1988-51

#X-4

RADON REDUCTION SYSTEMS IN SCHOOLS

D. Saum
Infiltec
P.O. Box 1533
Falls Church, Virginia 22041

A. B. Craig and K. W. Leovic
Air and Energy Engineering Research Laboratory
United States Environmental Protection Agency
Research Triangle Park, North Carolina 27711

ABSTRACT

Successful radon reduction techniques applied in houses have been modified and installed in a limited number of schools to reduce elevated radon levels. These mitigation techniques include subslab ventilation and to a lesser extent sealing and pressure control through the heating, ventilating, and air-conditioning (HVAC) systems.

Premitigation diagnostic data were collected and mitigation systems designed and installed in several schools in Prince Georges County and Washington County, Maryland, and Fairfax County, Virginia. The schools exhibited premitigation radon levels as high as 80 picocuries per liter (pCi/L*) and represent a range of air-handling systems and substructures. Case studies of five of these schools are presented.

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

INTRODUCTION

In late 1987, radon levels of approximately 20 pCi/L were found in several rooms of a school in Fairfax County, Virginia. This led to extensive radon measurements in schools in Fairfax County in addition to other counties in Virginia and Maryland. Several of these counties were contacted by EPA regarding radon diagnostics and installation and testing of radon remediation systems. Case studies of five of the schools selected for detailed mitigation work are discussed.

These five schools may not be representative of the U.S. school population and may not represent the most challenging aspects of radon mitigation in schools. However, they do represent the successful application of subslab depressurization, a well-established residential radon mitigation technique that can often be installed by school personnel with some assistance from an

* 1 pCi/L = 37 Bq/m^3

experienced radon diagnostician. In addition to subslab depressurization, pressure control through the heating, ventilating, and air-conditioning (HVAC) systems and sealing of radon entry routes were also applied to some of these schools.

Until mitigation systems are installed in a larger number of schools representing a broader geographic range, it is too early to determine how applicable these mitigation techniques will be to school buildings throughout the country. In addition, radon levels in these five schools will be monitored during the 1988-89 heating season to assess system performance. This monitoring will be particularly important since it will better reflect student exposures to radon.

METHODOLOGY

To assist in understanding radon entry into the schools and to design effective mitigation systems for the schools, continuous data were collected as part of the diagnostic measurements. Since HVAC system design and operation has been shown to have a significant effect on radon levels in schools, the continuous data were critical in selecting and designing mitigation systems for the schools.

A portable data monitoring system with the components listed in Table 1 was used to collect these data. This system allows for about 1 week of unattended data storage with up to 15 sensors. There was no interface between the continuous radon monitor (CRM) and the data logger, and software was developed so that the CRM and data logger data could be dumped into a computer and merged for further analysis.

Hourly data averages were computed from 5 second sensor readings that were stored in daily files. When these daily files were merged with the CRM hourly data files, each record of the merged file contained data for 1 hour. For a typical experiment, the merged data file consisted of hourly records containing the data words shown in Table 2. Not all of the sensors were used during each experiment, and the positioning of sensors varied according to building size and configuration.

MITIGATION STUDIES

CASE STUDY A: PRINCE GEORGES COUNTY, MARYLAND

Radon levels in this school were initially measured in February 1988: one classroom tested above 40 pCi/L; a teachers' lounge tested above 20 pCi/L; and several other classrooms tested between 4 and 20 pCi/L. The building is slab-on-grade construction with a large two-fan air handling system for HVAC. The HVAC system had a rated capacity of 51,000 cubic feet per minute (cfm*) of air distribution and 34,000 cfm of return air. This would result in positive

* 1 cfm = 0.47 liter per second

pressure in all rooms if the system were properly balanced. However, continuous radon and pressure measurements with the data logger indicated that many of the rooms were under negative pressure when both the supply and return fans were in operation. The room with the highest radon level measured 15 Pa negative pressure. As seen in Figure 1, there was a good correlation between negative pressure and radon levels in all rooms, with the highest radon levels in the rooms with the most negative pressures. When the return air fan was turned off the pressure in all rooms became positive, and radon levels decreased to less than 2 pCi/L. Examination of the air-handling system showed that the air distribution fan had been damaged and part of the housing cut away resulting in a great loss in capacity. It is believed that the distribution fan was actually supplying less air than the return air fan was removing, resulting in a negative pressure in many rooms.

The room with the highest radon level and the greatest negative pressure also had a very large floor-to-wall crack along one wall. This particular floor-to-wall crack was an expansion joint where two parts of the building were joined. The expansion joint had disintegrated, and the parts appeared to have separated about 1/2 inch (in.*) leaving a full 1 in. gap between the floor and wall. This gap was concealed by an aluminum angle iron installed when the building was built. The expansion joint and angle iron continued vertically up both corners so that it was serving as an expansion/contraction joint between the two parts of the building. When the return fan was operating, initial tests in this room showed a large flow of radon-containing soil gas out of this crack. The radon level was about 500 pCi/L in the soil gas exiting the crack, the same measured under the slab in the middle of the room. When the return air fan was turned off and the room was pressurized, room air flowed into the crack and consequently no soil gas was entering. Radon levels in the room quickly dropped below 2 pCi/L. The floor-to-wall crack was sealed with backer rod and urethane caulking. This sealing decreased radon levels only slightly when both fans were off indicating other soil gas entry points in the room.

The impact of HVAC operation on radon levels in this room is displayed in Figure 2 for a 7 day period. (The return air louvers were closed during these measurements.) While the HVAC system is operating, the room is at a higher pressure than the subslab area and, consequently, radon entry is reduced. However, when the HVAC system is turned off during night and weekend setback, pressure in the room drops and radon levels increase.

As a temporary solution to reduce radon levels, the return air fan was left off and the HVAC system operated with only the air distribution fan. Under these conditions, all rooms showed positive pressure and had radon levels below 2 pCi/L. The damaged supply fan has now been replaced and the air distribution and air return systems are being balanced.

As a precaution to reduce radon entry when the air handlers are

*1 in. = 25.4 mm

not operating during night or weekend setback, active subslab depressurization points are being installed in the rooms with the highest radon levels. It is anticipated that this will be an effective mitigation system since the school construction plans specify 4 in. of aggregate under the slab. Follow-up tests will be done in the next few weeks after the air flows are balanced and the subslab depressurization system is installed.

CASE STUDY B: WASHINGTON COUNTY, MARYLAND

This is a small school, 80 by 150 feet (ft*) built on the side of a hill with a 21 by 150 ft basement along the lower side with a walkout entrance. The unexcavated area is slab-on-grade with the slab extending over the basement area and resting on steel bar joists. The foundation walls are concrete block. The interior wall of the basement supports the end of the bar joists and the slab. This wall is not painted or waterproofed on either side. Building plans specify 4 in. of subslab aggregate.

The HVAC system consists of a single fan system on each floor supplying heat or cooling. A fresh air intake into the return air duct is under negative pressure during fan operation. Measurements made with the data logger indicate that the building is under positive pressure even when the fresh air intake is set for minimum supply. However, the HVAC system is normally set to run only when heat or cooling is required. As a result, the system may not come on during mild weather. In addition, the temperature in the below-grade part of the school is often buffered and, consequently, the HVAC system does not run as often in the basement as upstairs.

Charcoal canister measurements taken over a weekend in March 1988 averaged 10.5 pCi/L in the basement and 4.3 pCi/L on the first floor. It is unknown how the air handlers were operating during the test. All rooms were retested over a weekend in May 1988 with air handlers off and measurements ranged from 78 to 82 pCi/L in the basement and from 18 to 33 pCi/L on the first floor. Subslab and block wall radon levels measured as high as 1500 pCi/L.

Continuous radon measurements were made on both floors of the school during all phases of mitigation. Before mitigation, radon levels rose dramatically at night if the air handlers were off but did not rise if they were operated continuously. Pressure measurements indicated that the air handlers produced a slight positive pressure when in operation, thus reducing soil gas entry. In the hottest part of the summer, radon levels rose dramatically overnight when the air handlers were off. It is suspected that a night stack effect resulted since the hot inside daytime temperatures did not decrease as rapidly at night as the outdoor temperature. Overnight levels as high as 150 pCi/L were reached in the basement and levels as high as 100 pCi/L were reached on the first floor when the air handling fans were off. Continuous operation of the HVAC reduced radon levels to below 4 pCi/L within an hour.

*1 ft = 0.305 m

As a temporary solution, the HVAC system was run continuously while the school was occupied. For a permanent solution, subslab depressurization points were installed in phases in both the basement and on the first floor. Due to the high radon levels and complex foundation, it was anticipated that several suction points would be needed. A subslab suction point was first installed in the basement using a 1 ft diameter suction hole and a Kanaflakt T-2 fan (rated at 140 cfm at 0.75 in. static pressure). Radon reduction was about 50 percent; the pressure field extended less than 30 ft. The subslab suction hole was then enlarged to a diameter of about 3 ft with an additional decrease in radon levels and an increase in pressure field extension.

The T-2 fan was replaced with a larger Kanaflakt T-3B fan (rated at 310 cfm at 0.75 in. static pressure) resulting in further reduction in radon levels. This also increased pressure field extension to 40 ft. The suction point also caused some measurable depressurization under the first floor slab at the top of the stairs indicating some communication between the slabs.

To evaluate the performance of a single-point subslab suction system and to investigate the effects of a single-fan HVAC system on mitigation performance, Figure 3 shows radon and pressure measurements in the school over a 10 day period. The first floor single fan HVAC system was operated continuously during the week to provide mitigation while the school was in session on the first floor. Since the basement was unoccupied during the monitoring period the basement HVAC system was not operated. Over the weekend (day 156), the HVAC system and the single point subslab suction system were turned off, and the radon levels rose quickly on both floors. On day 157 the subslab suction system remained off, but the first floor HVAC system was turned on. Radon levels on both floors dropped, and the differential pressure across the slab and block wall became slightly negative. During the school week (days 158-163), both the HVAC system and subslab suction system were operating, and radon levels remained low. During the following weekend (days 164 and 165), the subslab suction system was operated and the first floor HVAC system was off, resulting in an increase in radon levels. As seen in Figure 3, radon levels on the first floor reached 40 pCi/L under these conditions, so another suction point was installed on the first floor using a Kanaflakt T-3B fan (rated at 310 cfm at 0.75 in. static pressure) and a 3 ft diameter suction hole. The first floor suction point was located on the west end of the building because radon levels were always higher there than on the east end. Subslab radon measurements also showed greater source strength on the west end. Addition of this suction point reduced levels on the first floor although radon levels on both floors still rose above 10 pCi/L at night with the air handlers off.

Pressure field extension measurements indicated incomplete coverage of both floors. Consequently, two additional suction holes were installed in the basement, each with a T-2 fan and a 1 ft diameter suction hole. A 1 ft diameter suction point was also installed on the first floor and manifolded to the existing suction point.

Pressure field extension measurements indicated overlapping fields between suction points in the basement area. Consequently, it was believed that all of the basement subslab was adequately depressurized. Basement radon levels measured below 2 pCi/L with the air handlers off and the mitigation systems operating; however, first floor radon levels still rose above 4 pCi/L at night with the air handlers off.

Based on mapping of subslab radon levels on the first floor, three additional suction points were installed, each with a 6 in. riser and a 1 ft diameter suction hole. Two points were manifolded to a single Kanaflakt T-4 fan, and a separate fan was installed on the other suction point. After installation of these last three suction points, radon levels stayed below 4 pCi/L on both floors with the exception of occasional brief excursions above 4 pCi/L at night. The causes of these excursions are being further investigated.

Although subslab suction was effective in solving a serious radon problem at this school, it was surprising that it took so many suction points. Aggregate under the slab was confirmed visually at every suction point; however, the aggregate used was probably unscreened "crusher run," containing a great deal of fines. This tends to confirm our belief that screened, coarse aggregate (3/4 to 1-1/4 in.), essentially free of any material less than 1/4 in. diameter, is preferred for optimal operation of subslab depressurization systems.

CASE STUDY C: WASHINGTON COUNTY, MARYLAND

This entire school building is slab-on-grade with block walls and no utilities below grade except sanitary sewers. The original building was constructed in 1956 and has four area air handlers for heating and ventilating with a central boiler room. A classroom wing was added in 1968 and unit ventilators are in each room. None of the building is air-conditioned. Construction plans specified 4 in. of subslab aggregate under the entire building. Elevated radon levels were found in the locker rooms on each side of the gymnasium in the original building and in the new classroom wing. Mitigation of each of these areas is discussed separately.

Original Building - Locker Room Mitigation

Although the locker rooms and gymnasium are on the same air handler, the gymnasium measured 1.8 pCi/L whereas the girls' locker room measured 4.9 to 6.3 pCi/L and the boys' locker room measured 5.3 to 19 pCi/L. Further examination indicated that each locker room area had large exhaust fans to remove odors and shower steam. Differential pressure measurements (using a micromanometer) with the air handler and exhaust fans operating correlated with the radon levels showing that the gym was slightly positive, the girls' locker room area slightly negative, and the boys' locker room area significantly negative.

Construction plans showed that each six room locker area was a continuous slab with aggregate beneath it. As a result, a 6 in. subslab suction point was placed in the two locker room areas with a 1 ft diameter hole and a Kanaflakt GV-9 fan (rated at 200 cfm at 0.75 in. static pressure). Both locker room areas measured less than 4 pCi/L with the exhaust fans and the subslab depressurization systems operating.

New Classroom Wing

Weekend charcoal canister measurements were made in April 1988 in this wing with the unit ventilators off. All but one room were above 4 pCi/L, with a room in the northeast corner measuring 26.7 pCi/L. Levels decreased from north to south in this wing as did subslab radon levels. A CRM was placed in the room with the highest radon levels. When the unit ventilator was off, levels above 20 pCi/L were reached nightly but remained below 2 pCi/L when the unit ventilator was run continuously. Pressure measurements made with a micromanometer confirmed that the unit ventilator was pressurizing the room slightly.

Since the unit ventilators are off at night except in extremely cold weather (when they are cycled), it was decided to install two subslab depressurization points in the wing. These 4 in. pipes were installed in the hall and manifolded with an above ceiling 6 in. pipe running to the north end of the building to a Kanaflakt GV-12 fan (rated at 510 cfm at 0.75 in. static pressure). One suction point was installed with a 3 ft diameter hole about 20 ft from the east end of the hall and the other suction point installed with a 1 ft diameter hole about 60 ft from the end of the hall. Pressure field extension measurements indicated that the two fields overlapped, and all of the wing was depressurized to the outside walls except for the most southern classrooms.

Since the pressure field extension around the 1 ft diameter suction hole was not as great as around the 3 ft suction hole, the 1 ft subslab suction hole was increased to 3 ft in diameter. This extended the measurable depressurization area by 10 ft to the south (enough to reach the last two classrooms) and about doubled the amount of depressurization in the test holes in all directions around the suction point. With the subslab depressurization system operating, radon levels were below 4 pCi/L in all classrooms with the unit ventilator fans off.

CASE STUDY D: WASHINGTON COUNTY, MARYLAND

The original building of this school was built in 1958 and is heated with hot water radiant heat in the slab. In 1978 a kindergarten room was added to the original building, and a separate building (referred to as Building B) containing four classrooms, a library, a teachers' workroom, a conference room, and restrooms was built. The kindergarten room is heated with hot water radiant heat, and the new building is heated with unit ventilators. Office space in the original building is air-conditioned with a window unit. No other area of either building is air-conditioned.

The original building has two 3600 cfm roof-mounted fans that could be used to exhaust air in plenums over the hall ceiling. Each room has a ceiling vent connecting to these hall plenums. However, the exhaust fans are never used. Consequently, the building presently has no active ventilation system. Plans showed that the initial building had 6 in. of aggregate under a 6 in. thick slab (containing hot water pipes) and Building B had 4 in. of aggregate under a 4 in. slab.

All rooms in both buildings were tested with charcoal canisters over a weekend in mid-April. The eight rooms in Building B measured between 17.1 and 20.3 pCi/L. It is believed that the unit ventilators were off during the testing weekend, but this could not be confirmed. Seven tests in the classrooms, library, and multi-purpose room in the original building measured between 11.9 and 23 pCi/L. Mitigation of the two buildings is discussed separately.

Building B (Unit Ventilators)

A CRM was placed in one of the classrooms in Building B to measure the effect of unit ventilator operation on radon entry. It was found that radon levels would rise overnight to above 20 pCi/L with the ventilator off but would remain below 2 pCi/L with the ventilators on. Again, this shows that this type of ventilator can pressurize the room slightly, preventing radon entry when run continuously.

Since the ventilators are off during night setback, a four point subslab depressurization system was installed to reduce radon entry. The risers are 4 in. pipes connected to two 6 in. manifold pipes above the drop ceiling. (Two risers are manifolded to each pipe.) A Kanaflakt GV-9 fan (rated at 200 cfm at 0.75 in. static pressure) is used to exhaust each system. Pressure field extension measurements indicated that depressurization extended 50 ft, the minimum distance necessary to reach all parts of the slab.

With the subslab system operating and the unit ventilators off, all rooms remained below 4 pCi/L. However, based on the pressure field extension measurements, the system may be marginal during cold weather. If radon levels rise above 4 pCi/L it is believed that subslab depressurization can be improved by sealing the floor-to-wall opening. A 1/2 in. expansion joint around all of the slabs in the building is deteriorating, leaving significant openings to the subslab. This probably leads to some short circuiting of the subslab depressurization system.

Original Building (Intra-Slab Radiant Heat)

Subslab suction on this intra-slab radiant-heated building was a challenge since construction plans showed that the hot water pipes in the slab were 15 in. or less apart over the entire building. As a result, it was difficult to locate an area where a 6 in. subslab suction point could be put through the slab without running the risk of damaging a hot water pipe. A 3 ft square area without water pipes was finally located in each room. A hole was successfully cut through one of these areas. The plans indicated that the aggregate was a minimum of 6 in. deep, much deeper than any other school examined. A 6 in. suction point was installed with a 3 ft diameter hole with a Kanaflakt KTR150-8 fan (rated at 510 cfm at 0.75 in. static pressure). Pressure field extension was far greater than expected, and depressurization could be measured as much as 90 ft from the suction hole. These results were surprising since the aggregate appeared to be some type of "crusher run" aggregate with a certain amount of fines. However, in leveling the aggregate before pouring the concrete it is probable that most of the fines had sifted to the lower portion of the aggregate bed leaving a fairly thick area of large diameter aggregate immediately under the concrete. It is believed that this layer of coarse stone made for a much greater pressure field extension and will be studied further. Although final testing is not complete, it appears that this one suction point will solve the problem in the original building. If this one suction point is not sufficient to treat the entire building, it may take a second point operated on a separate fan to completely mitigate the building.

To analyze the effectiveness of a single point subslab suction system and to investigate the pressures that control radon levels in schools during hot weather, radon, pressure, and temperature were monitored continuously in one classroom, as seen in Figure 4. The classrooms were kept closed during this period of very hot weather, and there is no ventilation system in this building. When the subslab ventilation system was turned off from day 222 through day 225, the radon levels quickly rose and followed a diurnal cycle that seems to match the temperature cycle. When the outdoor temperature is coolest relative to indoor temperature, the radon levels are highest. This can be expected from the stack effect, as discussed in Case Study B. Although a small positive pressure was measured across the slab during this period, it does not show significant diurnal variation. The differential pressure across an outside classroom wall does not show much correlation with the radon levels, except for a sharp dip in the middle of day 224 that may be due to wind.

Since the kindergarten room is an addition, the subslab area does not communicate with the original building. Consequently, a suction point was put in a closet adjacent to a restroom where the hot water pipes were spaced 24 in. apart to clear the sewer line of the commode. A Kanaflakt T-2 fan (rated at 140 cfm at 0.75 in. static pressure) installed on this point lowered radon levels to below 2 pCi/L. No pressure field extension measurements were made for fear of damaging a heating water pipe.

CASE STUDY E: FAIRFAX COUNTY, VIRGINIA

This was the initial school with elevated radon levels identified in the Washington, DC, area and, consequently, received a great deal of publicity. The building was initially diagnosed by EPA's Office of Radiation Programs (ORP) personnel and by Infiltec who was under contract to Fairfax County school authorities.

The building was heated by hot water fin heaters along the outside walls. Each room had a ventilation exhaust register connecting to the plenum over the rooms and the hall. A number of roof-mounted exhaust fans in this plenum caused severe depressurization (15 Pa negative pressure) of the entire building since makeup air entered the building only through infiltration. As a result, subslab soil gas was pulled into the building. Fortunately, the radon source strength was not very high or the building could have had much higher radon levels.

The two end classrooms of the southwest wing had levels of 21.9 and 16.5 pCi/L with three other rooms above 4.0 pCi/L. The southeast wing had three rooms with moderately elevated levels of 5.4, 6.0, and 6.5 pCi/L.

Subslab suction points were put in the two end rooms of the southwest wing, manifolded overhead, and connected to one Kanaflakt GD-9 fan (rated at 310 cfm at 0.75 in. static pressure). With this system in operation there was good pressure field extension to at least three rooms on each side of the hall. In addition, all of the floor-to-wall joints were carefully sealed in all of the rooms of both wings. Following sealing and installation of the two suction points, all of the rooms in both wings tested below 4 pCi/L.

CONCLUSIONS

The following tentative conclusions can be drawn from EPA's experience in installing radon mitigation systems in five schools in Maryland and Virginia. These tentative conclusions are based on limited studies and will be verified and expanded with further research.

1. Although pressure control through continuous HVAC fan operation can often be an effective temporary solution to reduce elevated radon levels in schools, its use as a permanent mitigation method could be unpredictable due to night and evening HVAC setback.

2. A subslab depressurization system can usually overcome negative pressures induced by HVAC operation in schools if there are no return air ducts under the slabs.

3. Increasing suction hole size increases pressure field extension in schools, resulting in a more effective subslab depressurization system.

4. Effective mitigation of schools using subslab depressurization requires greater fan capacities and suction pipe diameters than for houses.

ACKNOWLEDGMENTS

We would like to thank all the school personnel who contributed to the information presented in this paper.

TABLE 1. Monitoring System

Qty	Component	Description
1	FOWLKES SAM 8.12.4	32 channel portable data acquisition module
1	NEC 8201A	Portable computer with 32 kb
4	AD-590 Sensor	TO-52 calibrated temperature sensors
3	MODUS Sensor	Pressure transducers (+/- 0.5 in. WC*)
3	PYLON AB-5	Continuous radon monitors
3	PYLON PRD-1	Passive radon cells
1	SENTRA Sensor	Barometric pressure sensor
1	GRAINGER Sensor	Sail switches

TABLE 2. Measurements

Data Word	Measurement	Description
1	Julian Day	includes fraction to indicate hour
2	hour	0 to 23
3	pressure A	room-to-outdoors (in. WC)
4	pressure B	room-to-outdoors (in. WC)
5	pressure C	room-to-upstairs (in. WC)
6	Sail switch	HVAC % on time (0 to 100)
7	barometer	in. mercury
8	temperature A	outdoors (degrees Fahrenheit)
9	temperature B	inside near ceiling (degrees Fahrenheit)
10	temperature C	upstairs (degrees Fahrenheit)
11	temperature D	inside near floor (degrees Fahrenheit)
12	radon A	room 1 (pCi/L)
13	radon B	room 2 (pCi/L)
14	radon C	room 3 (pCi/L)

*1 in. WC = 248 Pa

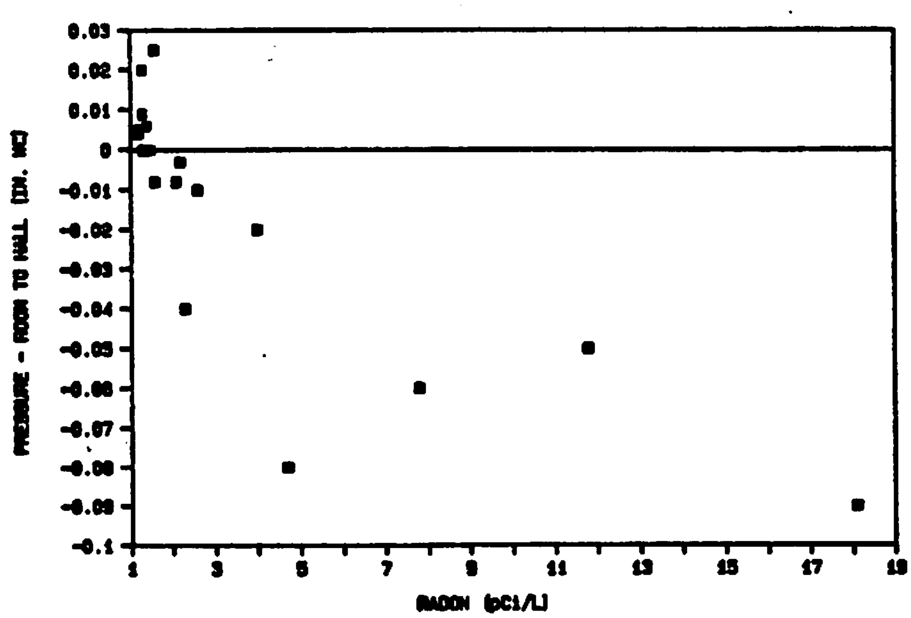

Figure 1. Correlation Between Radon Levels and Pressure (Case Study A)

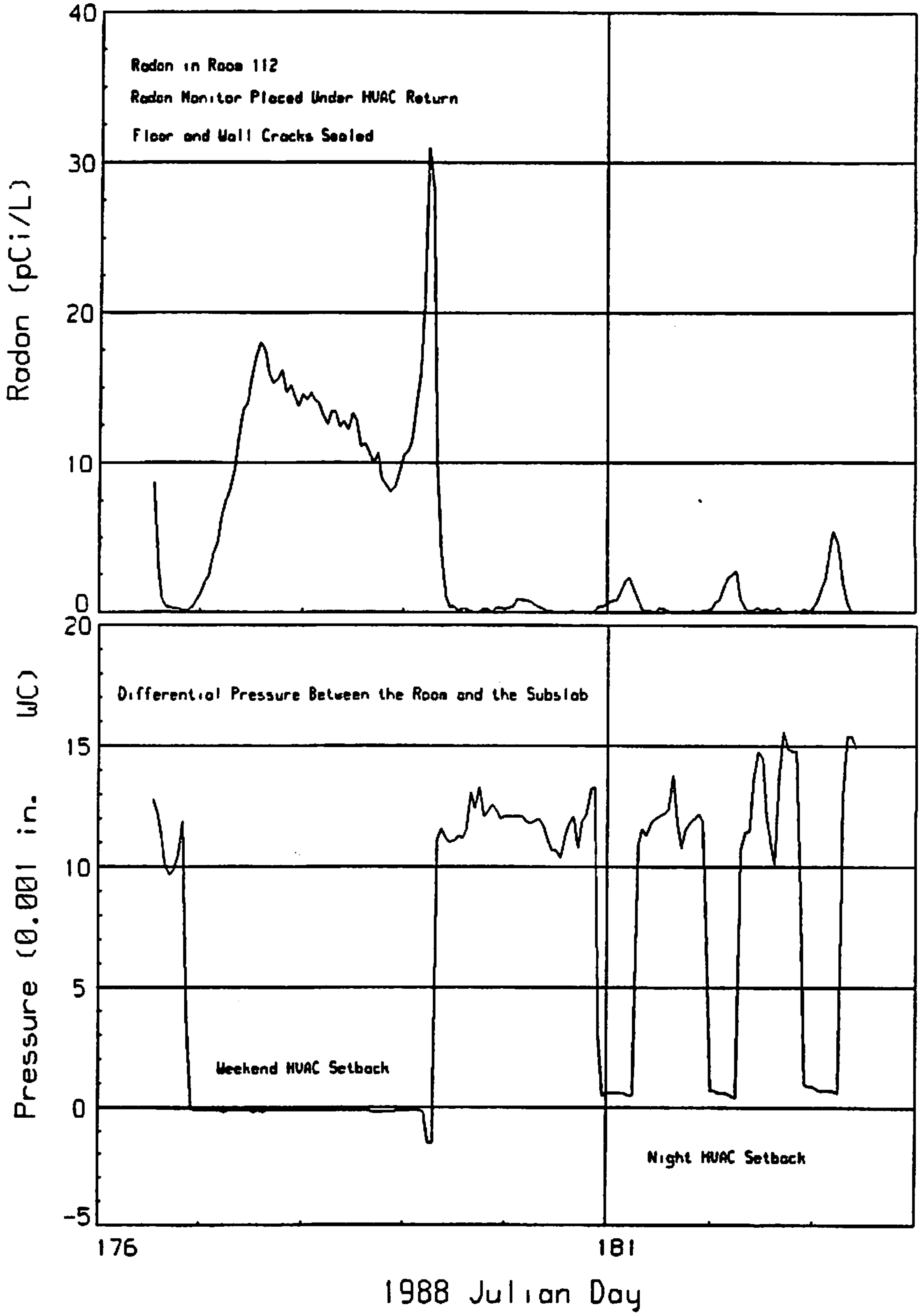

Figure 2. Influence of HVAC Operation on Radon Levels (Case Study A).

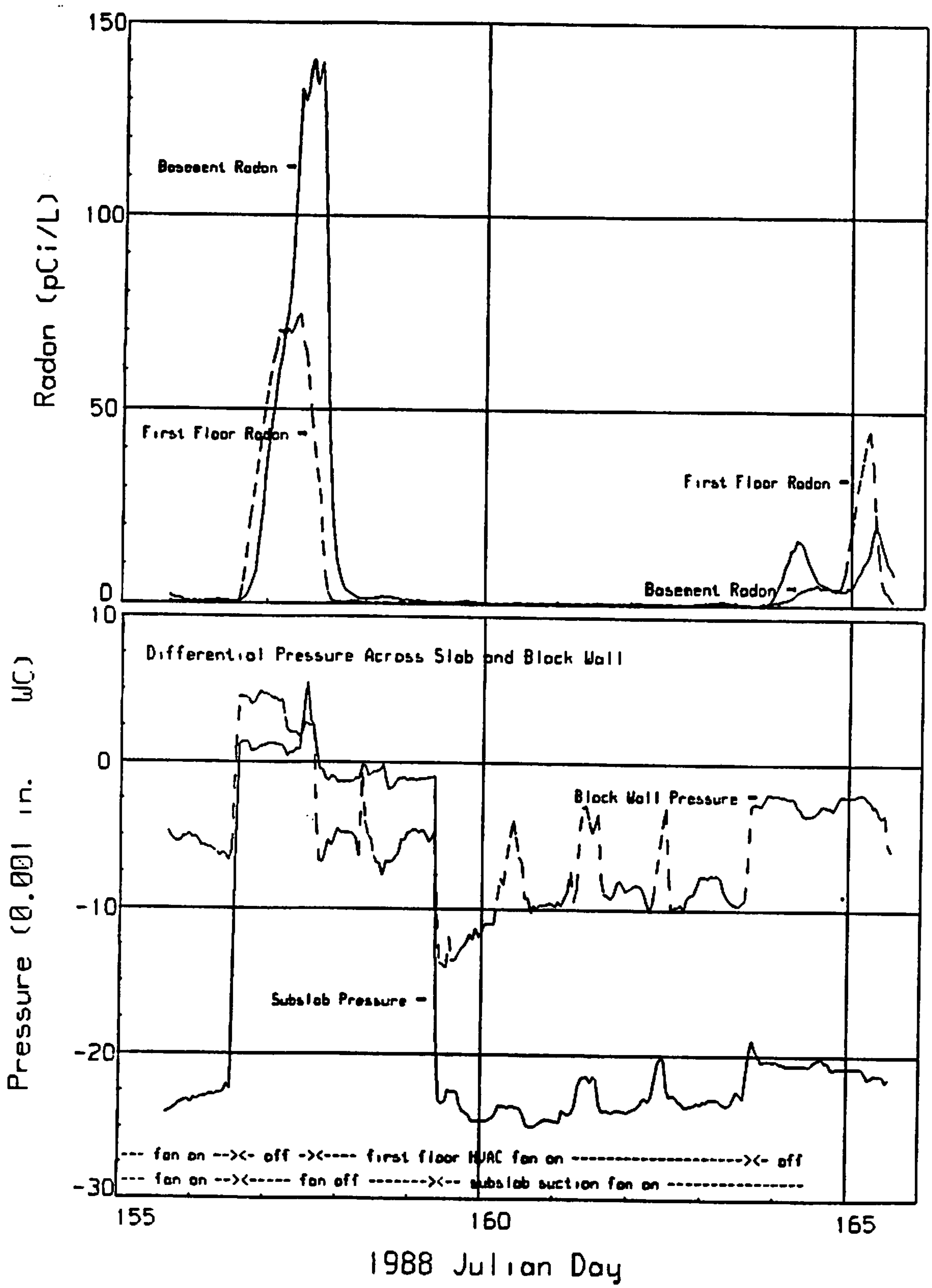

Figure 3. Influence of HVAC Operation and Single Point Subslab Depressurization on Radon Levels and Pressure (Case Study B).

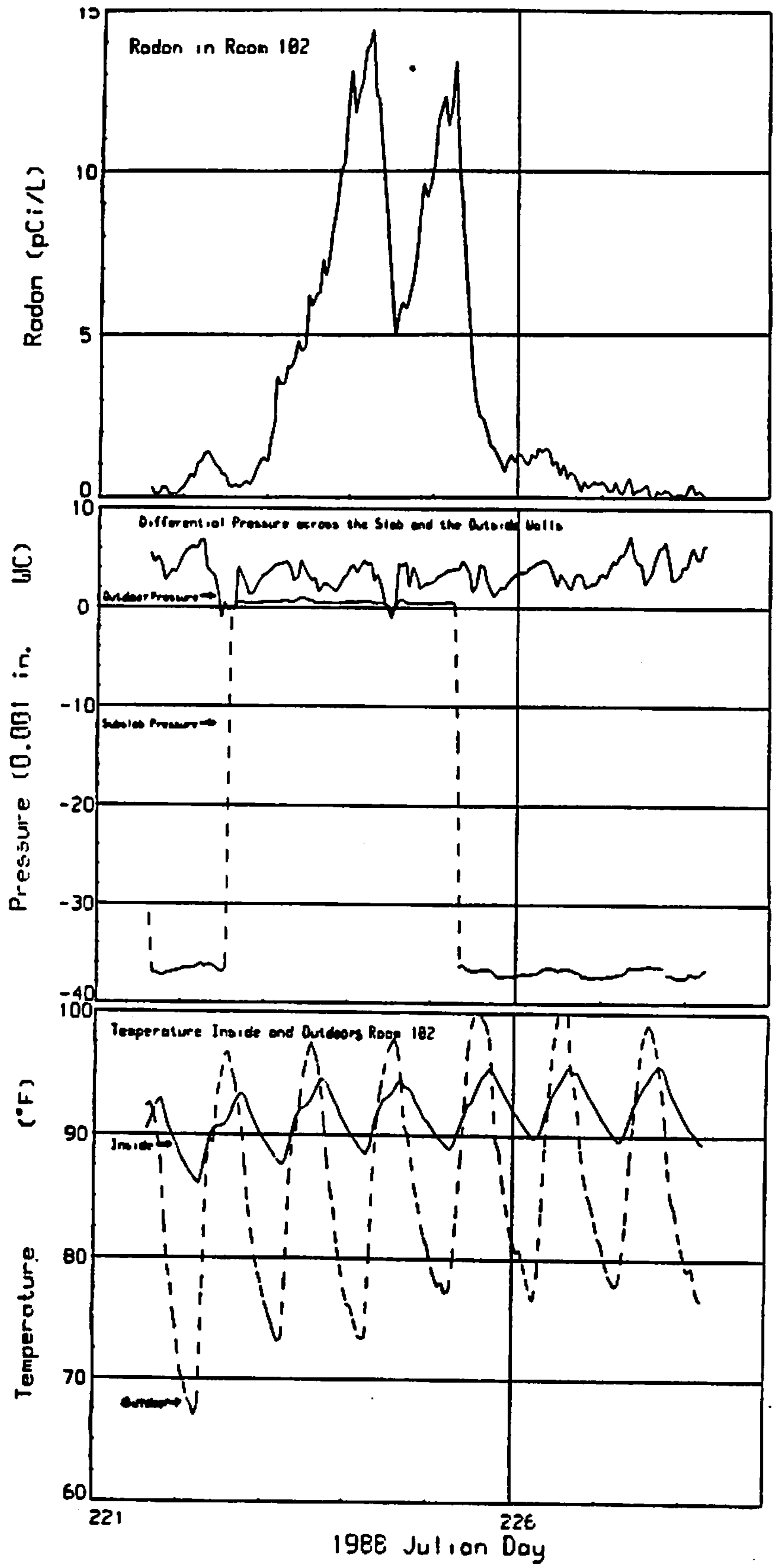

Figure 4. Effect of Single Point Subslab Depressurization on Radon Levels (Case Study D).