Radon Risk Reduction in Public Buildings with Regular Occupancy: A Case Study in Minho Region, Portugal

A Curado1,3, J P Silva1, S I Lopes2,4

1ProMetheus, Instituto Politécnico de Viana do Castelo, Viana do Castelo, Portugal
2ARC4Digit, Instituto Politécnico de Viana do Castelo, Viana do Castelo, Portugal
3CONSTRUCT LFC, Faculty of Engineering (FEUP), University of Porto, Portugal
4Instituto de Telecomunicações, Aveiro, Portugal

E-mail: acurado@estg.ipvc.pt

Abstract. Radon gas is considered by the World Health Organization (WHO) as one of the most relevant indoor pollutants with proven relationship with higher lung cancer risk. Hence, indoor radon exposure in badly ventilated and extensively occupied rooms increases drastically the risk of health problems. Due to the geological nature of local soil, the Northwest region of Portugal is critical concerning indoor radon exposure. The new legislation is already in force to combat the problem by adopting a remediation strategy in order to reduce the occupants’ risk in local buildings. However, a remediation strategy involves not only manual or automatic mitigation actions to reduce indoor radon concentration, but also awareness-raising campaigns developed amongst buildings’ occupants and local community making part of an action plan to deal with the problem. In this paper we present a new case study of 15 public buildings assessed in 2018 through short-term measurements to characterize indoor radon gas concentration, in an inner city in the Northwest region of Portugal. Radon risk was assessed to evaluate occupants’ risk exposure and to define an Action Plan concerning radon gas remediation.

1. Introduction

Radon is a natural radioactive gas which derives from continuous decay of uranium series elements. This natural gas is found predominantly in uranium-rich soils mainly formed of schist and granite, extremely abundant on North and Center regions of Portugal [1].

Radon propagation into buildings heavily depends on gas emissions by diffusion through soil and bedrock gaps, cracks and cavities. Given radon gas is colorless, tasteless, odorless and inert it can freely concentrate in the lower floor of the building. Inside the building, radon dissipation relies on...
ventilation. In fact, by opening windows, doors and vents the radon levels get reduced however, this is only a temporary solution that cannot be used as a long-term mitigation strategy [2][3][4][5]. The investigation of radon health consequences proved to exist a probable correlation between indoor radon and lung cancer. In fact, the radon radioactive nature makes it one of the most important causes of lung cancer [2][3][4][5].

In order to assess indoor radon concentration, 15 public buildings located in an inner city in the Northwest of Portugal, Western Europe, were monitored based upon short-term measurements on the ambit of the R&D project RnMonitor, which includes the offline characterization of two sets of 15 public granitic buildings geographically distinct. The first set of 15 public buildings was conducted between January and September 2018 and the results were presented in [18][19]. In this paper we present and analyze the results obtained in the second set of 15 buildings. In situ measurements were conducted throughout two distinct year terms (spring and autumn 2018). The monitored sample was constituted by buildings providing different municipal services, like schools, offices, theaters and galleries, local police stations, etc. In the end, the aim of the research is to present a set of radon risk reduction measures based on short-term measurements, according to the new Portuguese radiation protection law. After results discussion, a remediation strategy for the most problematic building will be outlined along with some information sessions focused on buildings’ user.

2. Some Previous Works
Some previous research regarding indoor radon characterization has been already conducted by authors in the same region, i.e. Northwest Portugal. Referred investigations were focused not only on the implementation of radon assessment campaigns but also on the study of buildings’ occupancy influence on indoor radon concentration through the adoption of specific ventilation actions as a practical way for radon mitigation. In fact, Curado A. et al. [6] assessed in 2016 radon concentration in basements and ground floor rooms in a set of nine residential buildings in Viana do Castelo, Northwest region of Portugal. The study evidenced a positive effect of the ventilation actions undertaken by buildings’ users on the reduction of indoor radon concentration. In the same direction, Curado A. et al. [7] in 2017, by studying radon concentration along different floors of three granitic residential buildings placed in Barcelos, Northwest region of Portugal, concluded that air renovation by windows opening or air extraction in buildings’ toilets and kitchens determined a significant reduction on indoor radon concentration and other air pollutants. Moreover, the study revealed higher radon concentrations on basements and ground floor rooms. Besides residential buildings monitoring, a higher education institution building occupying an ancient retrofitted monastery was extensively assessed by Lopes SI. et al. [8] to monitor indoor radon concentration in classrooms and offices during winter and summer 2017. The research stressed the ventilation relevance on indoor radon reduction, mainly on summer season when outdoor temperature allowed natural ventilation by windows opening. In order to implement a continuous and online monitoring platform to assess radon concentration, Lopes SI. et al. proposed in [9] the design of a Human-in-the-Loop Cyber-Physical System for online monitoring and active mitigation of the indoor radon gas. The proposed system takes advantage of a web-based platform for integrated radon risk management that performs real-time radon gas monitoring and promotes specific mitigation actions. The proposed solution includes specific IoT-based device designed to collect and communicate data to a cloud-based server. Subsequently, data is reasoned and specific mitigation actions are triggered by the platform based on two distinct approaches: i) automatic ventilation actions (closed-loop control) and ii) manual ventilation actions (human-in-the-loop control).

3. Methods

3.1. Indoor Measurements Overview
A set of 15 public buildings chosen by the local municipality to make part of a case study for indoor radon assessment during spring and autumn 2018. Selected buildings are all located within the urban
area of an inner city located in Minho region, Northwest Portugal, South from the Spanish border and about 40Km far from the Atlantic Ocean. Indoor radon measurements were conducted in periods of 1 week (short-term measurements) for each season (spring and autumn). Active radon sensors were placed in compartments where occupants spend their majority time. Each building was measured in 2 different indoor spaces: a top floor and a ground floor or basement room in which higher levels of radiation exposure were expected. To carry out the study it was assumed that monitored spaces were ventilated by windows opening during rooms’ occupation period.

3.2. Experimental Campaigns

The experimental campaigns were implemented in spring and autumn 2018, during which mild outdoor air temperatures were expected, thereby facilitating natural air renovation. As referred, the monitoring was conducted based on short-term assessment corresponding to a one-week measurement involving a total of 15 buildings:

— 1st instrumentation campaign (spring) was carried out from March 6 to May 10, 2018. During the campaign no heating or cooling systems were operated by the occupants. Ventilation actions by daily windows opening were performed during rooms’ occupation period.

— 2nd instrumentation campaign (autumn) was carried out from September 11 to October 16, 2018. Like in spring campaign, no heating or cooling systems were used and daily ventilation actions were undertaken by the occupants.

In both experimental campaigns, rooms’ occupancy played an important role on the monitored parameters. To assess occupancy influence, each monitored building was assigned with an alphabetic letter from A to O. Each letter is associated to a sample, which has been split into 2 subsamples corresponding to each monitored room.

In total, 30 rooms were monitored representing 30 subsamples, as further described in Table I. Buildings’ architectural features and the way they were constructed have a great influence on the level of radon [6][7][8]. Most part of the assessed compartments run administrative municipal services, therefore monitored rooms are occupied by public officials and municipal staff during working day. Other instrumented buildings are school buildings, occupied during classes by teachers and students, and leisure buildings like theaters, museums and galleries, occupied by employees and some other management personnel and technical staff during work schedule (Table I).

Table 1. Experimental campaign overview

| Instrumentation period | Code | Municipal building | Type of room | Floor location |
|------------------------|------|--------------------|--------------|---------------|
| 1st - 06 to 13/03     | A    | Municipal council  | Help desk    | Ground        |
| 2nd - 02 to 09/10     | A    | Help desk          | Help desk    | Upper         |
| 1st - 06 to 13/03     | B    | Local museum       | Technical room| Ground        |
| 2nd - 11 to 18/09     | B    | Exhibition hall    | Help desk    | Upper         |
| 1st - 06 to 13/03     | C    | Tourist office     | Technical room| Ground        |
| 2nd - 11 to 18/09     | C    | Help desk          | Help desk    | Upper         |
| 1st - 13 to 20/03     | D    | Municipal library  | Technical room| Upper         |
| 2nd - 18 to 25/09     | D    | Help desk          | Help desk    | Upper         |
| 1st - 13 to 20/03     | E    | Exhibition centre  | Exhibition hall| Ground        |
| 2nd - 18 to 25/09     | E    | Exhibition hall    | Exhibition hall| Upper         |
| 1st - 13 to 20/03     | F    | City archive       | Consultation room| Ground       |
| 2nd - 18 to 25/09     | F    | Archive            | Archive      | Upper         |
| 1st - 20 to 27/03     | G    | Theatre facilities | Help desk    | Basement      |
| 2nd - 25/09 to 02/10  | G    | Work office        | Work office  | Ground        |
| 1st - 20 to 27/03     | H    | Municipal theatre  | Technical office| Basement     |
| 2nd - 25/09 to 02/10  | H    | Cabin              | Cabin        | Basement      |
Both administrative and leisure buildings receive people from outside, however the time spent by visitors inside each building is not relevant when compared to people that are subject to regular work schedule. Among all instrumented buildings, the higher radon risk exposure due to its intense occupancy are samples \( \text{H} \) to \( \text{O} \). In fact, these buildings have a large number of rooms (work offices and classrooms) where occupants spend permanently at least 7 hours a day during working time.

### 3.3. In Situ Monitoring

In situ measurements were carried out continuously using radon detectors in which data can be recorded within 1 hour with below 10% error from starting time of measurement, with incorporated data log to register indoor air temperature, relative humidity, and radon concentration.

The devices were placed in the working areas in places deemed representative of the air breathed in each monitored room. The equipment was not directly exposed to sunlight or moisture and was placed at least 0.50 m above floor level, and at least 1.50 m from the nearest door, window, air vent, radiation source or electronic equipment. To allow accurate measurements the device was not moved during measurement.

Despite long-term measurements are suitable to identify potential radon health hazards, short-term assessment is generally used to provide an \textit{in situ} evidence of radon levels. When the long-term measurement is not possible for technical reasons or for being a human-demanding process, short-term assessment can give a straightforward diagnosis by applying a 1-week measurement procedure and it may provide relevant information about the existence (or not) of a radon-related problem. On the other hand, long-term assessment is mandatory for effective radon risk analysis. The devices main technical specifications are detailed in [12].

### 4. Results and Discussion

Indoor samples were collected to evaluate indoor exposure levels of radon. The measurements were conducted, at the same time, in two different rooms: one located on the ground floor level, and another located on the top floor. Fig. 1 and 2 summarizes measurements carried out along spring and autumn 2018. Experimental results are depicted in Fig. 1 and 2 by means of Boxplot diagrams which constitute a standardized way of displaying the data distribution based on five statistic figures (“minimum”, low quartile (Quartile25), median, top quartile (Quartile75), and “maximum”). Each room is represented by a box which represents the range between Quartile75 and lower Quartile25. The middle value of the dataset, called median, is marked on the box at mid-distance between the “maximum” and the “minimum” figures.
For simplification, isolated points without statistical relevance called outliers were not represented. The X inscribed on the box marks the average radon level for the instrumented period.

Additionally, two lines parallel to the abscissa axis represent, respectively, the WHO limit (100 Bq.m$^{-3}$) and the national limit for indoor radon concentration (300 Bq.m$^{-3}$).
Values represented in the ordinate axis are dimensionless — the base reference is the National legal limit of 300 Bq.m\(^{-3}\). Since buildings were instrumented in two different rooms throughout 1-week measurements (ground floor and upper floor room), Fig. 1 and 2 show 30 boxplot diagrams corresponding to 30 monitored rooms (2 rooms per building).

During spring, radon levels across monitored rooms averaged 557 Bq.m\(^{-3}\) and ranged from 16 to 1485 Bq.m\(^{-3}\) in ground floor, while averaged 303 Bq.m\(^{-3}\) and ranged from 35 to 1007 Bq.m\(^{-3}\) in upper floor rooms. The same analysis for autumn, showed an average radon level of 455 Bq.m\(^{-3}\), ranging from 52 to 1303 Bq.m\(^{-3}\) in ground floor rooms, and an average level of 287 Bq.m\(^{-3}\), ranging from 53 to 730 Bq.m\(^{-3}\) in upper floor rooms. Results show that the most critical rooms are basement or ground floor rooms. The average level is higher during spring, given the lower number of ventilation actions during this season. The same applies to radon level dispersion since values tend to be more spread out during the spring measurements.

Boxplot diagrams analysis for the spring season, cf. Fig. 1 allows concluding that 16 out of 30 samples (53%) stay above the National legal limit of 300 Bq.m\(^{-3}\) for radon concentration. When the considered limit is the WHO action level of 100 Bq.m\(^{-3}\), samples number rise to 25 (83%). The graph in Fig. 2 (autumn) depicts similar results — 14 out of 30 (47%) samples exceed the National legal limit of 300 Bq.m\(^{-3}\) and 25 out 30 (83%) are above the WHO limit.

Radon levels were considerably higher in ground level rooms as compared to other rooms because of the radon origin. In fact, radon in buildings originates mainly from granitic soils adjacent to the foundation.

The 3 most problematic samples both for spring and autumn measurements are samples H1, I1, and N1. Samples labeled with “1” correspond to rooms placed in the ground floor, hence there’s strong evidence for higher radon concentrations in rooms placed in the ground floors or basements. In fact, this is in line with the literature [2][3][4][5], since radon gas enters buildings from granitic soils mainly through cracks in floors and walls. As a consequence, radon levels are higher in ground floors and basements.

5. Conclusions

An experimental campaign was carried out in spring and autumn 2018 to assess radon indoor concentration in a set of 15 municipal buildings placed in an inner city in Minho region, Northwest of Portugal, Western Europe, under the scope of the R&D project RnMonitor, by taking short-term measurements during one-week campaigns. In situ results allow the following conclusions:

1) Radon level, in most cases, is higher in the basement and ground-floor rooms. Radon is a heavy gas so its concentration is generally highest in the lower level of the building. However, since radon level varies with the type of construction, the building insulation and air sealing, the season of the year, the type of heating or cooling system, etc., in some buildings highest concentrations occur in upper floors.

2) Radon level reduces with the occupancy. The most buildings are occupied and ventilated the less indoor radon concentration decrease. Low occupied buildings with poor ventilation determine higher radon level.

3) A radon management strategy for the critical buildings detected after short-term measurements is crucial. Part of this strategy includes the implementation of a long-term experimental campaign over a time period, not less than 3 months according to National legislation in force.

4) Radon risk should be assessed according to dosimetric approach validated by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Afterward, an action plan for buildings with higher risk impact is strongly recommended.

5) To implement effective mitigation actions for critical buildings regarding effective building occupancy. If mitigation actions fail to reduce radon risk, the solution must involve a rooms’ occupation redefinition by avoiding people presence for a large time period in order to reduce radon gas exposure.

6) To develop awareness-raising actions among building users and occupants.
7) To create an integrated platform for radon gas real-time visualization in the monitored buildings.

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