THE SCHOOL EVALUATION PROGRAM

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ABSTRACT

A pilot program to provide classroom and field training to school facility operators was implemented by the U.S. Environmental Protection Agency's Office of Radiation Programs in 1989. This program consisted of two phases. The first phase developed and delivered a three-day workshop in Nashville, Tennessee. As a result of the workshop a second phase was initiated. The second phase investigated several school buildings with elevated indoor radon levels in the Western United States. Radon entry mechanisms were identified. Measurements to evaluate soil depressurization as a radon control method were made and HVAC systems were characterized. Measurements were made to evaluate HVAC modification as a radon control method. Building shell tightness measurements were made and information was collected to judge the suitability of potential sites for additional EPA sponsored "hands on" school training. Physical and institutional problem areas were identified.

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

I. INTRODUCTION

In response to an emerging need for information on the mitigation of elevated levels in United States schools, the Office of Radiation Programs, Radon Division embarked on a limited program to provide technical assistance for building facility managers of school systems. This program, called the School Evaluation Program (SEP) is an extension of an earlier state technical assistance and training program, the House Evaluation Program (HEP), which focused on residential indoor radon.

The goal of the SEP is to develop and implement a technology transfer program which will provide state of the art technical assistance on large building diagnostics and mitigation techniques to school officials and private sector contractors. It is anticipated that EPA's Regional Training Centers will be the vehicle for such a transfer program. Information already collected and currently being gathered by EPA's Radon Division and the Radon Mitigation Branch of the Office of Research and Development, Air and Energy Research Laboratory will serve as the resource base for the SEP.

For Fiscal Year 1989 six schools were investigated and are reported on in this paper. Approximately fifteen additional schools will be visited in 1990 afterwhich a few pilot technology transfer training programs will be field demonstrated. SEP training programs are expected to be made available for delivery by the Regional Training Center in the fall of 1990.

II. INVESTIGATION OF SCHOOLS

Investigations were made in six school buildings. Three were located in Spokane, Washington (designated S1, S2 and S3) and three were located in Los Alamos, New Mexico (designated LA1, LA2, LA3). All of these buildings had been tested for indoor radon and found to have elevated levels in at least some of the rooms. The radon levels in each measured room are shown in Figure 1. As in previous work done in schools by Air and Energy Engineering Laboratory the investigation included characterizing the building structure, subslab characteristics, HVAC effect on air pressure differential across the building shell and radon entry (1). Additionally, in this effort information was collected on the building shell tightness, the operational status and control strategy of the HVAC equipment and airflow rates of ventilation equipment.

III. RADON ENTRY

All of the schools were slab on grade construction. The major penetrations through the slabs were the joint at the edge of the slab and water pipe penetrations. In school LA1 there were two laboratory rooms that had trenches containing sink drains covered by steel plates. The lines drained into a sump pit, also covered by a steel plate. Not much radon appeared to enter from these trenches. One school (LA2) had a trench that is used as an air supply and another (School S2) a return. The wing of LA2 that had supply air ventilation through the trenches also had low radon concentrations in the rooms. It is unknown whether this is from supply air pressurization or lack of a radon source. The return air trench in the gym ventilation system of S2 was contributing radon to the school air whether it was operating or not. Measurements made in the trench revealed radon concentrations of about 60 pCi/L. The radon concentrations beneath the slabs of schools S1, S2, LA1 and LA2 were measured. The results are shown in Figure 2, along with a summary of the HVAC equipment in the schools. As can be seen they varied from a low of 400 pCi/L to a high of 1,300 pC/L. While high compared to all but the most extreme cases of indoor levels these are relatively low subslab concentrations for buildings with elevated radon. They are typical of residential buildings with permeable soils (sands and gravels). (Figure 2 summarizes the radon levels in all the schools).

SOIL DEPRESSURIZATION TESTS

In order to assess the potential for radon control by soil depressurization, a vacuum suction test was made in schools S1, S2, LA1 and LA2. The results were encouraging for LA2 (stone pebbles beneath the slab, suction <30 feet) and LA1 (sand and gravel beneath the slab, suction <28 feet), not as encouraging for S2 (coarse sand beneath the slab, suction <20 feet) and discouraging for S1 (fine sand beneath the slab, suction <15 feet). Figure 3 shows the suction versus distance curves for LA1 and S2. Notice that the pressure field decays exponentially with distance from the suction point. A possible explanation for this is that in fine materials the flow exponent is nearer .5 than 1, resulting in a nonlinear function.

An interesting observation was noted during the vacuum suction test in school S2. The first time the vacuum test was performed no pressure field was developed under the slab even 8 inches away from the suction point. The vacuum could not compete with the suction (minus 28 pascals) put on the building by the exhaust fans and soil air was still entering the school through the test holes. By opening an outside air vent and one window in each room the negative pressure across the building was far smaller (minus 2 pascals). Under these conditions it was possible to extend a pressure field that was nearly 1 pascal at 30 feet and 2 pascals at 12 feet by exhausting 28 cfm at 18 inches WC from beneath the slab. Additionally the pressure field extended from room to room and across the corridor into rooms on the opposite side. This is rather encouraging for soil depressurization if the negative pressure in the building can be controlled.

IV. HVAC CHARACTERIZATION

The HVAC systems in all six buildings were characterized in terms of heating and cooling, ventilation types, control strategy, and the potential impact on radon levels. The ventilation systems in four of the six schools were primarily individual exhaust fans with only a small amount of either powered supply air or outside air. In the two schools that did have powered supply air, S3 and LA3, the measured indoor radon levels were relatively low. The highest level in S3 and LA3 were 7.3 pCi/L and in LA3 6.4 respectively and 50% of the rooms in each school were below 4 pCi/L. Both of these buildings have air supply systems in which the outside air damper position is controlled by the need for cooling with in the building (economizer type systems). For this reason it is expected that the amount of outside air being supplied is dependent on occupancy status. Therefore a screening measurement made on a weekend with a weekday schedule, but unoccupied status may not be representative of the actual occupied radon levels (see the details of investigation in S3). The HVAC features are summarized in Figure 2.

One of the prominent features of the HVAC systems was the number of problems found. These problems covered a range that included inoperative equipment (broken belts, fans, controls), poorly maintained equipment (disabled damper linkage, dampers painted shut), poorly designed equipment (ventilators too small or not used because they are too noisy and there is individual control within classrooms) and unwitting modification of the ventilation system (replacing the rolled steel sash window walls with insulated wall). The extent to which these types of problems were present was remarkable. Every school visited suffered from at least one of these problems. The following summarizes them for each school:

S1 Ventilation capacity lower than present ASHRAE guidelines of 15 cfm per student. Make up air damper closed. No ventilation system was found in the graphics room. Because this is an area where a number of indoor air contaminants are produced, ventilation should be suggested to the building owner.

S2 Too little outside make up air in school design. The only ducted outside make-up air into the school was inoperative (broken control).

S3 Heating, cooling and ventilation are supplied by a Variable Air Volume (VAV) system housed in the third story mechanical room. There are local exhausts in the lavatories, gym and kitchen. Even though this is a modern, sophisticated system, one of the exhaust air blowers was inoperative due to a broken belt.

LA1 Rest room fan has a broken belt. All but one of the previously operable small windows on the south wall of the library were sealed with caulk, leaving a single operable window as the total ventilation capacity.

LA1 Annex has a damaged gravity type relief opening which originally appears to have been a large exhaust fan. Of 10 unit ventilators observed only 5 showed any outside air flow when operated, many had the outside air intakes sealed closed.

LA2 Southwest Addition The ventilation feature of the unit ventilators has been abandoned and many of the blower motors are no longer operational. Core area's rooftop relief vents with pneumatically actuated dampers could not be made to operate by school personnel. The majority of rooftop fans were found to be operable only after the rooftop disconnect switches were turned on and a loose fuse was tightened. Northeast Addition Linkage controlling the outside air damper disconnected. A large rooftop exhaust fan inoperative. A strong odor of mold was noted in the south end of this addition. Mold growth covers the exterior insulation material in the mechanical room. Mechanical room unit heater inoperative.

LA3 School officials report unit ventilators often turned off by room occupants (complaints of noise). Most outside air intake manual dampers (located on the roof office area unit) were in the closed position. The ventilation feature of some units were abandoned or not utilized. Short circuiting was observed in the outside air intakes of unit ventilators causing room air entrainment into the make up airstream at roof penetration.

V. BUILDING SHELL TIGHTNESS

The tightness of the building envelope was estimated by depressurization techniques in three of the schools investigated. They were the S1, S2 and LA1. This type of measurement had been made in only a small number of large buildings and only in one school (the one school previously measured was part of the ORP school work done in 1988 and was located near Albany, New York). Other researchers have made similar measurements in a small number of buildings, Shaw in eight (2, 3) and Persily and Grot in seven (4). Most of the results from these buildings are reported by Persily and Grot in the paper "Pressurization Testing of Federal Buildings" in the ASTM Special Technical Publication 904, "Measured Air Leakage of Buildings". In this paper Persily presents two methods for comparing the tightness of one building to another.

The first compares the air exchange rate at an induced air pressure difference of 25 pascals (see Figure 4). It can be seen that the schools studied span the range of building tightness reported by Persily for the Federal office buildings. Two of the schools are substantially leakier than the office buildings and S1 is the tightest building measured. This represents a large range of building shell tightness for schools.

In an effort to account for surface to volume ratio differences, the second method normalizes the airflow rate at 25 pascals to a unit area of exposed envelope (see Figure 4) the office building data again from Persily (4). Notice that there is a larger range of values for this index of building tightness and that the ranking of the building is somewhat changed. Problems with this method may occur if the flowrate at 25 pascals is normalized to the exposed wall area rather than the exposed envelope area. This is because roof area is a small fraction of envelope area for high rise buildings and a large fraction for low rise buildings.

A third method of comparing building shell tightness is to calculate an Effective Leakage Area. The method used here is to calculate the leakage area at a pressure differential of 4 pascals according to the method developed by Grimsrud and Sherman at Lawrence Berkley Laboratories (LBL) (5). The results of these calculations are shown in bar chart form in Figure 5. The schools fall within the range of ELA's calculated for the office buildings. These range from 414 square inches to 14,133 square inches.

A fourth effort to interpret the building shell tightness measurements compared air exchanges at 25 pascals to air exchanges measured using tracer gas measurements. Analysis was performed on the three schools measured in the SEP so that they could be compared with the office buildings reported by Persily and the Albany school reported by Brennan. Figure 6 is reproduced from Persily (4) and shows measured ventilation rates versus ACH at 25 pascals for the office buildings studied. While there is a fair amount of scatter in the data a relationship is apparent. Using this as a guide the infiltration rates in the three schools when mechanical ventilation is not in operation can be estimated to be .07 ACH for S1, .15 ACH for S2, .51 ACH for the Albany School and .7 ACH for LA1. These are very rough estimates of the infiltration rates in these buildings. However, they can be compared to the installed power ventilator capacity of .07 ACH for S1, .57 ACH for S2, 1.1 ACH for the Albany School and .79 ACH for LA1. It is obvious from these values that naturally powered ventilation plays an important role in the ventilation rate of schools.

VI. RECOMMENDATIONS

In each of the school buildings both a soil depressurization and an HVAC approach to controlling indoor radon levels were addressed. An HVAC system approach was considered to be the first choice in four of the schools (S1, S2, S3 and LA3). In LA1 and LA2 a soil depressurization system is suggested in conjunction with an HVAC approach. Unlike the work reported by Saum et al. (6) this program found only one building with stone pebbles beneath the slab. Most of the schools investigated had fine sands under the slabs and would require numerous suction points to establish a low pressure field beneath the entire slab. This severely limits the application of soil depressurization as a first choice control technique.

Note: It is important that any approach that is used in school buildings comply with state requirements for qualifications in the design and installation of mechanical systems. Any HVAC work should involve a professional engineer experienced in air handling systems and their interaction with the building shell.

In S1 HVAC modification was the first choice because the ventilation system did not meet current recommended ventilation guidelines, the building is tight enough to pressurize with the appropriate amount of ventilation air and the results of the vacuum suction test were very discouraging (many suction points would be needed).

In S2 HVAC modification was the first choice because the exhaust only ventilation depressurized the building to such an extent (minus 28 pascals) that the vacuum suction test would not work against the exhaust fans. HVAC supply must be addressed in order for soil depressurization to work at all, at which time the radon levels may well have been dramatically lowered. So a soil depressurization method is a second, but possible approach. If implemented it would take 1 suction point for each affected room.

In S3 HVAC adjustment is recommended because it is an economical, straight forward process. The probability of this approach working is considered high because the building is already under positive pressure with all the exhaust fans on and that, the room with the highest screening measurement (unoccupied) 7.3 pCi/L, averaged 1.6 pCi/L for 38 hours when normally occupied and less than 1 pCi/L for the occupied time alone (7 hour school day).

In LA3 HVAC repair and operation is suggested as the first choice because the relatively low radon levels, the presence of closed or short circuiting outside air dampers (levers locked in place with canned foam), and a control system that opens outside air dampers on an economizer cycle indicate a high chance of success.

In LA1 a combination HVAC and soil depressurization approach is suggested because the radon levels are high in each room and because the highest rooms are between 20 and 40 pCi/L. This means that an HVAC approach would have to pressurize the building. It would take 20,000 cfm of supply air to do this when each exhaust blower was on. If the exhaust blowers were all eliminated except in the areas of pollutant generation (bathrooms, chemical storage rooms, maintenance closets and science laboratories) then the building could probably be pressurized with 12,000 cfm of supply air. This approach is not out of the question. Soil depressurization is suggested because of the difficulty of pressurizing this building and the somewhat encouraging results of the vacuum suction test. It would still take 16 to 17 suction points if all the rooms need to be treated. So the suggestion is to modify the HVAC system with every effort made to pressurize the building. It is likely that this approach will not successfully lower all the rooms and that one suction point will have to be used in each affected room. If the soil depressurization approach is tried before the HVAC approach it will take 16 to 17 suction points.

In LA2 a combination HVAC and soil depressurization approach is suggested. The soil depressurization method would almost certainly reduce radon in the affected rooms with one or possibly two suction points, one in room 6 and another in room 2. However, there are so many inoperative components in the school ventilation system (fans, dampers and controls) as well as an obvious fungus problem that it is felt that the entire ventilation system should be evaluated, repaired and amended to provide acceptable ventilation according to ASHRAE Guidelines.

VII. CONCLUSIONS

DIFFICULTIES WORKING IN SCHOOLS

There are a number of areas that make controlling indoor radon in schools more complex than in residences. It begins with screening measurements. Radon levels in buildings can be affected by the operation of the mechanical systems. This is more complicated in schools than in houses because the mechanical systems and their control systems are more extensive and complex. This difference is most important in the ventilation system. Many residences have ventilation systems that consist of natural infiltration and exhaust fans in bathrooms and kitchens. Each exhaust fan is rather small and operated by the occupant, not a central control. The ventilation systems in schools fall into one of the following types:

o Exhaust Air consisting of:
  - individually controlled fans
  - centrally controlled fans or pressure relief hoods.

o Outside Air entering:
  - through leaks in the building shell (often rolled sash windows)
  - centrally controlled Unit Ventilator dampers
  - centrally controlled outside air dampers
  - centrally controlled supply fans
  - individual controlled Unit Ventilator dampers

Problems arise when the operation of the ventilation system could affect the indoor radon concentration and the control of the ventilation system is not easy to characterize. For example, a school that has individually controlled exhaust fans (e.g. nine fans delivering a total of 8,832 cfm in the core of LA1) and makeup air supplied by leaks in the building shell. It is difficult to identify a normal operating pattern when exhaust fans are controlled by a variety of individuals. Differing operational and occupancy combinations may result in different radon concentrations. It is presently unclear as to how to interpret time integrated measurements.

Another example. A school with centrally controlled exhaust and supply (e.g. S3 has a VAV system and other schools have Unit Ventilators) often has the outside air dampers controlled with an economizer cycle that opens the dampers in response to outside temperature and cooling load. This means that in the spring and fall months the occupied building has far more outside air than the unoccupied building. Screening measurements made in unoccupied buildings are not as representative even though the HVAC timing schedule is the same as for the weekday. Time integrated radon measurements made when ventilation rates depend upon occupant status can be difficult to interpret.

A second difficulty is with the shear size of the buildings. Indoor and subslab radon measurements sampled in only a few areas probably do not represent even the average values much less establishing the range of values. In large buildings HVAC characterization alone can take more than a day.

A third difficulty is that design and installation work in schools is regulated in most states. Often this regulation includes minimum educational and experience qualifications of installers and designers, permits and/or inspections by State and/or local officials. The regulation is designed to protect the public from health and financial risk in the design, construction and operation of schools. As this applies to radon control with HVAC systems the important points are that the system actually perform its functions of conditioning the space and supplying adequate ventilation while at the same time controlling radon. Additionally the building as a system must maintain an appropriate fire control rating to protect against life loss and injury in the event of fire.

Lastly, the design and installation of new HVAC systems or major modification of existing HVAC systems are time consuming, disruptive and costly. However, these should not be considered obstacles when the existing HVAC system is failing to meet the primary goals of comfortable conditioned space with acceptable air quality. A system that does not supply adequate ventilation because it is not operated, is operated improperly, has been changed or is in need of repair is not performing its function and should be repaired, modified or replaced in accordance with State and local codes and regulations. This may require a financial procurement and design and installation process that will take some time to complete. In these cases it is suggested that a good short term response to extremely elevated school room radon problems could be soil depressurization systems which can sometimes be designed and installed for a much smaller budget on a more streamlined timeframe (often less than a week for the installation). Some school systems have undertaken this type of radon control as ordinary maintenance operations.

VIII. QUESTIONS RAISED

There are important questions about radon measurement and control in schools that have been raised.

- How can population exposures be estimated from time integrated measurements?

- What effects on indoor radon levels are engendered by the operation of HVAC systems, the control strategies of HVAC systems and the occupied status of the building? Are these effects important?

- What do indoor radon measurements mean in a building that does not meet recommended ventilation guidelines or has a ventilation system that is wholly or partially disabled either by neglect or by building modifications that unknowingly after the ventilation system (closing off rolled sash window walls)?

- How can indoor levels of radon be controlled in schools that have fine but porous soil beneath the slab and are not amenable to building pressurization?

- Must there be a suction point for every room?

A number of these questions are currently being addressed by the EPA ORP School Radon Protocol Development Study and by the EPA Air and Energy Engineering Research Laboratory's School Radon Program but others can only be answered by an increased data base size.

IX. ACKNOWLEDGEMENTS

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Figure 1 Radon Levels in School Rooms
Error bars are one stndard deviation

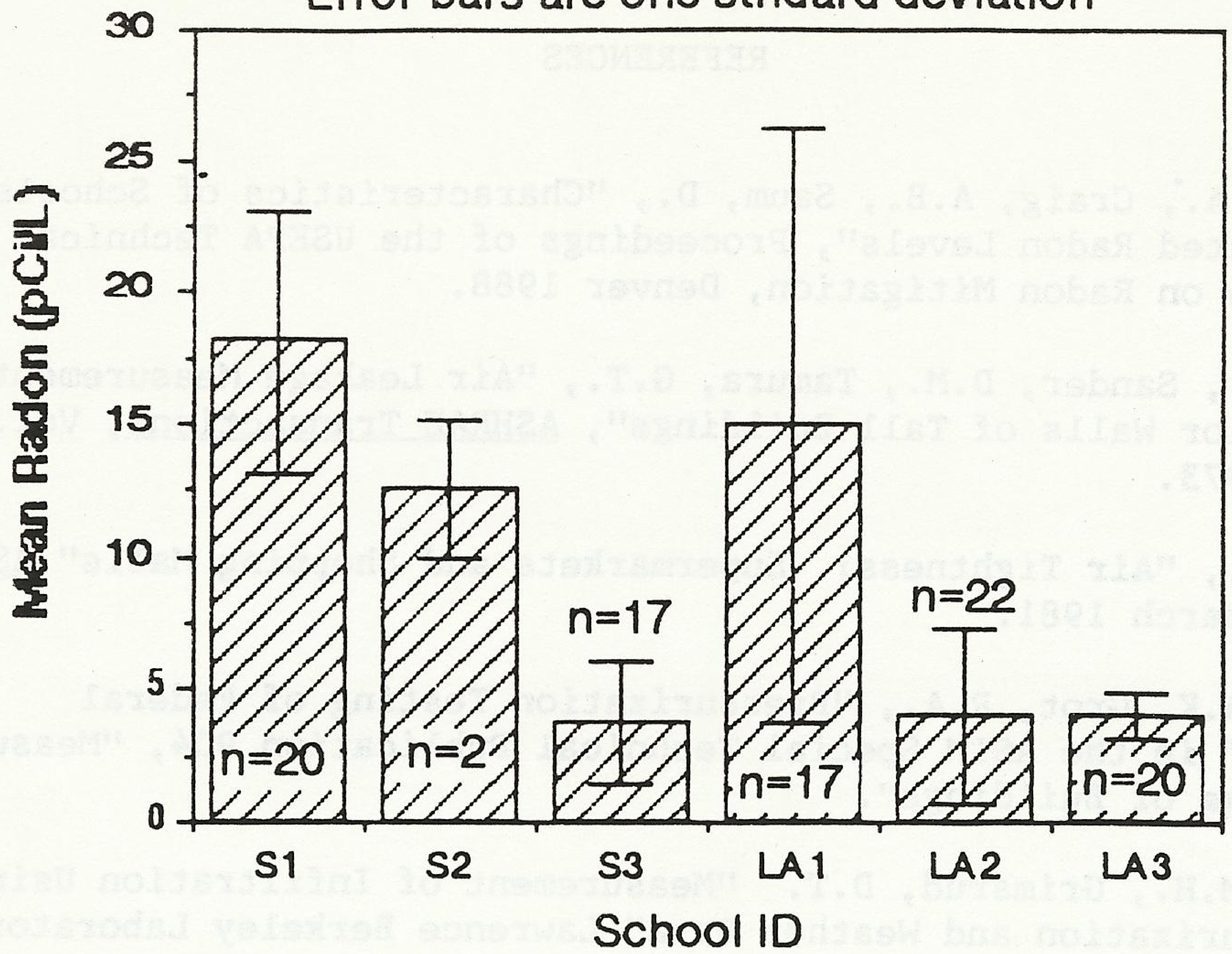


Figure 2 Summary of School HVAC and Sub Slab Characteristics

			Ventilation (cfm) measured				Sub Slab		Vac.
Sch. ID	Heating	Cooling	Exhaust	Make up	cfm/per.	Control	Material°°	Rn pCi/L	cfm
S1	Warm air	AC	1000	170/OA	10	thermostat/SB	FS	600±200	6
S2	Hot Water	None	5800	Inoper.*	11	thermostat/SB	CS	1100±200	27
S3	Warm Air	AC	NT	VAV		CPU man.	NT	NT	
LA1	Hot Water	None	10000	400/UV	14	thermostat/SB	S&G	500±50	20
LA2	Hot Water	None	NT	None		Thermostat**	SP	900±100	38
LA3	Warm Air	AC	NT	NM/UV	14	Thermstat°	NT	NT	

* the supply damper to the gym system was not working
** an installed enrgy management control had been disabled
° the controls for the Unit Ventilators were in each classroom and teachers reported they didn't operate them because they were too noisy
°° FS – Fine Sand CS – Coarse Sand S&G – Sand and Gravel
SP = Stone Pebbles NT = Not Tested

Figure 3 Distance vs. Suction for the Vacuum Suction Test in Two Schools

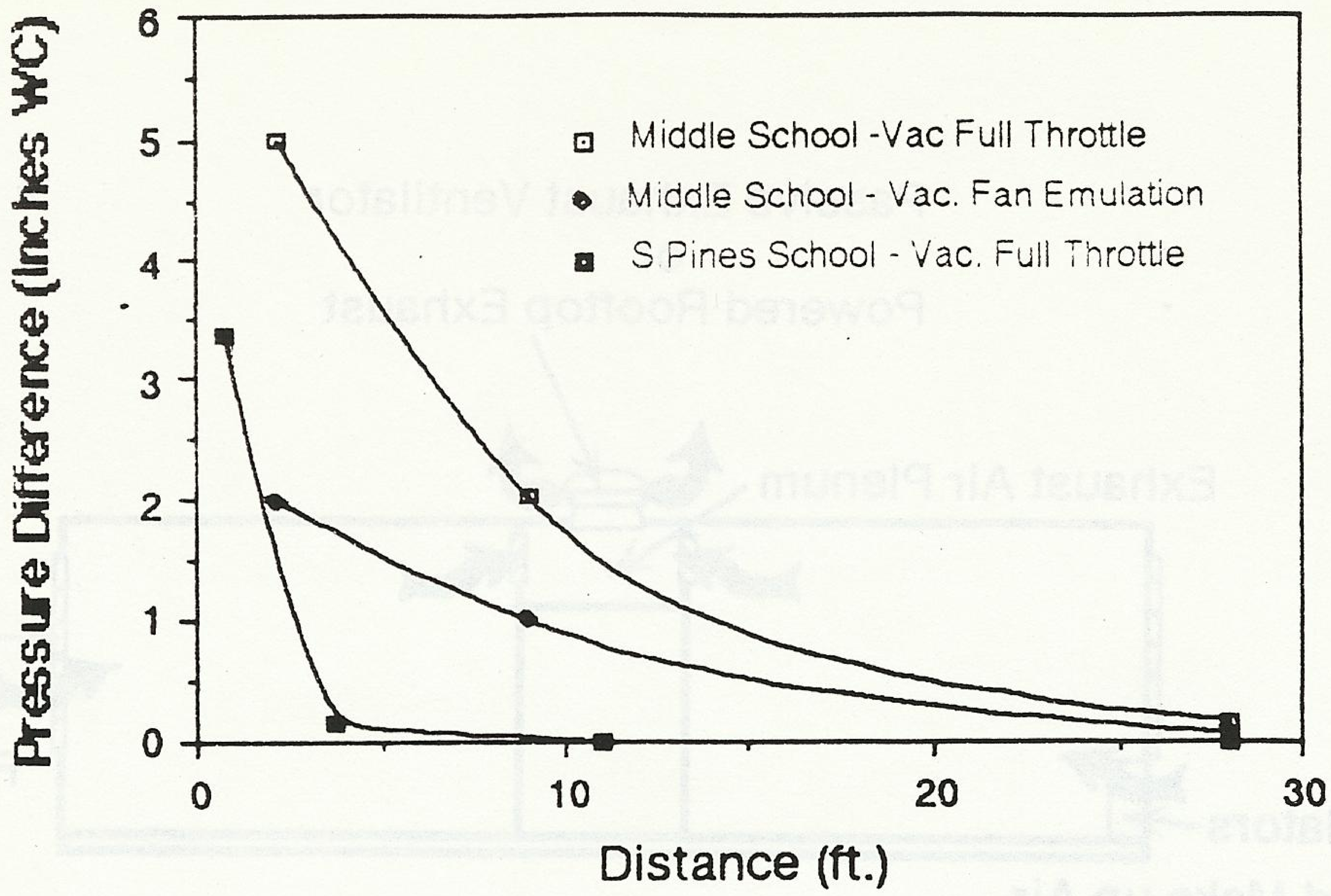
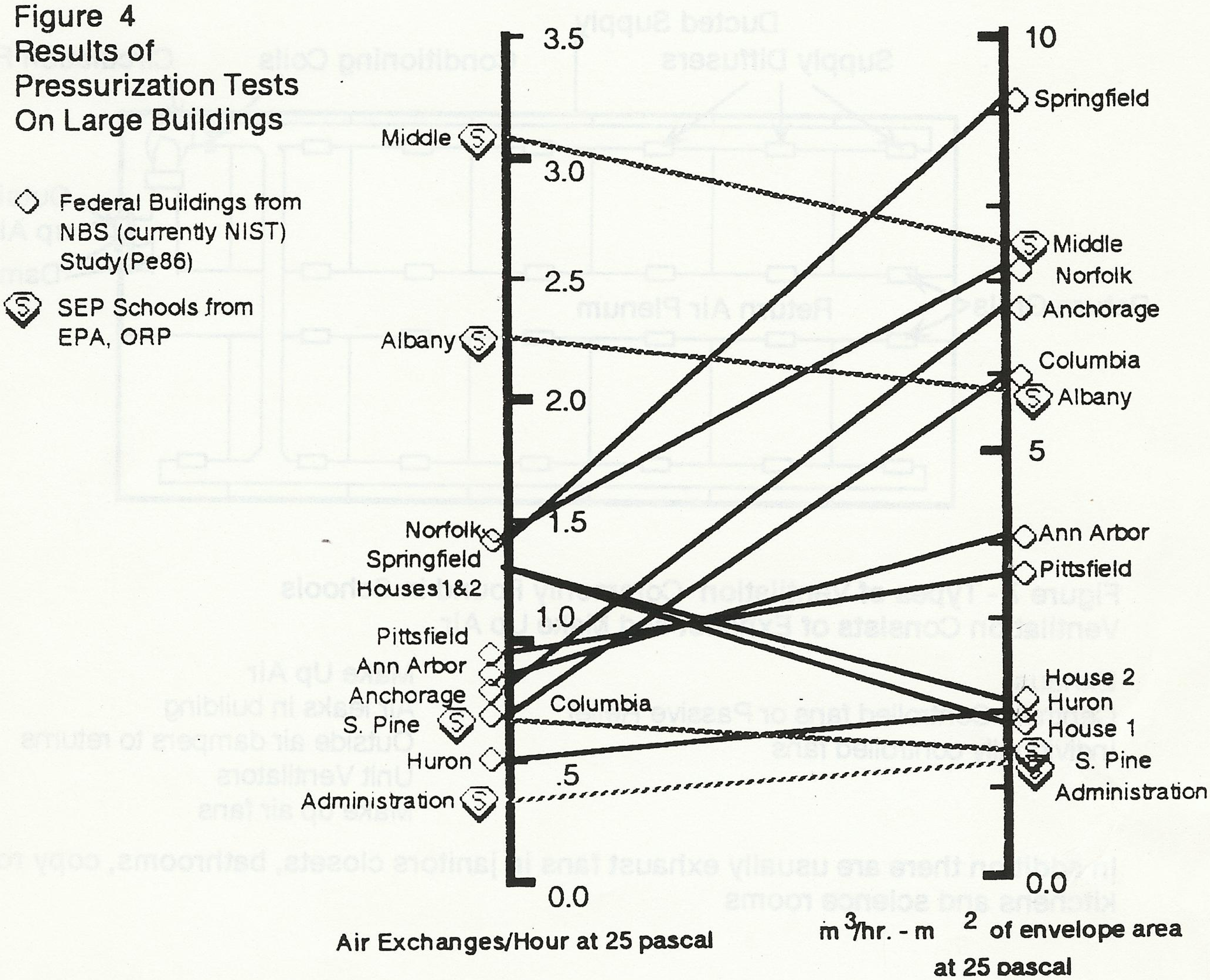
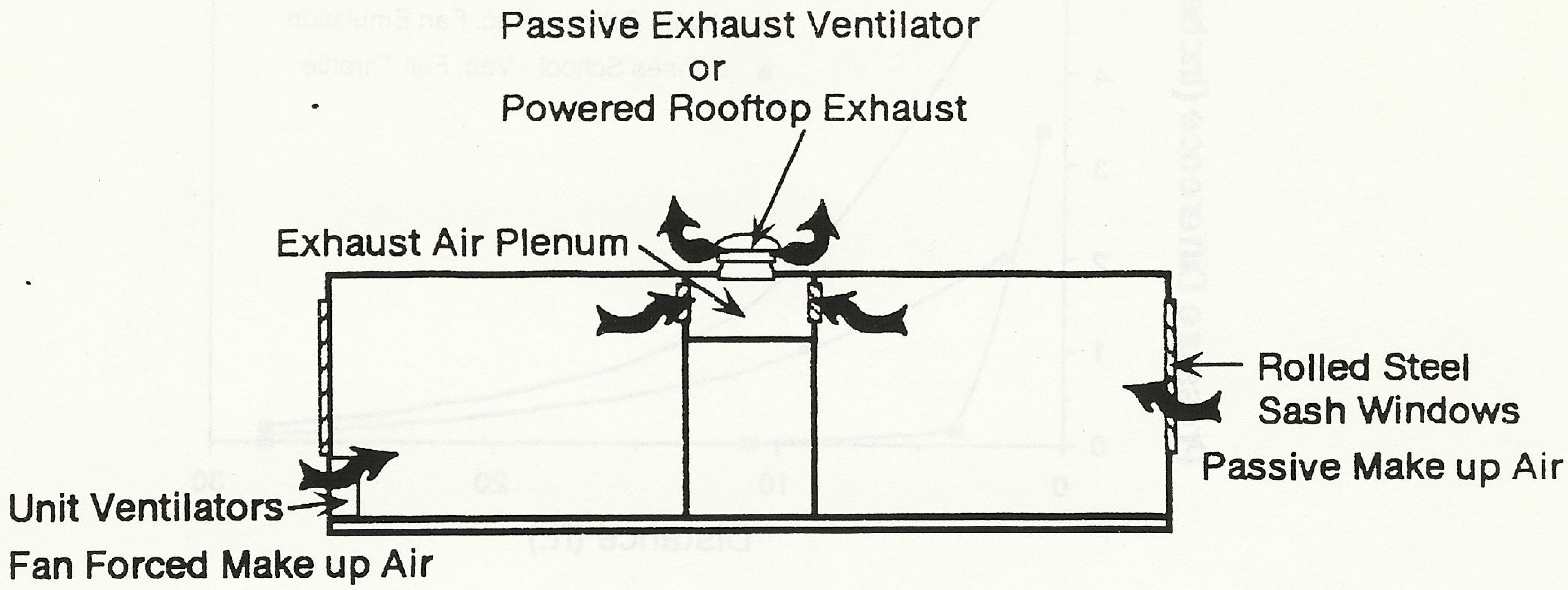


Figure 4
Results of
Pressurization Tests
On Large Buildings





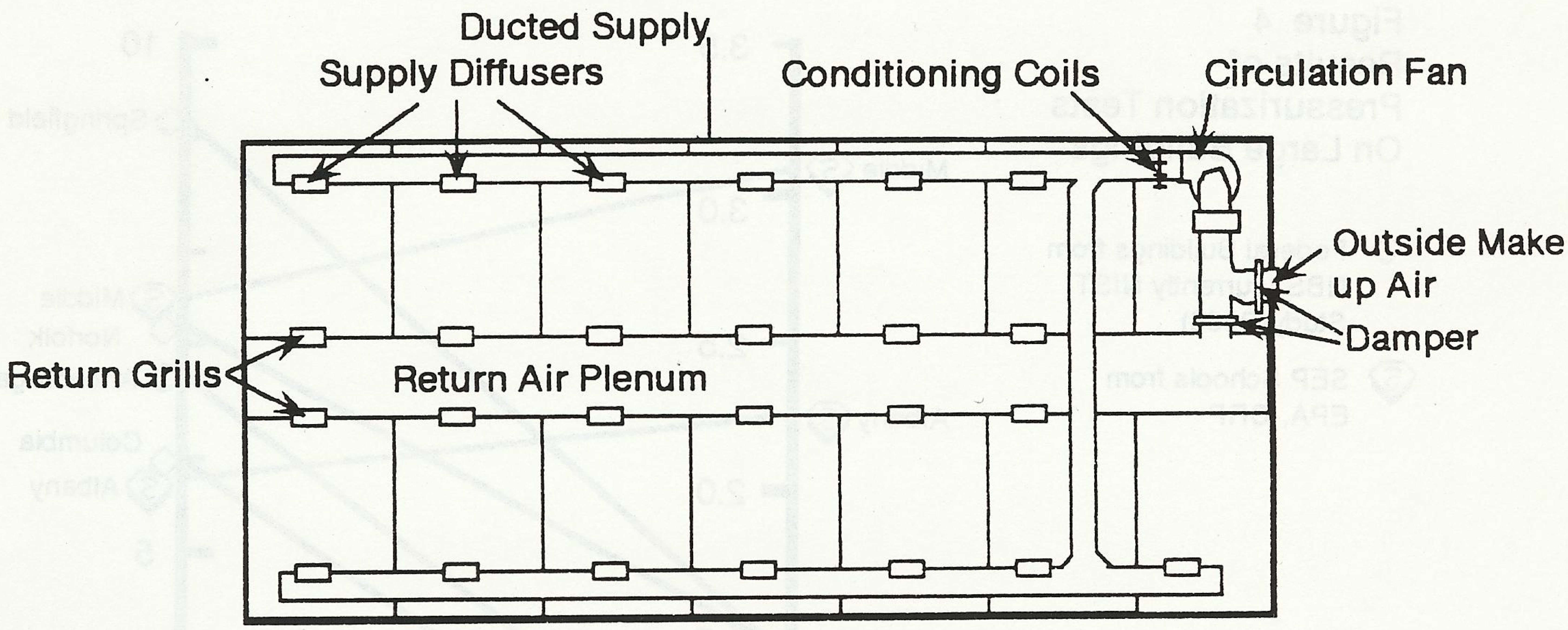


Figure 7 - Types of Ventilation Commonly Found in Schools
Ventilation Consists of Exhaust and Make Up Air

Exhaust
Centrally Controlled fans or Passive Relief
Individually controlled fans

Make Up Air
Air leaks in building
Outside air dampers to returns
Unit Ventilators
Make up air fans

In addition there are usually exhaust fans in janitors closets, bathrooms, copy rooms kitchens and science rooms

Figure 5
Effective Leakage Areas of
Office Buildings and Schools

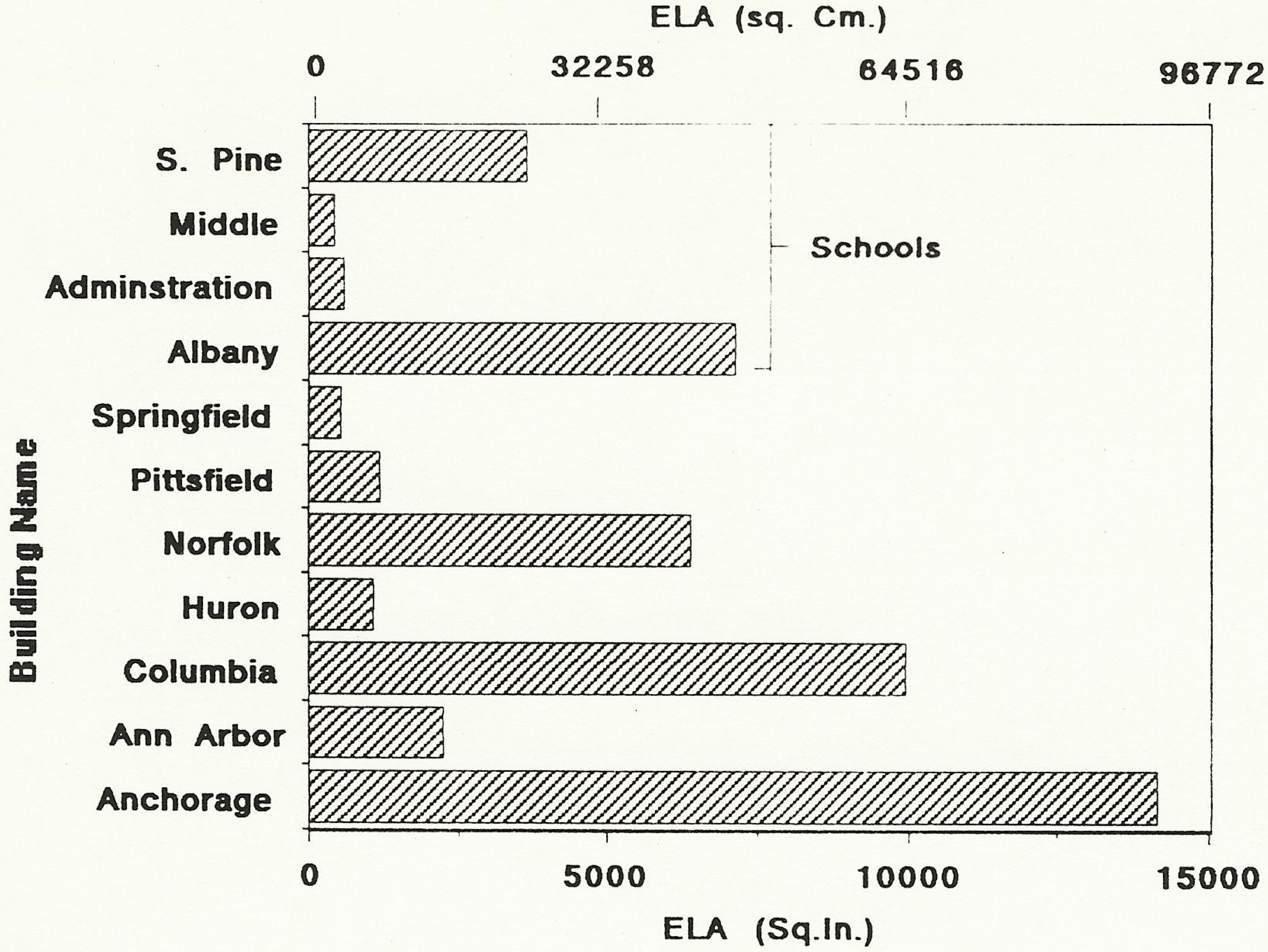


Figure 6
Measured Infiltration vs. ACH at 25 pascals
in Eight Office Buildings (Pe86)