Short-Term Indoor Radon Gas Study in a Granitic School Building: A Comparative Analysis of Occupation Periods

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Abstract. Granite territories continuously release radon, a radioactive gas that can be very harmful to human health. The assessment of radon gas indoor concentration is relevant for granitic buildings that lie over this substrate. In this work we use a sensor system to study the variation through time of indoor air quality (IAQ) parameters like radon concentration, temperature, and humidity following the occupation pattern of a school building made of granite. We identify distinctive radon concentration patterns that can be related with the time of day and week days that result from human occupation of the building and establish a basic indicator for radon exposure risk. The results of this analysis identify critical periods during the day that should be the subject of future mitigation strategies through an actuator system in order to improve the IAQ.

Keywords: Radon gas · Indoor Air Quality · Public granitic buildings · Public health

1 Introduction

Granite territories continuously release radon, a radioactive gas that can be harmful to human health. According to World Health Organization (WHO) indoor radon gas is the second largest risk factor associated with lung cancer [1]. The assessment of radon gas indoor concentration is relevant for granitic buildings that lie over this substrate. Several studies have been carried out, in the North of Portugal, to perform a short-term characterization of indoor radon gas showed evidence of high indoor radon gas concentration in several public buildings with granite construction [2]. In European Union (EU) countries, according to Council Directive 2013/59/Euratom, the reference

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levels for the annual average radon activity concentration in air shall not be higher than 300 $Bq.m^{-3}$ [3].

This work is part of a research project for developing a Cyber-Physical System (CPS) for continuous and online monitoring of the radon concentration and other relevant Indoor Air Quality (IAQ) parameters like temperature, relative humidity, and air pressure. The goal of this study is to identify radon concentration patterns according to the time of day and week days that result from human occupation of the building and to estimate the radon exposure risk. The use of a sensor system will enable the environmental safety assessment for radon concentration inside buildings and to deploy on premises a permanent monitoring system that consists of multiple remote sensors and a centralised control station with a web interface [4].

This paper is organized as follows. In the next section, we present relevant studies about indoor radon gas concentration in public buildings and the measurement equipment used on it. The third section describes the data analysis approach, including the sample characterization. The results from the study are discussed in the fourth section. The last section refers to the final conclusion.

2 Related Works

Several studies have been carried out to evaluate the influence of occupation on indoor radon concentration in public buildings. In 1996, a team of researchers analysed the radon concentration in a public school of a small village, next to Barcelona, Spain, including some dwellings [5]. The indoor radon concentration values obtained in the buildings were comparable to the mean world values. In [6], Madureira et al. assessed radon concentration in 45 classrooms from 13 public primary schools located in Porto, Portugal, and observed that in 92.3% and 7.7% of the measurements, the limit of 100 and 400 $Bq.m^{-3}$, established by WHO IAQ guidelines and in the national legislation, respectively, was exceeded.

The radon concentration in a centenary monastery recently converted to a polytechnic school building in an inner village in the Northwest region of Portugal was assessed in a recent study [7]. The in situ campaign involved a set of radon concentration short-term measurements in 17 rooms during 2 different time periods. The study reinforced the ventilation influence on the radon concentration reduction and stressed the year season influence in which the monitoring campaign is carried out, on the radon concentration performance.

A study for the assessment of the radon concentration, performed in 19 school buildings in a city located in the Midwest of Italy, obtained the minimum, median and maximum (interquartile range—IQR) values of 45.0, 91.6 and 140.3 Bq/m3 [8]. The authors of the study found evidences that radon concentration was significantly correlated with the number of students and teachers, foundation wall construction material, and with the absence of underground floors.

In [9], Gordon et al. examined the regulations and statutes in all US states concerning radon exposure in schools. The main goal was to identify key features of policies and discrepancies among states that may have public health implications. The study concluded that US state regulations related to the testing, mitigation, and public dissemination of radon levels in schools are inconsistent and the lack of nationwide indoor radon policy for schools may result in unacceptably high radon exposure levels in some US schools.

Currently, radon concentration assessment can be performed with active radon detectors that enable continuous monitoring. In [10], Baskaran et al. present a recent survey that compiles and compares several offline fast responding, highly sensitive radon air probes.

The use of sensor systems to monitor Indoor Air Quality was already proposed by multiple authors, like Schieweck et al. [11] and Cociorva et al. [12] among others. The use of gas sensors to control both the IAQ and the energy efficiency is reviewed by Guyot et al. [13]. In particular, the work Chao et al. already takes in consideration the use of a radon sensor for a dual goal actuator system for maintaining IAQ and energy consumption [14]. Lopes et al. introduce the design a Human-in-the-Loop Cyber-Physical System for online monitoring and active mitigation of indoor radon gas concentration in public buildings [4]. The proposed technology allows, not only a continuous and online monitoring of the radon gas concentration, but also the implementation on time of active mitigation strategies to reduce the indoor radon gas concentration.

3 Analysis Approach and Data Characterisation

The analysis approach adopted for this study is illustrated in Fig. 1. The measurements took place over a period of 41 days in 2018 from May 16 to June 25 at a school in Viana do Castelo in northern Portugal. The school selected for the measurements is running in a hundred years old granite building. The public building is used from 8:00 to 18:00 during working days, from Monday to Friday. The building is closed during the weekends and holidays.

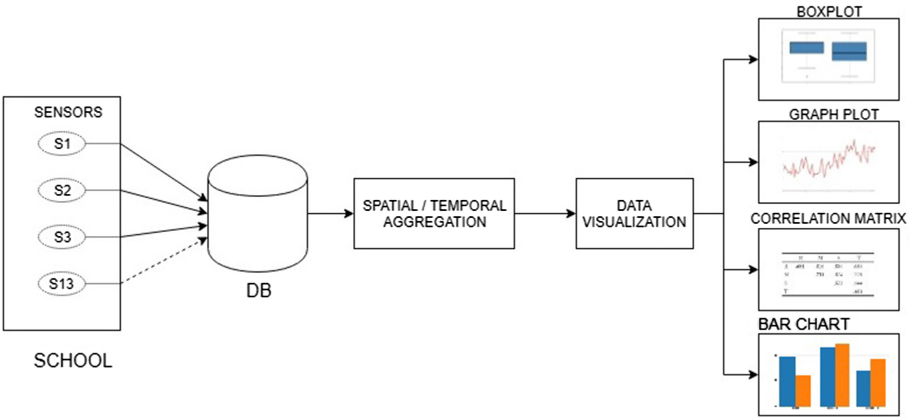

Fig. 1. Adopted analysis approach

The data measurements used in this study were obtained by 13 portable devices Airthings Corentium Plus that were placed inside different divisions on the two floors of the building. The data was gathered and stored into each devices' internal memory hourly during 41 days. The sample rate of the device is hourly. Each record has a timestamp in the Date ISO8601 standard and includes the parameters: radon, temperature, relative humidity, and atmospheric pressure. We did not consider the (indoor) atmospheric pressure as it was measured on the sensor itself. We found no direct relation with the remaining parameters. We plan to study the indoor and outdoor atmospheric pressures in a future work. Table 1 presents these parameters and its related aggregation types.

Table 1. Parameters and aggregation types

	Radon concentration	Temperature	Humidity
Measurement unit	Bq/m^3	°C	%RH
Data type	Floating point	Floating point	Floating point
Aggregation type	Spatial/hourly/daily	Spatial/hourly/daily	Spatial/hourly/daily

A data spatial/temporal aggregation was made afterwards, combining the data from the sensors and integrating it within a single aggregated view. The aggregation function used was the average of the measurements grouped by the hour which is the smallest temporal granularity available. Finally, after performing the aggregation, three techniques have been used to visualize the data (graph plot, boxplot, and bar chart), so that a graphical representation of the data facilitates the extraction of useful information. The different techniques are described in more detail below:

- **Boxplot:** This standardized type of figure shows the variation in samples of statistical population as a graphic representation of five numbers (minimum, first quartile(Q1), median, third quartile(Q3) and maximum). Outliers can also be displayed on the same figure. The first quartile (Q1) leaves 25% of the observations below while the third quartile (Q3) leaves 25% of the observations above.
- **Graph Plot:** This type of data visualization, allows the graphic representation of a dataset and shows the relation of a variable in function of another one, being possible to represent several variables in the same figure.
- **Bar chart:** This type of data visualization presents data with rectangular bars with heights proportional to the values they represent. Several bar charts can be overlapped to represent different measures. In our study, data is represented using a vertical bar chart.

Figure 2 depicts the radon concentration during the five consecutive weeks, with an average hourly graph plot. An initial observation reveals a possible repeating pattern in the radon concentration during the week and during each day.

The normalized radon concentration, temperature and humidity during the 41 days are presented in Fig. 3. All the measurements have been first aggregated hourly and then normalized to get a common representation scale. A first look at the graphic does not reveal any visible strong correlation between radon and the other two parameters. The

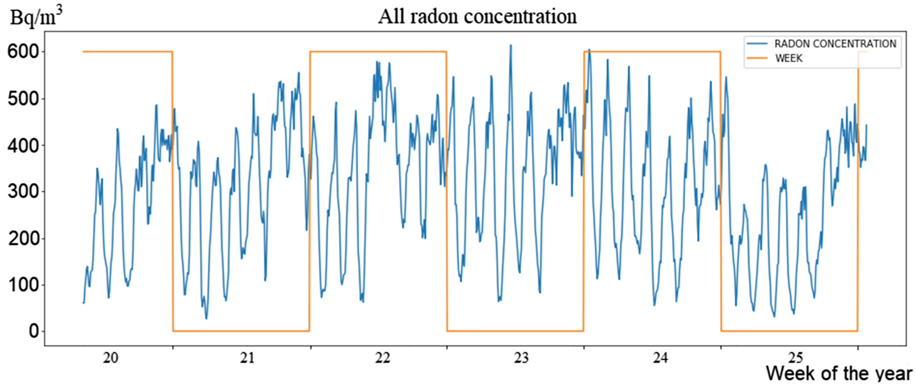

Fig. 2. Radon concentration during five consecutive weeks.

Fig. 3 shows that radon concentration seems to follow humidity variation and to change inversely with temperature. In the following section, we will look in more detail to the correlation between these parameters.

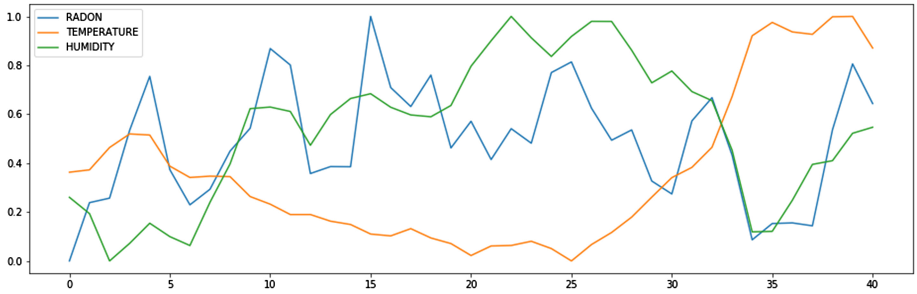

Fig. 3. Normalized radon concentration, temperature and humidity over a 41 days period

4 Discussion

In order to study with deeper detail the data collected, and without any visible relation among the values, we analysed the temporal variation of the radon throughout the day of the week. First, we performed a spatial aggregation, already described above, and then grouped the data by the day of the week. The result is the boxplot depicted on Fig. 4.

The results highlight a clear difference of the boxplots for weekdays and weekends. On Saturday and Sunday, the mean and minimums are higher when compared to weekdays and the variation interquartile is much lower. It therefore seems appropriate to carry on with a separate analysis for weekdays and weekends since the variation seems to be different.

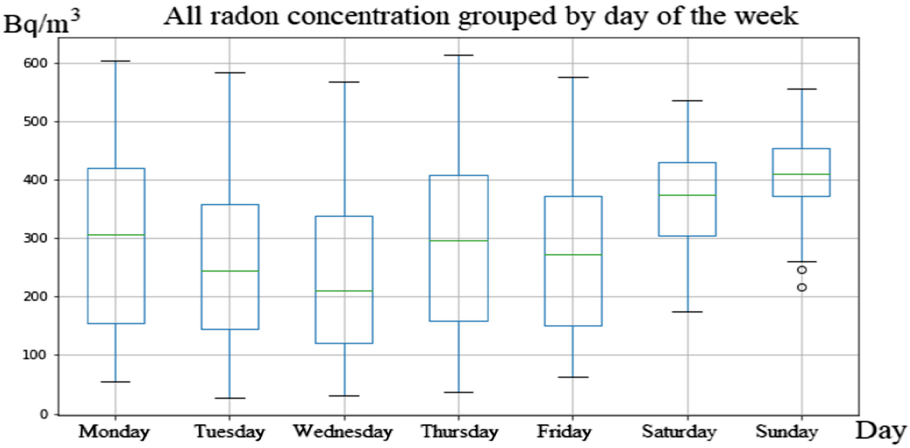

Fig. 4. Radon concentration boxplot aggregated by day of the week

4.1 Concentration Values for Weekday Versus Weekend Periods

An initial characterisation of the data was made by evaluating the mean and standard deviation for all the measurements, measurements during the week days and finally during weekends. The values obtained on Table 2 reveal that when considering only weekends, the mean concentration is higher than both all data and weekdays. Furthermore, the weekdays reveal a smaller mean and higher std. dev., indicating that the concentration is more stable and higher on weekends and more volatile during the weekdays.

Table 2. Radon concentration mean and standard deviation values (units Bq.m^{-3})

Measure type	All days	Weekends & holidays	Weekdays
Mean	307	395	264
Standard deviation	137	83	138

Based upon a loose visual correlation between the concentration and the humidity, and an inverse correlation with the temperature for both parameters, we proceed to study the correlation values among the three parameters for the weekdays (Table 3) and weekends (Table 4). The Table 3 reveals a correlation between the radon concentrations and the humidity by 0,44 and an inverse correlation between the temperature with the radon concentration by −0,49 and between the temperature and the humidity by −0,67, being the last one an already known correlation result. The Table 4 shows that the correlations are weaker for the samples taken on weekends and holidays.

Table 3. Weekdays correlation matrix.

	Radon concentration	Temperature	Humidity
Radon concentration	1.00	−0.49	0.44
Temperature	−0.49	1.00	−0.67
Humidity	0.44	−0.67	1.00

Table 4. Weekend and holiday correlation matrix

	Radon concentration	Temperature	Humidity
Radon concentration	1.00	−0.26	0.31
Temperature	−0.26	1.00	−0.57
Humidity	0.31	−0.57	1.00

4.2 Variation of the Concentration During the Day

We proceed to study the variation of the radon over the hour of day. To do so, data was grouped by hour, thus obtaining measurements that go from 0 o'clock to 23 o'clock. As in the first approach, we analysed the data in two different cases. First for all the weekdays and then for weekends and holidays. The Fig. 5 depicts a boxplot for the hourly concentration on a) weekdays and b) weekends. The occupation time frame is represented in Fig. 5 a) during the hours where the building is occupied by people.

The hourly evolution during the weekdays (Fig. 5a) reveals a clear higher values during the early morning, up to the moment the building is opened to the public (8:00), a clear tendency for the concentration to decrease during the day gradually up to the end of the working day (18:00) where it reaches the lowest concentration. Then, when the building is closed, the concentration increases again until reaching its highest peak again. This variation pattern was not clearly observed during the weekends (Fig. 5b), where the mean variation is smaller. This might be explained by the fact that the building is always closed and ventilation barely exists during this period.

4.3 Risk Factor: Total Time Versus Occupation Period

Ultimately, it is necessary to quantify the people's exposure to radon, by calculating the mean radon concentration only during human presence. Although the mean concentration for all measurements exhibits a high value, in fact, the mean exposure to humans should only consider the opening hours of the building. First, radon concentration was aggregated daily in order to obtain the daily mean value, and then the mean exposure value was calculated considering that the school is open from Monday to Friday, from 8:00 to 18:00, resulting on the bar chart depicted on Fig. 6.

The Fig. 6 shows that the mean concentration value for the entire day is much higher than the value for only the opening hours of the building which is when people are

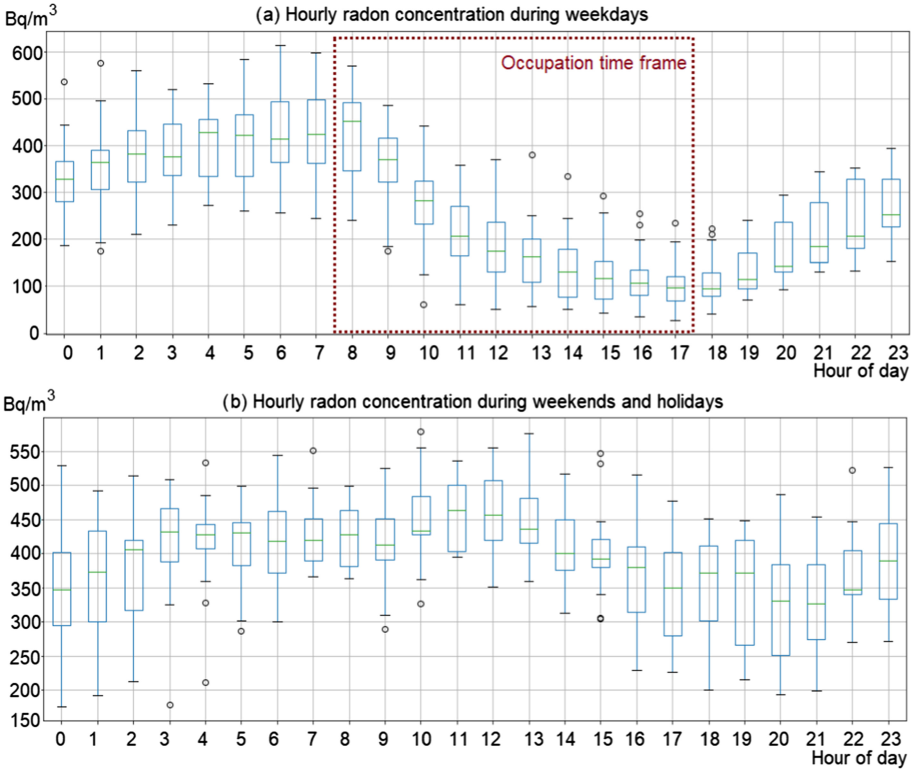

Fig. 5. Hourly radon concentration boxplot

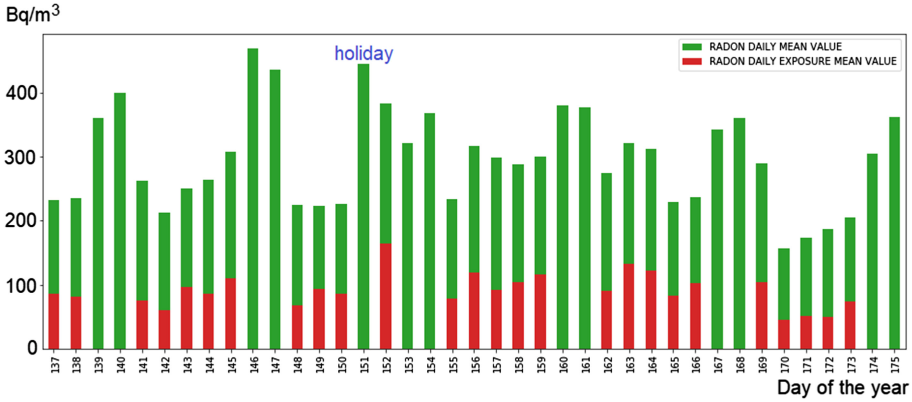

Fig. 6. Radon concentration daily mean value and mean exposure value

exposed to the gas. On day 151 in the Figure, one can see that the daily mean value is one of the highest, despite being a week day. This day is a holiday, and hence the building was closed in this day.

5 Conclusions

The analysis of the data shows that the average radon concentration measured is high, on average 306 Bq.m^{-3}, which is above the WHO guidelines, but below the legal limit in Portugal. A correlation with other air quality parameters like temperature and humidity were not relevant, with values of $-0{,}49$ for the temperature and 0,44 for the humidity.

Despite the lack of correlations, a variation pattern was identified with weekly and daily cycles. A more detailed look at the variation of the radon concentration during weekdays (usually working days) and weekends (usually days where the building is closed) revealed a cyclic behaviour. The concentration is lower during working days than during weekends. Within working days, it is higher during the early morning, and lower at the end of the working day (around 18:00). We conclude that this pattern is caused by the human presence and use of the building, which follows the working timetable of the public school. The use of the building implies some kind of ventilation, arising from people entering and leaving the rooms and the building in itself. When a building is ventilated and the air is refreshed, the radon gas concentration drops. Furthermore, an exception was found in day 151, that while being a weekday, it was a holiday, which made the building be closed and exhibited the same pattern observed on weekends. During the weekends, when the building is closed, the variation of the concentration was smaller and had a consistent higher mean.

Although the global average concentration of the radon gas was high, the risk of a high gas concentration exposure to people is lower, because during working hours, the average concentration is smaller.

We conclude that, while on average the radon gas concentration is higher than desirable, in practice the exposure to the gas to people is not as high as the global mean and is diminished by the usage of the building in itself. Nevertheless, the initial evaluation of this sensor system reveals a case of public attention that should be continuously monitored and acted upon, in order to ensure that the gas concentration values are permanently within desirable limits through a mitigation system. The design of a mitigation system that automatically controls and limits the gas concentration is the focus of future work.

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