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WIND AND BAROMETRIC PRESSURE EFFECTS ON RADON IN TWO MITIGATED HOUSES

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ABSTRACT

Several short duration but dramatic rises in indoor radon were noted during continuous radon monitoring in the basements of two homes in the Reno area after the installation of sub-slab suction radon mitigation systems. Indoor radon increased following periods of high winds accompanied by sharp drops in barometric pressure. In the most dramatic case, indoor radon levels increased tenfold during the wind event. Moderate winds or moderate drops in barometric pressure alone do not appear to be sufficient to overcome the depressurization systems; however, the combined effect of a sharp drop in barometric pressure and concurrent high winds over a sustained period overpowered the depressurization systems installed in the two houses in this study, allowing radon to build up to 29 and 34% of the pre-mitigation concentration. This factor should be taken into consideration when designing mitigation systems and retesting after mitigation in areas prone to frequent high winds.

INTRODUCTION

The effects of barometric pressure or wind on indoor radon (radon-222) concentrations have been noted and discussed by others (Jonassen, 1975; Stranden and others, 1979; Hernandez and others, 1984; Cohen, 1985, 1986). This paper discusses the effects of the meteorological factors of wind and barometric pressure on indoor radon concentrations in two houses (House A and House B) with sub-slab depressurization mitigation systems installed. The Nevada Bureau of Mines and Geology (NBMG) has been studying various aspects of radon in indoor air, outdoor air, soil gas, and water for three years under a grant from the United States Environmental Protection Agency (EPA) State Indoor Radon Grants (SIRG) program. During the fourth year of the SIRG program, work included the demonstration mitigation of two homes with very high indoor radon concentrations. The meteorological effects on indoor radon were first noted during post-mitigation retests in House B using a continuous radon monitor (Pylon Electronics Inc. Model AB-5 alpha scintillometer) to confirm the effectiveness of the installed sub-slab mitigation system. During the measurements, a dramatic rise in indoor radon concentration appeared to coincide with the passage of a severe windstorm. In order to investigate this occurrence more completely, detailed hourly weather data were obtained from the National Weather Service for the period of time during which radon had been measured in House B. In addition, the Pylon instrument was set up to record hourly radon concentrations at House A, where a sub-slab mitigation system had recently been installed, for several days when more windstorms were predicted for the area. Weather data were also obtained for a period of time prior to the mitigation of House B when the home's radon concentration was measured over several days with the Pylon instrument to assess the extent and variability of the radon problem in this house. Meteorological data and radon concentrations for these time periods at the two houses are charted in Figs. 1, 2, and 3.

METHODS AND MATERIALS

Background on Homes and Mitigation Systems

House A first came to the attention of NBMG radon staff when a commercial house inspector reported to NBMG that he had obtained a charcoal canister radon measurement of 3659 Bq m^{-3} in the occupied basement of a 70-year-old, 3-story frame home, and that the occupants wanted advice on mitigation. NBMG staff retested both the basement and ground floor of House A in January 1993, using 7-day charcoal canister detectors provided and analyzed by the EPA radon laboratory in Las Vegas. Conditions of the house inspector's radon measurements could not be duplicated because the homeowner persisted in keeping basement windows slightly open during the test period. Even with the open windows, radon in the basement hallway was measured at 2472 Bq m^{-3}, and 3907 Bq m^{-3} in a closed basement storeroom that had no windows. Ground floor measurements in two rooms during the same time period in January were 1436 and 1317 Bq m^{-3}.

Diagnostic testing was done by NBMG radon staff working in conjunction with a local contractor listed with EPA Radon Contractor Proficiency (RCP) program, and the home was mitigated by this contractor in February 1993. Mitigation consisted of two separate sub-slab depressurization systems with RadonAway DynaVac GP500 fans installed near opposite ends of the house, which has a slab area of approximately 177 m^2. Each fan has a maximum pressure rating of 10.9 cm water column. Mitigation efforts were complicated by poor sub-slab communication, pervasive cracks in the slab, buried footings, finished walls, a multi-level slab floor, and a crawl space/stem wall foundation under a more recent addition to the house. A passive system of perforated drain pipe vented to the outside was also installed under a polyethylene radon barrier sealed to the foundation walls of the crawl space. All major visible and accessible cracks in the slab were sealed using a commercial radon sealant. Post-mitigation radon retests in March 1993 using 7-day charcoal canisters yielded radon measurements of 148 and 185 Bq m^{-3} in the basement and 44 Bq m^{-3} on the ground floor under closed-house conditions.

House B was brought to the attention of NBMG radon staff when an occupant of the house contacted NBMG staff with the information that he had obtained a commercial charcoal canister test result of approximately 4810 Bq m^{-3} in the occupied lower level of a home about 26 km north of Reno. NBMG staff retested this 10-year old, 3-story frame house in late January using 7-day charcoal canisters provided and analyzed by the EPA laboratory in Las Vegas. Side-by-side charcoal canisters on the ground floor/basement (actually a concrete slab foundation with minimal ground contact along walls consisting of soil and bedrock less than halfway up the walls around less than half the perimeter of the house) yielded measurements of 6194 and 6568 Bq m^{-3}. A charcoal canister measurement on the second floor was 2945 Bq m^{-3}.

After diagnostic testing, a single-point sub-slab depressurization mitigation system was installed in March 1993 on the ground level of House B, which has a slab area of 206 m^2, by the same contractor used for House A. The system uses a high-suction RadonAway DynaVac HS2000 fan capable of up to 45.7 cm water column of pressure. All major visible and accessible cracks in the slab were sealed using a commercial radon sealant. Seven-day charcoal canister retests in March yielded values of 44 Bq m^{-3} on the ground/basement floor and 30 Bq m^{-3} on the second floor. A Pylon AB-5 continuous radon monitor was run for several days prior to installation of the system and for several days immediately following installation in order to document the drop in radon concentration and the amount of time necessary to reach a relatively constant lower radon level following start-up of the mitigation system. It was during this post-mitigation testing period that the meteorological effects on the indoor radon concentrations were first noted.

Meteorological Data

Hourly surface weather observation data were obtained from the National Weather Service for the time periods during which indoor radon was measured at the two homes. Weather observations were made at the Reno-Cannon Airport, which is located about 5 km east-southeast of House A, and about 26 km southwest of House B, but all sites are under generally the same air mass. Elevation at the airport is about 1340 m above sea level, House A is at about 1390 m, and House B is at about 1780 m elevation. Although these differences in elevation cause the absolute value of barometric pressure at the homes to be different than that at the airport, the observations that are being studied in this report involve changes in radon relative to changes in barometric pressure, which should be similar to those changes observed at the airport weather station. Similarly, the onset and duration of wind events recorded at the airport can be generally extrapolated to the two house sites although wind speeds recorded at the airport are probably somewhat different than those at the two house sites. House B is situated in a very wind-prone area on an exposed hilltop and probably is subjected to significantly higher wind speeds than those observed at the airport. All reported barometric pressures are corrected to sea level.

Indoor Radon Measurements

Radon was monitored continuously with a Pylon Electronics Inc. Model AB-5 alpha scintillometer under normal closed-house conditions with windows closed and doors opened only for normal occupant entry and exit. Indoor air was pumped continuously through a Lucas cell (Lucas, 1957) attached to the Pylon instrument and radon concentrations were recorded hourly in picocuries per liter of air on a printer connected to the Pylon instrument. The Pylon instrument has a measurement error of ±37 Bq m^{-3} under these conditions.

RESULTS

Indoor radon measurements for the two houses and meteorological data were converted to SI units and graphed in Figs. 1, 2, and 3. Fig. 1 shows the radon concentration at House B, with corresponding wind speed and barometric pressure over a 3 -day period immediately prior to mitigation (which began at 1400 hours, 13 March). This graph shows the extreme daily variation in indoor radon concentration at House B with peak values usually occurring in the hours just before and after midnight, and generally lower radon values in the pre-noon hours. Peak radon concentration during this time period was 4858 Bq m^{-3} at 2000 hours on 12 March, about 9 hours after the onset of a sharp drop in barometric pressure that began at about 1100 hours. Another peak radon concentration of 4440 Bq m^{-3} at 1800 hours on 10 March occurred about 5 hours after a drop in barometric pressure and the beginning of a period of elevated wind speeds. It should be noted that a high-efficiency gas furnace was in operation at House B during this time, with a direct line of outside air for combustion make-up air and a direct outside exhaust line.

Fig. 2 shows the indoor radon concentration on the ground floor/basement at House B, with corresponding wind speed and barometric pressure over a period of approximately 5 days beginning immediately after start-up of the mitigation system at 1600 hours on 14 March. The first eight hours show the drop in indoor radon concentration attributable to the operation of the mitigation system. After this, radon concentration levelled out for more than two days from 0000 hours on 15 March until 0900 hours, 17 March at 106 Bq m^{-3}. Indoor radon concentration began to rise sharply at about 0900 hours and peaked at 1600 hours on 17 March at 1854 Bq m^{-3}, which is approximately 29% of the pre-mitigation radon concentration of 6194 to 6568 Bq m^{-3} measured using charcoal canister detectors. This sharp rise in radon concentration began approximately 21 hours after the onset of a sharp drop in barometric pressure coupled with a severe windstorm lasting about 36 hours with sustained wind speeds of up to 13 m sec^{-1} and with gusts to 21 m sec^{-1}. During this windstorm and air pressure drop, the basement radon concentration increased tenfold from an average of approximately 100 Bq m^{-3} in the 24 hours preceding the event, to an average of 973 Bq m^{-3} during the course of the 10-hour long wind event, eventually reaching a peak of 1854 Bq m^{-3}. Indoor radon concentrations began to taper off as barometric pressure rose and the wind subsided shortly before 2400 hours on 17 March. An earlier period of high winds beginning at about 1200 hours on 15 March which was not accompanied by a substantial drop in barometric pressure did not have any appreciable effect on the indoor radon concentration at House B.

Fig. 3 shows the indoor radon concentration in the basement of House A, with corresponding wind speed and barometric pressure over a period of approximately 7 days from 30 March to 6 April, about a month after installation of the mitigation system. Post-mitigation testing with charcoal canisters from 15 March to 22 March yielded measurements of 148 and 185 Bq m^{-3} in the basement of House A. Radon concentrations for the first two days of continuous monitoring (30 March-31 March) were fairly constant, averaging 141 Bq m^{-3}. Indoor radon concentration began to rise sharply at about 2400 hours on 31 March, peaking at 1300 hours on 1 April at 1270 Bq m^{-3}, which is approximately 34% of the pre-mitigation closed-house radon concentrations of 3659 to 3907 Bq m^{-3} measured using charcoal canister detectors. The abrupt rise in radon concentration began approximately 14 hours after the onset of a sharp drop in barometric pressure accompanied by the beginning of a severe windstorm that lasted about 40 hours, with sustained wind speeds of up to 10 m sec^{-1} and with gusts to 18 m sec^{-1}. Indoor radon concentrations fell to pre-wind event levels as barometric pressure rose and the wind lessened shortly before 2400 hours on 1 April. A less distinct peak in indoor radon concentration on 4 April followed a more gradual drop in barometric pressure on 3 April, accompanied by another windstorm with sustained wind speeds of up to 13 m sec^{-1} and with gusts to 20 m sec^{-1} that lasted about 30 hours.

DISCUSSION OF DATA

Several significant drops in outdoor air pressure, accompanied by prolonged periods of high winds, resulted in a pronounced rise in radon concentrations in the basements of House A and B. This study was not designed as a rigorous scientific experiment, but rather as an empirical observation of related phenomena, nonetheless, certain quantitative observations can be made.

In both houses, both before and after installation of radon mitigation systems, a lag time of several hours was noted between the minimum barometric pressure and the maximum radon concentration in the homes. This effect has been noted by previous investigators and interpreted as the time necessary for radon to reach equilibrium with its daughter products in the room where it is measured. Jonassen (1975) noted a lag time of "few hours" as did Stranden and others (1979; interpretation of their Fig. 4). In the case of the homes in the present study, a lag time of approximately 3 to 9 hours was noted from the time that the barometric pressure reached a minimum value until the indoor radon reached a maximum concentration in the basements of the two homes, or approximately 9 to 21 hours after the onset of air pressure falls. Due to the variable nature of winds, (especially short-term wind gusts) it is difficult to attempt to correlate peak wind speeds with peak radon concentrations during the passage of the weather fronts. In some cases, indoor radon concentrations appear to reach their peak at about the same time as wind speeds (including wind gusts) reach their peak, but at other times, peak indoor radon concentrations appear to lag behind peak wind speeds as they do with falling barometric pressure.

Taking into account a lag time of several hours between fall in barometric pressure and peak in indoor radon, this study corroborates the conclusions of previous investigations of the effect of changes in barometric pressure or wind on indoor radon concentrations (Jonassen, 1975; Stranden and others, 1979; Hernandez and others, 1984; Cohen, 1985, 1986). That is, that a rise in indoor radon concentration can be correlated with periods of falling barometric pressure or increasing winds. Unlike previous studies, however, this study investigated the combined effects of barometric pressure and high wind on homes with operating active sub-slab depressurization systems.

The results of the present investigation show that before mitigation (House B only; Fig 1) there is an increase of approximately 8 to 15% of the mean radon concentration with every decrease in atmospheric pressure of 1 mbar, comparable to the increase of 6% in mean radon concentration for each decrease of 1 mbar in atmospheric pressure found by Jonassen (1975) in an unventilated room in an unmitigated house, and somewhat more than the increase of 4 to 5% of mean radon concentration per decrease of 1 mbar in pressure found by Stranden and others (1979) in unmitigated homes. The increase in radon concentration of 8 to 15% of the mean concentration per pressure drop of 1 mbar in House B appears to hold true for both relatively large (7 to 8 mbar) and relatively small (2 to 3 mbar) changes in atmospheric pressure.

After mitigation, however, relatively small decreases in air pressure of 2 to 3 mbar seem to have little effect upon the indoor radon concentrations in House B. Fig. 2 shows only minor variations in indoor radon concentration (generally less than the ± 37 Bq m^{-3} error of the continuous radon monitoring equipment used) for the basement of House B in response to small (2 to 3 mbar) changes in barometric pressure on 15 and 16 March, for example. It is not until the prolonged and relatively large (7 mbar or more) drop in air pressure on 16-17 March coupled with persistent intense winds (up to 15 m sec^{-1}), that the indoor radon concentration shows a significant rise.

Since the passage of a weather system resulting in a drop in atmospheric pressure is also usually accompanied by increased wind in this area, it is difficult to determine which effect, decrease in air pressure, or increase in wind speed, has the greater effect on the observed increase in indoor radon. In pre-mitigation House B, the large increase in indoor radon associated with falling barometric pressure on 10 March (Fig. 1) was accompanied by a period of somewhat higher winds, but the similarly large increase in indoor radon in this house associated with falling barometric pressure on 11 March was not accompanied by significantly higher winds.

Nothing can be said of the pre- versus post-mitigation effects of air pressure and wind speed changes in House A since continuous radon measurements were not obtained in this house prior to installing the mitigation system. However, in post-mitigation House A, it does appear that relatively small (2 to 3 mbar) decreases in air pressure, whether accompanied by significantly increased winds or not, do not have any significant effect on indoor radon in the basement of this house (Fig. 3). This relationship is similar to that noted in post-mitigation House B, above. On the other hand, a large and prolonged decrease in air pressure (up to 8 mbar), accompanied by a severe windstorm, as on 31 March and on 3-5 April, does have a dramatic effect on indoor radon concentrations in House A, similar to the relationship noted above in House B. In House A, as in House B, it is difficult to separate the effects that increased wind speed has on indoor radon as all the large decreases in air pressure shown on Fig. 3 were accompanied by prolonged periods of significantly higher winds.

CONCLUSIONS

The observations made in this study confirm that extreme drops in barometric pressure accompanied by severe windstorms can cause temporary increases in indoor radon concentrations, even in homes with operating active sub-slab depressurization systems. Observations also show that small to moderate drops in barometric pressure apparently are not sufficient to cause increased indoor radon in mitigated houses with active depressurization systems, whereas they can in unmitigated houses. The results of this study should be of interest and concern to radon testers and mitigators, as well as to homeowners who test their homes for radon. These results confirm that short-term screening tests, or retests following mitigation, should not be conducted during windstorms or during times of rapidly falling barometric pressure. In homes located in areas prone to frequent high winds, radon mitigators should consider installing higher suction capacity fans in their sub-slab depressurization mitigation systems than would normally be necessary.

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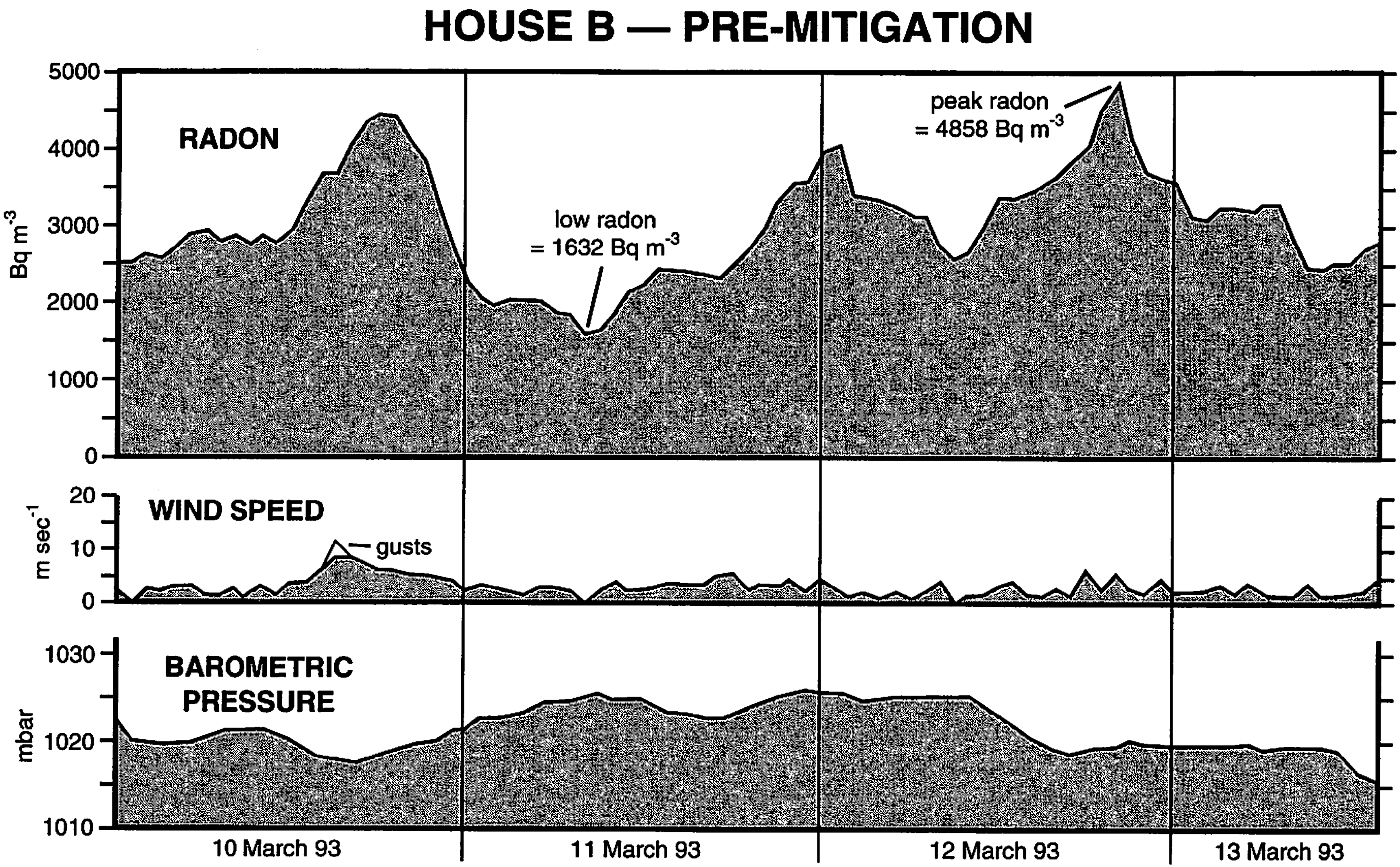


Figure 1. Indoor radon concentrations measured over the 3 1/2 days preceding the installation of a sub-slab depressurization radon reduction system in House B. Radon concentrations in the basement of House B were recorded hourly in the basement of House B beginning at 0100 hours on 10 March 1993, and ending at 1400 hours on 13 March 1993. Wind speed and barometric pressure, as measured at Reno-Cannon International Airport, were recorded hourly at about the same times that the radon measurements were recorded. Short-term gust speed is superimposed on the sustained wind speed curve.

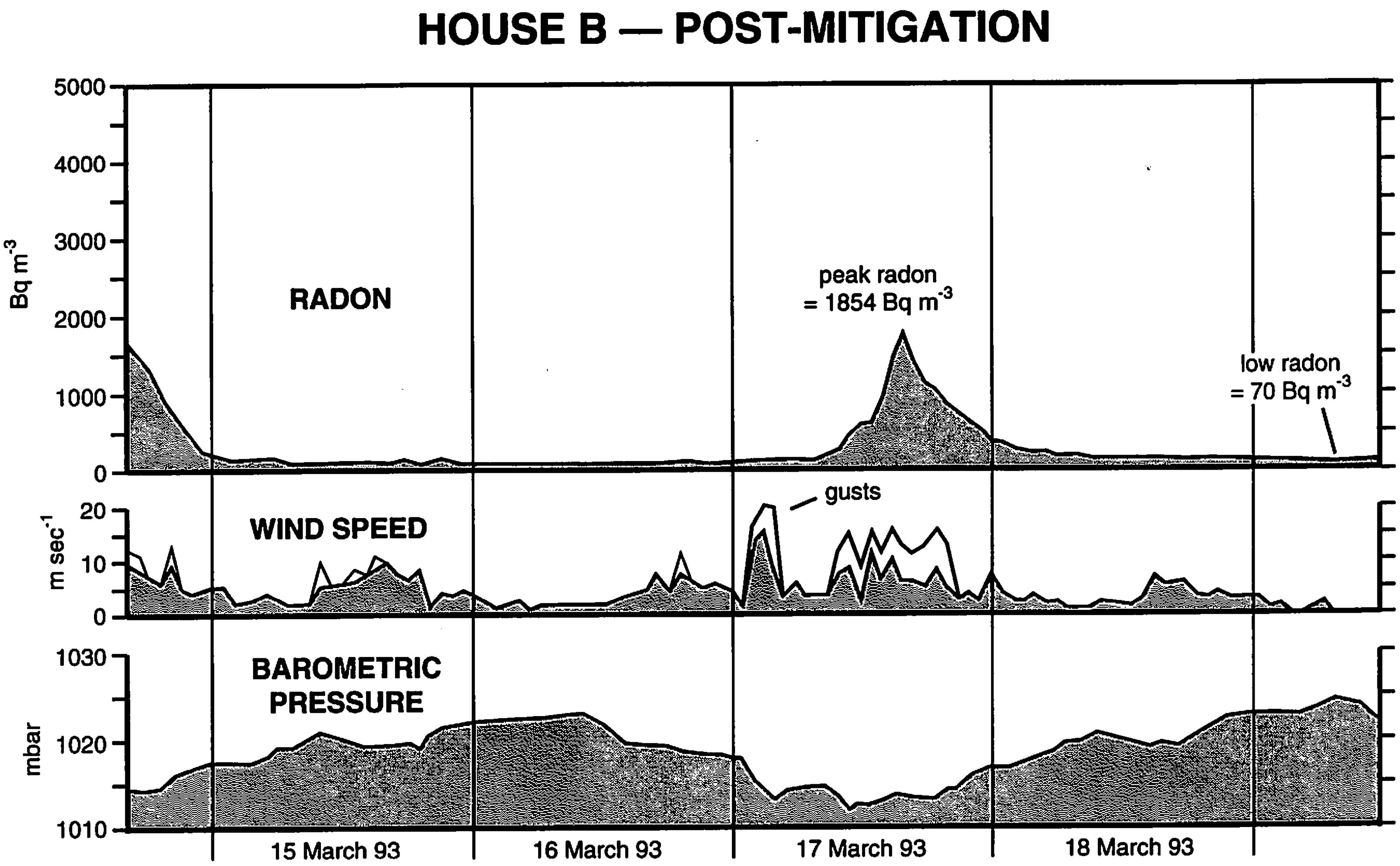
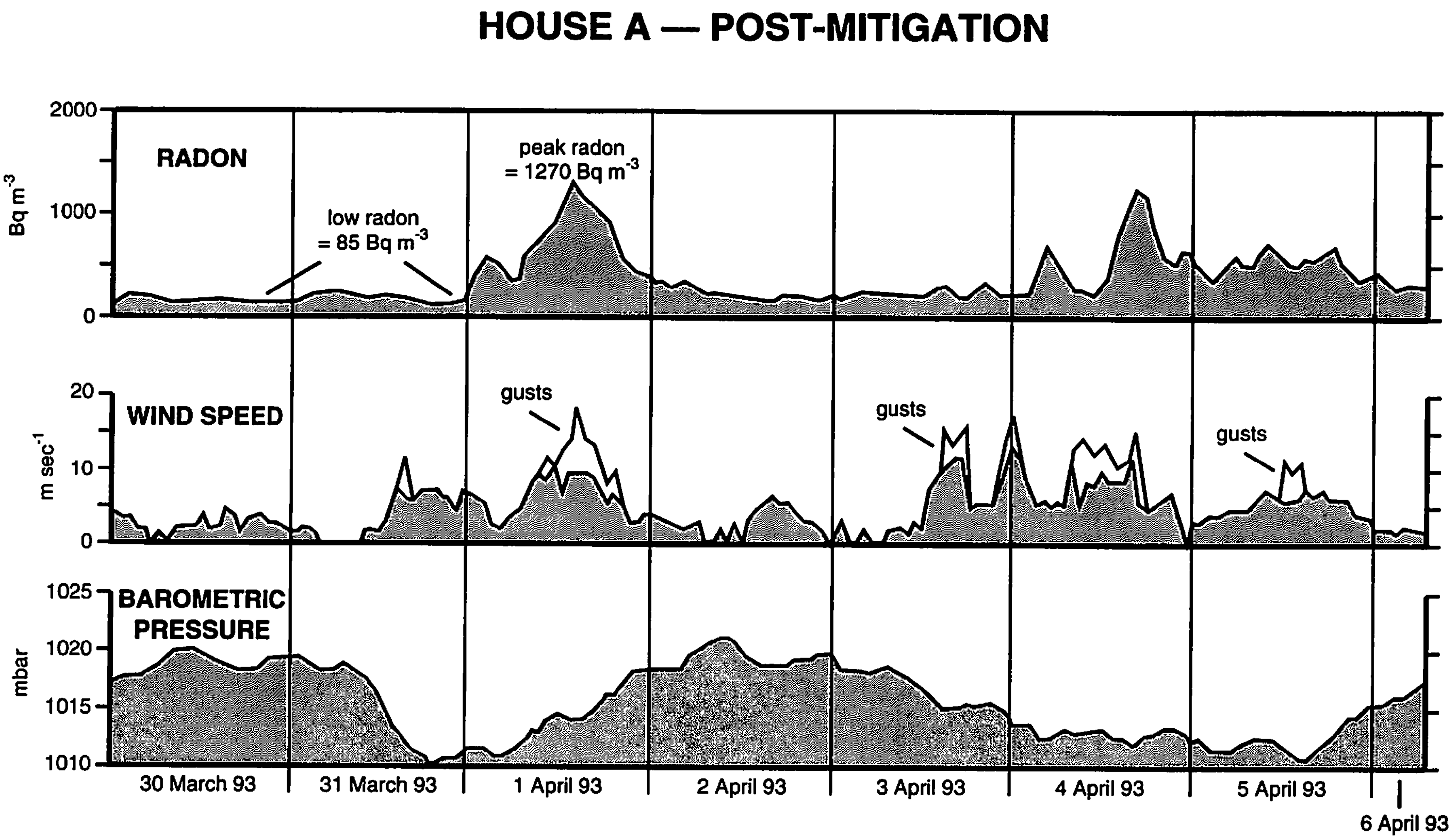

HOUSE B — POST-MITIGATION

Figure 2. Indoor radon concentrations measured over the 5 days following the installation of a sub-slab depressurization radon reduction system in House B. Radon concentrations in the basement of House B were recorded hourly in the basement of House B beginning at 1600 hours on 14 March 1993, and ending at 1500 hours on 19 March 1993. Wind speed and barometric pressure, as measured at Reno-Cannon International Airport, were recorded hourly at about the same times that the radon measurements were recorded. Short-term gust speeds are superimposed on the sustained wind speed curve.



HOUSE A — POST-MITIGATION

Figure 3. Indoor radon concentrations measured over approximately 7 days, a month after the installation of a sub-slab depressurization radon reduction system in House A. Radon concentrations in the basement of House A were recorded hourly beginning at 0100 hours on 30 March 1993, and ending at 0700 hours on 6 April 1993. Wind speed and barometric pressure, as measured at Reno-Cannon International Airport, were recorded hourly at about the same times that the radon measurements were recorded. Short-term gust speeds are superimposed on the sustained wind speed curve.