Log-normal distribution for radon measurements in one room

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ABSTRACT

Increasing attention is being paid to radon concentrations in the assessment of indoor climatic comfort. Radon is a naturally occurring radioactive element that, under unfavourable circumstances, accumulates in excess in a building. Elevated concentrations of it can adversely affect the health of building occupants, resulting in increased interest in this element. The purpose of this study is to carry out a pilot study analysing the distribution and statistics of radon measurements as a preliminary to the analysis of how long radon measurements should be carried out in a given room in order to obtain results that can be regarded as reliable information on annual average radon concentrations. To this end, studies of radon concentrations in a selected room of a building located in central Poland were carried out over a year. Active meters were used for the measurements. Log-normal distributions were fitted to the long-term measurements and statistical measures were generated. As a result of the analyses, two periods of radon concentration were distinguished - summer and winter. It was noted that the distribution for the whole year is a composite of two log-normal distributions. In the situation where the room was used in a typical manner and the comparative level studied was appropriate for the selected measurement period for the winter months, shorter than monthly measurement periods generated meaningful information on radon concentrations. The expected value of the distribution can then be approximated by the median, the geometric mean or the arithmetic mean. Median is probably the best statistical measure for radon measurements.

KEYWORDS

radon, distribution, statistics, measurements, IAQ

1 INTRODUCTION

Radon is a radioactive chemical element that is produced by the decay of radium. Radium, which is one of the elements of the uranium-radium chain, is found in rock minerals. As a result of leaks in the foundations and building materials, radon gets from the soil into the rooms. An indoor radon concentration limit has been set by the World Health Organisation (WHO) at 100 Bq/m3 level (WHO, 2009). Researchers note that radon concentration measurements show a log-normal distribution (Aladeniyi et al., 2020; Antignani et al., 2019; Daraktchieva et al., 2014; Vukotic et al., 2019). However, researchers note that this distribution may be a composite of several log-normal distributions (Bossew, 2010). The aim of the work is to determine on a pilot basis how long radon concentration measurements should be made so that the results obtained can be considered reliable information on the average annual radon concentrations. For this purpose, radon concentration tests were conducted for over a year in a selected room of a building located in central Poland. Active meters were used for measurements. Pilot studies involve fitting statistics and distributions to measurements.

2 METHODOLOGY

Radon measurements were taken using Ethera meters, an active radon meter with an interval of 10 minutes. Parametrics of the device are given in an earlier article by the authors (Kubiak and Basińska, 2023). Measurements were taken between 3.12.2022 and 22.01.2024 - non-physical measurements (coarse errors) were removed and data were split. The building is a single-family house on the outskirts of the city with natural ventilation. The room where the measurements were taken is used almost daily as an office and during the day it is used as a bedroom. R software was used to calculate basic statistical measures from the weeks. A Cullen and Frey chart was drawn to fit the distribution to the measurement data. Based on the graphs and knowledge from the literature, a log-normal distribution (density function - equation 1) was fitted to the entire measurement period. The MATLAB environment was used to fit the log-normal distribution.

$$f(x) = \frac{1}{\sqrt{2 \cdot \pi} \cdot b \cdot x} \cdot e^{\frac{-(\log(x)-a)^2}{2 \cdot b^2}} \quad (1)$$

where:
a, b - distribution parameters,μ, σ
x - random variable

Using the Matlab environment, the log-normal distribution density function was fitted to the probability density function graphs in a way that made it possible to read the values of the parameters a and b (equation 1). Given the values of a and b, the expected value, median and modal were calculated from equations 2-4.

$$E(x) = e^{a+\frac{b^2}{2}} \quad (2)$$

where:
E(x) - expected value

$$M(x) = e^{a} \quad (3)$$

where:
M(x) - median

$$D(x) = e^{a-b^2} \quad (4)$$

where:
D(x) - dominant

The Cullen and Frey chart will be used to analyze the evaluation of the data distribution feature (Tsapalov and Kovler, 2022).

3 RESULTS

Histogram with an interval of 5 Bq/m^3 has been prepared (Fig. 1). Observing the graph, you can see two distinctive peaks, which indicates that the distribution of measurements may probably be a composite of two or more distributions. After seeing the histogram, it was decided to divide the measurement period into two periods - summer and heating season. When the division took place and histograms were generated for individual periods, not two peaks were observed, but one.

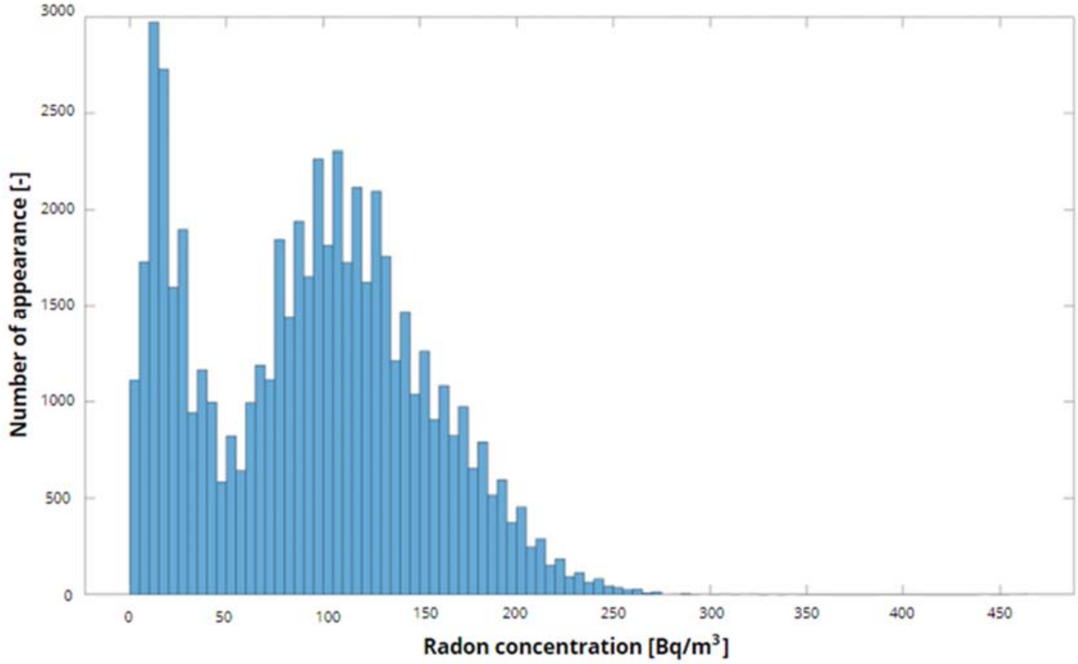
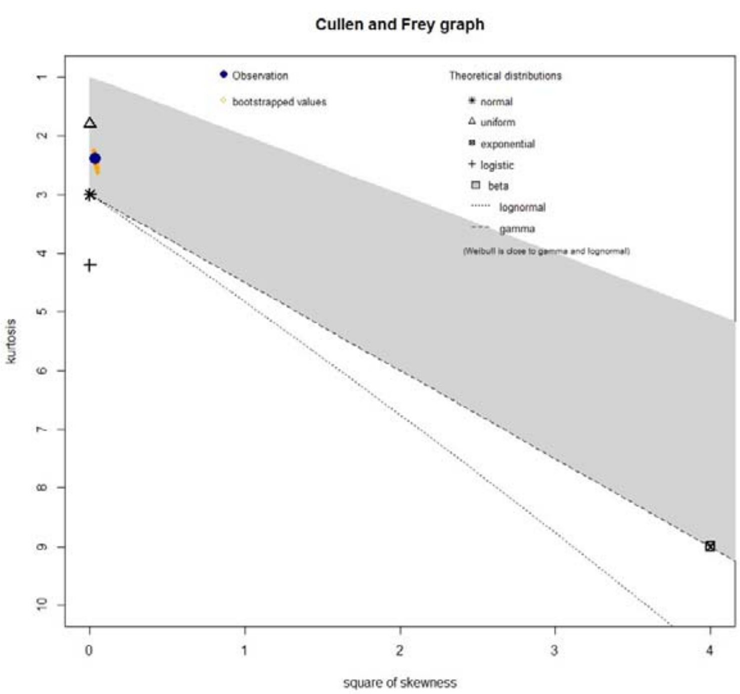


Figure 1 Histogram showing the frequency of occurrence of given measurement values during the year

3.1 Fit distribution

A Cullen and Frey Graph was generated for the entire measurement period and for the heating season (Fig. 1).

a)



b)

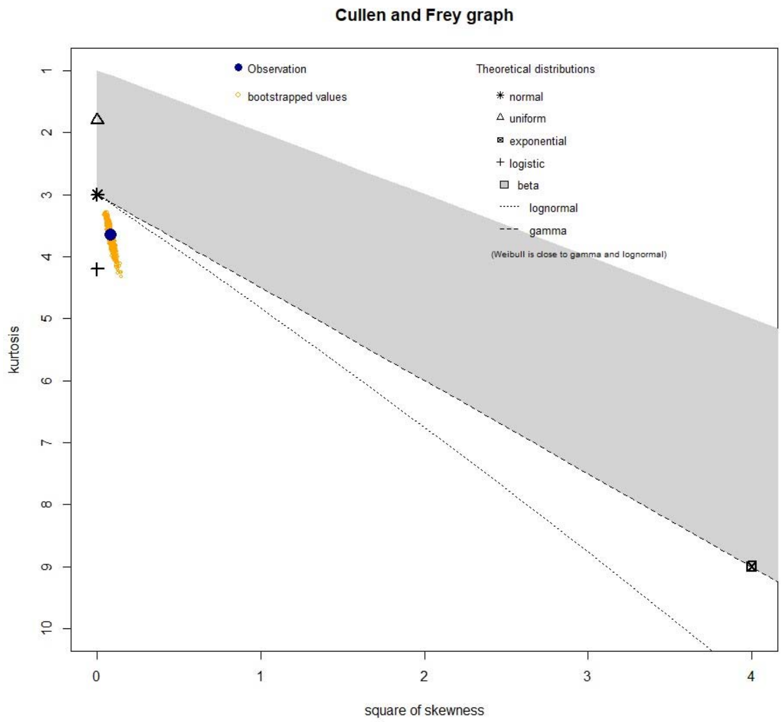


Figure 2 Cullen and Frey Graph a) the entire measurement period b) for the heating season (October to April)

A fit of the log-normal distribution was performed (Fig 2). It is noted that for year-round measurements, there is an overlap between the two log-normal distributions on one chart. When the entire measurement year is included in the Cullen and Frey diagram, the measurement data show a beta distribution, whereas if the measurement data from the summer period are removed from the period, the distribution tends towards a log-normal distribution (Fig. 2b). When the measurement period is divided into the heating period from October to April and the summer period, there is a significantly better fit to the measurement data (Fig. 2).

3.2 Distribution and statistical parameters

After considering the type of distribution, a lognormal distribution was fitted to the measurements. The probability density distribution function of the log-normal distribution was fitted for the whole year and the separated heating months, for which the following distribution parameters were obtained (Tab 1).

Tab. 1 Distribution parameters

Parameters of the log-normal distribution	**a**	**b**	**R^2**	**E(x) [Bq/m^3]**	**M(x) [Bq/m^3]**	**D(x) [Bq/m^3]**
Entire period	4.641	1.169	0.6030	205.1	103.6	26.4
Heating season	4.773	0.351	0.9897	125.8	118.2	104.5

Then basic statistics were generated for the measured data (Tab 2.).

Tab. 2 Basic statistics

Parameters	arithmetic mean [Bq/m^3]	geometric mean [Bq/m^3]	standard deviation [Bq/m^3]	median [Bq/m^3]	harmonic mean [Bq/m^3]	coefficient of variation [Bq/m^3]	asymmetry [Bq/m^3]
Whole year	93.8	67.1	57.6	97.4	26.6	0.614	0.189
Heating season	118.7	107.6	43.6	115.0	70.4	0.368	0.241

From the statistics generated, it can be seen that the fitted distributions differ, with a much better fit of R^2 =0.99 being obtained for the heating season fit. A poor R^2 =0.60 compared to the heating season fit of the distribution generates significant deviations in the values calculated from the distribution (for example E(x)) compared to the statistics calculated from the data (arithmetic and geometric mean). In the case of the heating season, all parameters such as geometric mean and median differ slightly, while in the case of the annual period, the geometric mean deviates from the median and arithmetic mean. There is right-handed asymmetry in both measurement periods. The coefficient of variation for the entire measurement period shows a strong correlation for the heating season, being 50% lower. For the entire period, lower average radon concentrations are observed compared to the heating season.

4 DISCUSSION

The way the room is used by people has a strong influence on the radon concentration profile in the room (Yarmoshenko et al., 2021). When analysing the results obtained, the season in which the survey took place must be taken into account. The statistics as well as the distributions in the summer and heating seasons differ significantly from each other. In the heating season, the differences between statistical measures (minimum - maximum) do not exceed 10%, so meticulous consideration of the selection of the appropriate statistic for analysis - median, geometric mean, arithmetic mean - does not seem very necessary. For the entire measurement period, the difference between the maximum and minimum statistical value is more than 45%. The proposed statistical measure proposed by the authors to estimate the annual radon concentration is the median, which reflects well the expected value of the distribution of radon measurements, taking into account the asymmetry of the distribution. The geometric mean, although it seems appropriate, considering the coefficient of variation, underestimates the measurements which was also evident in the results from other researchers (Ptiček Siročić et al., 2020). The question of how long radon measurements have to be recorded with active meters in order to give a meaningful result on an annual basis and how to take into account the correction for a given measurement month is still under discussion. Studies by other researchers indicate that it is possible to estimate annual variability from short-term measurements, however, seasonal variability is important (Li et al., 2023), which is probably strongly influenced by the user (Kubiak and Basińska, 2022), and meteorological conditions (Rey et al., 2023), building-related parameters such as air tightness also have a significant influence (McGrath et al., 2021). Some researchers claim that estimation of long-term measurements is not possible (Nunes and Curado, 2023). However, such conclusions may be the result of an inaccurate choice of measurement location and measurement period. Undoubtedly, determining how long short-term measurements must be in order to estimate the indoor situation will contribute to reducing the costs of measurement campaigns, which currently amount to millions of euro (Gruber et al., 2021). However, pilot studies have shown that it is potentially possible to assess long-term measurement statistics on the basis of short-term measurements, but this requires a strategy to take appropriate corrections into account, which is already being considered by researchers (Tsapalov and Kovler, 2022).

5 CONCLUSIONS

Radon measurements are characterised by a log-normal distribution. However, the measurement period should be divided between the heating season and the summer season to obtain a good fit. For the heating season, the expected value of the distribution can be approximated by the median, the geometric mean, the arithmetic mean, for the whole year the statistical parameters differ - the geometric mean is then recommended due to the large coefficient of variation for all measurements, while the median also appears to be a good fit due to its closeness to the value calculated from the distribution. The geometric mean underestimates the expected value of the distribution and the median for the entire measurement period better reflects the expected value of the heating season. For the heating season, the distribution of radon measurements is characterised by right-handed asymmetry with mean variation.

Further analyses need to be carried out in order to determine the periods of radon measurements that clearly resonate in the analysis carried out. The above analyses should also be checked in other building types.

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