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DESIGN AND APPLICATION OF ACTIVE SOIL DEPRESSURIZATION (ASD) SYSTEMS IN SCHOOL BUILDINGS

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ABSTRACT

During 1990, building investigations and subslab pressure field extension (PFE) measurements were made by the U.S. Environmental Protection Agency's (EPA) Air and Energy Engineering Research Laboratory (AEERL) in several school buildings located in Colorado, Kentucky, Maine, and Washington. The recommended ASD system design for each school was based on the construction characteristics of each building including: subslab material and fan selection, subslab barriers (i.e., footings), utility tunnels, active vs. passive soil depressurization, and interior vs. exterior suction points.

These school research projects, together with previous mitigation research by the authors in nearly 40 schools over the past few years, are discussed in terms of the influences that various building construction features have on the design of the ASD system. Specific examples and data for recent or on-going research projects in Kentucky and Maine are presented.

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

INTRODUCTION

School characteristics that influence radon entry and subsequent mitigation have been discussed in previous papers on radon diagnostics and mitigation in schools (1,2,3,4,5). The purpose of this paper is to detail the effects of some of the more significant school construction characteristics and how these characteristics can influence designs of ASD systems. The ASD systems designs should be applicable for other schools with similar characteristics.

The school building construction characteristics discussed in this paper include: subslab materials and fan selection, subslab barriers (i.e., footings), utility tunnels, active vs. passive subslab depressurization systems, and interior vs. exterior suction points. Following a general discussion of how each building characteristic can affect ASD system design, specific examples and data from recent or on-going research in Kentucky and Maine schools are presented. Conversion factors are displayed in Table 1.

This paper focuses on radon mitigation with ASD systems rather than radon reduction through heating, ventilating, and air conditioning (HVAC) system pressurization and/or dilution. The authors recognize that for acceptable indoor air quality a minimum of 15 cfm of outdoor per person should be delivered to occupied classrooms according to ASHRAE guidelines (6); however, many schools are not designed and/or operated to provide adequate conditioned outdoor air for pressurization or ventilation and, as a result, reduction of radon levels using an HVAC system is not a current option without an extensive (and expensive) retrofit. Although it is strongly recommended that such schools take the necessary steps to meet minimum ASHRAE indoor air quality guidelines as soon as possible, installation of a properly designed and operated ASD system will reduce radon levels in many schools at a relatively low cost (5).

SUBSLAB MATERIAL AND FAN SELECTION

Initial experience with radon mitigation in schools has indicated that in schools with at least 4 in. of clean, coarse subslab aggregate (at least 0.75 in. in diameter with few fines) the ASD system normally requires larger fans and pipe sizes than typical ASD systems in houses because of the greater air flow through the aggregate (2). However, many schools do not have subslab aggregate and the slab may be poured over a tightly packed material such as sand or clay.

Example - Maine School

In one school currently being researched by the EPA in Maine, a multi-point ASD system was installed with both a conventional radon mitigation fan and a high vacuum fan to make direct performance evaluations between the two fans. This 1968 addition to the existing school is slab-on-grade construction with radiators for heating and an exhaust fan for ventilation. No conditioned outdoor air is provided to any classroom in this wing.

The wing being researched has seven classrooms, a library, and a multi-purpose room with a storage area. Suction points were installed in four of the seven classrooms, and two points were installed in the library. (The multi-purpose room has a separate ASD system.) All six suction points and overhead piping for the classroom and library ASD system are 4 in. diameter PVC piping and are manifolded overhead in the dropped ceiling. A suction pit (approximately 1 ft deep and 2 to 3 ft in width) was excavated at each point. The two fans were installed near an outside door. One fan is a standard radon mitigation fan (0 in. WC at 520 cfm and 1 in. WC at 230 cfm) and the other fan is a high pressure, low flow fan (30 in. WC at 0 cfm and approximately 5 in. WC at 30 cfm) being evaluated for its applicability in low permeability soils.

Data were collected from late November 1990 through mid-January 1991 while the high suction fan was in operation. The suction pressure of the fan was varied to determine the effect on radon levels. Continuous radon levels were measured in each of the seven classrooms by State of Maine Indoor Air Program employees using Honeywell Model A9000A monitors. Figure 1 displays the results of the average radon levels in each classroom under the following conditions: 1) ASD fan off, 2) fan at 1 in. WC, 3) fan at 2 in. WC, and 4) fan at 4.5 to 5 in. WC. The results show that fan suction pressures of 1 and 2 in. WC are not sufficient to reduce radon levels in these rooms. In fact, in some of the classrooms levels are slightly higher with the fan operating at 1 or 2 in. WC than with the fan off. These increases in radon levels are likely attributed to typical variations in radon rather than any detrimental effects caused by operating the fan at low suction pressures.

The data for all seven classrooms in the wing are averaged in Figure 2 for each of the four fan suctions. Radon levels averaged approximately 7 pCi/L with the ASD fan off and with the fan at 1 and 2 in. WC. indicating little, if any, change in the three conditions. Adjusting the fan to increase suction to 4.5 to 5 in. WC decreased average radon levels in the seven classrooms to below 3 pCi/L.

A datalogger was installed in this school in January 1991 to collect continuous radon, differential pressure, and temperature data for each of the fans. These data will be part of a long-term research project that will compare different mitigation techniques in all three wings of this school.

SUBSLAB BARRIERS

Subslab barriers, such as below grade footings, can increase the cost and complexity of ASD systems. PFE measurements in schools have indicated that in many instances one suction point will be required for each area surrounded by below-grade subslab footings. If the school has relatively permeable subslab material, it may be possible to reach across one subslab barrier. The PFE will need to be determined on a case by case basis for each school (or school design if more than one school is constructed from a set of plans). The different types of subslab barriers and their effects on subslab PFE are discussed thoroughly in Craig's paper to be presented at this Symposium (7).

UTILITY TUNNELS

In many slab-on-grade schools, utility lines are located below the slab in utility tunnels that typically run parallel to the corridor either down the center of the corridor or along the perimeter wall of the classrooms. These tunnels vary in size from about 1 ft wide and 0.5 ft deep to 5 ft wide and 5 ft deep (to allow entry by maintenance workers). These tunnels may or may not have poured concrete floors, and even tunnels with concrete floors typically have many openings to the soil. In many classrooms with unit ventilators or fan coil units, the piping from the utility tunnel penetrates the slab under the unit creating a radon entry route around each penetration. Limited studies have looked at utility tunnel depressurization for reducing radon levels in the classrooms above (8). Since utility tunnels are very common in slab-on-grade schools, depressurization of the tunnels could present a relatively easy and inexpensive mitigation technique if no friable asbestos is present in the tunnel (because of increased air movement), the tunnel contributes to elevated radon levels in the room, and the tunnel is not too leaky.

Example - Kentucky School

This Kentucky school is slab-on-grade construction with the utility lines in the wing under study located in a relatively small tunnel that runs along the perimeter wall on each side of the corridor. Pipes from the tunnel connect to the wall-mounted unit ventilators in each classroom. PFE across the corridor is poor since below grade footings are present along the corridor under each of the interior walls. The soil under the slab is a reddish brown clay with some rock fragments. Subslab sniffs with a Pylon AB-5 monitor showed a wide range of levels from below 1000 to over 9000 pCi/L. The subslab radon levels in the four rooms of interest averaged about 4000 pCi/L. A radon sniff measurement in one of the tunnels was about 1000 pCi/L.

During the building investigation it was noted that there was an access to the utility tunnel outdoors on one side of the corridor. It was determined that, if depressurization of this tunnel from the outdoors could reach into the four classrooms serviced by the utility lines on this side of the corridor, this would be a relatively easy and inexpensive radon mitigation technique. (No asbestos was present in tunnel.) School maintenance personnel covered the tunnel access with a sheet of plywood and attached a mitigation fan to depressurize the tunnel.

The results of the subslab to classroom pressure differentials are presented in Table 2. As seen by the negative pressures measured in the middle of three of the four rooms, this tunnel depressurization system was a very simple and effective means of creating a negative pressure under the slab.

Pre-mitigation radon levels in the four classrooms affected by the tunnel depressurization averaged 5.3 pCi/L in June 1990, and with the tunnel depressurization fan operating, levels in August 1990 averaged 1.8 pCi/L. Since data from school personnel indicate that this school tends to have higher radon levels in winter than summer, these measurements were repeated in January and February of 1991.

This school is an example of how a very simple and inexpensive approach can sometimes be effective in reducing radon levels depending on building design. The material costs for this system were approximately $300 and approximately 10 labor hours were required. A standard one-point ASD system installed in another wing of the school covered three classrooms and cost $500 in materials and required about 30 labor hours, not including diagnostics.

ACTIVE VS. PASSIVE SOIL DEPRESSURIZATION SYSTEMS

Research of passive soil depressurization (PSD) in schools is limited. Since there can be significant negative pressures to overcome from building exhausts and the stack effect, experience suggests that active systems are preferred to passive systems in existing schools.

Example - Maine School

An ASD system was installed in the basement of a three-story wing of a Maine school. Each floor of this wing is about 3000 sq ft in area, and the basement is about 4 ft below grade. No building design drawings were available to provide information on subslab fill or footings although excavation of the suction pits indicated that the material under the slab is mostly fine-grained sand. The basement contains occupied classrooms, and in the 1000 sq ft area affected by the ASD system, HVAC is provided by ceiling mounted unit ventilators. Inspection of the unit ventilators indicated that they were not operated to bring in outdoor air. A vertical ventilation shaft runs from the basement to the roof and is a likely contributor to the stack effect in this three-story building. It was thought that this building might present a good opportunity to compare PSD and ASD because of the building height.

Subslab PFE measurements made in the basement with the ASD fan on and off. Subslab pressures were measured at the 2 suction points, and at 11 test holes distributed throughout an area of about 1000 sq ft. As seen in Figure 3 and Table 3, although negative subslab pressures can be achieved at the suction points with PSD, this negative pressure does not extend to any of the test holes within the 1000 sq ft area. When the fan is activated (to pressures of about -2.5 in. WC at the suction points) the negative pressure field extends throughout the area to points that were positive with PSD.

PSD needs merit further study in new schools where it is known that the slab is underlain with a layer of clean, coarse aggregate; however, these results, together with previous experience in house mitigation, indicate that its applicably will be very limited in existing schools. Because of the reliability and effectiveness of ASD in consistently reducing elevated radon levels (even when negative pressures in the building are caused by building exhausts and the stack effect) it is recommended over PSD in existing schools.

INTERIOR VS. EXTERIOR SUCTION POINTS

Radon mitigation research in slab-on-grade houses in Ohio has shown generally comparable results for ASD points placed inside the house and exterior to the house; however, it was found that interior points were preferable in the larger houses (9). Evaluation and comparison of PFE results in schools with both interior and exterior ASD points is limited. In schools where accessibility to the classroom interior is limited (e.g., due to chalkboards), placement of exterior ASD points needs to be investigated for effectiveness.

Example - Kentucky School

In another wing of the Kentucky school discussed above (in Utility Tunnels section) suction was applied in a teachers' lounge that was located between two classrooms (Nos. 2 and 3). The results of PFE measurements in classrooms 2 and 3 are shown in Table 4. Results indicated that PFE was relatively good. To compare these PFE results with suction applied from the exterior, a hole was drilled from the exterior of Room 3 to the subslab area. With suction applied at this exterior point, no effect was apparent at the test hole located in Room 3, compared to a pressure of -0.016 in. WC when suction was applied to the interior point. As a result, school officials chose to install an interior ASD point in the teachers' lounge to mitigate Rooms 2 and 3 and the teachers' lounge.

Pre-mitigation radon levels in Rooms 2 and 3 and the teachers' lounge averaged 8.2 pCi/L in June 1990. With the ASD system operating, levels in August 1990 averaged 1.3 pCi/L in Rooms 2 and 3. (No data are available for the teachers' lounge.) These measurements were repeated in January and February 1991.

The comparison of PFE for interior and exterior suction points in this school indicates that interior suction produces a much more effective pressure field under the slab. The area of the three rooms is approximately 2100 sq ft (the size of a large house) so these results are somewhat consistent with previous house data (9).

Future research should repeat these measurements in additional school buildings, particularly in those with clean, coarse aggregate under the slab.

CONCLUSIONS

1. In the Maine school with low permeability material (sand) under the slab, a higher suction fan was required in order to adequately depressurize the subslab area and reduce radon levels.

2. Results from the Kentucky school show that utility tunnel depressurization may be an effective and relatively inexpensive technique for reducing elevated radon levels if the tunnel does not contain asbestos, is a contributor to elevated indoor radon levels, and is not too leaky.

3. Since there can be significant negative pressures to overcome from building exhausts and the stack effect, previous experience and the measurements in the Maine school suggest that active subslab depressurization systems are typically preferred to passive systems in existing schools.

4. In the Kentucky School studied, PFE was greater when suction was applied to an interior point rather than from the building exterior. Interior vs. exterior PFE should be researched in additional schools, especially those with clean, coarse subslab aggregate.

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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)
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)

TABLE 2. SUBSLAB PRESSURES WITH TUNNEL FAN OFF AND ON

Location,date	Distance (ft)	Fan Off (in. WC)	Fan On (in. WC)
Pit at Fan Base,6/90	0	-0.007	-0.750
Center Room 19,6/90	15	-0.001	-0.045
Center Room 17,6/90	45	0.000	-0.028
Center Room 19,7/90	15	-0.001	-0.030
Center Room 14,7/90	105	0.000	-0.003

Subslab pressures were not measured in Room 15 (located between Rooms 14 and 17).

TABLE 3. SUBSLAB PRESSURES WITH ASD FAN OFF AND ON

Location	Fan Off (in. WC)	Fan On (in. WC)
Suction Point 1	-0.010	-2.53
Suction Point 2	-0.012	-2.52
Test Point Fb	0.012	-0.010
Test Point Fc	0.009	-0.038
Test Point Fd	0.003	-0.019
Test Point Fe	0.005	-0.015
Test Point Ff	0.001	-0.005
Test Point Fg	0.002	-0.005
Test Point Fh	0.006	-0.017
Test Point Fi	0.002	-0.339
Test Point Fj	0.005	-0.016
Test Point Fk	0.003	-0.024
Test Point Fm	0.000	-0.156

TABLE 4. PFE MEASUREMENTS FROM SCHOOL INTERIOR

Location	Suction Off (in. WC)	Suction On (in. WC)*
Room 2	-0.002	-0.010
Room 3	-0.000	-0.016

* Suction applied in teachers' lounge located between Rooms 2 and 3.

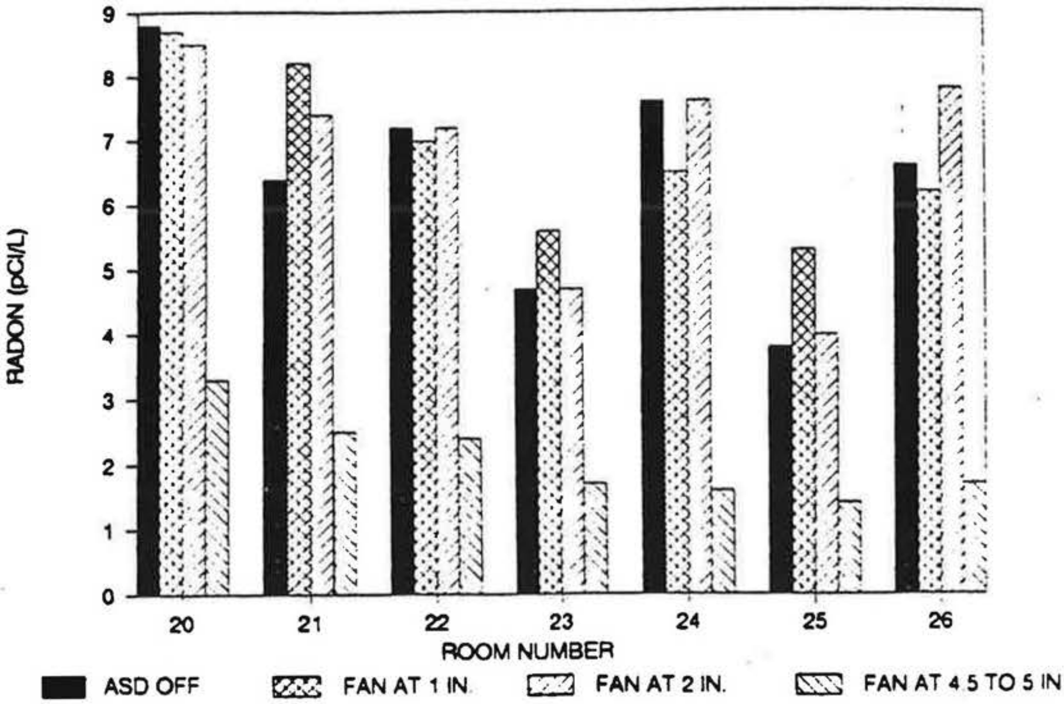

FIGURE 1. Comparison of radon levels at various fan pressures.

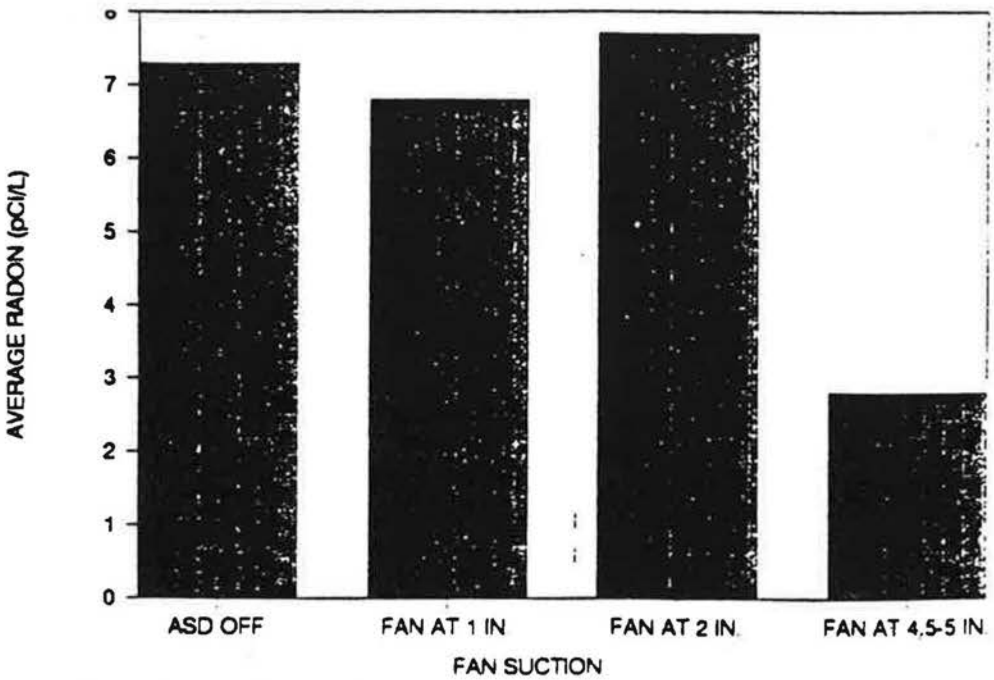

FIGURE 2. Comparison of average radon levels at various fan pressures.

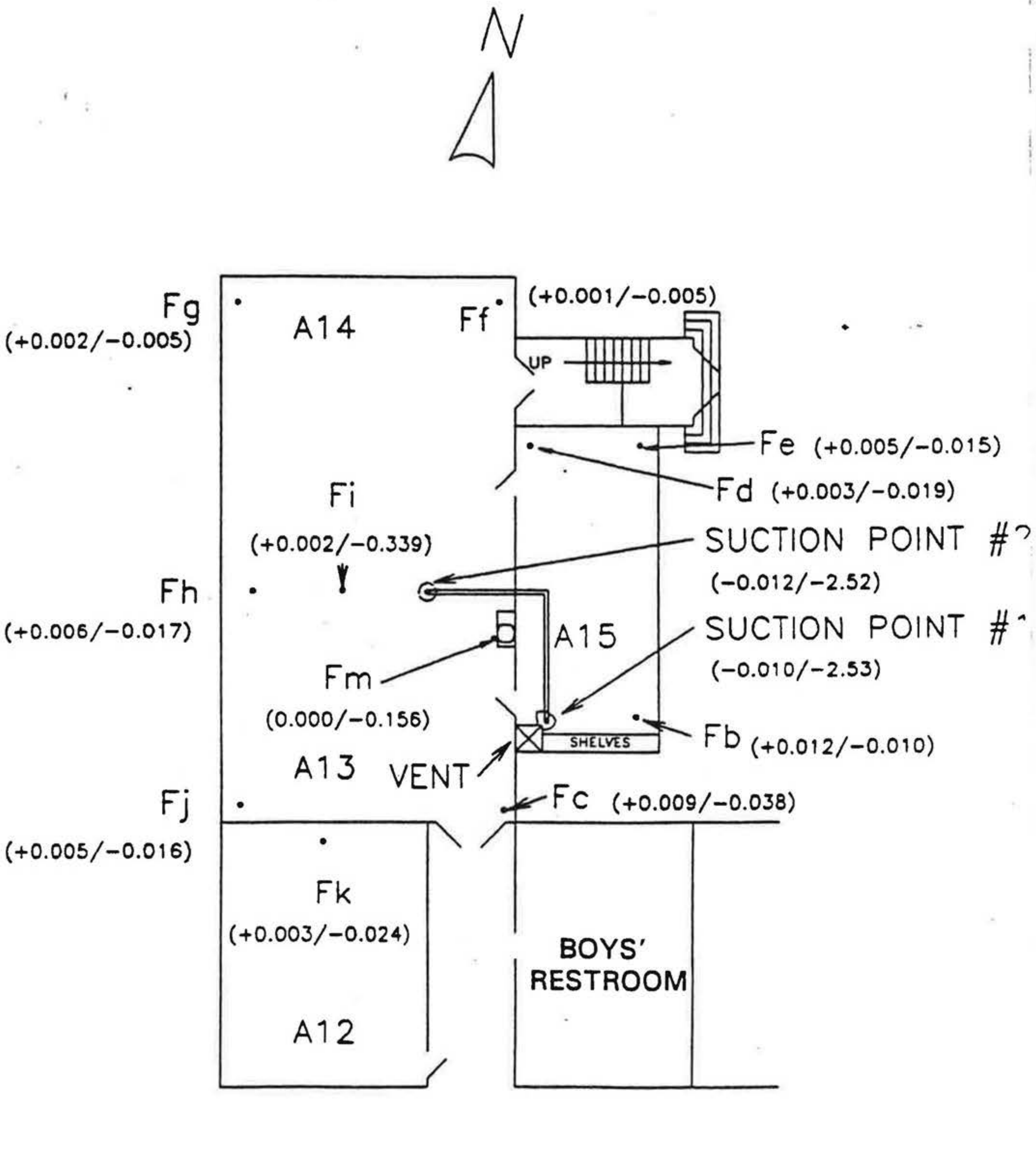

Figure 3. Results of PFE measurements in Maine school (in. WC fan off/in. WC fan on).