Development of a Pre-Diagnosis Procedure for the Evaluation of Indoor Radon Potential in Buildings

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Abstract: - Indoor radon accumulation is considered the main source of human exposure to ionizing radiation. Depending on the average radon level, indoor long-term exposure can significantly increase the risk of lung cancer onset. The publication of international regulations on the protection of human health the exposure of ionizing radiation, defining threshold values over whom health consequences for occupants could be expected, led to the control and testing of radon levels in workplaces and premises using multiple techniques and approaches. In particular, since the main source of radon is soil, many efforts have been done for the redaction of maps of the geogenic potential risk, as well as the definition of proper measurement standards and techniques for indoor monitoring. Radon maps, based on geology and measurements of radon and/ or the natural radioactive content in the soil, constitute an evaluable tool for decision-making authorities in radon policies giving the possibility to characterize areas for radon risk where indoor radon measurements are not available. But, of course, they are not completely descriptive of the potential risk, so indoor monitoring in buildings is also required. The correct design of an indoor monitoring campaign is a crucial topic.. Scientific literature has largely demonstrated that many site-specific features influence the accumulation process, as well as most building materials represent a significant source, after the soil. The preliminary complete investigation in buildings should be properly defined since radiation safety in a situation of radon exposure completely ensured during the building's construction and maintenance phases as well as during the selling/rental ones. So, the aim of this work is to put the basis for the development of a pre-diagnosis procedure as a tool for the screening of buildings susceptible to high indoor radon activity concentrations. The work represents a very early stage of implementation of a qualitative method for the design of a measurement campaign for the indoor radon assessment. A pre-evaluation selection of the variables that play a leading role in the accumulation process is presented. A prior survey, based on evidence in scientific literature, was done to identify all relevant characteristics that most affect indoor radon levels, mainly concerning local geology, building features, ventilation, and occupancy factors. The selected parameters, classified into levels according to defined indicators and then combined, allow a more refined sample selection for measurements campaign in the indoor radon assessment process. Future development will be oriented to the validation of case studies and the implementation of the procedure in a software environment which will be the first tool available to systematize and regulate the radon monitoring process for short-term decision-making.

Key-Words: - Radon monitoring, indoor radon , radon, radon in buildings

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1 Introduction

Human exposure to natural background radiation is an inevitable event since the main sources of radiation are the cosmic rays and the primordial radionuclides contained in the earth's crust. The main contribution of exposure arises from natural radiation either than from cosmic rays and nuclear processes. Referring only to the larger contribution, i.e. ionizing radiation of natural origin, more than three-quarters of the entire total comes from radionuclides present in the earth's crust, such as uranium and thorium whose decay product is radon. Radon is a radioactive gas, which, under certain specific conditions, can accumulate in closed rooms and constitute a serious hazard to human health because of its well-known carcinogenicity, [1]. For this reason, the control of indoor radon levels, based on the measurement of radon activity concentration (CRn), integrated over a year and expressed in terms of effective annual dose, D (mSvy-1), is crucial for the assessment of the radiological risk related to the inhalation of radon and its progeny, [2].

Radon exhalation from the ground beneath and surrounding buildings is generally the main source of indoor radon, entering buildings through cracks in the floor, gaps, windows, drains, or spaces around cables and pipes. In temperate and cold climate areas, radon easily accumulates in the indoor environment due to the pressure-driven flow of gas which arises because buildings are normally under a slight under pressure compared to pressure under the building, especially in wintertime when heating systems are on.

Moreover, some specific building materials can act as significant sources of radon exposure. Generally, it happens when they contain high levels of Radium-226, which decays into radon, and high porosity, allowing the radon gas to easily escape out of the material to the external air as, for example, in lightweight concrete with alum shale, phosphogypsum, Italian tuff, etc. The use of material from old uranium tailings (by-products of uranium mining) as filling under the buildings can also contribute to significant concentrations of radon indoors.

Radon in water also can be released into the indoor air during routine water use such as showering or laundry but in general, water tends to not be a significant source of indoor radon than the soil beneath buildings or construction materials.

Also, indoor/outdoor air exchange has a great influence on the growth process of concentration levels since a low air exchange rate with the atmosphere is responsible for the accumulation process.

For all these main reasons, indoor radon concentrations tend to differ among countries and even individual buildings mainly because of different climates, construction techniques and materials, types of ventilation provided, domestic habits, and soil geology.

Because of the complexity of this issue, which requires border synergies in terms of different competencies for the management and monitoring of radon assessment, radiation safety in a situation of radon exposure should be conceived in line with buildings codes and ensured in the context of controlling natural radioactivity during the buildings design, construction, and maintenance phases as well as during the selling/rental phases. In this last regard, the tasks of optimization of protection against radon could be solved also in line with other building construction issues such as energy efficiency, as largely explained in, [3].

All this assumed the development of a systematic approach to define a qualitative pre-diagnosis method for the design of the measurements campaign and the evaluation of indoor radon potential in the building could fill the gap in the short-term monitoring process related to the construction, maintenance, retrofit and selling/rental phase of a building.

It has been conceived as a tool for authorities to identify buildings where the potential risks could be high and for professionals to properly design monitoring campaigns. In particular, the proposed procedure turns out very useful for the preliminary evaluation of indoor radon concentrations when annual measurements cannot be performed. Indeed, according to international legislation radon activity concentration should be measured integrated over a year, but during the design, construction, and maintenance of a building is not feasible to wait for 3 months or 1 year. Moreover, people buying their premises could be interested in being informed about the presence of this hazard by requesting fast preliminary investigations.

So, the main objective of this work is to propose a methodology for the assessment of the radon potential and design of building monitoring based on the building analysis. A set of selected influencing variables have been selected, systematized, and categorized after a prior survey, based on evidence in scientific literature. Then, they have been classified in levels, from low to very high with also a color scale descriptor assigned, and then incorporate into a complete monitoring protocol that starts from the acquisition of the site information to the elaboration of the radon preliminary measurements results.

The pre-diagnosis approach constitutes a ‘pilot’ assessment to evaluate the indoor radon potential of a certain site taking into account the local geology, the ventilation and occupancy factor, and the building’s features. By means of this approach, a meaningful and efficient experimental campaign can be implemented without employing unnecessary time and resources because environments with high radon indoor potential can be easily identified. Indeed the common approach, in this absence of a defined procedure, is based only on the monitoring of buildings and environments required by law without considering specific cases or all other important features that govern the phenomena.

The work represents a very early stage of implementation of a comprehensive qualitative procedure for the design of a measurement campaign for the indoor radon assessment. It comes from the idea to introduce a sort of qualitative performance indicator to support the decision-making process in the management of an initial monitoring. The decision-maker, considering the several options, will be in this way equipped to properly analyze the status quo and to predict the outcomes of future actions.

Future development will be oriented to the application of case studies of the procedure in order to refine the methodology and the implementation of the procedure in a software environment representing the results of the measurement campaign surveys on the building 3D model.

2 Problem Formulation

The mapping and monitoring of indoor radon in private and public buildings is mandatory in many countries all over the world, [4]. One of the main approaches for preliminary investigations aimed to identify susceptible areas is a statistical analysis based on soil or indoor measurements generally performed with passive systems, some of which are easily manipulated. Basically, according to many international regulations, only environments at underground and ground levels have to be investigated. But, scientific literature has demonstrated that also work and living spaces on upper floors are susceptible to high indoor radon concentration. It happens when some defined features, related to the building material used and the construction technique and architectural plant, occur. For this reason, preliminary inspections should be extended, in some particular cases, also to environments on different floors. Advances in scientific literature and research about the development of more accurate technologies for radon monitoring should be applied to support authorities and professionals in improving the protection of population health by using the most recent findings and technologies. In this context, a systematic approach aimed to better identify all the buildings and indoor environments susceptible to indoor radon concentration by using an active monitoring system is proposed. The strategy is aimed to allow authorities and professionals to improve the performance of investigations and increase the level of protection of the population's health. The strategy gives well-defined criteria for the design of the monitoring campaign, avoiding economic loss with a no-sense monitoring measurements campaign based on the elaboration of data with no clear and complete information.

2.1 Methodology

To set up a strategy, criteria for structural and geological features should be defined, first. Regarding the technologies to adopt for preliminary investigations the short-term radon concentration measurements, performed according to defined experimental protocols, fit for the purposes thanks to the fast and quite accurate response. Many instruments of this kind, available on the market, can be used for monitoring with fast responses. Instead, regarding the selection criteria a more wide description is necessary and in the following subsections described.

Identification of factors affecting indoor radon concentration has been the crucial idea of many research studies and the results presented in scientific literature demonstrate that the main factors are: geology, building materials, building features, and ventilation (related, in particular, to a number of floor and type of windows, foundations). For example in, [5], a deep review gathering systematic information collected from previous experimental campaigns on different types of buildings: residential, school, kindergarten, administrative offices, historical buildings, etc. was carried out highlighting the importance of the above-mentioned factors above di other ones.

Building features and materials used are strongly related to the period of the building construction. So this data appears to be significant for easily identifying indoor CRn. For example, in buildings built in the period after 1960 (the 'concrete age'), lower radon concentrations are easier to find in comparison to buildings built in the previous periods because of the presence of aerated foundations, building materials with low natural radioactive contents and improvements in the indoor natural ventilation thanks to regulations defining the minimum windows area and ceiling height according to the room size and use, respectively. Moreover, the difference in CR originates also from the building aging since new buildings are nonporous and crack-free in comparison to the old buildings. The above-cited findings were similarly obtained in many different studies, [6], [7], [8], [9], [10].

On this basis inclusion and exclusion criteria determining which environment or building of the target group can or cannot be included in the preliminary investigations can be outlined. Inclusion criteria comprise the characteristics or attributes that buildings must have in order to be included in the study. Exclusion criteria comprise characteristics used to identify what should not be included in a study (for example environment where there is no hazard or exposure).

Each criterion defining an inclusion feature can be quantified through levels as follows.

Table 1. Descriptors of the radon potential

Level	
low	green
medium	yellow
high	orange
very high	red

2.1.1 Criteria n.1: Radon Potential from Soil

Characterization of soil gas radon in an environment based on superficial geology is a useful tool for determining indoor radon concentration. In line with the national action plan recommendations of the International Commission on Radiological Protection, [11], suggesting the use of radon maps for the optimization of the search of homes or areas with high radon concentration, in many areas radon soil maps are available, [12], [13]. When priority areas are already defined by the national guidelines, geographic areas where building monitoring is mandatory are already defined. Alternatively, soil gas radon measurement on site is a useful tool for the assessment of environmental radon potential and for the prediction of potential indoor radon concentrations in a geographic area, as demonstrated by many worldwide studies, [5], [12], [13], [14], [15]. In these cases, Table 1 can be used in line with values of radon concentrations measured in the soil.

2.1.2 Criteria n.2: Radon Potential from Building Material

The second screening criterion is the identification of the radon potential from building materials. As demonstrated by many scientific works structural and decorative materials could be susceptible to high radon potential, [16], [17], [18], [19]. A list of hazardous materials used for structural purposes is defined in, [4]. Also in this case, Table 1 can be used in line with the values of natural radioactive content measured according to, [4], or national legislation.

2.1.3 Criteria n.3: Buildings and Environment Features

Building-specific factors affect indoor radon concentrations, [6]. In particular, the type of foundation and the presence of openings favoring natural ventilation play a very crucial role in the radon accumulation dynamics in closed environments. For example, higher radon concentrations are revealed in buildings without basements because, without the physical barrier of the foundation, radon penetrates into the flat directly from the soil which is the main source of radon, [7], [20].

In buildings like schools, hospitals, or public offices a great number of people, than a private/residential ones, are exposed. Also, in these structures, people use to spend many hours per day. So, according to the use, it is very important to monitor indoor concentrations in all more susceptible environments, from underground to higher floors. Table 2 could be used to classify the different features of the building and the indoor environment.

Table 2. Descriptors of the radon potential for criteria 3

Foundation type	
Indirect /direct but aerated	green
In contact with soil /no aerated	yellow
Direct contact with soil	orange
No foundation	red

Ventilation of the environment	
3 or more openings/forced ventilation systems	green
2 openings	yellow
1 openings	orange
No openings	red

Destination	
Occasional place (b&b, Hotel rooms, museum..)	green
Public offices	yellow
Residential/ working places	orange
Schools/ /hospitals	red

Use	
Occasional (less than 10h in a month)	green
Services local, kitchens	yellow
Bedrooms and offices	orange
Classrooms and rooms of Schools/hospitals	red

2.2 Monitoring Protocol

The theoretical building's tendency concerning indoor radon exposure through the combination of the above-presented criteria (Figure 1) is crucial to design a measurement campaign.

In buildings where all 4 criteria have a high impact (red light), the monitoring should be extended also to the environment on the upper floors.

In particular, according to the criteria and descriptors introduced the monitoring should prioritized in buildings presenting no green light or just one and more than two orange or red.

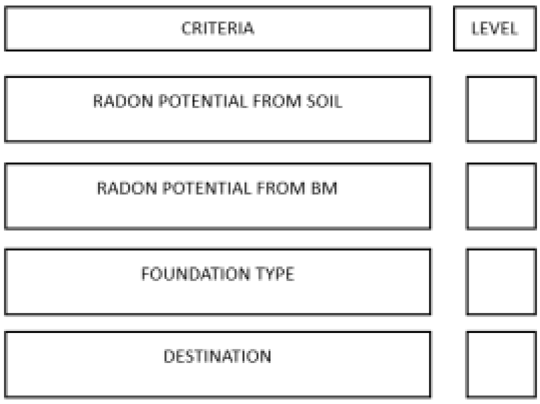

Fig. 1: Pre-monitoring criteria tables

The monitoring protocol is made up of the following main steps:

1. identification of the closed spaces to monitor.
2. information measures for people living/working in it.
3. Performing short-term measurements.

Environment to monitor should be closed for a minimum of 48 hours, in order to assess the maximum indoor radon concentrations. In this time period, it is important to avoid the opening of windows and doors and the activation of heating/ventilation systems. This approach, proposed and validated by the authors also in previous work, [21], aims to detect the maximum reachable level of concentration in the room i.e. to estimate radon ingrowth in the room in low ventilation conditions, qualitatively.

The complete flow chart of the approach is reported in Figure 2, instead.

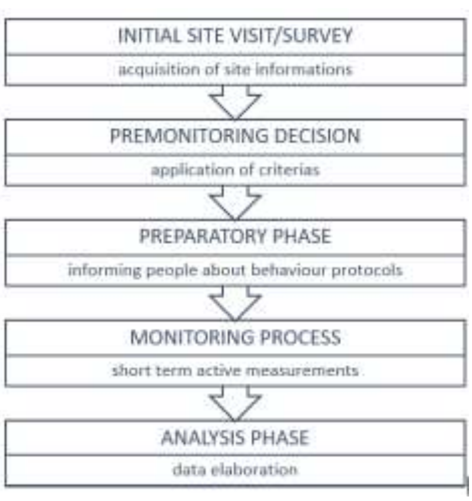

Fig. 2: Flow chart of the total approach

3 Discussion

The geology and phenotype of buildings are crucial in indoor radon accumulation dynamics.

According to international legislation radon activity concentration should be measured, on underground and ground floors, over a year, but in some cases is not feasible to wait for 3 months or 1 year, [22]. In other cases, the threshold limits can be overcome also in upper floors. When the building has been never monitored, to demonstrate the improvements of a mitigation intervention or to identify other susceptible environments to monitor, according to the regulation for the safety in working environments, short terms measurements performed with active instruments represent a valid method for preliminary investigations and outcomes. Of course, in case of high potential results, it will be recommended to proceed to a detailed indoor radon concentration assessment and to implement remediation measures to reduce radon risk exposure. The described approach based on the assessment of the presence of radon sources (soil and building materials) and environmental design metrics (buildings features) would like to represent a strong starting point for:

1. design a measurements campaign for the indoor radon assessment identifying all the susceptible environments. Indeed, the approach overcomes the limits defined by law guaranteeing more protection to the population by extending the monitoring also to buildings not identified in radon-prone areas maps or environments at floors upper than the ground.
2. ‘phenotyping’ buildings whose features can determine higher or lower radon CRn

This last point is crucial in the patchy situation. In Italy, for example, the architectural background is characterized by an old building heritage, with a great number of structures built in different times before the 1900s and1980s.

In this irregular background, it could be very useful to identify areas where buildings with the same building features, according to the design of the age, are concentrated. For example, buildings before the 1950s according to the Italian construction tradition are built with structural walls of natural stones and with direct foundations, often without aerated basements. Moreover, because of the stone’s characteristics structures are characterized by big thick walls and small openings (doors and windows) and indoor spaces without widows. According to the above-mentioned criteria, this phenotype could be more susceptible to high CRn and should be investigated also in areas where radon potential from the soil is not classified as high.

4 Conclusion

An early stage of implementation of a comprehensive experimental qualitative procedure for the design of a measurements campaign for the indoor radon assessment and for the phenotyping of the building susceptible to high indoor radon concentrations has been presented. The procedure should be intended as an assessment tool based on radon performance indicators related to different inclusion criteria.

Firstly, a selection of the variables that play a leading role in the radon accumulation process was carried out. Then, once identified all relevant characteristics that most affect the indoor radon levels, mainly concerning local geology, building features, ventilation, and occupancy factors, the selected parameters were classified into levels, according to defined indicators, and combined in a ‘pre-monitoring criteria table’ for decision making. This table constitutes an important tool in the pre-monitoring decision process which constitute an important phase in the framework of the global monitoring protocol presented in Figure 2.

As the approach is at its early stage of implementation, only the main ‘primary’ criteria have been included. Of course, future development will be oriented to the validation of case studies but also to the inclusion of other secondary criteria and the implementation of the complete procedure in a software environment. In particular, the authors are currently working on the application of the proposed approach to case studies in Italy that will be presented in future works.

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