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HVAC Retrofit for Healthy Schools

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ABSTRACT

The Environmental Protection Agency has evaluated the impacts of HVAC systems and building dynamics on radon concentrations in 26 schools across the United States. Diagnostic data indicated that radon was not the only indoor air pollutant in these schools. As a result, an essential step in the School Evaluation Program is determination of the feasibility of using HVAC technology for radon remediation in addition to general indoor air improvement. In 1990, the EPA sponsored the HVAC retrofit of two schools in Maine. This paper presents the information gained by these case studies. First, the extensive pre-retrofit diagnostics and characterizations of the two schools are reviewed. Then follows a discussion of why and how the HVAC systems, including unit ventilators, central air-handling units, and heat recovery ventilation, were retrofitted. Finally, an appraisal of the post-retrofit radon and CO_2 levels is made, along with presentation of related data such as retrofit costs and energy and comfort impacts.

INTRODUCTION

Two of the selection criteria established by the School Evaluation Program (SEP) were (1) diverse geographic locations, which would provide a variation in climatic conditions and structural styles, and (2) the schools must have radon screening measurements greater than the EPA action level of 4 pCi/L. As a result, a potential bias of these school data is that the schools had known radon problems.

Early in the School Evaluation Program, diagnostic data showed a strong trend that radon was not the only indoor air pollutant in these schools. Elevated levels of CO_2 indicated that ventilation, and therefore probably the general indoor air quality, was inadequate. Because of this combination of indoor air problems and because the traditional radon mitigation practice would not benefit general indoor air quality, a new approach was recommended to the majority of the schools—an HVAC retrofit. It became apparent to the EPA that a demonstration of the feasibility of this control technology was necessary and, consequently, case studies, as noted by this paper, were performed on two of the schools.

Three elements must be present for radon to become a problem: a radon source, a pathway, and a driving force. The first two elements are typically too difficult to reduce, so modification of the driving force becomes the prevention tool of choice. Driving forces are caused by the stack and wind effects on a building and by the air movement of HVAC systems.

It is because of this driving force that HVAC can be both a cause and a cure for elevated radon in buildings. If the HVAC system is exhausting and leaking more air than is being supplied to the building, the earth contact areas of the building will become negatively pressurized relative to the soil gas pressure. When the building is negative, soil gases, including radon, will be immediately sucked in through the pathways and into the building. But if the earth contact areas of the building are slightly pressurized, then radon will be prevented from entering the building.

It was theorized that the HVAC systems, which were causing a negative pressurization in all 26 schools, could be used to slightly pressurize the schools and thereby prevent radon entry. In addition, the increased outdoor air supply could be used to quickly dilute radon that had accumulated in the schools during the HVAC off-cycle, such as nights and weekends. The targeted outdoor air supply rate was 15 cfm (8 L/s) per person, as established by *ASHRAE Standard 62-1989* (ASHRAE 1989). Figure 1 shows some of the additional parameters that have an influence on indoor radon and general indoor air quality (IAQ).

To date, active subslab depressurization (ASD) has been the primary radon mitigation method. ASD is a simple technique that uses a fan and piping to draw soil gases from below the slab and exhaust the gases outdoors. The suction causes the air pressure below the slab to be more negative than the air pressure inside the building, thus preventing radon entry. It has proved very effective at reducing radon levels in schools (Leovic 1990) when the soil or aggregate below the slab is porous and allows easy movement of air. In cases where the soil is tightly packed, or where large numbers of separate subslab areas exist due to foundations, or if pressures above the slab counteract the ASD system, then an alternative radon remediation method is required. Also, another point when considering ASD is that it provides no benefits other than soil gas control.

PROCEDURE

In order to understand the building dynamics and how these dynamics affect radon levels and general IAQ, an extensive diagnostic evaluation requiring between 32 and 40 person-hours was performed at each school. Diagnostic procedures included plan evaluations, personnel interviews, and site walk-throughs. Diagnostic measurements included HVAC system parameters, subslab communication testing, air pressure differentials on the building shell, building shell tightness, and CO_2 concentrations throughout the school. Also, the general structural styles, HVAC systems, and radon pathways of each school were characterized. Details of the diagnostic procedure and equipment used are defined in Brennan et al. (1990).

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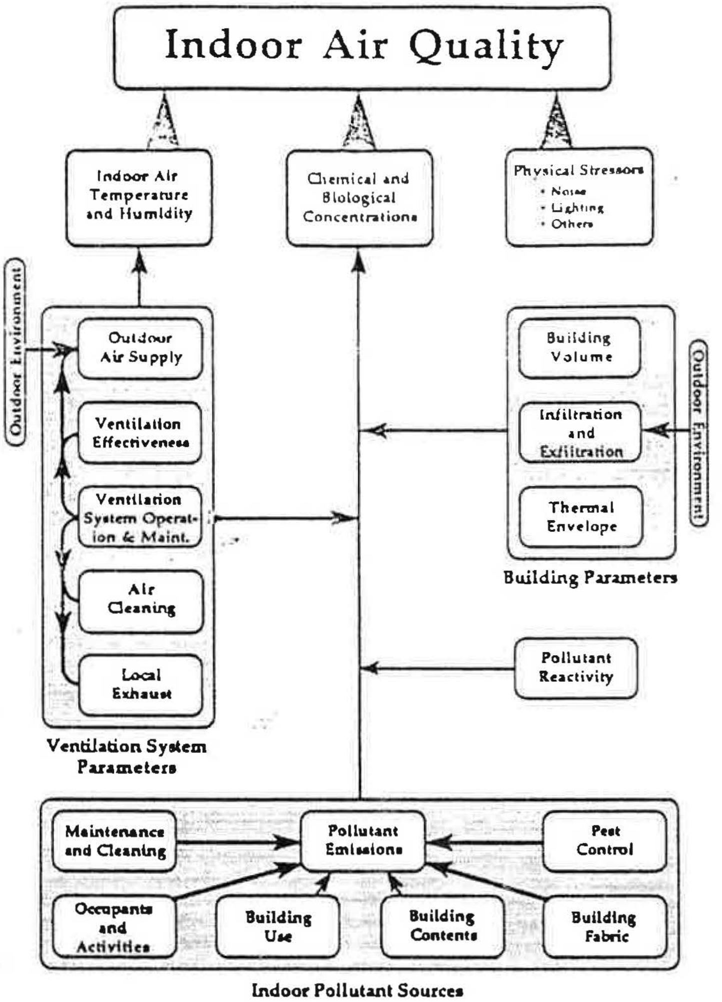

Figure 1 Factors influencing indoor air quality

Radon measurements were originally made as screening tests using charcoal canisters. These values were confirmed during diagnostic evaluation using pulse ionization and semiconductor continuous radon monitors. These continuous monitors were also used during the retrofit evaluation phase. CO_2 measurements were made at what was estimated to be peak CO_2 periods, using an infrared spectrometer. Continuous pressure measurements were made using variable-capacitance sensors. All pressure measurements are differential between indoors and outdoors.

CHARACTERISTICS OF THE TWO SCHOOLS

School A, at 106,400 ft^2 (9,884 m^2) and 586 students and faculty, was one of the largest of the 26 schools evaluated. The original portion, which makes up 38% of the school area, was constructed in 1961. In the original building, classroom heat is provided by hot water baseboard radiation, and a fan-powered exhaust ventilator is ducted to each room. The gym has built-up air-handling units with dampered outdoor air supply. Offices have the "open-the-door" form of natural ventilation. In the 1975 addition, all classrooms have unit ventilators with air economizer and passive reliefs. All other areas of the addition incorporate exhaust fans and built-up air-handling units with economizer outdoor air provisions (see Figure 2 for a plan view and additional details).

School B, with three wings, is much smaller and simpler than School A. The wings were built in 1950, 1963, and 1968, and have 7,000 ft^2 (650 m^2), 9,000 ft^2 (836 m^2), and 14,000 ft^2 (1,300 m^2), respectively. The HVAC systems, respectively, are hot water radiant heat with a passive exhaust system in each classroom, hot water baseboard radiation with fan-powered exhaust, and unit ventilators with a central corridor fan-powered exhaust. There are 418 students and faculty in the school (see Figure 3 for a plan view and additional details).

Each of the schools is located in central Maine, with a 7,374 heating degree-day annual average. Both schools had either defeated or greatly reduced the amount of outdoor air supply that was originally designed to be provided by the HVAC system. This was done, as it was in most of the other schools, to save money on energy costs.

HVAC RETROFIT

In both schools, the thermal conditioning portion of the HVAC systems was working adequately, so only the ventilation portions of the equipment would need retrofit. Before materials were ordered, an energy use analysis was performed for School A using modeling software with hourly weather data. The analysis indicated that conditioning the additional 10 cfm (5 L/s) of outdoor air per person would have a minimal impact on the operating budget. The cost would be approximately $900 per

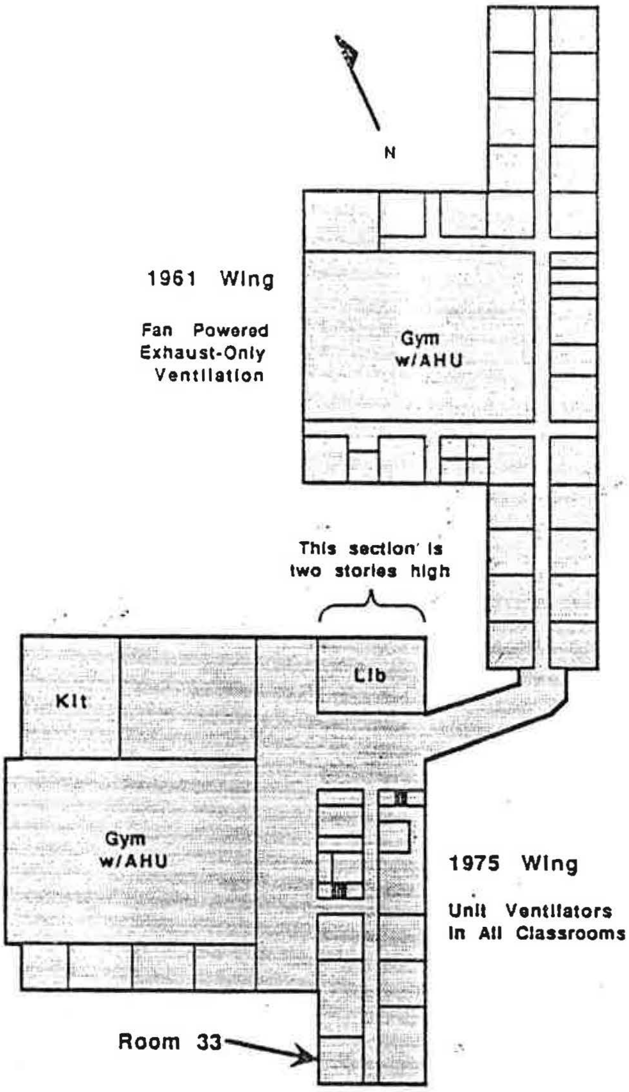

Figure 2 Plan view of School A

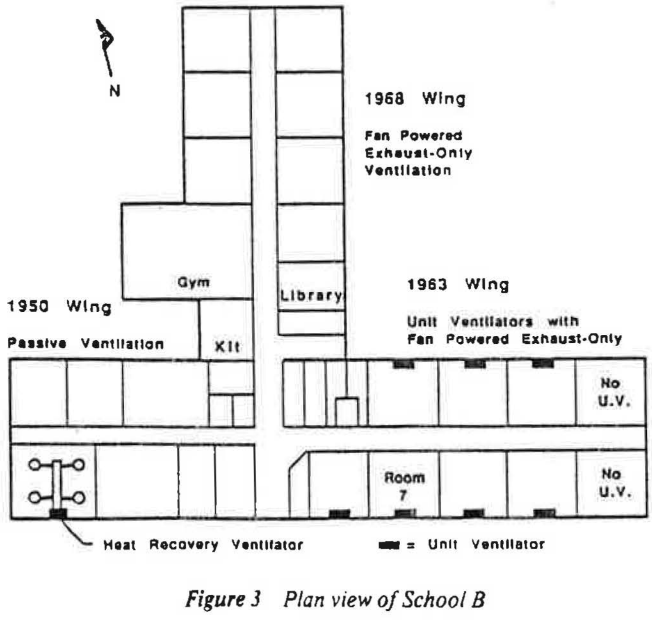

Figure 3 Plan view of School B

year, which is less than $2 per student. This minor increase was assumed to be proportionately similar for School B.

The goal of the retrofit, at a minimum, was to restore existing ventilation equipment to original design specifications and, preferably, to increase the minimum setting of outdoor air supply (OAS) to 15 cfm (8 L/s) per person. Since the heating control medium is water and the climate is cold, the unit ventilator coils do not have sufficient capacity to condition this amount of OAS, so the OAS had to be limited to less than 15 cfm per person to prevent potential coil damage. All built-up air-handling units do have sufficient capacity.

In general, the retrofit work was simple, requiring the repair or replacement of mechanical components such as damper actuators and linkages, the replacement of inoperative sensors and control components, and modification of control logic and setpoints. In one classroom, mechanical ventilation equipment was added because mechanical ventilation was nonexistent. All work was performed by local contractors.

In School A, the retrofit work involved 23 unit ventilators, 8 air-handling units, and the exhaust fan, which is in the original section. In School B, only two of the three wings involved HVAC work. In the 1963 wing, seven unit ventilators were repaired, and in one classroom of the 1950 wing, a 450-cfm (213 L/s) heat recovery ventilator designed specifically for classrooms was installed. Figure 4 shows a detailed layout of the heat recovery ventilator installation.

RESULTS

The HVAC retrofit was very effective at reducing the levels of radon and CO_2 in both schools. Figures 5 and 6 indicate the average changes in radon and CO_2, on a pre- and post-retrofit basis, for School A and School B, respectively. For brevity, one monitored room of School A has been chosen as representative of all unit ventilator rooms (Figure 5).

The radon cycles in Figure 7 show the relationship between building pressurization and HVAC operation. Each time the HVAC system is turned on, typically early in the morning, the radon instantly reverses its upward trend and radon levels begin to fall. A close-up of one of these cycles is shown in Figure 8. The important point noted in this figure is that the mean level of radon during occupied hours is less than the 24-hour mean level, and if the HVAC system timer were set to turn on three hours earlier, then the radon levels during occupation would be less than half that of the 24-hour average.

One approach to understanding the effects of HVAC operation on radon is to apply the tracer gas decay theory. This has been done in Figure 9, which was created by taking the decay curves for this classroom for all the occupied days during the monitoring period and plotting them on this single graph. The best fit decay curve does not match the theoretical radon reduction rate because the classroom was still slightly negative, which did not completely stop the entry of radon. Note that if the schools had been positively pressurized, radon levels would most likely be well below the EPA action level of 4 pCi/L. In addition, the slope of the decay curve would be much steeper, which would allow a more reasonable HVAC system turn-on time, yet still ensure the lowest possible radon exposure during the occupied period (see previous paragraph).

On the human side of these case studies, many occupants of these schools have volunteered that they believe the indoor air quality is substantially improved. Also, the conscientiousness of all school personnel on indoor air issues has been improved. Maybe someone will now think twice before placing garbage cans and chemicals (and charging the floor care machinery) in

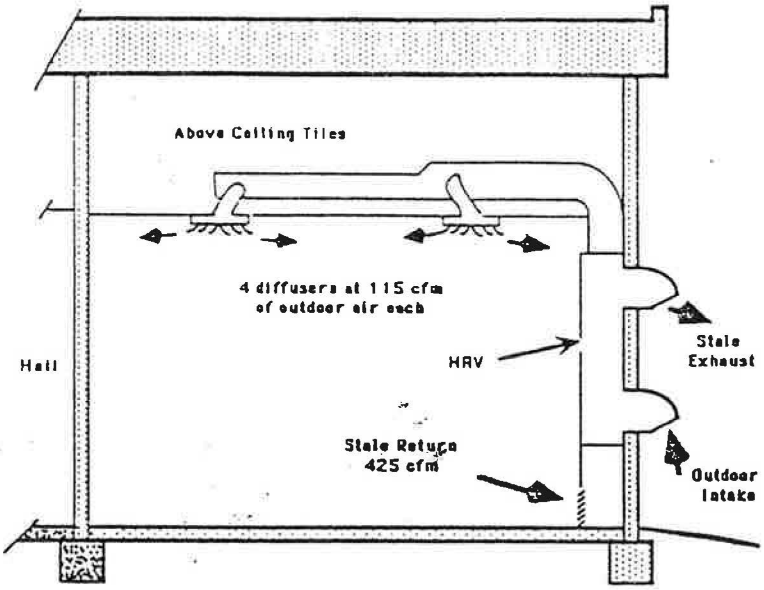

Figure 4 Cross section of HRV room in School B

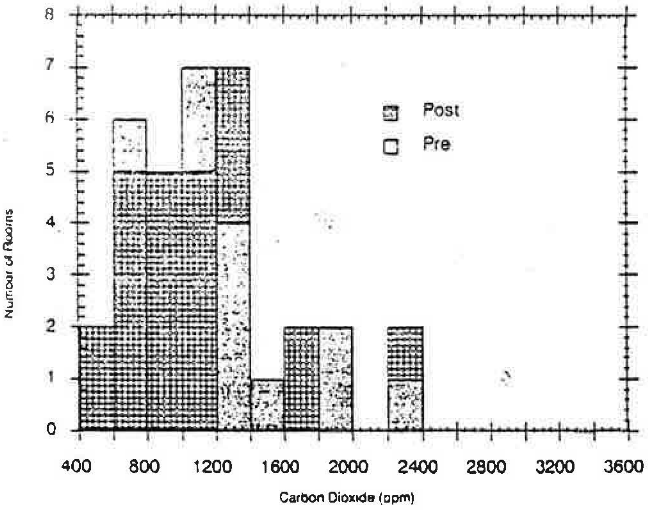

Figure 5 School A pre-post CO_2 levels

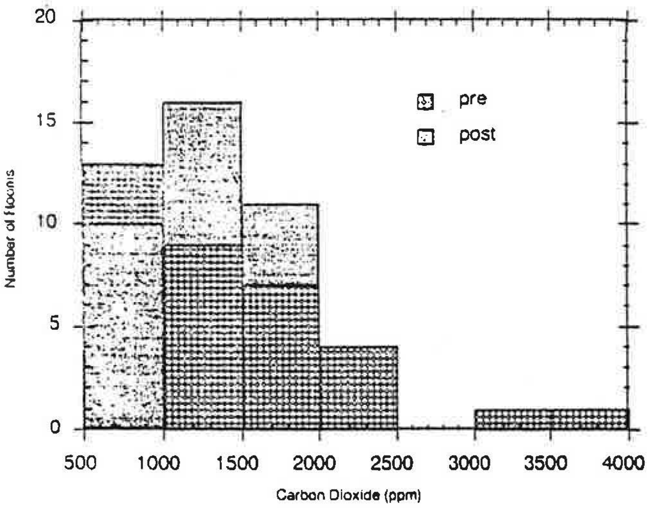

Figure 6 School B pre-post CO_2 levels

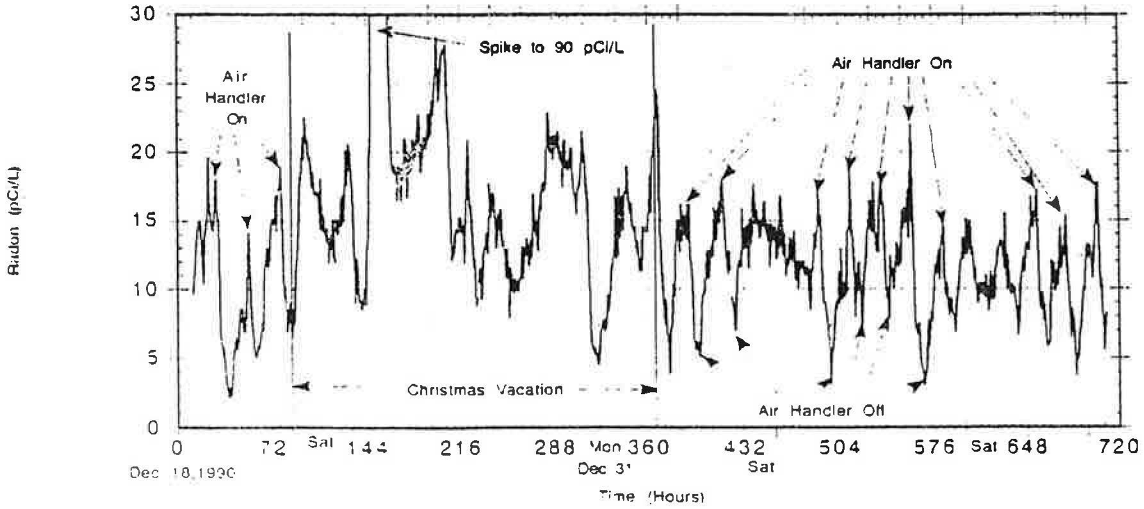

Figure 7 Radon vs. time, Room 33

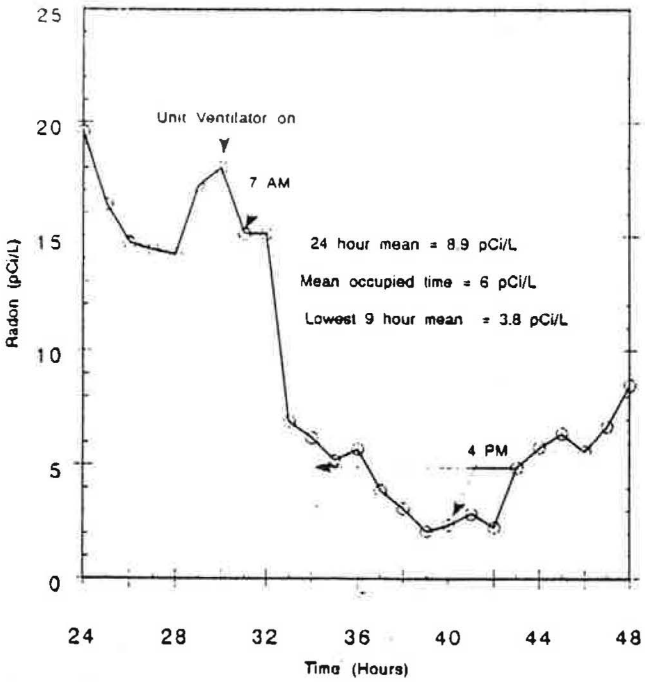

Figure 8 Unit ventilator effects on Room 33 radon—24-hour, occupied, and lowest 9-hour means, December 19, 1991

one of the mechanical rooms that served as the mixing chamber.

The total cost, including the value of donated equipment, for the retrofit of the two schools averaged $0.155 per ft^2 ($0.014 per m^2). This figure does not include the cost of the diagnostic/evaluation phase. The HVAC retrofit did not cause changes in maintenance schedules and practices and, during the winter of 1990-91, "did not cause a noticeable increase in energy costs," which affirms the pre-retrofit computer modeling (Quinn 1990).

DISCUSSION

Many questions and interesting points have been generated by the results of the case studies. Some of the points will be investigated further. The following list is in no particular priority.

Upon completion of the retrofit work, it became apparent that although the technicians were skilled and knowledgeable about the parts and equipment, they did not have the measurement devices to properly adjust the amount of outdoor air supply. As a result of the "adjustments on the linkages always set to the same spot," the OAS ranged from virtually zero to well over the specified OAS, which was determined by measurement with flow hoods. This was disconcerting because if we had relied on the technicians' beliefs, the data would have been quite skewed and the maximum level of radon reduction would not have been achieved. Knowing the capabilities of the retrofit team and utilizing a commissioning plan (as noted by ASHRAE Guideline 1-1989) are vital.

Although increasing the OAS rate, such as applying *ASHRAE Standard 62-1989*, will typically improve general indoor air quality, it is imperative that building pressure relationships be controlled if soil gases such as radon are a problem. Initial data seem to indicate that if the earth contact areas of the building go only slightly negative, the instant influx of soil gases may be too concentrated for a "proper" ventilation rate to dilute adequately.

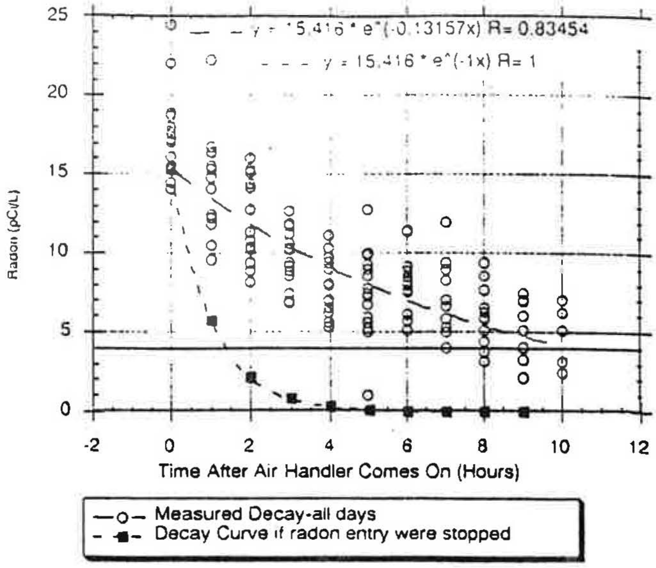

Figure 9 Chart summarizing actual vs. theoretical radon reduction in Room 33

Since positive pressurization is a prerequisite for soil gas control, a leaky building shell will reduce the amount of control possible. For example, the passive pressure relief vents in the unit ventilator classrooms of School A will need modification so their opening will not cause loss of positive pressurization in the earth contact areas of the room.

Because the HVAC subsystem is only one component in what constitutes the complete building system, HVAC alone cannot be expected to guarantee good IAQ. (See Figure 1 for an overview of the subsystems that affect IAQ.)

Probably the single biggest concern about the HVAC approach to improving IAQ is the question that it may not be reliable enough to maintain good IAQ in the future. Unlike thermal discomfort, it is hard to know when an OAS damper breaks or when some other problem affects IAQ, because people do not detect IAQ problems as well as they do thermal problems, and therefore this important feedback loop about equipment operating condition is lacking. HVAC has had problems in the past and, left unchanged, will continue to have problems in the future. These problems are usually caused by a lack of understanding of the costs associated with poor IAQ and of the importance of system design, installation, commissioning, operation, maintenance, and servicing. How these problems will be overcome is complex at best. Some suggestions that may help include certification for building operators; more highly automated controls, which greatly reduce operator interaction and perform self-diagnosis; alarms that monitor building dynamics and cannot be permanently turned off until the problem is fixed; better documentation and labeling, since each system is so unique; and, finally, regulations and codes with penalties for noncompliance.

CONCLUSIONS

Based on the information and questions generated by these case studies, the School Evaluation Program will continue by remediating several more schools using HVAC technology. In addition, the EPA Office of Research and Development will be developing data based on HVAC retrofits for radon control. Four of the major points learned are:

1. For these schools, an HVAC retrofit was a very effective and economical means for improving the IAQ. When compared to current radon remediation practice, an HVAC retrofit has an added benefit—improvement of overall IAQ.
2. A thorough commissioning process must be implemented to ensure that the goals of the HVAC retrofit are met.
3. An HVAC retrofit can make major improvements in IAQ, but pollutant sources and building dynamics must be considered if good IAQ is to be ensured.
4. An HVAC retrofit that reduces radon and improves indoor air quality can encompass a full range of costs, from inexpensive, such as resetting or servicing a controller, to expensive, such as installation of a complete outdoor air supply system that was nonexistent in the building.

Past practices have shown that we have a tendency to forget the key role that HVAC systems play in maintaining a healthy and productive learning environment. We recommend that the possibility of an HVAC retrofit receive consideration anytime a major school renovation or addition is planned.

ACKNOWLEDGMENTS

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