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Article

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Radon risk assessment in a low-energy consumption school building: A dosimetric approach for effective risk management

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Abstract

A high-occupancy elementary school building recently retrofitted, with low energy consumption and no central climatization systems for heating, cooling and ventilation, located in the North region of Portugal was widely monitored to assess radon risk as a measure of indoor air quality. The experimental campaign was implemented in the spring of 2018 and during a period of one month, the radon gas concentration was continuously assessed. The main goal of the study is to evaluate the influence of variables such as the occupancy, the location of the monitored rooms and ventilation actions that were undertaken, to effectively evaluate the risk to radon exposure in a scenario of very low energy spent for heating, cooling and ventilation. The final results showed that 46% of the rooms exceeded the limit of 300 Bq.m^{-3} imposed by the Portuguese legislation in force. However, when considering a dosimetric approach reflecting the school building occupation profile (SBOP), by the calculation of the Indoor Annual Effective Dose (IAED), 93% of the rooms were above the occupational dose limit of 1 mSv/year, recommended by the International Commission on Radiological Protection (ICRP). Based on the results, there is evidence that the risk associated to the exposure to radon gas in indoor environments does not depend only on its concentration in the monitored room, but also on the number of occupants, period of occupancy, ventilation rate and on the location of the room in the building.

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Keywords: Radon risk assessment; Occupancy; Ventilation; Radon mitigation; Low-energy consumption

1. Introduction

A three-floor elementary school building in the North region of Portugal, originally built at the beginning of the last century and recently refurbished, was surveyed to assess the radon risk. The study was based on data obtained

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continuously, over a month, in a set of 13 samples distributed along distinct building floors, i.e. classrooms and offices, and labeled from A to M (Fig. 1). Besides the radon concentration assessment, the study involved the register of the occupancy periods of all instrumented rooms and the analysis of all ventilation actions undertaken by the occupants. Despite the building was recently refurbished, no heating or cooling systems were installed, and no mechanical devices to promote air circulation. Hence, the energy spent to achieve thermal comfort and to promote indoor air quality is very low since the building is unheated, during winter season, and not cooled, during summer. Very sporadically, during the colder periods, the building is operated with intermittent electric heating.

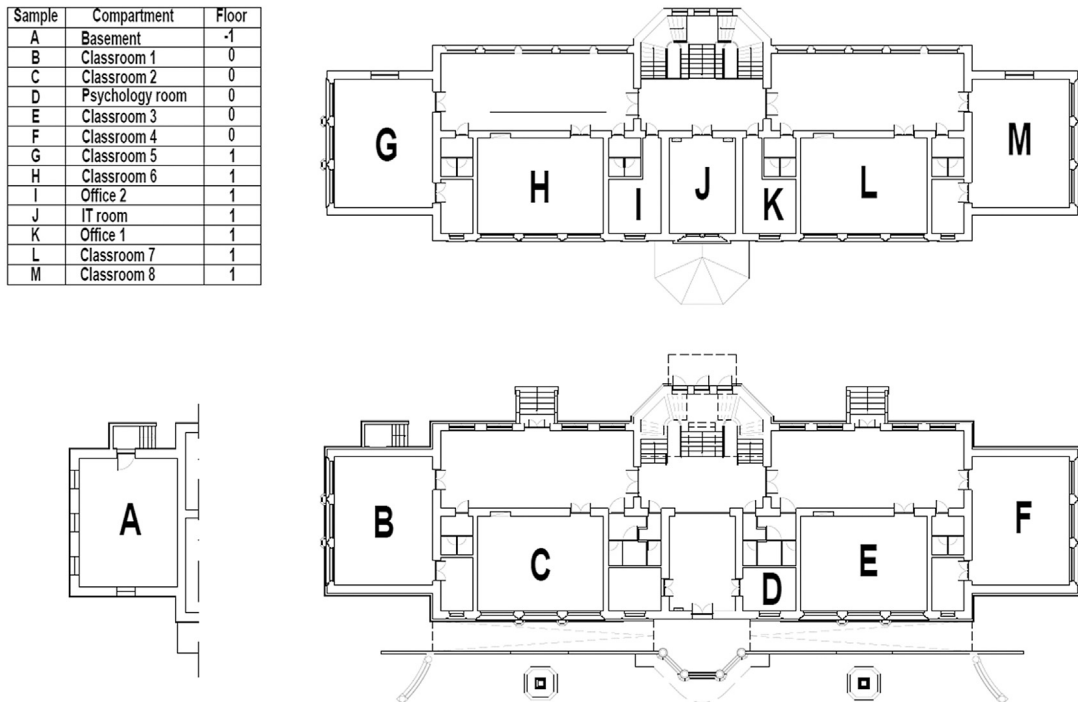


Fig. 1. School building taken as a case study for radon risk assessment.

The building presents a typical architecture very popular at the beginning of the last century, being made of granite walls and partitions without thermal insulation, windows in wooden frames with single glazing and floors in a heavy timber structural framing. The foundation materials are formed by granite soils and rocks, a geomorphologic configuration very prevalent in the region.

The main goal of this study is to evaluate the effective radon risk in a school building occupied by students aged between 6 and 10 years old, in a scenario of low energy spent for heating, cooling and ventilation. In this study, the authors defined the school building occupation profile (SBOP) as follows:

- 10 months per year (average school months per year);
- 4 weeks per month (average school weeks per month);
- 5 days per week (average school days per week);
- 7 h per day (the average period at school per day).

Two distinct approaches will be used in the evaluation process: (1) the new Portuguese regulatory approach (Decreto-Lei n.º 108/2018, 2018), which states in Article 145 that the “reference level” for radon concentration in buildings with a high occupancy level, should never exceed 300 Bq m^{-3} ; and (2) the approach recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), which lies on the calculation of the indoor annual effective doses (IAED) from radon exposure [1,2]. In the end, it is discussed which approach is more adequate do this particular case study, in terms of radon risk analysis.

2. Energetic refurbishment of the constructive envelope

The refurbishment intervention involved the improvement of the building envelope in order to increase its energy efficiency, with particular concern to facades, roofs, and windows. The original facades were made of granite walls without thermal insulation applied, the pitched roofs constituted with a wooden structure and covered with ceramic tiles, and the windows made with wooden frames covered with simple glass.

After retrofitting, the facades were covered with an external insulation layer made of extruded polystyrene (ETICS), the pitched roofs were insulated with a layer of Mineral Wool at the ceiling level, and the windows frames were sealed and covered with double glass. The windows' refurbishment included the installation of indoor solar protections with blackout blinds operated by the occupants.

The building retrofitting did not involve the change of the original ventilation schemes. No mechanical ventilation system was installed, so the air renovation of classrooms and offices still need to be made by windows opening. Just like mechanical ventilation, no heating or cooling system was installed, therefore the building energy consumption to climatize occurs very sporadically during the winter season, by the use of intermittent electric heating in order to improve occupants' thermal comfort.

3. The dosimetric approach on radon assessment

The radon gas (^{222}Rn) is a radioactive gas originated by the decay of the chemical element uranium, a metal found in granite formations on the soil. In buildings poorly ventilated, radon gas can accumulate in high concentrations, having a known negative impact in public health, namely regarding lung cancer risk increase. In fact, the radon progeny combined with aerosol particles can be trapped in the lungs on inhalation [1]. After a certain time, this can trigger lung cancer [3]. The World Health Organization (WHO) classified the radon in buildings has the second cause that leads to lung cancer, right after tobacco smoking.

Given radon gas is a radioactive gas the radon exposure determines the absorption of a radiation dose. To assess indoor radon gas concentration, we used the metric AMRC (Arithmetic Mean Radon Concentration) that is expressed in Bq m^{-3} and is computed according to Eq. (1):

$$AMRC = \frac{1}{N} \sum_{i=0}^N x_i \quad (1)$$

In Eq. (1) x_i is the i th periodic measurement obtained by a specific radon sensor, and N represents the total number of radon measurements in a specific period of time.

3.1. Indoor annual effective dose — (IAED)

In order to convert the indoor radon concentration into an Indoor Effective Dose (IED) metric it is necessary to adopt a radon dose conversion factor. The adopted conversion factor for an indoor effective dose is $9 \text{ nSv per } (\text{Bq m}^{-3} \text{ h})^{-1}$. Additionally, an equilibrium factor (F-factor) of 0.4 is used for the indoor case [1,2]. The F-factor is used to describe the ratio between radon and its progeny. An F-factor of 1 means equal amounts of radon and its progeny. An F-factor of 0.4 is taken as representative for homes. To calculate the Annual Indoor Effective Dose (IAED), we used the approach defined in [1], cf. Eq. (2):

$$IAED \text{ (mSv)} = AAMRC \text{ (Bq m}^{-3}\text{)} \times 0.4 \times AAO \text{ (h)} \times 9 \text{ (nSv(Bq m}^{-3} \text{ h)}^{-1}\text{)} \quad (2)$$

In Eq. (2) AAMRC represents the Annual Arithmetic Mean Radon Concentration in the units of Bq m^{-3} and AAO represents the Annual Average Occupancy (AAO) in hours. As stated by the International Commission on Radiological Protection (ICRP) the public dose limit regarding radiation exposure is 1 mSv per year [1,2]. The referred ICRP limit is considered as a frontier established to prevent deterministic effects due to radiation exposure (death or malformation of somatic cells) and limit the probability of stochastic effects (cancer or development of cancer). ICRP estimates that radiation doses escalating over 1 mSv per year will need the establishment of safety measures for members of the general public [4].

As a reference, we will compute the IAED for the school building occupation profile defined previously in Section 1. For the given occupation profile, the overall AAO is calculated cf. Eq. (3):

$$AAO \text{ (h)} = 10 \frac{\text{months}}{\text{year}} \times 4 \frac{\text{weeks}}{\text{month}} \times 5 \frac{\text{days}}{\text{week}} \times 7 \frac{\text{hours}}{\text{day}} = 1400 \text{ h} \quad (3)$$

Therefore, if we consider an IAED limit of 1 mSv, from Eq. (2) we can calculate the correspondent AAMRC (cf. Eq. (4)):

$$AAMRC \text{ (Bq m}^{-3}\text{)} = \frac{0.4 \times 1400 \text{ (h)} \times 9 \text{ (nSv(Bq m}^{-3}\text{h)}^{-1}\text{)}}{1 \text{ (mSv)}} = 200 \text{ Bq m}^{-3} \quad (4)$$

This means that the value of 200 Bq m⁻³ obtained in Eq. (4), represents the annual average mean radon concentration occupational exposure limit when the school building occupation profile previously defined is considered.

4. The new Portuguese regulation on dosimetric approach on radon assessment

The new Portuguese legislation regarding protection against exposure to ionizing radiation was published on December 3, 2018 [5]. This new law results from the transposition of Directive 2013/59/Euratom [6].

Concerning radon gas exposure, the Portuguese law specifies a so-called “reference level” of 300 Bq m⁻³ for the annual average limit of radon concentration in residential housing, buildings open to the general public and workplaces, above which some remediation measures are strongly recommended (Articles 145 to 150).

The existence of a reference level of 300 Bq m⁻³ specified to trigger a set of mitigation procedures in order to reduce indoor radon concentration, taken in isolation, seems to be a simplistic approach to the problem. In fact, a school building or a dwelling should not be analyzed in the same way as a conference room or a concert hall, since the period of occupation for the first type of rooms is much longer than it is for the second type. Moreover, the regularity of the occupation is also quite distinct, being important to distinguish between sporadic or regular occupation. Hence, the analysis based only in a reference level without considering important variables like the type of building and its occupancy, the ventilation actions that are undertaken by the occupants, can generate misleading conclusions.

5. Measurement campaign

5.1. Measurement procedure

The measurement campaign lasted one complete month and was implemented during the months of May and June 2018. The experimental work was carried out in a set of 13 rooms (8 classrooms and 5 technical offices) in all building floors. The school building is located in the north region of Portugal.

To assess indoor radon concentration, in situ measurements, with 1-h resolution, were undertaken using digital radon probes with data log embedded. The measurements were carried out on a continuous basis in cooperation with school teachers and students. The teachers were asked to fill out a form in order to register the ventilation actions performed during the measurements’ periods, mainly by opening and closing the windows.

The measuring probes were placed in the classrooms far away from the intervention of students. The places were chosen to avoid radiation energy sources and other electric equipment and devices. It was kept a distance from windows and entrance doors to avoid sudden pressure drops.

The probes used for experimental assessment were supplied by Airthings and have a calibration certificate issued in 2017.

5.2. Synthesis of results

Fig. 2 depicts the statistical results of the indoor radon concentration over the measurement period, using a boxplot representation, for the 13 instrumented rooms.

On the chart presented in Fig. 2 are drawn 2 horizontal lines which represent the legal limit for the indoor radon concentration of 300 Bq m⁻³, according to the new Portuguese legislation, and the limit of 200 Bq m⁻³ (Eq. (4)) obtained by the application of a dosimetric approach assessed according to the UNSCEAR methodology as referred in Section 2.

Note that, the value of 200 Bq m⁻³ is obtained when an Annual Indoor Effective Dose (IAED) of 1 mSv is considered for the school building occupation profile considered, i.e. a total number of 1400 h per year of occupation, which corresponds to a period of 10 months of classes, 5 days a week, during 7 h a day.

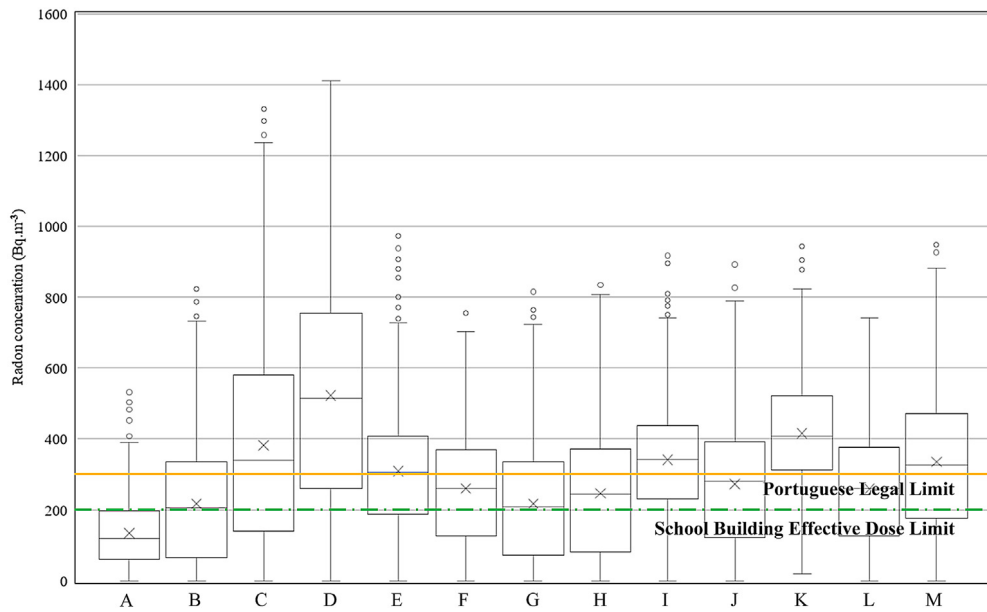


Fig. 2. Boxplot representation for radon concentration for the measurement period.

6. Results discussion

Table 1 represents the parameters AMRC (Arithmetic Mean Radon Concentration), SD (standard deviation) and IAED (Indoor Annual Effective Dose) during the measurement period of one month in all monitored rooms of the elementary school.

Table 1. Statistical results summary for all the rooms for the measurement period.

| Room | A | B | C | D | E | F | G | H | I | J | K | L | M |
|---------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| AMRC[Bq m ⁻³] | 135 | 216 | 381 | 522 | 309 | 261 | 219 | 246 | 342 | 273 | 414 | 258 | 336 |
| SD [Bq m ⁻³] | 96 | 171 | 287 | 318 | 168 | 161 | 160 | 180 | 155 | 178 | 164 | 162 | 203 |
| IAED [mSv/yr] | 0,7 | 1,1 | 1,6 | 2,6 | 1,6 | 1,3 | 1,1 | 1,2 | 1,7 | 1,4 | 2,1 | 1,3 | 1,7 |

Results presented in Fig. 2 and Table 1 allow to conclude that the majority of the instrumented rooms show indoor radon concentration above the limit of 200 Bq m⁻³. In fact, the limit obtained according to the dosimetric approach was exceeded 12 out of 13 times — the instrumented rooms B, C, D, E, F, G, H, I, J, K, M and M (Fig. 1) exceed the limit of 200 Bq m⁻³. Only room A, an office room placed in the basement, very well ventilated with ventilation grids installed in opposite walls, present an indoor radon concentration below 200 Bq m⁻³.

On the other hand, considering the limit specified in the Portuguese legislation (300 Bq m⁻³) only rooms C, D, E, I, K, L and M exceed the referred legal limit. The results analysis turns obvious the existence of a discrepancy between both approaches. The regulatory approach indicates strong evidence of higher risk – indoor radon concentrations above 300 Bq m⁻³ – in 46% of the instrumented rooms. However, when considering a dosimetric approach, the risk perception is extended to 93% of the compartments.

In fact, the attained results make clear that almost all of the rooms that were instrumented present effective radon risk for the occupants, according to the criteria presented by ICRP, according to which the public dose limit regarding radiation exposure is 1 mSv per year [4]. An increased risk is observed in classrooms C and M, rooms which gather a large number of students during 7 h a day. The implementation of specific mitigation actions is mandatory, especially on these compartments. The mitigation actions must inevitably include ventilation actions for effective reduction of the indoor radon gas concentrations. The technical solutions should allow air dilution and/or pressure change, achieved by the installation of an extraction fan. In any case, it is necessary to harmonize the

ventilation needs to preserve Indoor Air Quality (IAQ) with the requirements of the buildings in terms of energy efficiency.

Complementary to the mitigation strategies some awareness-raising activities should be promoted among teachers and students, in order to alerting the occupants of the school building to potential risks regarding permanence to high radon concentrations during large periods of time. Those campaigns must be focused on prevention, since their final objective is to alert teachers, students and their families about the main proceedings to implement a set of radon management strategies in order to get radon safe buildings. In a few words, the final purpose of the awareness-raising actions to be developed is to inform the community, and not to create unnecessary panic regarding the subject.

7. Conclusion

An elementary school building was extensively instrumented in order to assess indoor radon concentration in all occupied rooms, in a scenario of low energy spent for heating, cooling and ventilation. The *in situ* instrumentation was done continuously, during 1 month, 24 h a day, 7 days a week, and the occupants of the room were invited to fill a questionnaire in order to register the ventilation actions.

The main results of the study are the following:

- Despite mean radon concentration is above the national legal limit of 300 Bq m^{-3} , in only 48% of the rooms, the risk perception associated with radon exposure rises to 93% of the rooms, when considering the influence of the period of occupation;
- This study does not consider the cumulative effect of radon exposure in households. In fact, at home there is an additional effect regarding radon exposure for the occupants who live in buildings located in granite areas. In these cases, the overall risk tends to be higher, since the absorbed indoor effective dose is cumulative and results from the exposure to radon gas both in school and at home. On the other hand, the very low energy spent in the building may have biased the results obtained. Thus, it is important to make clear that the conclusions are valid for a scenario of very reduced energy consumption for thermal comfort and indoor air quality;
- Previous studies have been developed by the authors regarding indoor radon exposure in single-family houses in Minho region [7]. The results make clear that for houses with poor air renovation, the indoor radon concentration stays considerably above the legal limit of 300 Bq m^{-3} . This constitutes a matter of concern given the cumulative effects of radon in human health. The obtained results recommend the implementation of a long-term characterization for all instrumented rooms. Afterwards, an action plan for the school building is strongly recommended.

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References

- [1] Chen J. A review of radon doses. *Radiat Prot Manage* 2005;22(4):27–31.
- [2] Chen J, Moir D. An updated assessment of radon exposure in Canada. *Radiat Prot Dosim* 2010;140(2):166–70. <http://dx.doi.org/10.1093/rpd/ncq046>.
- [3] World Health Organization. Regional office for Europe. WHO guidelines for indoor air quality: Selected pollutants. World Health Organization. Regional Office for Europe; 2010. <http://www.who.int/iris/handle/10665/260127>.
- [4] ICRP. The 2007 Recommendations of the international commission on radiological protection. *Ann. ICRP*, vol. 37, ICRP Publication 103; 2007, p. 2–4. https://journals.sagepub.com/doi/pdf/10.1177/ANIB_37_2-4.
- [5] Decreto-lei no 108/2018 de 3 de dezembro da presidência de conselho de ministros. 1.a série, No. 232, Lisboa, Portugal: Diário da República; 2018. <https://data.dre.pt/eli/dec-lei/108/2018/12/03/p/dre/pt/html>.
- [6] European council directive 2013/59/Euratom. *J EU* 2014;L13(57):1–73. <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2014:013:0001:0073:EN:PDF>.
- [7] Curado A, Silva JP, Carvalho L, Lopes SI. Indoor radon concentration assessment in a set of single family houses: Case study held in Barcelos, North of Portugal. *Energy Procedia* 2017;136:109–14. <http://dx.doi.org/10.1016/j.egypro.2017.10.295>.