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HVAC SYSTEM COMPLICATIONS AND CONTROLS FOR RADON REDUCTION IN SCHOOL BUILDINGS

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ABSTRACT

School mitigation research to date has emphasized reduction of radon levels using a subslab depressurization (ASD). Although ASD has proven successful in a number of schools, it reasonably applicable in all school buildings since many schools do not have a layer of clean, c aggregate under the slab or may have many subslab barriers that would require an unreasc number of ASD suction points. Additionally, mitigation options that have relatively low installatic operating costs need to be researched for application to schools with moderately elevated radon (4 to 20 picocuries per liter, pCi/L). Since many schools are designed with heating, ventilating air-conditioning (HVAC) systems that can provide outdoor air to the building, research has initiated to determine the feasibility of using HVAC systems to pressurize the building interior to re elevated levels of radon in selected schools.

This paper discusses case studies of four schools where the U.S. Environmental Prote Agency's (EPA) Air and Energy Engineering Research Laboratory (AEERL) has recently initiated term research on the ability of HVAC systems to reduce elevated levels of radon. The schoo located in the states of Colorado, Maryland, Virginia, and Washington. Depending on the s building floor plan and HVAC system design, a specific wing or the entire building was selecte research. Two of the schools have unit ventilators in the rooms being researched and two have c air-handling systems. Initial results indicate that, when sufficient outdoor air is supplied by the H system, radon levels can be reduced. The amount of radon reduction depends on the specific H system design and operation.

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

BACKGROUND

Previous research efforts on radon reduction in schools have presented theoretical aspect limited short-term data on radon mitigation using HVAC systems (1, 2, 3); however, long-term res on the feasibility of radon mitigation using HVAC system pressurization is limited. As a result, summer of 1990 AEERL's Radon Mitigation Branch initiated several projects in an effort to b understand school HVAC systems and their ability to reduce radon levels in schools while improving overall indoor air quality.

To initiate this research on radon mitigation using HVAC systems, four schools (or wings of the schools) were selected. Two of the school wings contain wall-mounted unit ventilators in each classroom (Maryland and Washington), and two of the schools have central air-handling systems (Colorado and Virginia). The Maryland and Virginia schools had been part of previous research efforts by AEERL (1, 4), and the Colorado and Washington schools were identified during field studies in the summer of 1990. These four schools, in addition to three other schools (one in Maryland and two in Ohio), will be studied in more detail over the next year. In a few of the schools future research will also include a comparison of HVAC systems and ASD in reducing elevated levels of radon. Metric conversion factors are presented in Table 1.

CASE STUDIES

The following case studies discuss four schools located in Colorado, Maryland, Virginia, and Washington. In addition to background information on each school, each case study includes an HVAC system description, the results of initial measurements, and future research plans for the school. The summary characteristics of these schools are displayed in Table 2.

COLORADO SCHOOL

The original building was constructed in 1956 and includes seven classrooms and various other support offices and storage rooms with a total area of approximately 15,750 ft^2 of floor space as shown in Figure 1. The original building includes a 1,300 ft^2 boiler room located in a basement in the southwest corner. The boiler room is approximately 11 ft below grade and contains the HVAC system. The remainder of the building is slab-on-grade construction. In 1958 an additional six classrooms, a kitchen, several restrooms, and support rooms totaling about 9,500 ft^2 were added to the original building. In 1976, a 2,100 ft^2 media center was added to the end of the 1958 addition. The last addition to the building was in 1982 when a 200 ft^2 storage area was added to the southwest end of the multipurpose (gym) room. The total footprint of the building is approximately 29,000 ft^2 , with approximately 27,700 ft^2 in contact with the soil.

E-Perm measurements made in all classrooms from January 15 to 17, 1990, averaged 6.6 pCi/L with a minimum of 4.8 pCi/L and a maximum of 12.3 pCi/L. Most of the rooms were remeasured during followup tests from February 14 to 16, 1990. These later measurements averaged 7.6 pCi/L with a minimum value of 5.8 pCi/L and a maximum value of 10.2 pCi/L. The results of both sets of measurements are shown on the floorplans in Figures 1 and 2, respectively.

HVAC System Description

The building HVAC system includes a central air handler with a single fan and individual controls in each of the rooms. The HVAC system operates by time control with the system operating approximately 9 hours during the daytime and set back for approximately 15 hours at night. This schedule is apparently maintained even during the weekend when the school is not occupied. The HVAC registers are located in the floor and the supply ducts are located below the slabs and are composed of cylindrical cardboard ducts surrounded by poured concrete. In those areas where these ducts were visible, large gaps were found between the cardboard tubing and the surrounding concrete. It is highly likely that in most locations the cardboard tubing has deteriorated to the point that the supply air is in direct contact with the concrete. Since radon levels may build up in the supply ducts when the HVAC fan is not operating, these levels will be measured in future studies to determine the relative contribution to building radon levels.

The return air from each classroom exits through grilles into the hallway with the hallway of the building serving as a return air plenum. From the hallway the return air is ducted into a central subslab return-air tunnel that leads back to the air handler in the basement. The air in the gym is returned through floor grilles in the northeast and northwest corners of the room directly into the return air tunnel. The tunnel varies in size from about 3 by 3 ft up to 4 by 4 ft in cross section and accessed in the boiler room. The tunnel has numerous penetrations by utility lines that lead to soil contact and probably represent a major radon source. There is a provision for outdoor air air handler located at roof level with the air ducted directly into the HVAC fan chamber thro control damper. Visual observation of the outdoor air intake damper from inside the fan chamb the fan operating indicated that the damper did not open during fan operation. Subs investigation by the school maintenance staff confirmed that the control rod for the fresh-air damper did not operate properly, and this was repaired. However, it is not clear what control s operates the damper. During the cold winter days the damper may be only partially opened dep on the outdoor temperature.

Results of Initial Measurements

Room pressure differentials were investigated primarily in the kindergarten room us electronic micromanometer. These measurements were made before the outdoor air dampe repaired. The differential pressure in the kindergarten room relative to the subslab was meas be -0.005 in. WC with the HVAC on and the door to the hall open. When the door was clos differential pressure dropped to -0.003 in. WC. The differential pressure between the kinder room and the hallway was -0.005 in. WC with the HVAC on and the door closed. The pressure room relative to outdoors was -0.005 in. WC. Differential pressure was not measured with the system off. However, it appears that the HVAC system is depressurizing the classroom relat both the subslab region and outdoors. This indicates that, even in the warm summer months the HVAC system is used for ventilation purposes only, it causes room depressurization which r in soil gas flow from the subslab regions into the room.

Radon concentrations under the slab and at several possible entry points were measured a Pylon AB5 in a "sniff" configuration. The subslab radon levels measured through 0.5 in. dia holes drilled through the slab in the kindergarten room and the office in Room 6 were about 700 Levels of about 300 pCi/L were measured in a crack in the slab adjacent to one of the air s registers in the kindergarten room. Sniffing in one of the supply registers in the gym showed of about 15 pCi/L with the air handler off and about 25 pCi/L with the fan on. Measurements wall cracks of the air return tunnel showed levels of between 50 and 100 pCi/L with the fa These levels increased to about 350 pCi/L when the fan was turned on and the tunnel depressu This indicates that the depressurization of the return duct can increase radon entry from th through the cracks and penetrations in the tunnel walls.

Examination of the air handler fan chamber identified a relatively large crack (about 0 wide) in the slab. The investigators sealed the accessible part of the crack with duct tape for a l of roughly 4 ft and sealed the hose of the Pylon under the tape. The levels were measured about 700 pCi/L with the fan off and about 800 pCi/L with the fan on. The AB5 was placed in t chamber to sniff the air in the chamber. The radon levels were about 70 pCi/L with the fan o increased to 350 to 700 pCi/L with the fan on, indicating that the slab crack into the fan cham a major radon entry route. It was also observed that the crack was very clean with little or nc filling in the crack. Apparently there is sufficient air flow out of the crack (or turbulence in t above) to keep the crack clean. The pressure in the fan chamber relative to the boiler room measured to be approximately -2 in. WC.

Over the 1990 Christmas break a series of E-Perm measurements were made in all classr of this school with the outdoor air damper for the HVAC system opened and closed. Measurer were also made in another school in the district that has the same design but has not been sho have elevated levels of radon. In both schools the first set of measurements were made wi outdoor air dampers closed (December 21-26, 1990), and the second set were made with the da open (December 27-31, 1990). The weather during the second measurement period was exceptic cold and, as a result, it appears that the damper in the school with the radon problem did not op intended. Because of this, the measurements with the damper open were repeated in this school on January 1-2, 1991. For each of the two schools, Table 3 presents the average of the radon levels in all classrooms, the levels in the boiler rooms, and the levels in the return air ducts. School 1 is the school with the known radon problem, and School 2 is the other school.

As indicated by the results in Table 3, opening the outdoor air damper reduces average classroom radon levels in School 1; however, it does not bring the average of the average classroom levels to below 4 pCi/L. The results from School 2 show only a slight decrease in average radon classroom levels with the outdoor air damper open. The radon measurements in the return air duct exceed average levels in the classrooms in both schools. These results support the theory that the return air duct is a major contributor to elevated radon levels, particularly in School 1. Opening the damper helps to dilute radon levels in the tunnel but not enough to reduce average classroom levels to below 4 pCi/L.

Future Plans

A datalogger was installed in School 1 in January 1991 to collect continuous radon levels (in Room 6, the supply, and the return ducts), differential pressure, and meteorological data. Measurements will also be made to compare the radon source strengths in Schools 1 and 2. Once a series of baseline data are collected with the outdoor air damper opened and closed, the slab crack in the fan chamber will be sealed and the measurements repeated.

MARYLAND SCHOOL

This school was mitigated with ASD in 1988 and is discussed in detail in Reference 5. Previous measurements in a four classroom addition to the school (Building B in Reference 5) indicated that the unit ventilators in the classrooms could reduce radon levels of over 20 pCi/L to below 2 pCi/L; however, school personnel had decided to install an ASD system since radon levels increased at night when the unit ventilators were off. Measurements indicate that radon levels are typically well below 1 pCi/L with the ASD system operating and, as a result, this school presents an ideal opportunity to compare ASD and unit ventilator pressurization in the same school.

HVAC System Description

The area being studied is a four classroom addition, as shown in Figure 3. Each of the classrooms has a wall-mounted unit ventilator that has the ability to provide outdoor air when the damper is open. Although there is a large exhaust fan in the school (3600 cfm), according to school officials it is never used.

Investigation of the unit ventilators revealed that, although the design drawings called for a minimum of 16% outdoor air, the outdoor air dampers for two of the four units were not opening at all. After repairs, flow hood measurements for the units in Rooms 107 and 108 indicated that about 120 cfm of outdoor air was being supplied by each unit with the outdoor air damper in minimum (roughly 10% open) position. With the restroom exhaust estimated to be 50 cfm, Classroom 107 was at a neutral pressure. With the outdoor air dampers open to 100% outdoor air, Room 107 was about +0.003 in. WC relative to the outdoors, and the air flow into the unit ventilator was 450 cfm. All doors and windows in the room were shut during the data collection.

Results of Initial Measurements

A datalogger was installed in Rooms 105 - 108 over the holiday break (December 21 to 31, 1990) in order to collect preliminary data on the unit ventilators operating with the ASD system off. Measurements were made over successive 3-day periods with the unit ventilators operated as follows:

1) setback (no outdoor air), 2) normal operation (with evening setback), and 3) contint operation with no setback (outdoor air provided for entire period). The fans for these units o during setback unless room temperatures drop below 60°F. The radon levels measured in R during these three conditions are shown in Figure 4. As seen by these data, radon levels rer below 4 pCi/L while the unit ventilator is operated continuously but rise above 4 pCi/L d setback modes. Note that during the day-plus-setback operation, radon levels rise at night to about 4 pCi/L during the day.

Future Plans

A datalogger was re-installed in Rooms 107 and 108 to study unit ventilator operatic longer time period while the school is occupied. Continuous data being collected include: radc room to subslab differential pressure, unit ventilator damper position, and indoor/outdoor temp

VIRGINIA SCHOOL

This school was constructed in 1987 in an area with a known radon problem. As various steps were taken by designers to reduce the likelihood of elevated levels of indoor ra to facilitate post-construction mitigation if needed. (The construction of this school is coverec in Reference 4.) Initial post-construction charcoal canister measurements were made in Octot in all ground floor classrooms: all measurements were below 2 pCi/L, as shown in Figure 5 measurements were repeated in December 1990, and radon levels were consistently higher: rooms measured 4 pCi/L or higher as shown in Figure 6. Note that levels in the east win school tend to be highest. This is consistent with the higher subslab radon levels measure construction (4).

HVAC System Description

This school has eight air-handling units serving eight zones. The units are designed tc a total of 72,600 cfm with a minimum of 16,010 cfm outdoor air. Total building exhaust i cfm. This design should maintain the building at a positive pressure; however, the HVAC s Variable Air Volume (VAV), and outdoor supply is reduced if the temperature drops below a giv

Results of Initial Measurements

Differential pressure data showed the room to be at a negative pressure relative to the thus the air-handling units were not adequately pressurizing the building as intended. A datalog placed in a conference room December 21, 1990, to collect continuous radon, differential p and temperature data. These results, displayed in Figure 7, show that radon levels are about when the room is at a negative pressure relative to the subslab. Radon levels tend to drop sli the room-to-subslab differential pressure approaches zero.

Future Plans

The datalogger will remain in this school to collect additional continuous data. personnel are also considering installation of an ASD system to reduce radon levels on a c basis. If the ASD system is installed, its effectiveness in reducing radon levels will be compar that of HVAC pressurization.

WASHINGTON SCHOOL

This school has 16 classrooms, a multipurpose room (gym/cafeteria), and several purpose rooms and offices. Eight of the classrooms are built over a crawl space, and the re eight are slab-on-grade.

Several radon measurements were made over all four seasons (spring, summer, fall, and winter) under a number of ventilation conditions using 2-day charcoal canisters, short and long term E-perms, and alpha track detectors. The results of these measurements are to be presented at the 1991 International Symposium on Radon and Radon Reduction Technology in a paper entitled "The Results of EPA's School Protocol Development Study (6)."

Measurements indicated that the eight rooms built over the crawl space did not have elevated radon levels. As a result, research focused on four of the eight slab-on-grade classrooms that had consistently measured above 4 pCi/L. The layout of this part of the school is shown in Figure 8. These classrooms were located in the northwest wing of the school (Rooms 139-142), and the design drawings indicated the presence of aggregate under the slab. This school contained several classrooms additions, and the foundation drawings available were not particularly clear on specific subslab foundation locations. The subslab foundations included both poured concrete footings and thickened slab footings.

There was a utility tunnel located under the slab along the perimeters of the classrooms in each wing. This tunnel was approximately 4 ft wide by 4 ft high with a dirt floor. The walls of the tunnel were of poured concrete and had numerous penetrations leading to the soil. Accesses to the tunnels were in Rooms 140 and 141 in the west section and in Rooms 127 and 128 in the east section. The tunnel contained the steam pipes that connected the boiler with the unit ventilators in each of the rooms.

HVAC System Description

The HVAC system in this school consists of heating-only, three-speed unit ventilators located in each room. Each room had an electronic thermostat that controlled the outdoor air damper and the heating valve in the unit ventilator. Each unit had a low-limit thermostat that shuts off the outdoor air damper when the supply air temperature falls below 60° F. The units appeared to be in excellent working order in Rooms 139-142. Rooms 141 and 142 each have a wind-turbine exhaust ducted to the roof through the storage/coat closets. The turbine for Room 142 was inoperable (not turning) during the investigation, but school maintenance personnel planned to fix it promptly. A passive exhaust was located in Room 140, and there was no exhaust in Room 139 (library).

There was no automatic shutoff of the ventilators, nor was there an automatic temperature setback control. It appeared that each unit fan ran continuously and the unit cabinets and thermostats were inaccessible without special tools (a hex key); thus the fan speeds and temperature settings could not be adjusted by the teachers. The unit ventilator fans could be shut off at the electrical panelboard.

The piping was routed to each unit ventilator through tunnels under the slab, as seen in Figure 8. The return air for the unit ventilator was not isolated from the slab over the tunnel, thus any opening in the slab (e.g., a pipe sleeve, crack) would allow air from the tunnel to enter the unit ventilator and mix with the room air return and outdoor air. A high radon level in the tunnel could be the source of elevated radon levels in the room. Some openings were found around pipe penetrations, and radon levels in the tunnel averaged about 55 to 60 pCi/L.

Results of Initial Measurements

Air flow quantities were measured for each unit ventilator, and static pressure readings (relative to the outdoor pressure) were taken in Rooms 139-142. The readings were taken for the various operating modes of each unit ventilators: 1) unit ventilator off; 2) unit ventilator on low, medium, high fan speed; and 3) unit ventilator with outdoor air damper opened and closed. In addition to these unit ventilator modes of operation, room static pressure was measured with the hallway door opened and closed. The results of the differential pressure and flow measurements are shown in Tables 4 through 7, and the results of the differential pressure measurements are displayed graphically in Figures 9 through 12. These measurements indicate that the optimal operating mode for the reduction c gas infiltration would require the unit ventilator to be on (any speed) with the outdoor air damı the open (or 100%) position, and with the hallway door closed. It appears that no other oper mode, or door position, would allow for pressurization of the room. Only Room 139 (library) cou pressurized with the outdoor air damper in the minimum (roughly 10% open) position, with the ha door closed (probably due to the lack of any exhaust system in the room). With the unit ventilato the outdoor air damper open, and the hallway door closed, pressures in those rooms with wind tu or passive exhausts (140-142) ranged from +0.020 to +0.036 in. WC. These pressures shou adequate to prevent soil gas infiltration into the rooms.

To determine the ability of the unit ventilators to reduce radon levels during normal occup. a datalogger was installed in this school from November 29, 1990, to January 8, 1991. Contir radon levels were measured in Rooms 139, 140, and 141, and in the tunnel. Differential press temperatures, wind speeds and directions, classroom door openings and closings, and unit vent operations were also monitored. These data are currently being analyzed. For a general compar a summary of the data is displayed in Table 8. The results shown in this table were obtained o 2 week period (December 2 through December 15, 1990). During the first week (December 2 thr 8, 1990) the classrooms were operated in a normal manner with the classroom doors into th closed about 75% of the time (note that the doors were usually closed after class and througho weekend). During the second week (December 9 through 15) the teachers were asked to keep classroom doors closed as much as possible during class. As seen in Table 4, the percent of tim doors were closed increased to about 90%. The average radon level was reduced by approxim 50% as a result of the pressurization of the classrooms produced by the unit ventilators.

These data indicate that if the classroom-to-hall doors are kept closed, radon levels ir classrooms can be reduced. The slightly lower levels in Room 139 (the library) are probably due combination of factors including: a lower source strength, no exhaust (passive or turbine), anc library door is closed more frequently than the classroom doors.

Future Plans

Data collected from the datalogger are being analyzed. Depending on the need to kee classroom-to-hall doors closed to achieve adequate mitigation with the unit ventilators, the schoo make a final decision on the mitigation approach.

CONCLUSIONS

The initial data collected in these four schools confirmed that pressurization of classrc (using the HVAC system) reduces average radon levels. Pressurization, however, did not consist reduce the levels to below 4 pCi/L in all the classrooms studied. The schools used in this stud a small sample, but the HVAC systems found in these schools are expected to have a great de common with those installed in most school buildings constructed in the U. S. since the 1950s.

Those buildings with central air handling units are designed to be pressurized. It was fc that modifications to the control systems by owners and deterioration of the system components resulted in these systems no longer operating to pressurize the classrooms. These systems contributing to depressurization of the building interiors, thus increasing the potential for the ent radon-laden soil gas. (In one case, it appears that radon entry into the subslab return air duct is contributing to elevated radon levels in the building.) A change in the control strategy, returning t to original operations, should allow for pressurization of the classrooms and a reduction in radon le However, it should be noted that most control strategies will close outdoor air dampers in cold wea to reduce the likelihood of freezing the heating coil.

Unit ventilators are designed and operated in such a manner that the outdoor air damp modulated based on indoor and supply air temperatures. They were observed in this study to pressurize a classroom but usually only when the classroom door to the hallway was closed and the outdoor air damper was open. This may not be sufficient to reduce radon levels consistently below 4 pCi/L without additional efforts to reduce other negative pressures in the building.

Research in these schools and additional schools over the next year will focus on determining the optimal HVAC system operation for radon reduction. Limitations of HVAC pressurization will also be studied, and in some of the schools HVAC pressurization will be compared with ASD.

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TABLE 1. METRIC CONVERSION FACTORS

Non-Metric	Times	Yields Metric
cubic foot per minute (cfm)	0.47	liter per second (L/s)
degree Fahrenheit (°F)	5/9 (°F-32)	degrees Centigrade (°C)
foot (ft)	0.305	meter (m)
inch (in.)	2.54	centimeters (cm)
inch of water column (in. WC)	248	pascals (Pa)
picocurie per liter (pCi/L)	37	becquerels per cubic meter (Bq/m^3)
square foot (sq ft)	0.093	square meter (m^2)
square inch (sq in.)	0.00065	square meter (m^2)

TABLE 2. SUMMARY OF SCHOOLS*

State	Approximate Size of Area Under Study sq ft	HVAC	Initial Radon Levels pCi/L
Colorado	29,000	central	5-12
Maryland	3,500	unit ventilators	14-20
Virginia	1,200	central	2-7
Washington	5,000	unit ventilators	3-21

* Substructure of all schools is slab-on-grade.

TABLE 3. E-PERM MEASUREMENTS IN COLORADO SCHOOLS 1 AND 2

		Radon Levels, pCi/L				
		Classrooms		Boiler Room		Return Air
Dates	Outdoor Air Damper	1	2	1	2	1
Dec 21-26	closed	10.8	2.9	2.5	2.6	13.5
Dec 27-31	open in 2 open & closed in 1	7.0	2.5	3.5	2.0	14.6
Jan 1-2	open in 1	4.6	-	2.5	-	7.5

TABLE 4. DIFFERENTIAL PRESSURE AND FLOW MEASUREMENTS IN ROOM 139

DATA TAKEN: August 22, 1990

DIFFERENTIAL PRESSURE MEASUREMENTS, ROOM TO OUTDOORS (in. WC)

Room-to-Hall Door Closed

Outdoor Air Damper Position	Unit Ventilator Speed Setting: Off	Low	Medium	High
Open (100%)	-0.001	0.053	0.054	0.056
Closed (10% open)	-0.001	0.01	0.009	-0.012

Room-to-Hall Door Open

Outdoor Air Damper Position	Off	Low	Medium	High
Open (100%)	-0.001	-0.001	-0.001	0
Closed (10% open)	-0.001	-0.002	-0.003	-0.001

AIR QUANTITY MEASUREMENT (cfm)

Outdoor Air Damper Position	Low	Medium	High
Open (100%)			
Outdoor Air	460	470	500
Supply Air	1175	1306	1285
Closed (10% Open)			
Outdoor Air	30	47	109
Supply Air	N/A	N/A	N/A
Percent Outdoor Air			
Outdoor Air Damper Open	39%	36%	39%
Outdoor Air Damper Closed	3%	4%	8%
Outdoor Air Per Student (cfm - Based on 20 Students)			
Outdoor Air Damper Open	23	24	25
Outdoor Air Damper Closed	2	2	5

Avg Leak Area (in.^{2}) = 73.2

OBSERVATIONS: Room 139 (Library) could be pressurized with the unit ventilator, regardless of the outdoor air damper position, but only when the room-to-hall door was closed. It does not have an exhaust vent like the other rooms, thus it is easier to pressurize.

TABLE 5. DIFFERENTIAL PRESSURE AND FLOW MEASUREMENTS IN ROOM 140

DATA TAKEN: August 22, 1990

DIFFERENTIAL PRESSURE MEASUREMENTS, ROOM TO OUTDOORS (in. WC)

Room-to-Hall Door Closed

Outdoor Air Damper Position	Unit Ventilator Speed Setting: Off	Low	Medium	High
Open (100%)	0	0.02	0.021	0.024
Closed (10% open)	0	-0.002	-0.001	-0.002

Room-to-Hall Door Open

Outdoor Air Damper Position	Off	Low	Medium	High
Open (100%)	0.001	0	-0.003	-0.001
Closed (10% open)	0.001	-0.004	-0.002	-0.008

AIR QUANTITY MEASUREMENT (cfm)

Outdoor Air Damper Position	Low	Medium	High
Open (100%)			
Outdoor Air	361	438	449
Supply Air	1200	1263	1380
Closed (10% Open)			
Outdoor Air	45	23	44
Supply Air	1090	1135	1197
Percent Outdoor Air			
Outdoor Air Damper Open	30%	35%	33%
Outdoor Air Damper Closed	4%	2%	4%
Outdoor Air Per Student (cfm - Based on 20 Students)			
Outdoor Air Damper Open	18	22	22
Outdoor Air Damper Closed	2	1	2

Avg Leak Area (in.^{2}) = 101.1

OBSERVATIONS: Room 140 could be pressurized with the unit ventilator, only with the outdoor air damper in the fully open position, and the room-to-hall door closed. This room has a passive vent and is more difficult to pressurize.

TABLE 6. DIFFERENTIAL PRESSURE AND FLOW MEASUREMENTS IN ROOM 141

DATA TAKEN: August 22, 1990

DIFFERENTIAL PRESSURE MEASUREMENTS, ROOM TO OUTDOORS (in. WC)

Room-to-Hall Door Closed

Outdoor Air Damper Position	Unit Ventilator Speed Setting: Off	Low	Medium	High
Open (100%)	0	0.03	0.034	0.036
Closed (10% open)	-0.003	-0.002	-0.002	-0.003

Room-to-Hall Door Open

Outdoor Air Damper Position	Off	Low	Medium	High
Open (100%)	-0.002	-0.005	-0.001	-0.001
Closed (10% open)	-0.002	-0.002	-0.003	-0.003

AIR QUANTITY MEASUREMENT (cfm)

Outdoor Air Damper Position	Low	Medium	High
Open (100%)			
Outdoor Air	495	580	657
Supply Air	1001	1097	1160
Closed (10% Open)			
Outdoor Air	72	87	94
Supply Air	N/A	N/A	N/A
Percent Outdoor Air			
Outdoor Air Damper Open	49%	53%	57%
Outdoor Air Damper Closed	7%	8%	8%
Outdoor Air Per Student (cfm - Based on 20 Students)			
Outdoor Air Damper Open	25	29	33
Outdoor Air Damper Closed	4	4	5

Avg Leak Area (in.^{2}) = 113.0

OBSERVATIONS: Room 141 could be pressurized with the unit ventilator, only with the outdoor air damper in the fully open position, and the room-to-hall door closed. This room has a wind turbine exhaust and is more difficult to pressurize.

TABLE 7. DIFFERENTIAL PRESSURE AND FLOW MEASUREMENTS IN ROOM 142

DATA TAKEN: August 22, 1990

DIFFERENTIAL PRESSURE MEASUREMENTS, ROOM TO OUTDOORS (in. WC)

Room-to-Hall Door Closed

Outdoor Air Damper Position	Unit Ventilator Speed Setting: Off	Low	Medium	High
Open (100%)	0	0.03	0.034	0.036
Closed (10% open)	-0.003	-0.002	-0.001	-0.003

Room-to-Hall Door Open

Outdoor Air Damper Position	Off	Low	Medium	High
Open (100%)	-0.002	-0.005	-0.001	-0.001
Closed (10% open)	-0.002	-0.002	-0.003	-0.003

AIR QUANTITY MEASUREMENT (cfm)

Outdoor Air Damper Position	Low	Medium	High
Open (100%)			
Outdoor Air	266	230	251
Supply Air	1123	1218	1362
Closed (10% Open)			
Outdoor Air	150	160	184
Supply Air	1078	1250	1306
Percent Outdoor Air			
Outdoor Air Damper Open	20%	19%	18%
Outdoor Air Damper Closed	14%	13%	14%
Outdoor Air Per Student (cfm - Based on 20 Students)			
Outdoor Air Damper Open	11	12	13
Outdoor Air Damper Closed	8	8	9

Avg Leak Area (in.^{2}) = 46.2

OBSERVATIONS: Room 142 could be pressurized with the unit ventilator, only with the outdc air damper in the fully open position, and the room-to-hall door closed. T. room has a wind turbine exhaust vent and is more difficult to pressur although the turbine was inoperable during these measurements. The outdc air damper appears not to open fully.

TABLE 8. AVERAGE RADON LEVELS IN WASHINGTON SCHOOL DURING 1 WEEK OF NORMAL OPERATION AND 1 WEEK OF TESTING OPERATION

Location*	Normal Operation Average Radon (max) (pCi/L)	Normal Operation Persent Time Door Closed (%)	Test Operation Average Radon (max) (pCi/L)	Test Operation Persent Time Door Closed (%)	Subslab Radon Sniff Measurement (Aug. 1990) (pCi/L)
Room 139	2.6 (26.7)	76	1.4 (16.5)	97	400
Room 140	5.3 (29.2)	74	3.2 (7.4)	92	500
Room 141	4.5 (32.1)	75	2.2 (25.0)	88	700
Average	4.1	75	2.3	92	533
Tunnel	55.6 (202.8)		60.8 (129.2)		N/A

* Data for Room 142 not available; Pylon inadvertently "unplugged."

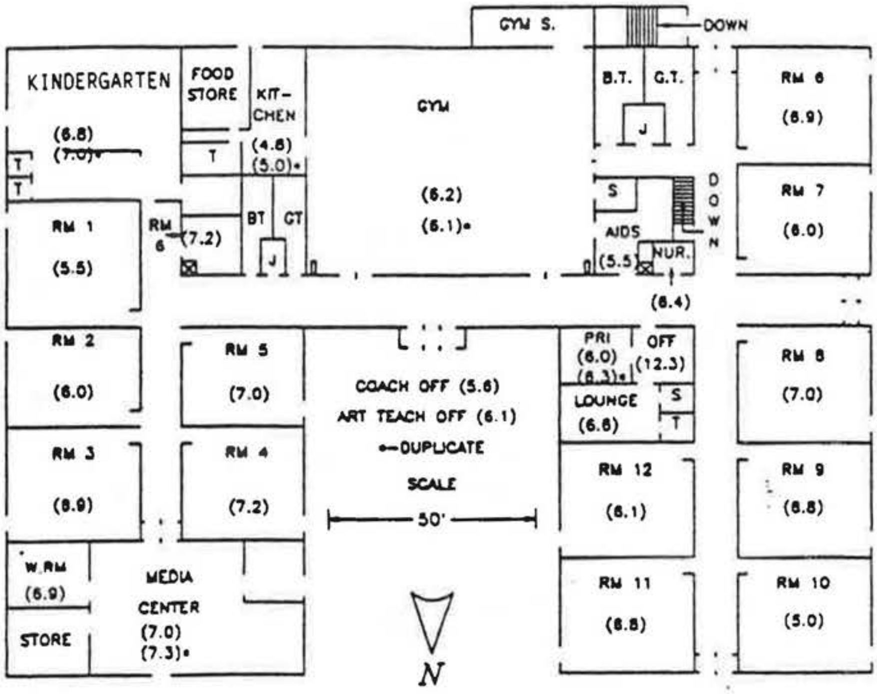

Figure 1. Results of January 1990 radon measurements in Colorado school, pCi/L.

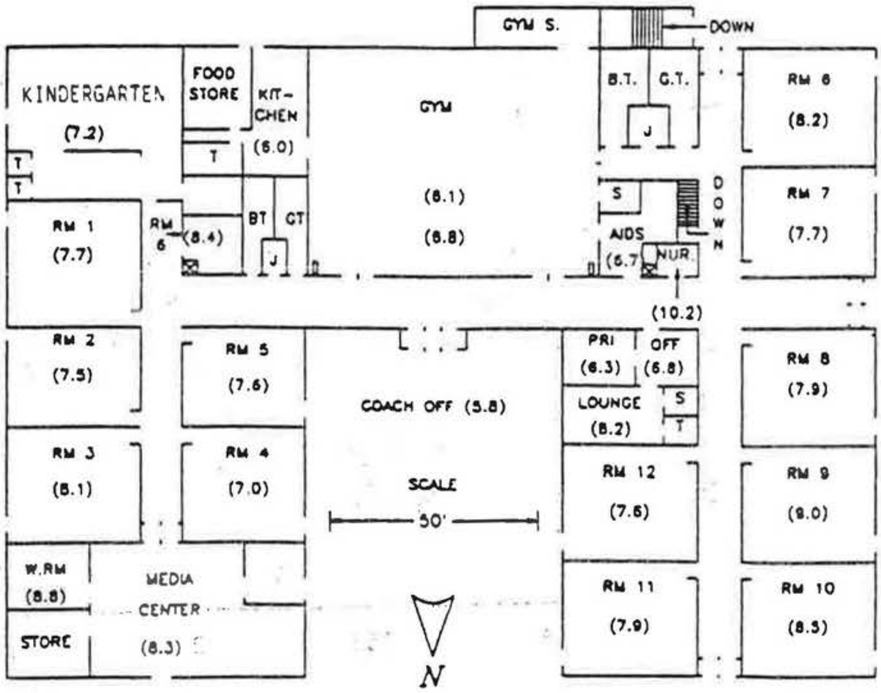

Figure 2. Results of February 1990 radon measurements in Colorado school, pCi/L

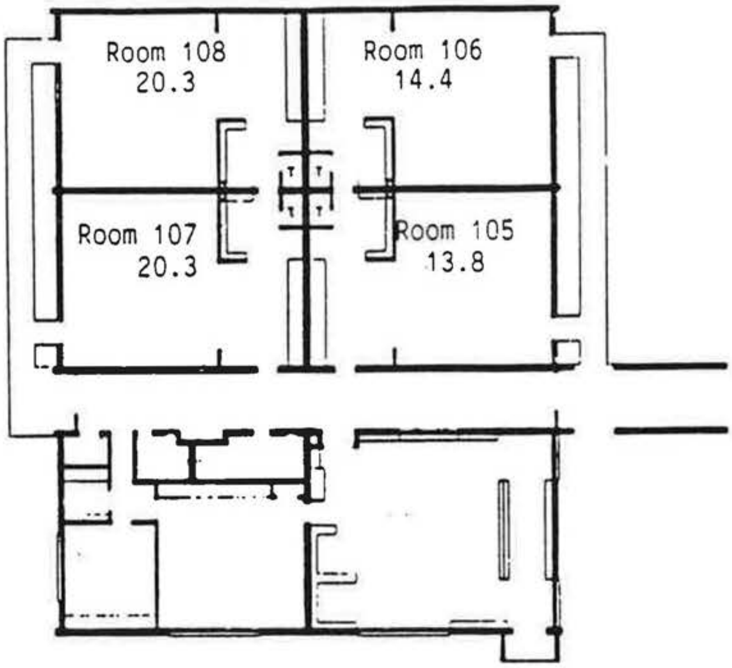

Figure 3. Results of initial radon measurements in wing of Maryland school, pCi/L.

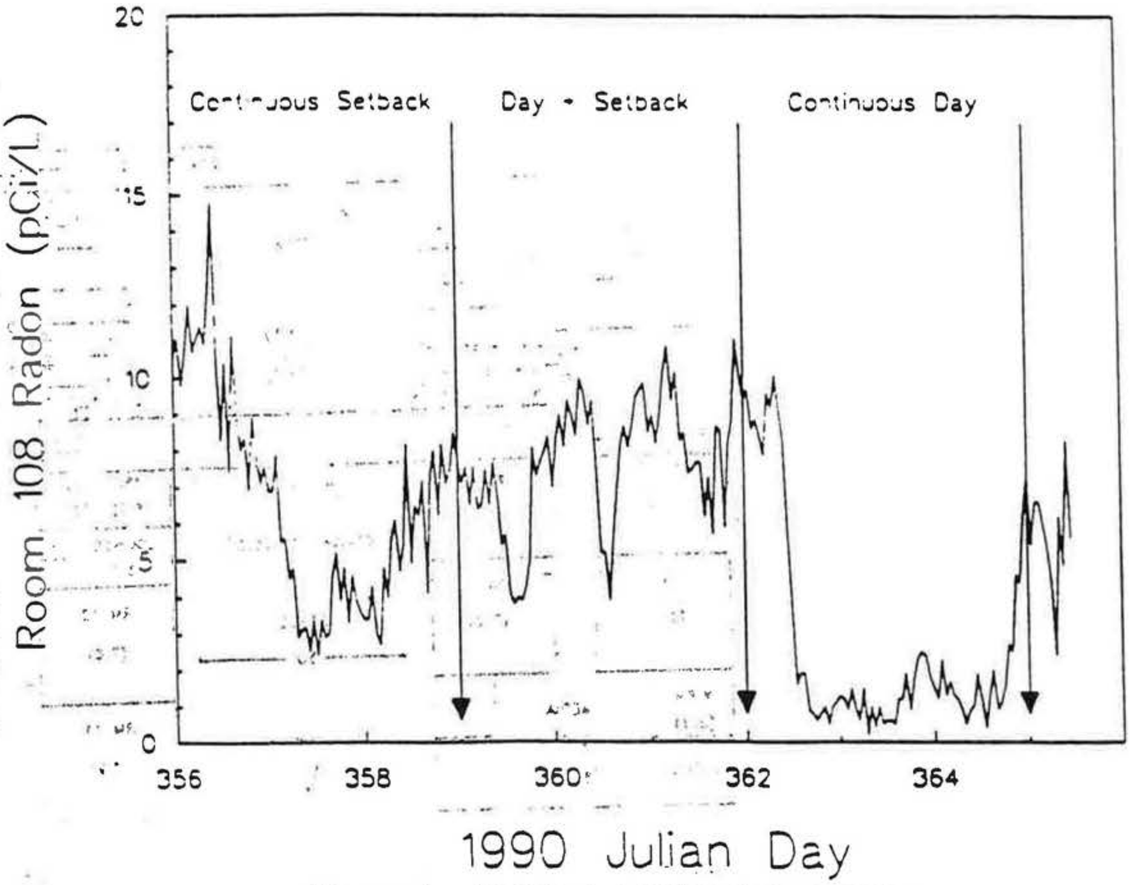

Figure 4. Continuous radon measurements in Maryland school.

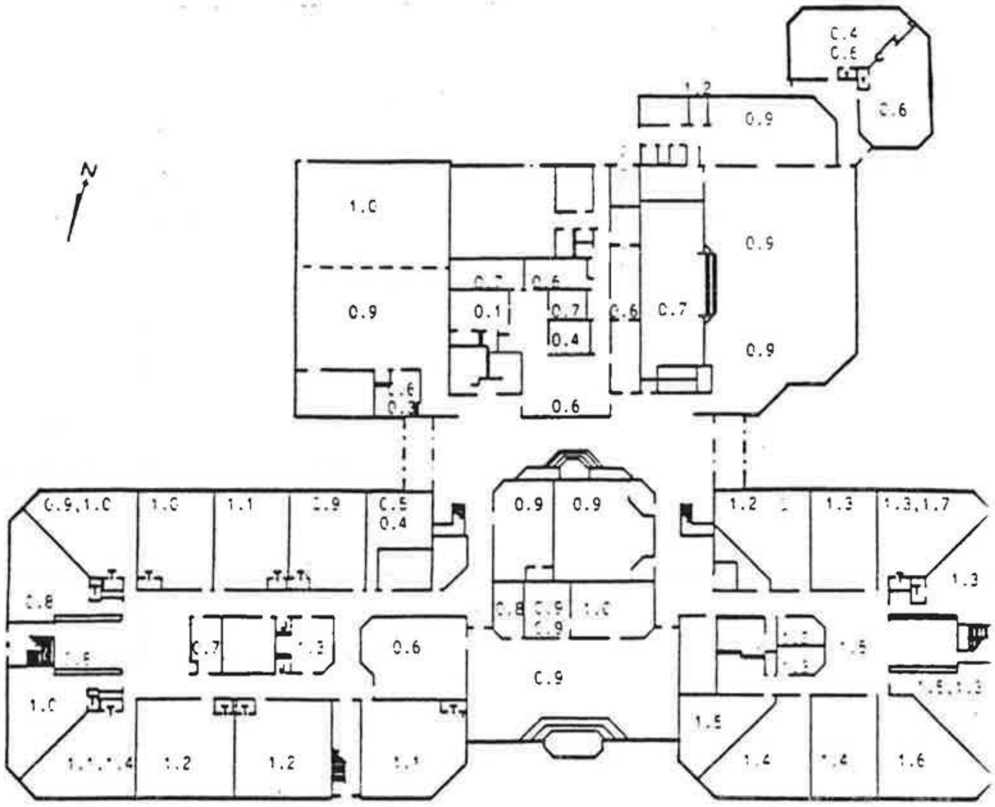

Figure 5. Results of October 1988 radon measurements in Virginia school, pC

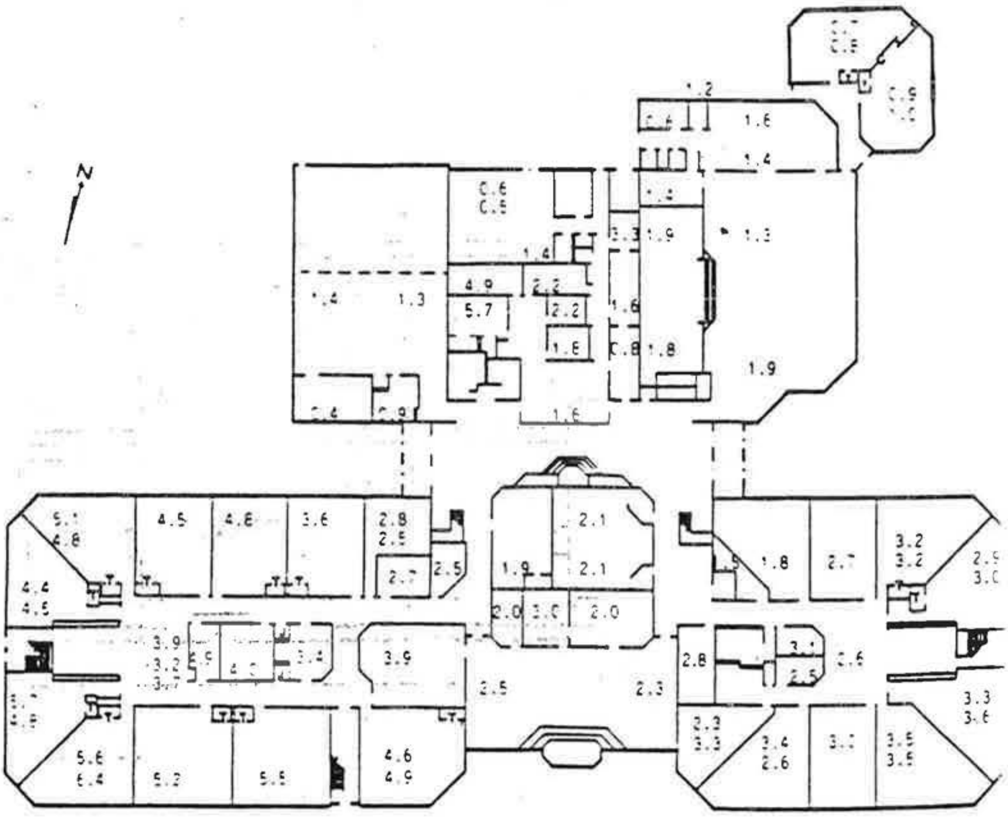

Figure 6. Results of December 1990 radon measurements in Virginia school, pC

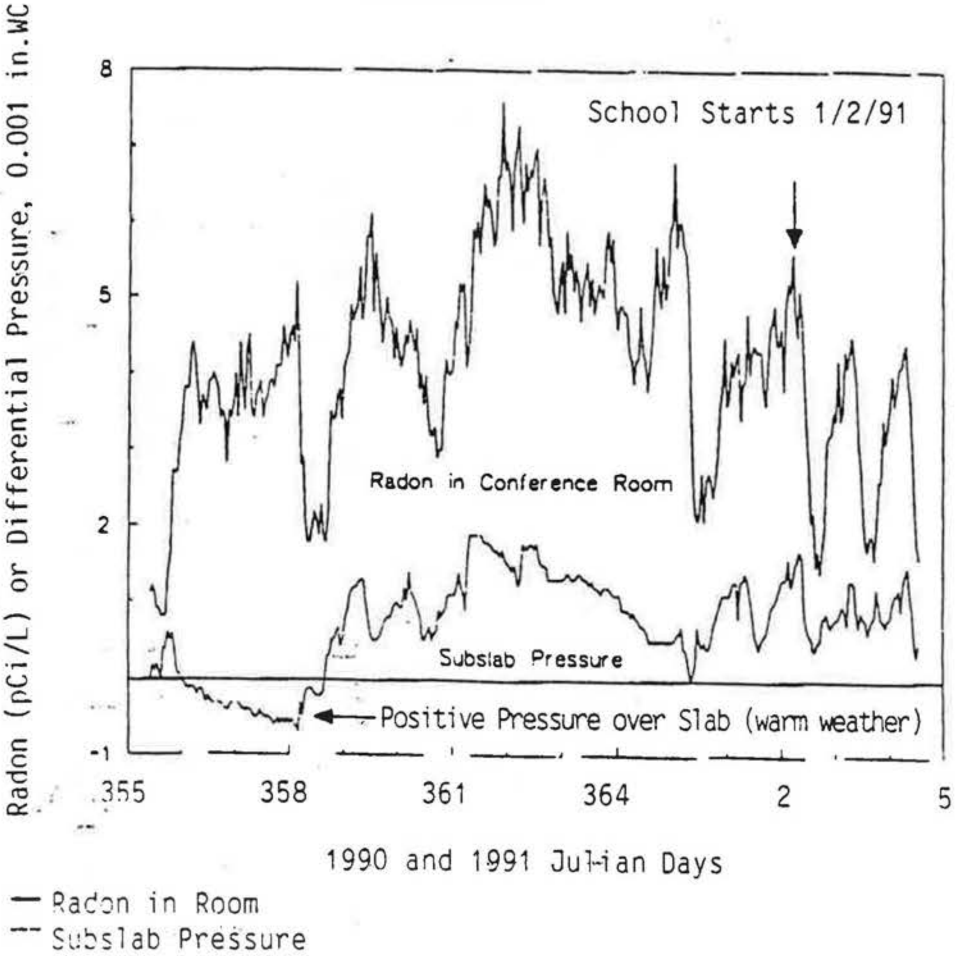

Figure 7. Continuous radon and differential pressure in Virginia school.

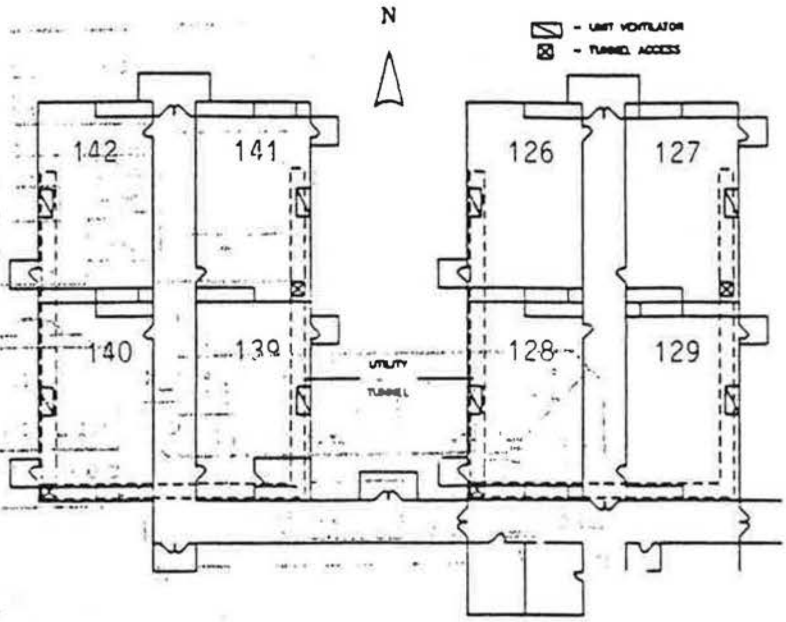

Figure 8. Partial floorplan showing utility tunnel and room locations in Washington school.

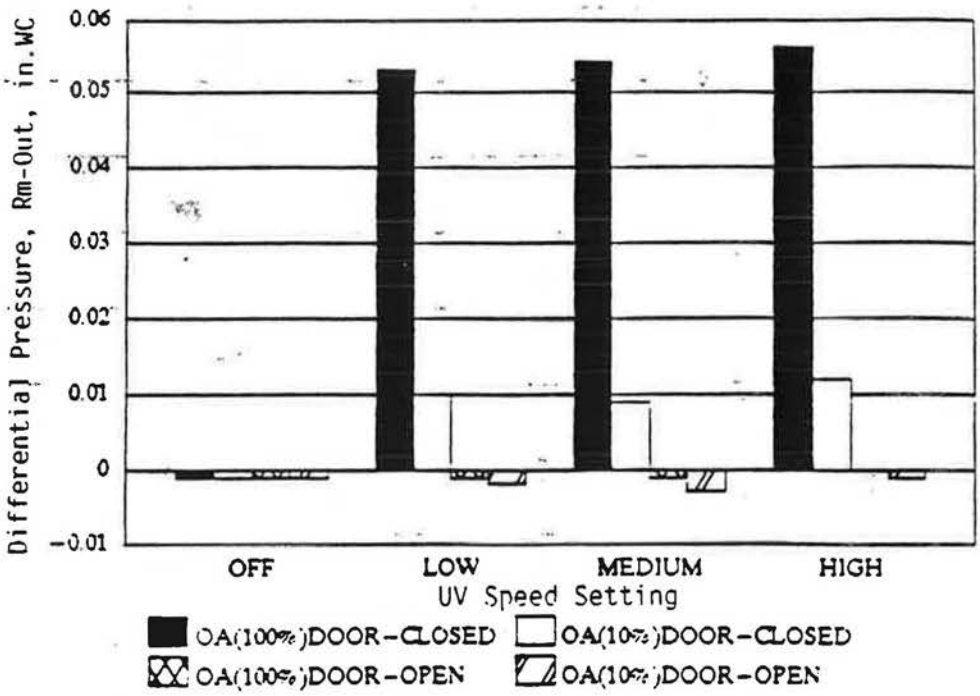

Figure 9. Differential pressure measurements in Room 139, August 1990.

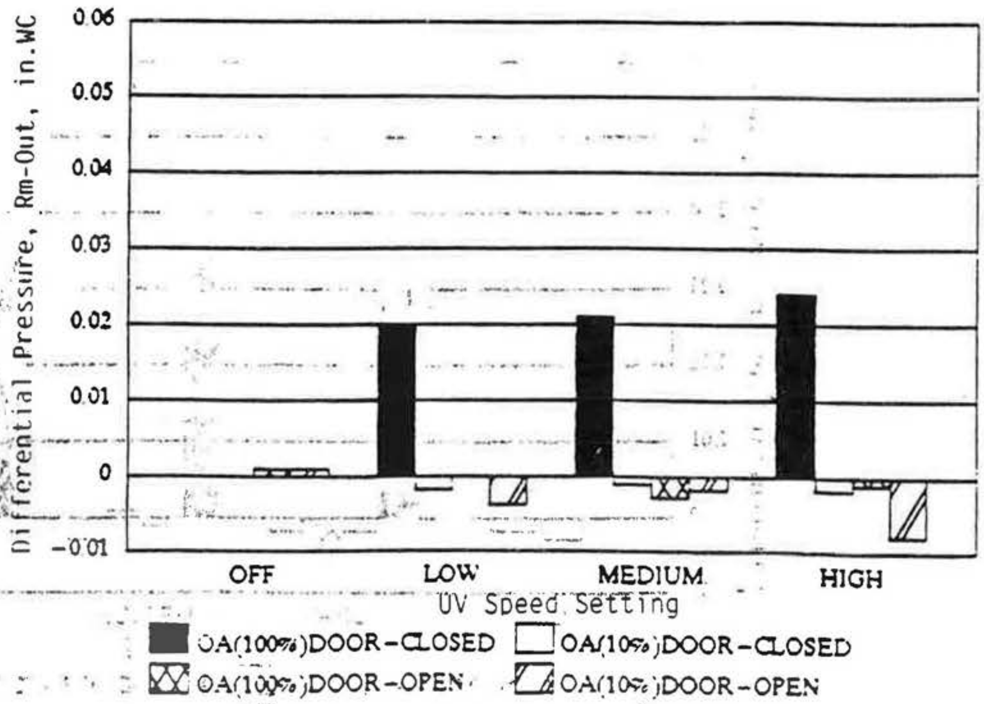

Figure 10. Differential pressure measurements in Room 140, August 1990.

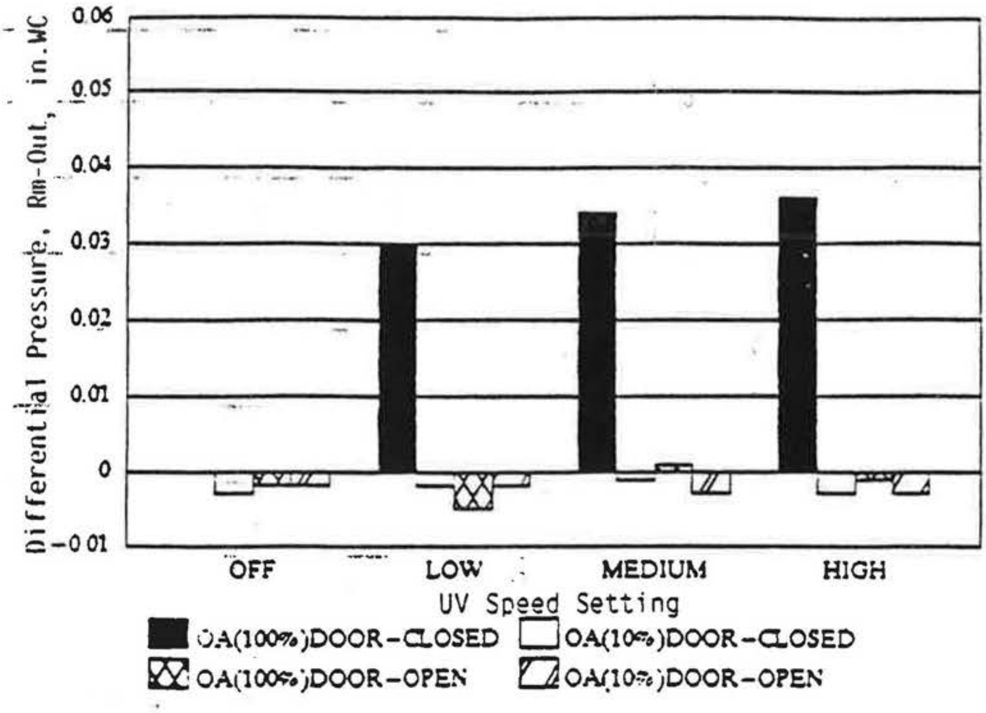

Figure 11. Differential pressure measurements in Room 141, August 1990.

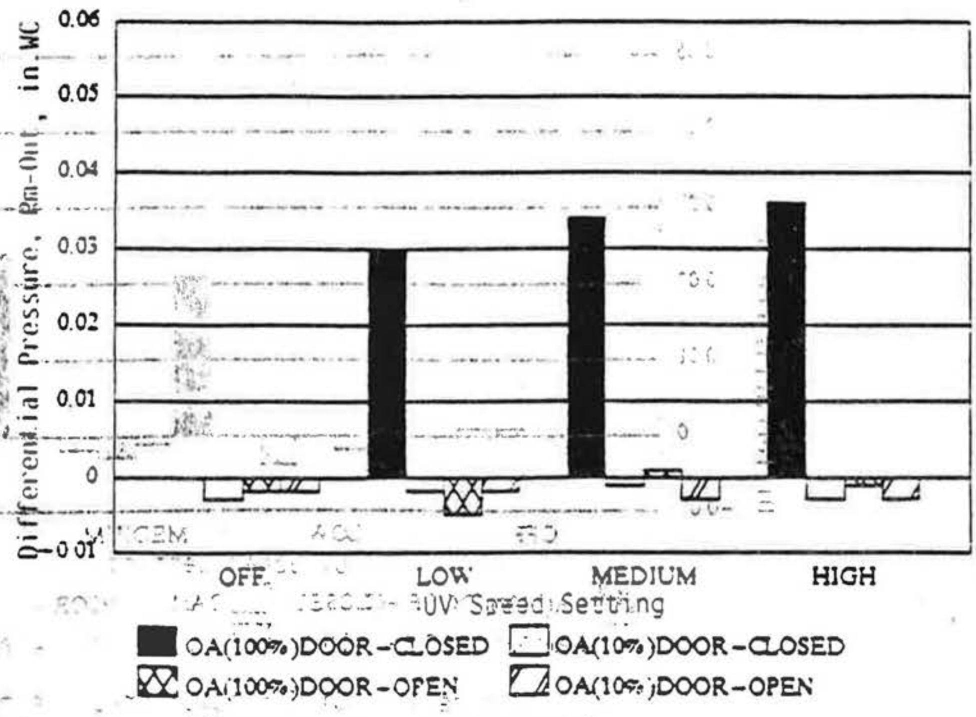

Figure 12. Differential pressure measurements in Room 142, August 1990.