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NOTE

MEASUREMENT OF INDOOR AND OUTDOOR RADON CONCENTRATIONS DURING SUPERSTORM SANDY

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Superstorm Sandy affected much of the US East Coast extending over 1800 km. It passed over the test location in the State of Maryland on 29 October 2012. Being 350 km away from the regions of highest intensity the storm was of lower intensity at the test location. Continuous radon monitors and passive radon monitors were used for the measurement. The test location was the basement of a single family home representing the indoor concentration. A partially opened garage of the same test home represented the outdoor radon concentration. In 24 h, the atmospheric pressure dropped from 990 to 960 mbar and the indoor radon concentration increased from 70 to 1500 Bq m^{-3} and returned to the normal of 70 Bq m^{-3} at the end of the storm. Throughout the storm, the outdoor radon concentration was not significantly affected. Probable reasons for such surprisingly large changes are discussed. However, the outdoor temperature dropped from 13°C to 7°C during the radon peak.

INTRODUCTION

Hurricane Sandy, often referred to as 'Superstorm Sandy', is of great interest due to its unusual and unique characteristics[1]. The largest intensity of this storm occurred in the States of New York and New Jersey on 28 October 2012. It passed over test home in the State of Maryland on 29 October 2012. Being 350 km away from the regions of highest intensity, the storm was of relatively lower intensity near test home, but still a strong storm. This prompted one to study how radon concentrations change during such a storm. Continuous radon monitors (CRMs) and passive radon monitors were deployed from the start of the storm on 29 October 2012 until the end of the storm, continued until 1 November 2012. The indoor radon measurements were conducted in the basement of a single family test home. The outdoor radon measurements were conducted inside a partially opened garage of the same test home. Atmospheric pressure was also continuously measured along with the outdoor radon measurement at the same location. At the test location the storm lasted ~24 h from 9 a.m. on 29 October 2012 to 9 a.m. on 30 October 2012, deposited ~10 cm of rain, and registered sustained wind speeds of ~60 km h^{-1} with occasional gusts of 90 km h^{-1}. CRMs and passive radon monitors were deployed from the start of the storm on 29 October 2012 until 1 November 2012. The objective of this study was to examine how radon concentrations can change during such a large storm. The test home was located at Darnestown, MD, USA (latitude and longitude, 39.013441 and 77.290817, respectively).

MATERIALS AND METHODS

Radon Scout CRMs manufactured by SARAD (Germany) were used for measuring hourly radon concentrations. These CRMs have been evaluated by United States Environmental Protection Agency and certified by certifying organisations in the USA for indoor radon measurement. The CRMs provide hourly readings of radon concentration, temperature, pressure and humidity. The passive radon monitors that were deployed during the storm were E-PERM® electret ion chambers[2]. One pair of Radon Scout CRMs was used for indoor measurements and another pair was used for outdoor radon measurements. The indoor measurements were conducted inside the basement of a single family test home from the start of the storm as indicated by high velocity winds to the end of the storm as indicated by normal wind velocities. The test was extended for a total of 4.6 d. One set of two passive radon monitors was used for measuring the average radon concentration during the first 2 d and a second set of two passive radon monitors was used for measuring the average radon concentration during first 4 d. Analysis was carried out according to the standard procedures specified by the manufacturer of these radon monitors.

RESULTS

Figures 1 and 2 provide the hourly radon concentrations for two collocated CRMs. These measurements were conducted in the basement of a single family test home. The first 'data' point on each figure represents

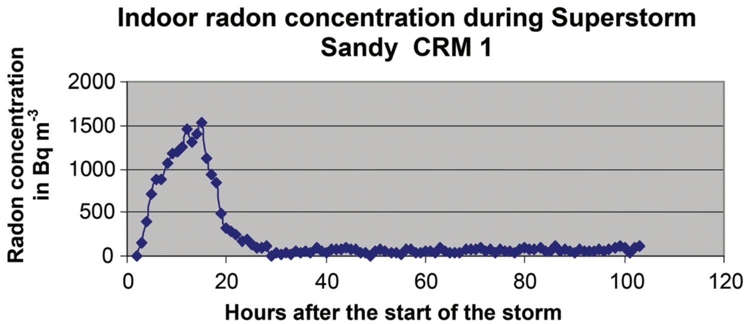

Figure 1. Indoor radon measurements in the basement of a single family home, closed house conditions, at 15808 Pioneer Hills Terrace, Darnestown, MD 20874 (latitude and longitude 39.013441 and 77.290817, respectively), measured with CRM 1.

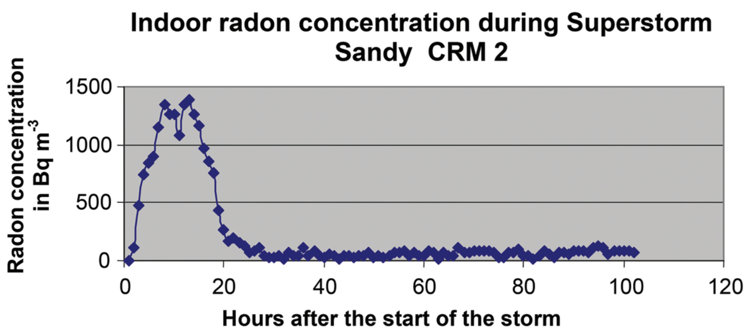

Figure 2. Indoor radon measurements in the basement of a single family home, closed house conditions, at 15808 Pioneer Hills Terrace, Darnestown, MD 20874 (latitude and longitude 39.013441 and 77.290817, respectively), measured with CRM 2.

the start of the storm at that location. Both Figures 1 and 2 indicate acceptable reproducibility, which authenticates the results. The radon peak appears to have a period of nearly 1 d. Later, the radon concentration returned to the background radon concentration of 70 Bq m^{-3}, which is normal for that home. For the outdoor radon measurement, the CRMs were located inside a partially opened garage, which provides a near outdoor environment. Figure 3 provides the outdoor radon concentration during the period of the storm. The outdoor radon concentration is in the range of 15 Bq m^{-3}, which is not significantly different from the normal background radon concentration[3] at this location. Figure 4 depicts the outdoor pressure during the storm. Figure 5 depicts the outdoor temperature. There is a very clear dip in the atmospheric pressure, which shows a clear correlation between the radon peaks in Figures 1 and 2 with the dip in pressure in Figure 4. The outdoor temperature dropped continuously during the storm. The indoor temperature remained steady at 20°C. Table 1 provides the results of radon concentrations as measured by the passive radon monitors. The 2- and 4-d average indoor radon concentrations showed significantly larger radon concentrations when compared with the normal concentration of 70 Bq m^{-3} for the test home. The data indicate that if a radon professional relied upon the radon concentrations sampled during 2 d that included the peak of the storm, he would have a reported radon concentration of 360 Bq m^{-3} in a home that has a normal radon concentration of 70 Bq m^{-3}. The corresponding results for a 4-d measurement would have been 224 Bq m^{-3} in a home that has a normal radon concentration of 70 Bq m^{-3}. These short-term tests would have significantly overestimated the average radon concentration in these homes. The short-term measurements which include events like storm Sandy should not be regarded as reliable test results, and in such cases, repeat measurements must be done, after abnormal conditions caused by the storm had passed.

DISCUSSIONS AND CONCLUSIONS

Observations

Outdoor atmospheric pressure decreased significantly from 990 to 960 mbar at the peak of the storm. Outdoor temperature dropped from 13°C to 7°C. The indoor radon concentration increased from a normal

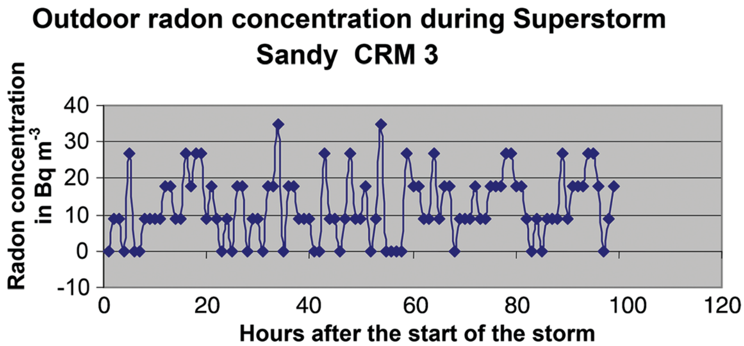

Figure 3. Outdoor radon measurements in a partially open garage of a single family home, at 15808 Pioneer Hills Terrace, Darnestown, MD 20874 (latitude and longitude 39.013441 and 77.290817, respectively), measured with CRM 3.

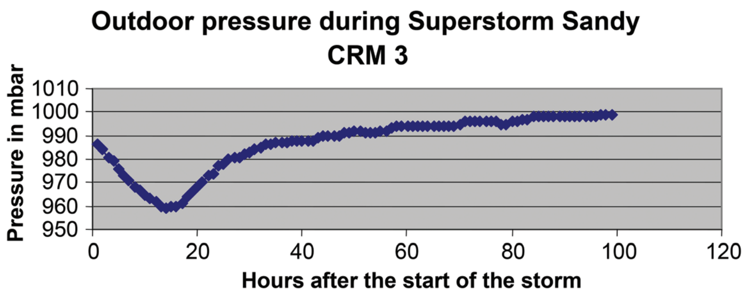

Figure 4. Outdoor pressure measurements in a partially open garage of a single family home, at 15808 Pioneer Hills Terrace, Darnestown, MD 20874 (latitude and longitude 39.013441 and 77.290817, respectively), measured with CRM 3.

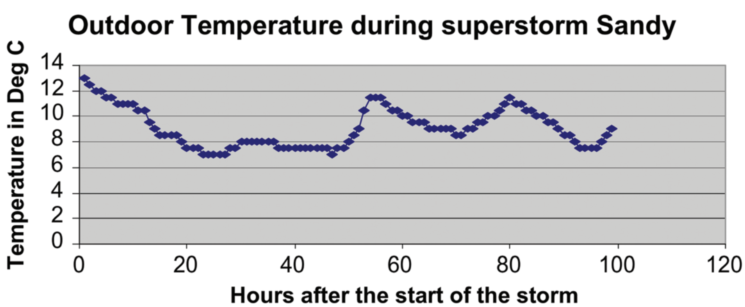

Figure 5. Outdoor temperature measurements in a partially open garage of a single family home, at 15808 Pioneer Hills Terrace, Darnestown, MD 20874 (latitude and longitude 39.013441 and 77.290817, respectively), measured with CRM 3.

Table 1. The radon concentration (Bq m^{-3}) in the first 2 d and first 4 d of the storm as measured by passive radon monitors.

Exposure days	Outdoor monitor 1 (Bq m^{-3})	Outdoor monitor 2 (Bq m^{-3})	Indoor monitor 1 (Bq m^{-3})	Indoor monitor 2 (Bq m^{-3})
2	29	34	350	370
4	11	<11	222	228

concentration of 70–1500 Bq m^{-3} at the peak of the storm, which is over a 20-fold increase. Storm peak ended after the first 24 h and the radon concentration returned to the normal level of 70 Bq m^{-3}. Unlike the indoor concentrations, the outdoor radon concentrations did not vary significantly during the storm. It is important to understand the difference between the indoor and outdoor environment. Sandy enhanced radon emanation from the ground in the same manner for both indoor and outdoor concentrations.

In the case of the indoor concentrations, the radon is drawn into the home by differential pressure gradients between the inside and outside atmospheric conditions and radon continues to accumulate inside the home. On the other hand, in the case of outdoor concentrations, radon gets dissipated into the atmosphere and there is no accumulation. Any possible enhancement is not measurable.

Discussions

These measurements were conducted at a distance of ~350 km from the most intense region of the storm. Full details of Hurricane Sandy are available[1]. The lowest pressure recorded at the most intense storm was 940 mbar, compared with the lowest noted in this work of 960 mbar. The highest wind speed recorded at the highest intensity of the storm was 175 km h^{-1} compared with 90 km h^{-1} in the present study. In general, any physical process, which leads to enhanced emanation of radon from the ground to the atmosphere, is expected to increase the radon concentrations in a home. These are typically the pressure decreases and wind velocities. There are several parameters responsible for transferring radon from outside to inside. Typically, these include pressure and temperature differentials. Superstorm Sandy provided rainfall of ~10 cm during the 24 h peak of the storm. Sandy further provided a sustained wind velocity of ~60 km h^{-1} with wind gusts of nearly 90 km h^{-1} during the storm peak. When Figure 1 or 2 is correlated with Figure 4, it is clear that the indoor radon concentration increases as and when the pressure starts decreasing. The upward peak of radon and the downward pressure dip occur almost at the same time. Short-term measurements using passive radon monitors during periods that include events such as heavy rain and high velocity winds (such as in storms) provide results which are higher compared with the average radon concentration in homes on a daily basis. If short-term measurements are made under storm conditions, the results may be an overestimate relative to the real concentrations. Short-term measurements should not be done during the storm conditions such as high winds and heavy rains. Earlier studies by Stranden *et al.*[4] and Rigby and La Pointe[5] reached conclusions similar to those reached in the current study. Correlation was found between the decreases in pressure to the increases in the radon concentration. A quantitative correlation was also attempted between the increases in the radon concentration with the decrease in pressure. This was reported to be an increase in the range of ~8–15 % in the radon concentration for a decrease of 1 mbar of pressure. In the current study, the radon increase is ~2100 % for a decrease of 30 mbar, leading to ~70 % increase per mbar. Several of these authors have reported a delay of 3–10 h for the radon peak to appear after the appearance of a downward dip in pressure. The current study did not indicate any such delay. Such comparisons with other studies do not have much meaning because no two natural episodes are similar. There are many meteorological factors that can affect the radon concentration. This study provides some of the parameters.

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