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Influence of environmental factors on indoor radon concentration levels in the basement and ground floor of a building – A case study

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HIGHLIGHTS

- Environmental variables and indoor radon levels were measured hourly over one year.
- Indoor radon levels negatively correlated with temperature, humidity and wind speed.
- Monthly and seasonal indoor radon correction factors were computed for a laboratory.
- Temperature difference and barometric pressure affected indoor Rn most significantly.
- Higher indoor Rn levels appeared during the autumn–winter season for cooler climate.

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ABSTRACT

A series of experiments was conducted to measure indoor radon concentrations variations and observe any correlations with indoor and outdoor atmospheric parameters for over a period of one year. Indoor environmental parameters and radon concentrations were measured on an hourly basis in a two-story building both in a laboratory on the well-ventilated ground floor and in the basement below it which had negligible ventilation. The monthly average indoor radon concentration value of 29 ± 21 Bq m^{-3} in the laboratory was below the ICRP recommended limit of 200–300 Bq m^{-3}. The monthly normalization factor for that location ranged from 0.5 to 2.0, while the seasonal normalization factor ranged from 0.78 to 2.0. In the unventilated basement, however, the average monthly indoor radon concentration was 1083 ± 6 Bq m^{-3} with little seasonal variation. The basement is only used for storage and thus the elevated radon concentration does not pose a serious health risk. The results indicated that indoor radon levels are higher in the autumn–winter season than in the spring–summer season. Analysis further showed that indoor radon concentrations negatively correlated with indoor humidity (correlation coefficient $R = -0.14$, $p < 0.01$), outdoor temperature (correlation coefficient $R = -0.3$, $p < 0.01$), outdoor dew point temperature (correlation coefficient $R = -0.17$, $p < 0.01$) and outdoor wind speeds (correlation coefficient $R = -0.25$, $p < 0.05$). Radon concentrations correlated positively with outdoor barometric pressure (correlation coefficient $R = 0.35$, $p < 0.01$), indoor–outdoor temperature difference (correlation coefficient $R = 0.32$, $p < 0.05$) and indoor–outdoor barometric pressure difference (correlation coefficient $R = 0.67$, $p < 0.01$). Indoor temperature, indoor barometric pressure and outdoor wind direction showed no clear correlations with indoor radon concentration.

1. Introduction

Radon is one of the most extensively investigated human carcinogens. Radon and its progeny in the air contribute to human exposure from natural radiation sources (UNSCEAR , 2009). Since people spend so much of time indoors, long-term exposure to elevated radon concentrations has been linked to increased lung cancer risk (Steck, 2009). Some residential case–control radon studies in North America showed a direct association between prolonged radon exposure and lung cancer (Field et al., 2006). Radon may contribute to an estimated 21,800 lung cancer deaths in the United States of America (USA) annually (BEIR, 1999).

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Furthermore, the health impacts of seriously elevated radon levels, such as measured radon concentration levels exceeding 410,000 Bq m^{-3} in indoor residential air (Kearfott, 1989), are not open to controversy. In order to evaluate the possible radon hazard to inhabitants of the buildings in the central northern, or midwestern, region of the USA, knowledge about the monthly and seasonal radon concentration variations is desirable.

Meteorological parameters, geology, building materials, building construction type and the degree of ventilation of closed environments are among the important factors affecting the radon in indoor air (Porstendorfer et al., 1994; Espinosa and Gammage, 1998; Baeza et al., 2003; Faheem and Matiullah, 2008; Rahman et al., 2010; Müllerová and Holý, 2010; Rafique et al., 2011, 2012a, 2012b; Matiullah and MalikRafique, 2012; Kropat et al., 2014). Because the relationship between indoor radon and the weather is mediated by regional differences in both building construction and ventilation practices, indoor radon concentrations typically show monthly and seasonal variations that are both significant and geographically variable. Indoor radon concentrations are reportedly more sensitive to meteorological parameters than building characteristics (Steck, 2009). Meteorological parameters including indoor and outdoor environmental variables were thus chosen for the focus of this study of indoor radon in the midwestern USA.

A long-term measurement period will give a much better indication of annual average radon concentration than measurements of shorter duration. Seasonal normalization factors (SNF) and monthly normalization factors (MNF) are numerical multipliers used to convert a short-term radon concentration measurements to estimates of annual average concentrations (S. Rahman et al., 2007; Kozak et al., 2011). K. Kozak et al. (2011) used a equation of $\frac{GM_Y}{GM_m}$ (where GM_Y is the geometric mean of annual radon concentrations and GM_m is the geometric mean of monthly radon concentrations) to calculate monthly correction factor. In this paper, K. Kozak et al.'s equation has been used to calculate seasonal and monthly correction factors. The SNF is calculated by dividing the annual arithmetic mean by the arithmetic mean calculated for each short-term period, i.e. the cycle or season, specifically spring, summer, autumn and winter for the SNF or the month for the MNF. Both factors are simple ways of accounting for the impacts of environmental parameters and building ventilation variations on indoor radon concentration.

Radon mapping data reveal not only substantial regional variations but complex indoor radon levels distributions within a single city or town (Burke and Murphy, 2011). In addition, geological characteristics and meteorological parameters likely present synergistic effects on indoor radon levels. The SNF is reported in some locations to be larger than 1.0 in the summer, with the smallest SNF values recorded for the winter–spring season (Kozak et al., 2011). In other highly radon-bearing places the opposite result is encountered, which may be caused by thermally induced subterranean air flow (Sundal et al., 2007).

Outdoor environment variables affecting the magnitude and variation of annual indoor average radon concentrations include indoor–outdoor temperature difference, barometric pressure, humidity, wind speed and direction, and precipitation. Published research on the correlation of indoor radon concentration with specific environmental parameters is not consistent. The irregularity most often observed is seasonal variation. For example, higher radon concentrations are most often observed in dwellings in the cool seasons of the year and lower radon concentrations in the warm periods (Denman et al., 2007). However, the opposite relationship occurs in Alabama homes, with the highest radon levels occurring during the summer (Wilson et al., 1991). The best explanation for this difference is that in locations where temperatures are hotter, homes are tightly sealed and air conditioned during the hottest months, and ventilated during the milder months during which heating is not needed. This is certainly the case in Arizona, with a climate similar to Alabama, where arrangements relating to the cooling of homes have even resulted in markedly elevated radon levels (Kearfott et al., 1992a, 1992b).

Detailed relationships between specific environmental parameters and indoor radon concentration have been the subject numerous publications. Porstendorfer et al. (1994), Nazaroff et al. (1988) and Müllerová and Holý (2010) all reported that indoor radon concentrations showed elevation with increasing indoor–outdoor temperature differences. Marley (2001) found that indoor radon was primarily dependent on the three atmospheric variables: barometric pressure, vapor pressure and wind variation. Kitto (2005) observed that diurnal indoor radon levels were heavily influenced by indoor and outdoor temperature differentials, with little correlation to barometric pressure and wind speed. Hubbard et al. (1996) demonstrated an opposite effect, namely indoor radon level was reduced as temperature differences increased because of increased ventilation with outdoor air with lower radon concentrations. Riley et al. (1996) and Nazaroff et al. (1988) reported that wind speed could generate over-pressure with a positive effect on radon entry into structures from soil radon. Rowe et al. (2002) reported that rainfall and barometric pressure had little effect on radon concentration. By contrast, it was reported that seasonal rainfall and increased snowfall could cause unexpected high indoor radon concentrations (Mose et al., 1991; Steck, 2009; Francesco et al., 2010). These seemingly disparate findings probably arise because the effects of environmental parameters on indoor radon are very complicated, with some parameters having cross correlations with other parameters with the relationships mediated by regional factors influencing both the weather, construction types, and building ventilation practices.

In the present study, the significance of multiple indoor and outdoor environmental factors on the amount of radon that actually enters and accumulates in two locations within a single two-story building was studied in depth. The primary goals of the present paper were to analyze monthly and seasonal indoor radon variations in a typical building with a basement in a northern latitude climate and to find the possible relationships between indoor radon concentrations and main environmental variables, such as pressure, temperature and relative humidity. It was envisaged that the results of this study would be useful in assessing overall temporal variations in indoor radon behavior in this specific region while contributing to an overall understanding of the relationships between environmental parameters and radon.

2. Description of study location and building

The building is located on a suburban university campus in the north central, or midwestern, USA. The town is located at north latitude 42°16′ and west longitude 83°43′. It experiences a typically midwestern humid continental climate, influenced by the Great Lakes. There are four distinct seasons. Winters (November–March) are cold (average temperature of −0.1 °C) with moderate to heavy snowfall, while summers (June–August) are very warm (average temperature of 21.6 °C) and humid. Spring (April–May) and autumn (September–October) are short but mild and have average temperatures of 12.4 °C and 14.5 °C, respectively. Precipitation tends to be the heaviest during the summer months, but is most frequent during winter. Snowfall, which normally occurs from November to April but occasionally starts in October, averages 147 cm per season. The area experiences “lake effect weather”, primarily in the form of increased cloudiness during late fall and early winter.