Regional Variation of Seasonal Behaviour for Indoor Radon Levels

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Introduction

Radon mapping projects have been conducted in numerous countries throughout the world (e.g. Ireland (Fennell et al. (2002)), France (Baysson et al. (2003)), Hungary (Hámori et al. (2006)), USA (Steck et al. (1996)) and the UK (NRPB (2004))). The published results indicate that radon levels vary greatly throughout each country. The reasons for this variation are not completely understood, however a major contributing factor is the underlying geology of the area (Bossew et al. (2008), Gillmore et al. (2005)). It has also been shown that radon levels are liable to seasonal variation (Burke et al. (2010), Dyck and Tan (1978)).

The majority of studies on seasonality in radon report one set of seasonal correction factors, or one seasonal pattern, for an entire country (Pinel et al. (1995), Wrixon et al. (1988)). The suggestion that seasonal patterns in radon do not vary between regions is implicit in such studies. Although there are several regional analyses of radon levels within the literature (Baysson et al. (2003), Bossew and Lettner (2007)) only a small subset of these, discuss the regional variation of seasonality.

Within this subset of the literature, the debate regarding regional seasonal patterns is ongoing. Pinel et al. (1995) query the appropriateness of one single set of seasonal correction factors for the UK. Denman et al. (2007b) review the progression of regional analyses within the literature, discussing analyses and conclusions drawn by Baysson et al. (2003), the NRPB (2004) and the UKCCSI (2000).

To summarise, there appears to be no definitive recommendation regarding regional variation of seasonality within the literature. A previous study conducted by Burke et al. (2010) indicated that a single national set of seasonal correction factors may not be appropriate for indoor radon concentrations in Ireland. The purpose of this paper is to examine in detail the variation in seasonal patterns throughout regions of Ireland, in order to definitively determine whether or not one national set of seasonal correction factors is sufficient for Irish indoor radon measurements.

Data

The data for this analysis contains 5,456 observations from dwellings around Ireland. Indoor radon concentrations are measured using passive alpha track-etch detectors, each of which consist of a two-part polypropylene holder and a CR-39 (poly-allyl-diglycol carbonate) detection element (Fennell et al. (2002)). Two detectors were used for each measurement; one placed in the living area and one in the main bedroom. The radon measurements were approximately three months in duration.

Ireland is a small country divided into 26 counties; the numbers of observations in our data are approximately uniformly distributed across the country although there were some counties which contained a low number of measurements. The data set includes variables for geographical location (at a county level), duration of measurement (approximately 3 months in duration (80 to 100 days)) and the raw measurement for each particular dwelling. Information regarding the start date and end date of each measurement is also available.

Method

Seasonal correction factors were calculated using a Fourier decomposition analysis (Pinel et al. (1995)). A full description of this methodology can be found in Burke et al. (2010), we provide a brief outline here.

Measurements are approximately three months in length and each measurement is assigned to a central measurement month. As in Burke et al. (2010), the measurement months are decided by using the following rule: `if an observation (approximately three months in duration) begins in the first half of month i, it is assigned to measurement month i+1, while an observation beginning in the second half of month i is assigned to measurement month i+2'. From this point on, `month' refers to the assigned measurement month of an observation.

The method for calculating the seasonal correction factors incorporates the common assumption that the background-corrected data follows a lognormal distribution (Murphy and Organo (2008)).
Considering the three-month duration of the observations in this data set, the background-corrected measurement for dwelling (j) may be expressed, as a moving average of three separate periodic terms, as follows:

$$Y_j - Y_b = \frac{1}{3} h_j \sum_{k=i-1}^{i+1} m_k, \tag{1}$$

where Y_b represents the background radon concentration appropriate for the area being tested (approximately 6 Bqm^{-3} in Ireland (Fennell et al. (2002)). House-to-house variation is captured within the term h_j which represents the difference between the radon level in dwelling j and a typical indoor radon concentration measurement. Finally, m_k is an unknown discrete periodic function (of period twelve) describing the radon level found in a typical home.

Following Burke et al., the terms of the discrete seasonal function, m_k, can be modelled as a simple Fourier decomposition

$$m_i = \beta_0 + \alpha_1 \sin\left(\frac{2\pi i}{12}\right) + \beta_1 \cos\left(\frac{2\pi i}{12}\right) \tag{2}$$

(for i = 1,…,12) which takes the twelve-month periodicity of the data into account. The Fourier parameters are estimated using a multivariate regression analysis – allowing for the three-month duration of the measurements and using the assumption of Normal residuals within the regression (Burke et al. (2010)).
The three-month seasonal correction factors are then calculated using the formula:

$$\hat{f}_i = \frac{3\sum_{k=1}^{12} \hat{m}_k}{12 \sum_{k=i-1}^{i+1} \hat{m}_k} \qquad \text{(for i = 1,…,12).} \tag{3}$$

It should be noted that in order to estimate an annual indoor radon concentration for an individual dwelling one should include certain additional variations. In particular, house-to-house variation (associated with the effect of construction type) and measurement error should be accounted for in the error bound of an individually adjusted measurement (Burke et al. (2010)).

Results

As mentioned previously, 'County' was the geographical indicator available for observations in the data set. Research regarding geographical location, geology, distribution of measurements throughout the year and climatic similarities, was carried out. We consulted with meteorologists and geologists and using data from weather stations across Ireland and geological maps we were able to identify five regions (Figure 1) consisting of counties with similar geology and climate.

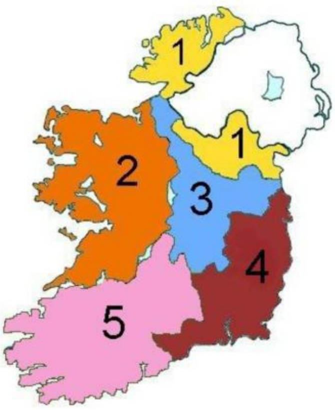

Figure 1: Division of Ireland into five regions

The Fourier decomposition analysis applied in this paper requires the assumption that the data follow a lognormal distribution. The Kolmogorov-Smirnov test was used to analyze the Normality of the log-transformed background-corrected regional data sets and indicated that this assumption holds. Mean seasonal correction factors were calculated for each region (Figure 2) using the Fourier decomposition analysis.

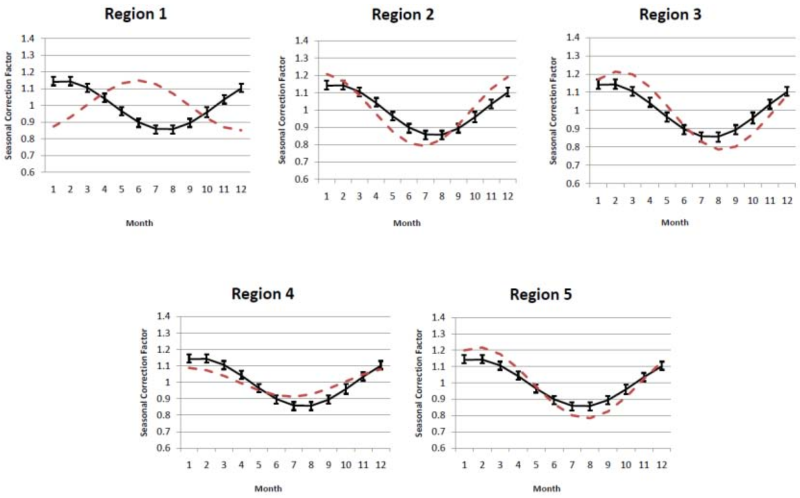

Figure 2: Mean Seasonal Correction Factors for Ireland (dashed) and Regions 1-5 (line) with 95% Confidence Interval for Mean Regional Factors

The subfigures within Figure 2 contain the mean regional seasonal correction factors and the 95% confidence interval on those factors. The mean national seasonal correction factors for Ireland (Burke et al., 2010) are also displayed on each subfigure in Figure 2. These mean national factors are represented by the dashed line that is replicated on each of the five subfigures. Figure 2 highlights the significant differences between the mean regional seasonal correction factors and the mean national factors, with the general exception of two months in each set. These two months correspond to the intersections of the graphs.

It is quite clear (Figure 2) that the mean seasonal correction factors estimated for Region 1 follow a completely different pattern to all of the other regions and the mean national Irish factors. The narrow width of the confidence interval for the Region 1 factors (along with the large size of the sample from this region) indicates that the seasonal pattern estimated for Region 1 is not simply an artifact of the data but rather a naturally occurring phenomenon. The literature, however, contains previous research (Li et al. (2010), Moreno et al. (2008), Perrier and Richon (2010)) which indicates that the geology found in Region 1 (granite, limestone with high karstic potential, volcanic geology, Namurian sandstone) is related to the presence of this opposing seasonal pattern.

Discussion and Conclusions

It is widely accepted that the radon levels vary within a country; however the assumption that the seasonal pattern remains constant for the entire area is implicit in the calculation and application of a single set of seasonal correction factors. Denman et al. (2007a) suggest that the use of one set of seasonal correction factors may not be appropriate in all cases. They further conclude that the use of regional seasonal correction factors increases the accuracy of measurement. It has also been shown that, in some cases, there are significant differences between correction factors associated with different geographical regions (UKCCSI (2002)).

However, as mentioned in the introduction, there are no clear recommendations within the literature regarding the use of regional seasonal correction factors. The results of this Irish regional analysis clearly highlight the dangers of using one set of seasonal correction factors for an entire country.

The results of our analysis of radon data from Ireland indicate that there is such a large regional variation in the seasonal patterns for indoor radon levels that one national set of seasonal correction factors may not be appropriate. The mean seasonal correction factors which have been calculated for each of five regions have been found to be significantly different from the mean national Irish factors. In particular, the set of factors calculated for one particular region (Region 1, Figure 1) follows the opposite seasonal pattern to the mean national factors. In such a case, applying the mean national factors to a measurement from this region could lead to over- or under-estimation of the true average indoor radon concentration within a dwelling.

To summarise, this paper consists of a study of the regional variation in the seasonality of indoor radon concentrations in Ireland. As such, it builds on previous work (Burke et al., 2010) and allows us to extend our knowledge of the seasonal behaviour of radon in Ireland. We are now in a position to provide mean regional seasonal correction factors and suggest that a regional adjustment approach should be considered.
There is no reason to assume that the results found in Ireland are exceptional and similar analyses may be warranted in other countries.

Acknowledgements
The authors would like to thank the Radiological Protection Institute of Ireland for their valuable input and for making available the data used in this paper.

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