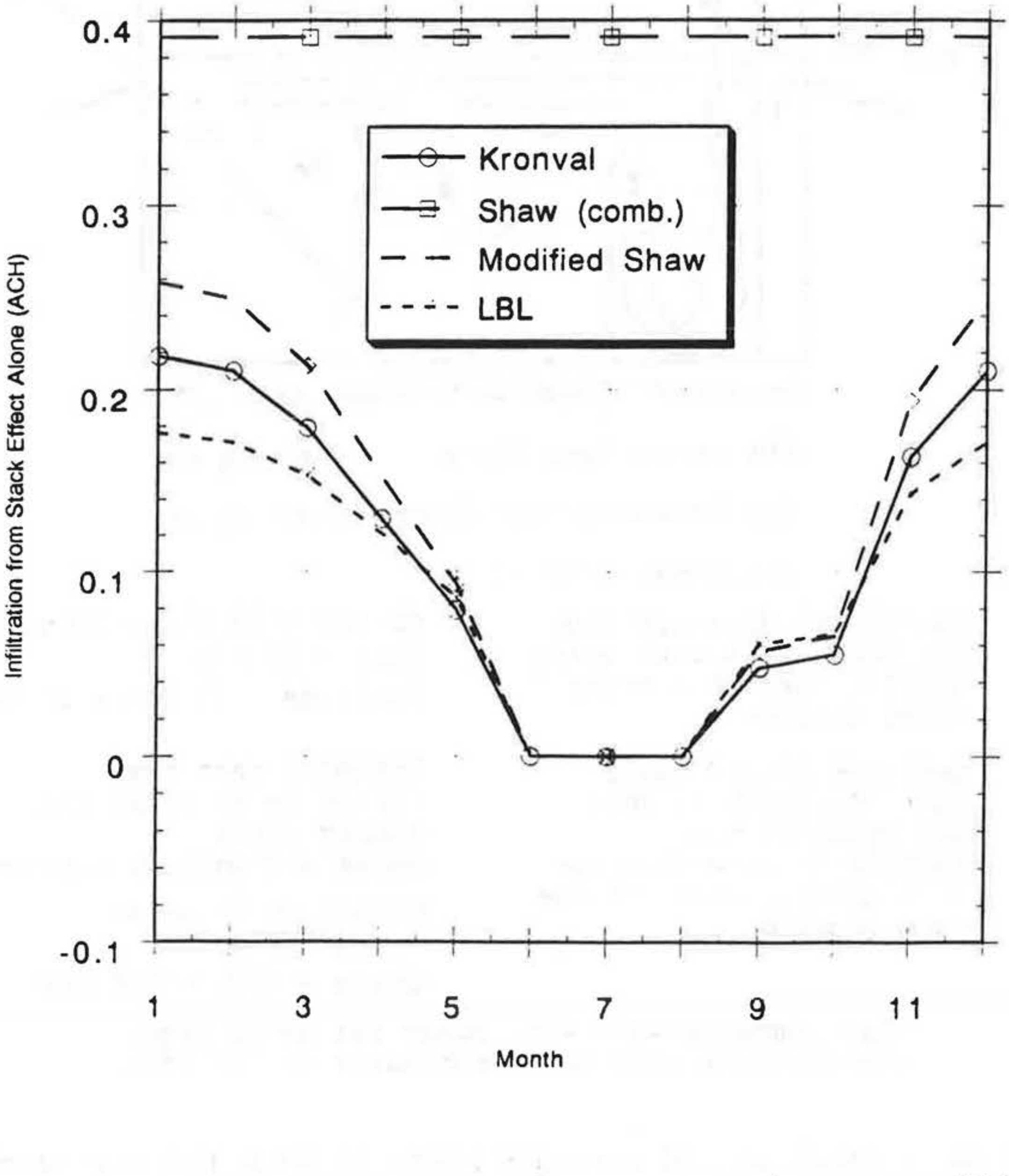


Figure 6. Estimated airflows through the test house resulting from stack effect alone. Four models have been used. The stack effect and the air handler produce countervailing pressure fields, to some extent canceling some of the effect of each.

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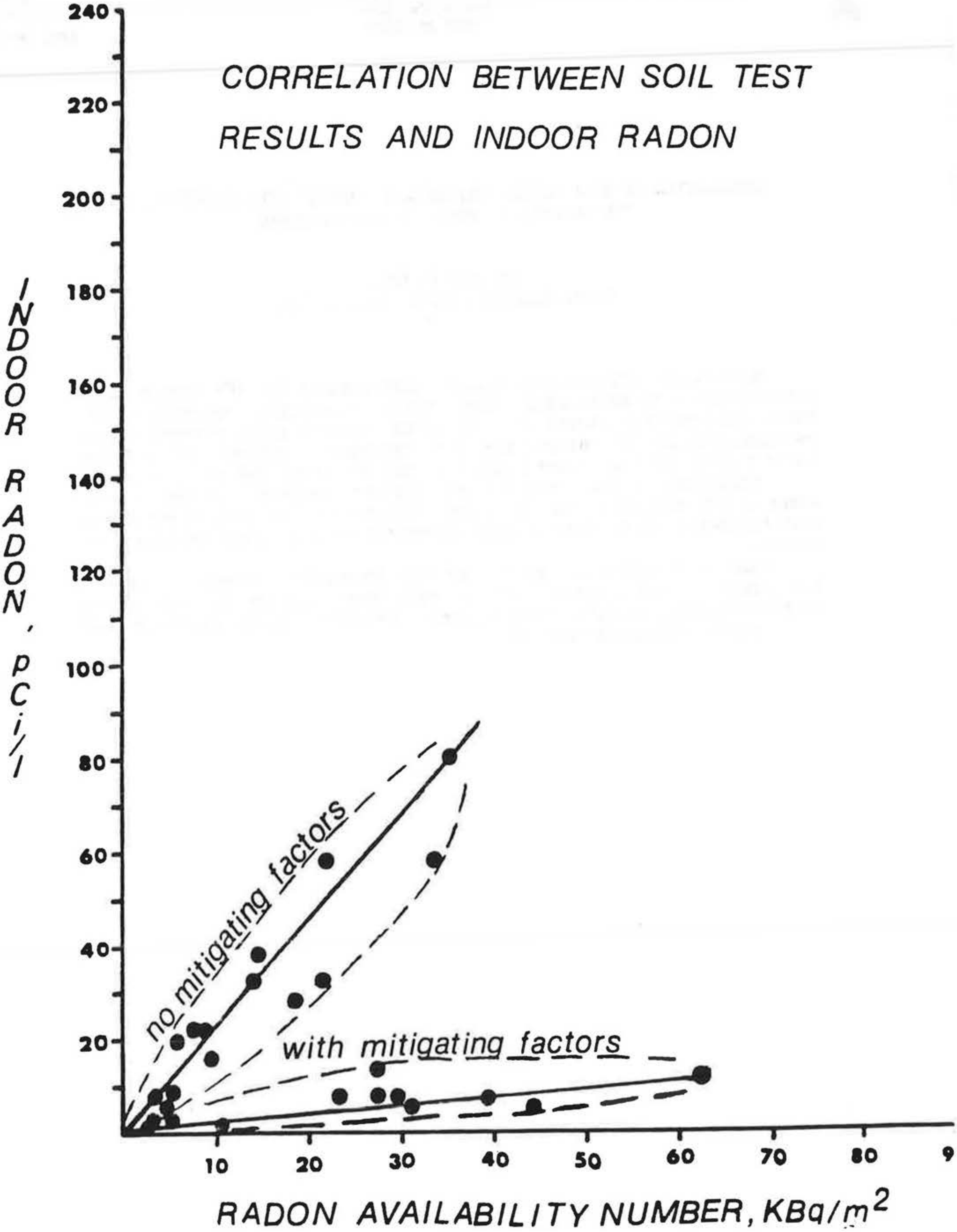
CORRELATION OF SOIL RADON AVAILABILITY NUMBER WITH INDOOR RADON AND GEOLOGY IN VIRGINIA AND MARYLAND

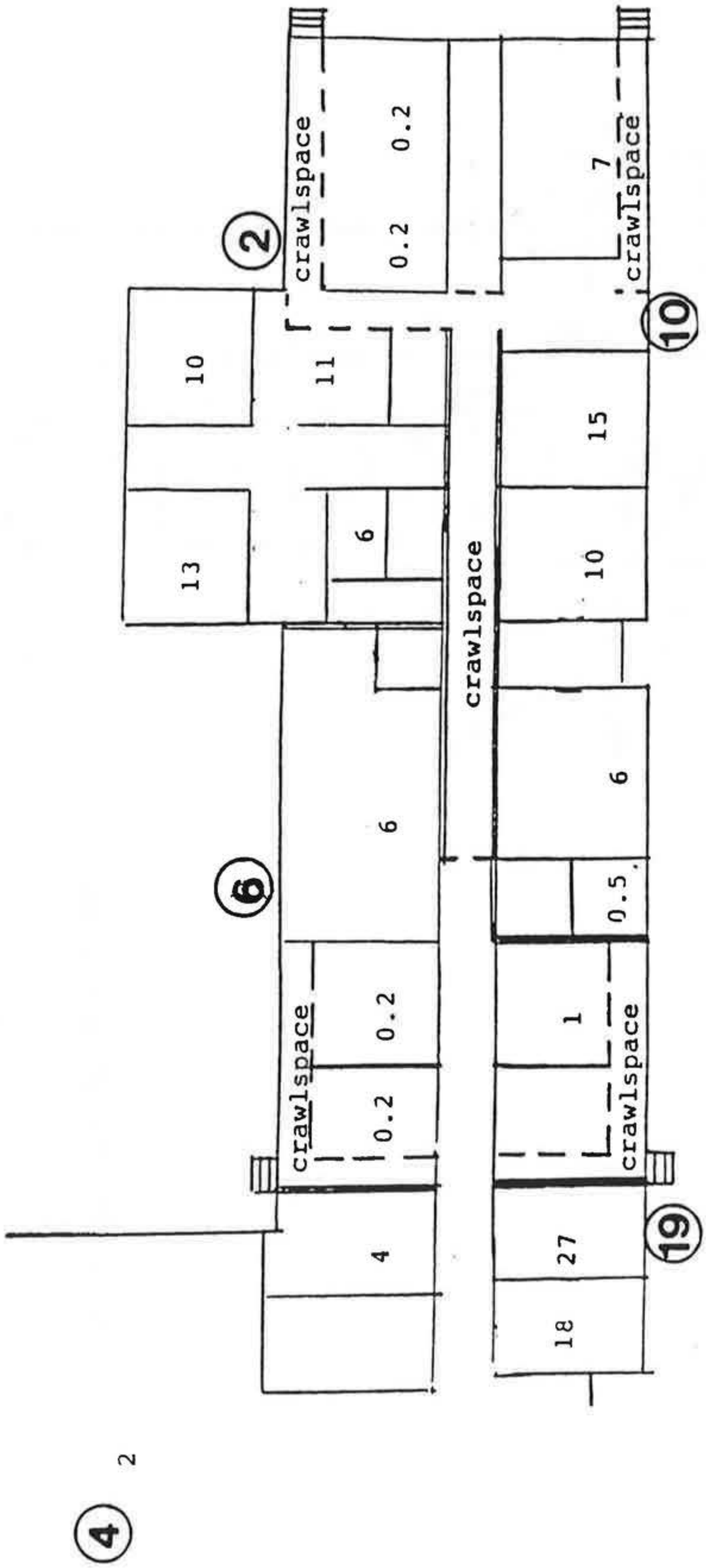
Stephen T. Hall
Radon Control Professionals, Inc.

Soil radon availability number measurements by RCP have yielded correlations with both indoor radon levels and various geologic units. Radon availability number is a function of soil radon concentration, permeability, and diffusion rate. The equipment consists of a Pylon radon monitor with attached Lucas cell and RCP-developed soil probe.

Determined radon availability numbers plotted against indoor radon levels revealed two distinct populations separating buildings with basements from those without basements or with other construction factors.

Thus, soil tests are being used with favorable success to predict the potential for elevated indoor radon levels and enable the design of pre-construction mitigation systems with the correct magnitude and location of ventilation points.


CORRELATION BETWEEN SOIL TEST RESULTS AND INDOOR RADON
INDOOR RADON, pCi/l
240
220
200
180
160
140
120
100
80
60
40
20
no mitigating factors
with mitigating factors
10
20
30
40
50
60
70
80
9
RADON AVAILABILITY NUMBER, KBq/m2



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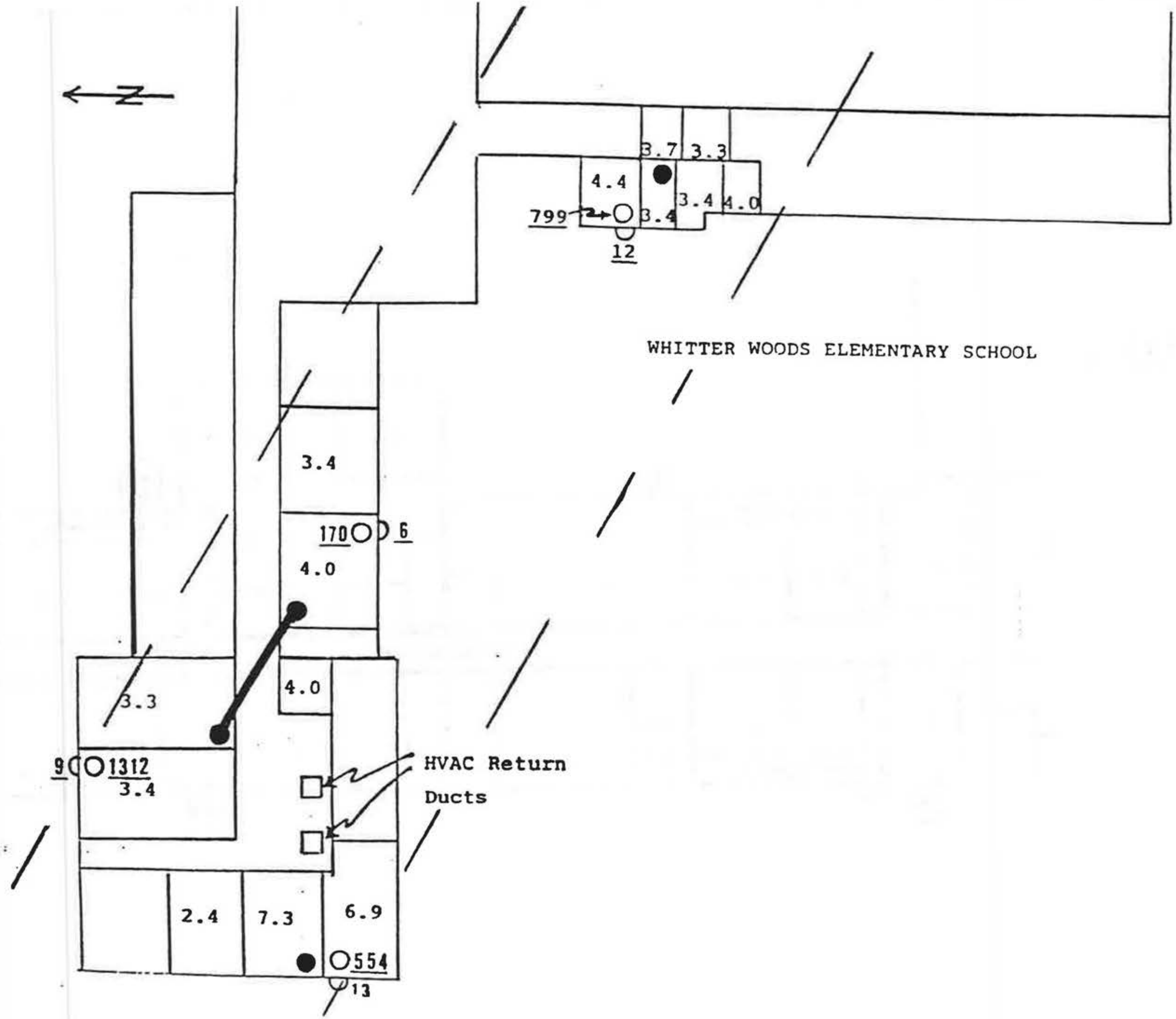
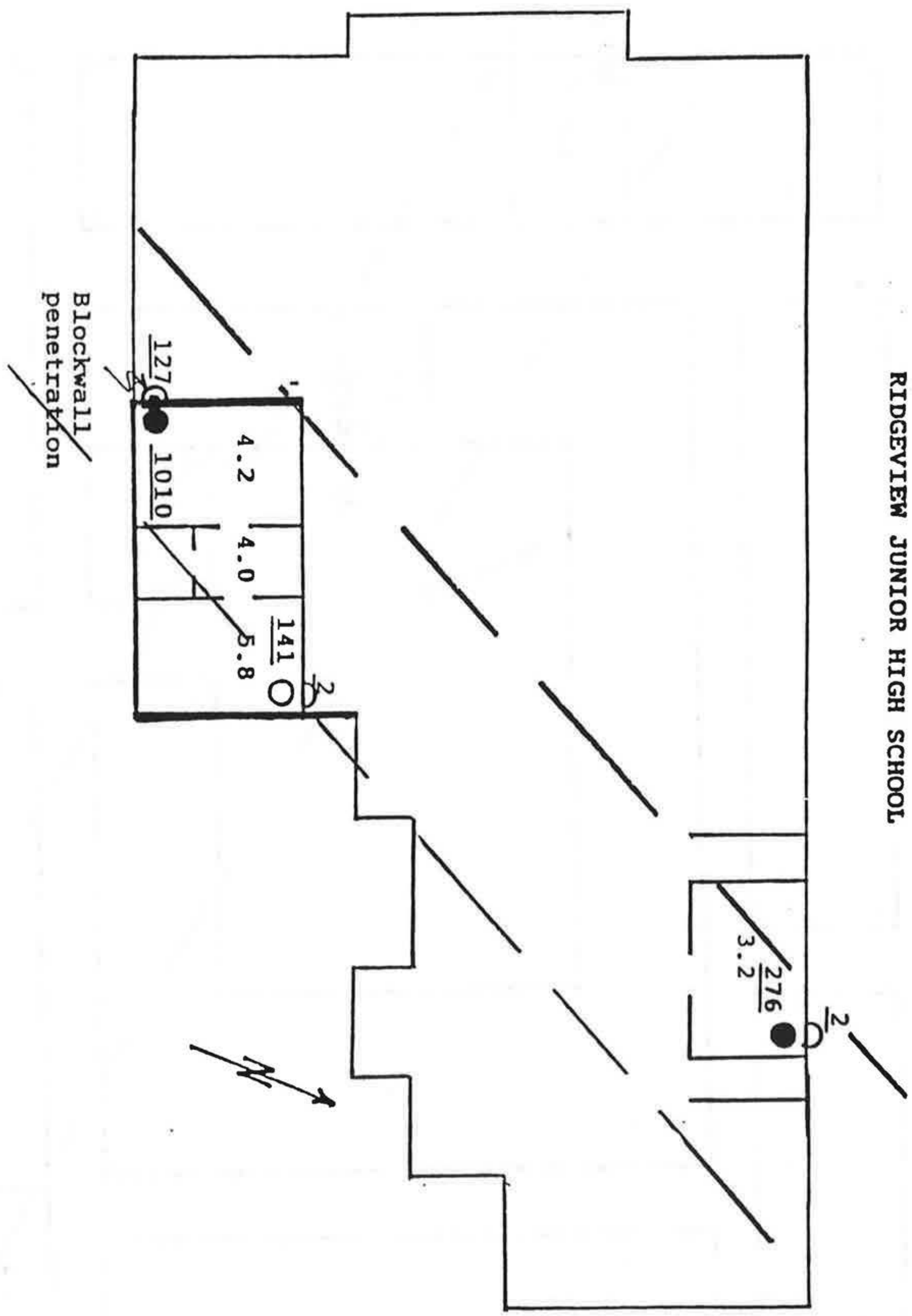
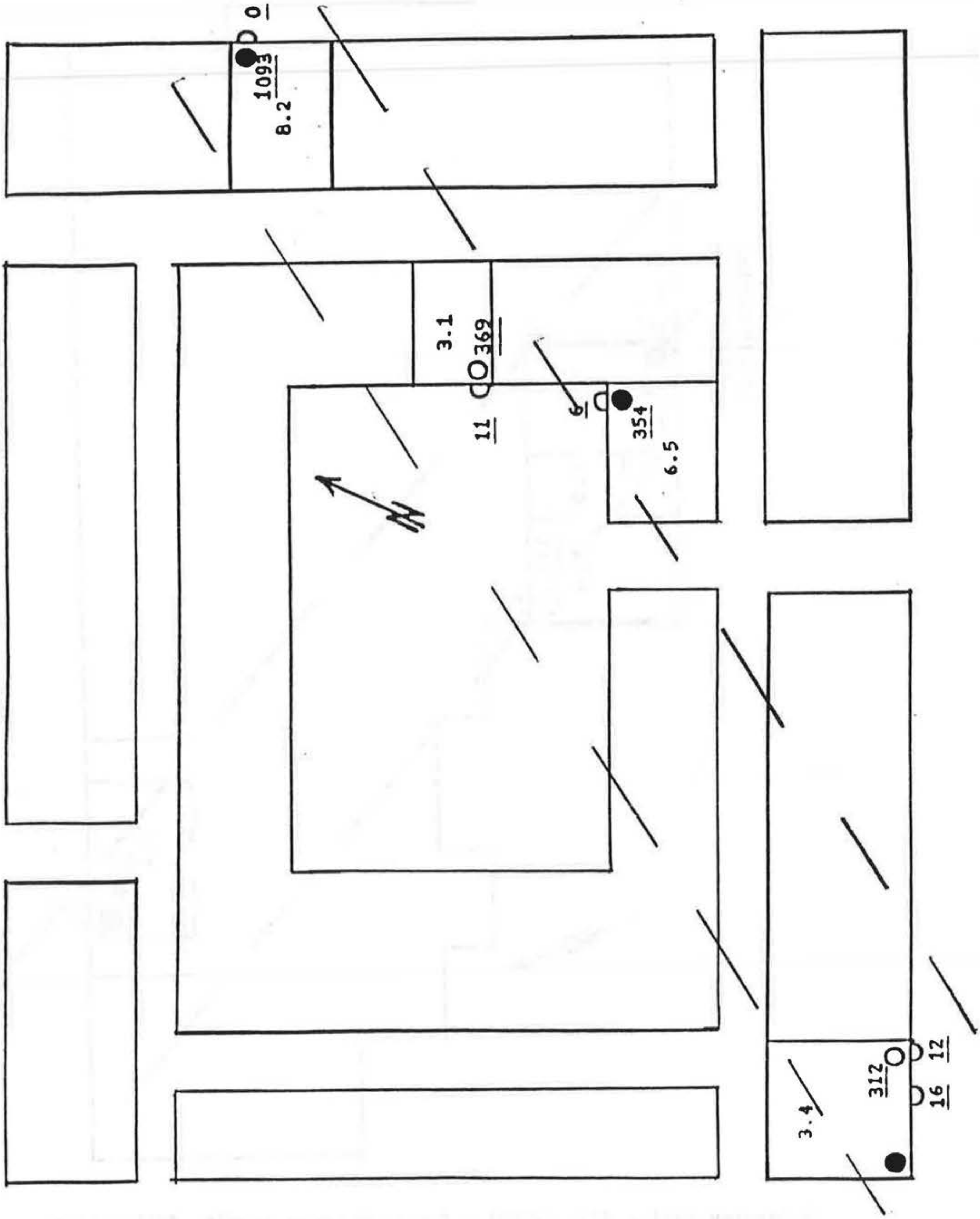
Completed school. Inside numbers = indoor radon, pCi/l.
Encircled numbers = radon availability number, KBq/m^2



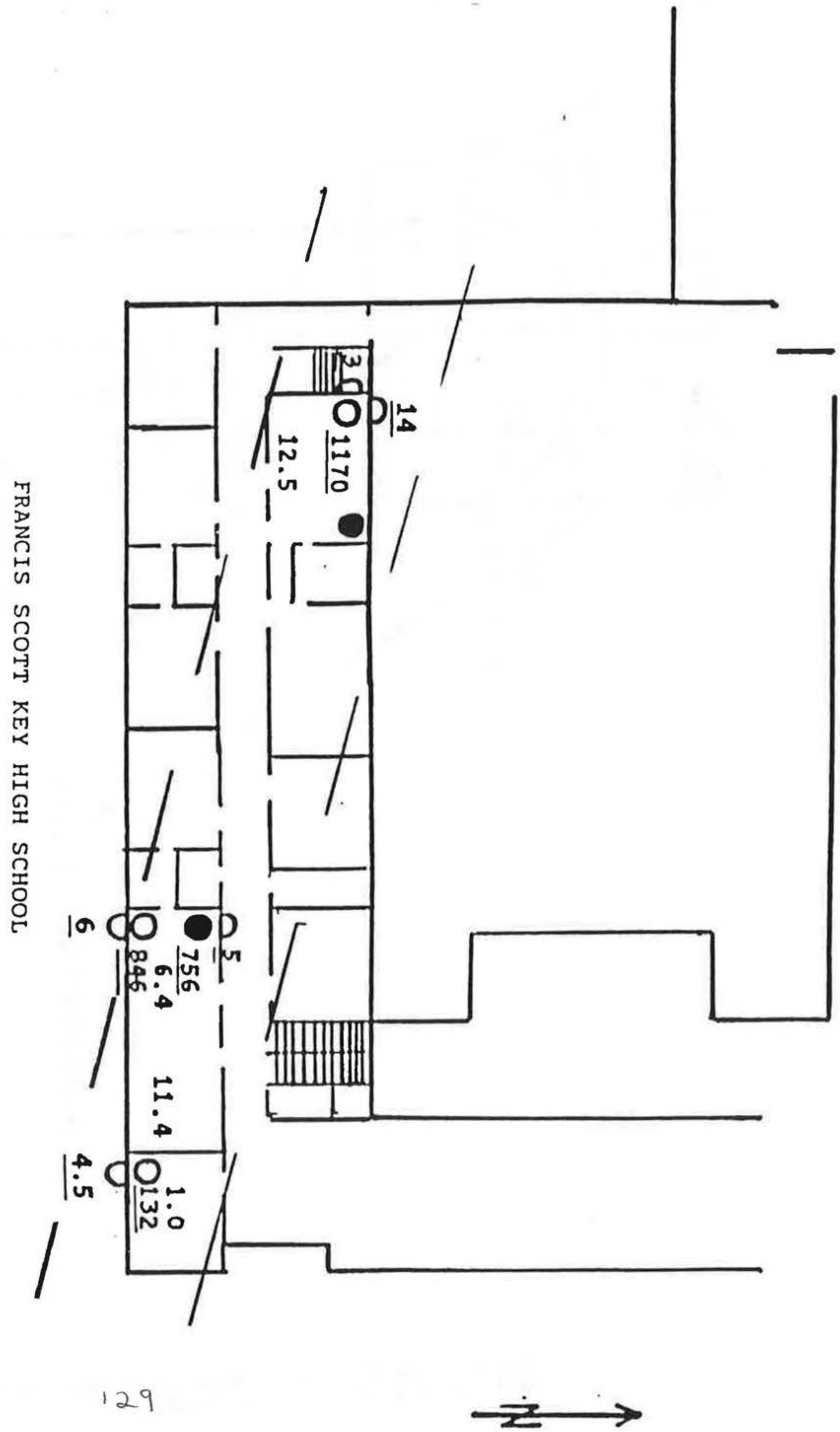
Whitter Woods Elementary School - Sub-slab radon levels delineating a N60°W fracture trend.



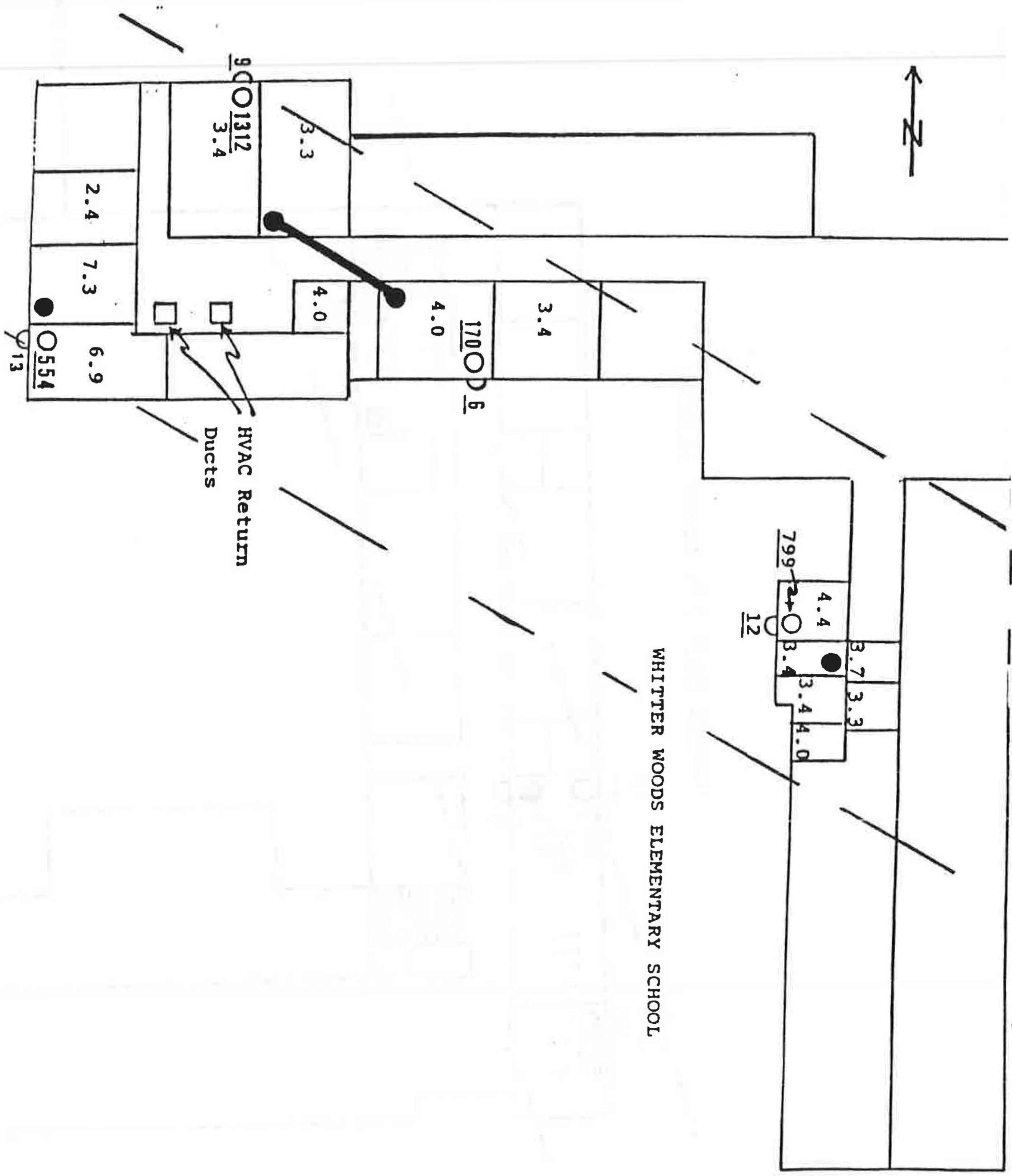
Ridgeview Junior High School - Sub-slab radon levels delineating a N30°E rock layer trend.



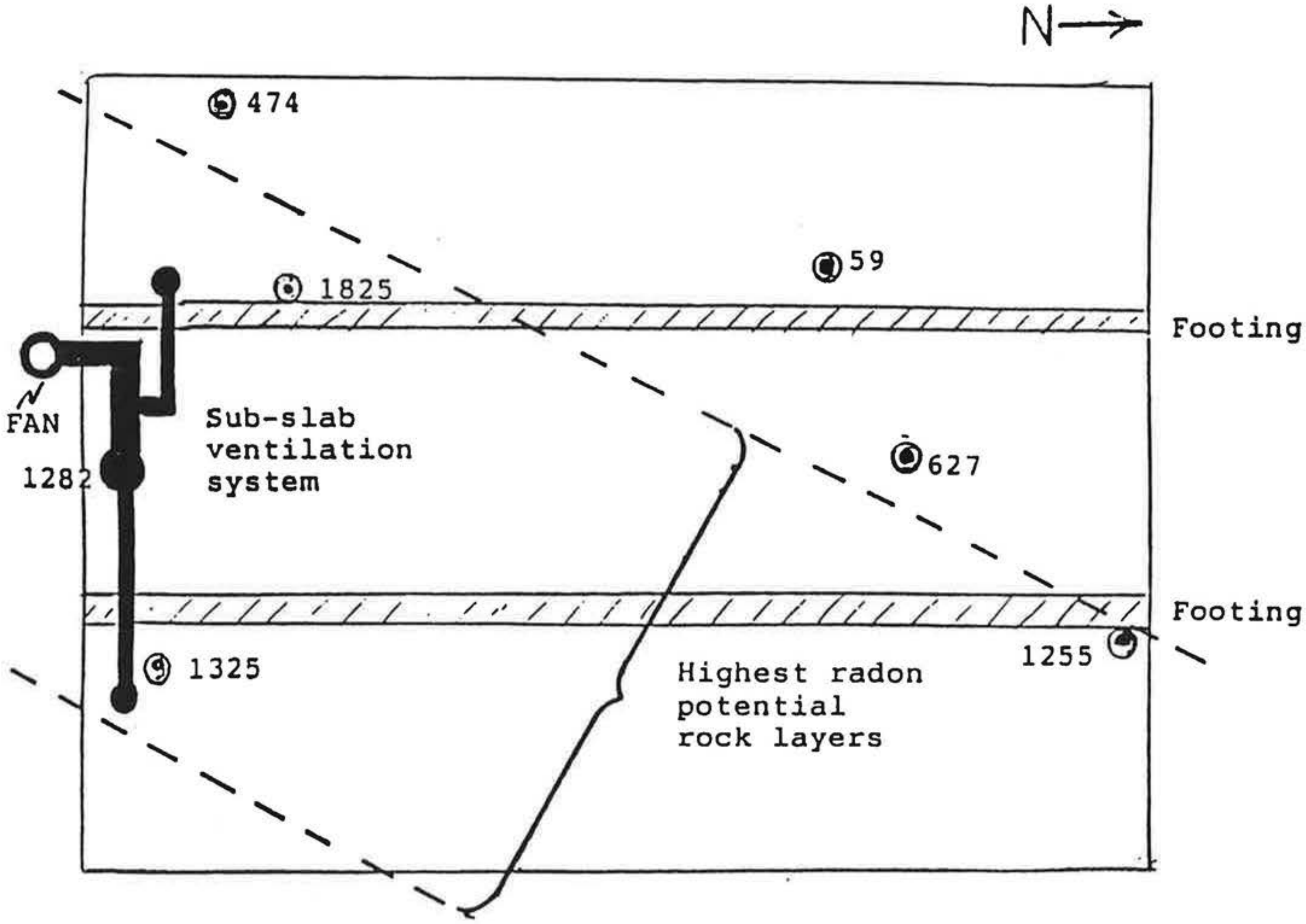
Cannon Road Elementary School - Sub-slab radon levels delineating a N30°E rock layer trend.



Francis Scott Key High School - Sub-slab radon levels delineating a N60°W fracture trend.



Whitter Woods Elementary School - Sub-slab radon levels delineating a N60°W fracture trend.



Footprint plan of a home showing numerical values of sub-slab and blockwall radon concentrations that indicate that the radon source is following N30°E rock layers, delineated by dash lines. Sub-slab ventilation systems penetrations are shown as darkened circles.

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Brian Fimian and John E. McGreevy, Radonics, Inc.

Radon and Water Vapor Co-Adsorption on Solid Adsorbents — Posters
Neguib M. Hassan, Tushar K. Ghosh, Sudarshan K. Loyalka, and Anthony L. Hines, University of Missouri-Columbia; and Davor Novosel, Gas Research Institute

Calibration of Modified Electret Ion Chamber for Passive Measurement of Radon-222 (Thoron) in Air — Posters
P. Kotrappa and J.C. Dempsey, Rad Elec, Inc.

Unit Ventilator Operation and Radon Concentrations in a Pennsylvania School — Posters
William P. Brodhead, WPB Enterprises and Norm Grant, Quoin Partnership, Architects and Engineers

Session IV: Radon Reduction Methods

Causes of Elevated Post-Mitigation Radon Concentrations in Basement Houses Having Extremely High Pre-Mitigation Levels
D. Bruce Henschel, AEERL; Arthur G. Scott, AMERICAN ATCON, Inc.

A Measurement and Visual Inspection Critique to Evaluate the Quality of Sub-Slab Ventilation Systems
Richard W. Tucker, Gemini Research, Inc.; Keith S. Fimian, Radonics, Inc.

Pressure Field Extension Using a Pressure Washer
William P. Brodhead, WPB Enterprises

A Variable and Discontinuous Subslab Ventilation System and Its Impact on R_n Mitigation
Willy V. Abeele, New Mexico Environmental Improvement Division

Natural Basement Ventilation as a Radon Mitigation Technique
A. Cavallo, K. Gadsby, and T.A. Reddy, Princeton University

Radon Mitigation Failure Modes — Posters
William M. Yeager, Research Triangle Institute; D. Bruce Harris, AEERL; Terry Brennan and Mike Clarkin, Camroden Associates

Mitigation by Sub-Slab Depressurization Under Structures Founded on Relatively Impermeable Sand — Posters
Donald A. Crawshaw and Geoffrey K. Crawshaw, Pelican Environmental Corporation

A Laboratory Test of the Effects of Various Rain Caps on Sub-Slab Depressurization Systems — Posters
Mike Clarkin, Terry Brennan, and David Fazikas, Camroden Associates

Analysis of the Performance of a Radon Mitigation System Based on Charcoal Beds — Posters
P. Wasiolek, N. Montassier, P.K. Hopke, Clarkson University; R. Abrams, RAd Systems, Inc.

Session VI: Radon Surveys

Factors Associated with Home Radon Concentrations in Illinois
Thomas J. Bierma and Jennifer O'Neill, Illinois State University

Radon in Switzerland
H. Surbeck and H. Völkle, Physics Institute, University Pérolles; W. Zeller, Federal Office of Public Health, Switzerland

A Cross-Sectional Survey of Indoor Radon Concentrations in 966 Housing Units at the Canadian Forces Base in Winnipeg, Manitoba
D.A. Figley and J.T. Makohon, Saskatchewan Research Council

Radon Studies in British Columbia, Canada
D.R. Morley and B.G. Phillips, Ministry of Health; M.M. Ghomshei, Orchard Geothermal Inc.; C. Van Netten, The University of British Columbia

The State of Maine Schools Radon Project: Results
L. Grodzins, NITON Corporation; T. Bradstreet, Division of Safety and Environmental Services, Maine; E. Moreau, Department of Human Services, Maine

The Effect of Subslab Aggregate Size on Pressure Field Extension
K.J. Gadsby, T. Agami Reddy, D.F. Anderson, and R. Gafgen, Princeton University; Alfred B. Craig, U.S. EPA, Air and Energy Engineering Research Laboratory

A Radiological Study of the Greek Radon Spas
P. Kritidis, Institute of Nuclear Technology - Radiation Protection

Seasonal Variation in Two-Day Screening Measurements of 222RN — Posters
Nat F. Rodman, Barbara V. Alexander, and S.B. White, Research Triangle Institute; Jeffrey Phillips and Frank Marcinowski, U.S. EPA, Office of Radiations Programs

The State of Maine School Radon Project: Protocols and Procedures of the Testing Program — Posters
Lee Grodzins and Ethel G. Romm, NITON Corporation; Henry E. Warren, Bureau of Public Improvement, Maine

Results of the Nationwide Screening for Radon in DOE Buildings — Posters
Mark D. Pearson, D.T. Kendrick, and G.H. Langner, Jr., U.S. DOE/Chem-Nuclear Geotech, Inc.

Session VII: State Programs and Policies Relating to Radon

Washington State's Innovative Grant: Community Support Radon Action Team for Schools
Patricia A. McLachlan, Department of Health, Washington

Kentucky Innovative Grant: Radon in Schools' Telecommunication Project
M. Jeana Phelps, Kentucky Cabinet for Human Resources and Carolyn Rude-Parkins, University of Louisville

Regulation of Radon Professionals by States: The Connecticut Experience and Policy Issues
Alan J. Siniscalchi, Zygmunt F. Dembek, Nicholas Macelletti, Laurie Gokey, and Paul Schur, Connecticut Department of Health Services; Susan Nichols, Connecticut Department of Consumer Protection; and Jessie Stratton, State Representative, Connecticut General Assembly

New Jersey Radon Program, 1991
Jill A. Lapoti, New Jersey Department of Environmental Protection

Quality Assurance - The Key to Successful Radon Programs in the 1990s — Posters
Raymond H. Johnson, Jr., Key Technology, Inc.

Radon in Illinois: A Status Report — Posters
Richard Allen and Melanie Hamel-Caspary, Illinois Department of Nuclear Safety

Session VIII: Radon Prevention in New Construction

A Comparison of Indoor Radon Concentrations Between Preconstruction and Post-Construction Mitigated Single Family Dwellings
James F. Burkhart, University of Colorado at Colorado Springs; Douglas L. Kladder, Residential Service Network, Inc.

Radon Reduction in New Construction: Double-Barrier Approach
C. Kunz, New York State Department of Health

Radon Control - Towards a Systems Approach
R.M. Nuess and R.J. Prill, Washington State Energy Office

Mini Fan for SSD Radon Mitigation in New Construction
David Saum, Infiltec

Building Radon Mitigation into Inaccessible Crawlspace New Residential Construction
D. Bruce Harris and A.B. Craig, AEERL and Jerry Haynes, Hunt Building Corporation

The Effect of Subslab Aggregate Size on Pressure Field Extension
K.J. Gadsby, T. Agami Reddy, D.F. Anderson, and R. Gafgen, Princeton University; A.B. Craig, AEERL

Radon Prevention in Residential New Construction: Passive Designs That Work — Posters
C. Martin Grisham, National Radon Consulting Group

Preliminary Results of HVAC System Modifications to Control Indoor Radon Concentrations — Posters
Terry Brennan and Michael Clarkin, Camroden Associates; Timothy M. Dyess, AEERL; William Brodhead, Buffalo Homes

Correlation of Soil Radon Availability Number with Indoor Radon and Geology in Virginia and Maryland — Posters
Stephen T. Hall, Radon Control Professionals, Inc.

Session IX: Radon Occurrence in the Natural Environment

Combining Mitigation and Geology: Indoor Radon Reduction by Accessing the Source
Stephen T. Hall, Radon Control Professionals, Inc.

Technological Enhancement of Radon Daughter Exposures Due to Non-Nuclear Energy Activities
J. Kovac, D. Cesar, and A. Bauman, University of Zagreb, Yugoslavia

A Site Study of Soil Characteristics and Soil Gas Radon
Richard Lively, Minnesota Geological Survey and Daniel Steck, St. John's University

Geological Parameters in Radon Risk Assessment - A Case History of Deliberate Exploration
Donald Carlisle and Haydar Azzouz, University of California at Los Angeles

Geologic Evaluation of Radon Availability in New Mexico: A Progress Report — Posters
Virginia T. McLemore and John W. Hawley, New Mexico Bureau of Mines and Mineral Resources; and Ralph A. Manchego, New Mexico Environmental Improvement Division

Paleozoic Granites in the Southeastern United States as Sources of Indoor Radon — Posters
Stephen T. Hall, Radon Control Professionals, Inc.

Comparison of Long-Term Radon Detectors and Their Correlations with Bedrock Sources and Fracturing — Posters
Darioush T. Ghahremani, Radon Survey Systems, Inc.

Geologic Assessment of Radon-222 in McLennan County, Texas — Posters
Mary L. Podsednik, Law Engineering, Inc.

Radon Emanation from Fractal Surfaces — Posters
Thomas M. Semkow, Pravin P. Parekh, and Charles O. Kunz, New York State Department of Health and State University of New York at Albany; and Charles D. Schwenker, New York State Department of Health

Session X: Radon in Schools and Large Buildings

Extended Heating, Ventilating and Air Conditioning Diagnostics in Schools in Maine
Terry Brennan, Camroden Associates; Gene Fisher, U.S. EPA, Office of Radiation Programs; and William Turner, H. L. Turner Group

Mitigation Diagnostics: The Need for Understanding Both HVAC and Geologic Effects in Schools
Stephen T. Hall, Radon Control Professionals, Inc.

A Comparison of Radon Mitigation Options for Crawl Space School Buildings
Bobby E. Pyle, Southern Research Institute; Kelly W. Leovic, AEERL

HVAC System Complications and Controls for Radon Reduction in School Buildings
Kelly W. Leovic, D. Bruce Harris, and Timothy M. Dyess, AEERL; Bobby E. Pyle, Southern Research Institute; Tom Borak, Western Radon Regional Training Center; David W. Saum, Infiltec

Radon Diagnosis in a Large Commercial Office Building
David Saum, Infiltec

Design of Radon-Resistant and Easy-to-Mitigate New School Buildings
Alfred B. Craig, Kelly W. Leovic, and D. Bruce Harris, AEERL

Design and Application of Active Soil Depressurization (ASD) Systems in School Buildings — Posters
Kelly W. Leovic, A.B. Craig, and D. Bruce Harris, AEERL; Bobby E. Pyle, Southern Research Institute; Kenneth Webb, Bowling Green (KY) Public Schools

Radon in Large Buildings: Pre-Construction Soil Radon Surveys — Posters
Ralph A. Llewellyn, University of Central Florida

Radon Measurements in North Dakota Schools — Posters
Thomas H. Morth, Arlen L. Jacobson, James E. Killingbeck, Terry D. Lindsey, and Allen L. Johnson, North Dakota State Department of Health and Consolidated Laboratories

Major Renovation of Public Schools that Includes Radon Prevention: A Case Study of Approach, System Design, and Installation; and Problems Encountered — Posters
Thomas Meehan

The State of Maine School Radon Project: The Design Study — Posters
Henry E. Warren, Maine Bureau of Public Improvement and Ethel G. Romm, NITON Corporation