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Monitoring of indoor Radon in historical heritage buildings by means of passive and active methods. A case study.

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***Abstract* – Indoor radon in buildings is a major cause of lung cancer in Europe, a risk enhanced by exposure to air pollution and tobacco smoke. Radon monitoring is, so, essential in determining the level of human exposure in living and workplaces. Recent literature has highlighted that historical buildings and archaeological sites could be affected by high Radon activity concentrations because of not only the entering from the soil but also due to the type of building materials and usage.This paper is aimed at monitoring Radon concentration measurement in an historical building in Salerno, Italia, where building material could highly contribute to indoor radon levels. The monitoring was performed over a period of 3 months. The measured concentrations ranged in a wide interval up to 263 Bq/m3 in living environments. Analysing the possible sources, both contributions of Radon from the building materials and from the soil were observed.**

I. INTRODUCTION

Radon (^{222}Rn) is a decay product of ^{238}U. It decays to its solid daughter, Po-218 within a half-life of 3.82 day. Radon occurs in the atmosphere mostly close to its source, i.e. the ground. When radon leaks into the indoor air, it tends to accumulate. Approximately 80% of the radiation to which the public is exposed is from indoor radon, which is the most dominant source among natural radiation sources.

Indoor environment of historical buildings and museums could be affected by high levels of Radon gas, coming from the soil and some buildings materials and artworks made with particular kind of stone as granite, travertine etc. The long exposure to the inhalation of high concentration of Radon is the second cause of lung cancer after smoke [1]. Because Radon is a noble gas it cannotbe filtered and for this reason its monitoring is the only solution to protect people health [2]. Indoor radon is very variable from buildings to buildings, but it can be elevated especially in the environment located in area where the soil and the building materials used are rich in primordial radionuclide contents. So, in addition to geological factors, indoor concentrations depend on types of building materials. Also, the age of the building and poor ventilation can influence radon concentration level in buildings [3], as well as construction methods. For this reason, old historical buildings located in area with high radon potential in the soil, made of building materials with natural radioactive content and direct foundation are more susceptible to high indoor radon levels. In the Italian panorama the Campania region is a very interesting area as its soils are characterized by a wide variety of geological environments of volcanic origin too. Geological features, soil characteristics and the widespread use, in traditional building constructions, of different stones of volcanic origin, especially yellow and green tuff coming from local quarries, have been considered responsible for the higher value of indoor radon mean activity concentration than the national average [4]. This study is aimed to determine the level of indoor radon activity concentration in a typical historical building of the Campania region, south Italy.

II. CASE STUDY

A. Study area

The building under study is one of the oldest ones in the municipality of Fisciano, Salerno, located in the south of Italy (Campania region). It constitutes one of the most representative building types of the local area.

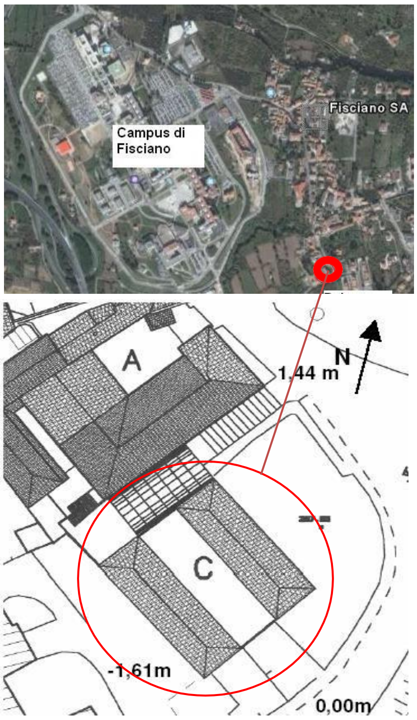

Fig. 1. Study area (Google maps copyrights)-aerial view.

Built in the XIV century, the ancient complex is a manor building of about fifteen hundred square meters distributed over four floors and a thousand square meters of garden, as well as a splendid internal courtyard. Several transformations and restorations occurred until the construction of the "new" version of the building in 1873 when it was modernized acquiring the current look in typical liberty style. The interiors are characterized by refined decorations: the monumental staircase, the halls, the richly frescoed ceilings in Art Nouveau style are the main component of this estate where one of the most important families of the local nobility lived. At the beginning of the twentieth century the rear part was built on three levels on the garden side and subsequently, in 1938, the modernization of the ground floor and first floor was carried out limited to the southern areas. After these interventions, it has not undergone significant structural changes up to the present day. The building, completely made with local yellow tuff, is located in the Irno Valley, in the north of Salerno, near the campus of the University of Salerno, exactly at the entrance of the urban centre of the small municipality of Fisciano (Figure 1).

From a geological and radiological point of view this area has been deeply investigated and a lot ofinformation are available. In particular, the soil is characterized by alluvial conoid deposits with a pyroclastic matrix (Upper Pleistocene), positioned above a dolomitic and dolomitic limestone substrate (Upper Triassic) belonging to the Picentini Mountains. The sedimentary sequence filling the valley is covered by a thin layer, which is underlain by unconsolidated air fall pyroclastic and alluvial deposit.

This sequence is 20-40 mthick and lays on a lithic basement formed by volcanic tuff [5-7].

From a radiological point of view according to the radon potential map, geology based, redacted in the context of the RAD_Campania project by the University of Salerno, in collaboration with the interUniversity Centre for Applied Research on the Prediction and Prevention of Major Hazards (CUGRI) and the Regional Agency for the Environmental Protection of Campania (ARPA Campania) [8], the expected soil activity concentrations in the area generally range from class 2 (low level) to 4 (medium level) , i.e. from 1000 to 30.000 Bqm^{-3}.

B. Materials and methods

The indoor monitoring has been conducted by means of passive system technique E-PERM (Rad elec), also known as an Electret Ion Chamber (EIC) (Fig.2a). It is a passive integrating ionization monitor consisting of a very stable electret mounted inside a small chamber made of electrically conducting plastic. The electret, a charged Teflon® disk, serves as both the source for ion collection and as the integrating ion sensor. Radon gas passively diffuses into the chamber through filtered inlets, and the alpha particles emitted by the decay process ionize air molecules. Negative ions produced inside the chamber are collected on the positively charged electret, causing a reduction of its surface charge. The reduction in charge is a function of the radon concentration, the duration of the testing period, and the chamber volume. This change in voltage is measured with Rad Elec's user friendly SPER-1 Electret Voltage Reader. The results are calculated according to a defined equation given by the manufacturer [8].

A soil gas measurement has been performed by means of radon and thoron detector (RAD7 DURRIDGE [9]) equipped with a stainless-steel soil gas probe, suitable for regular soil. The stainless-steel soil gas probe contains also a water stop, (a vacuum gauge mounted on a water shutoff valve) and it is equipped additionally with 3.05 meters of plastic tubing and an adapter of 0.8 cm inner diameter to link to the device and complete the measurement configuration (Fig.2b).

The detector uses a solid-state alpha detector, i.e. a semiconductor material that converts alpha radiation directly to an electrical signal. This makes it possible to identify which isotope (polonium-218, polonium-214, etc.) produced the radiation, so that it can be immediately distinguish old radon from new radon, radon from thoron, and signal from noise. The technique, known as alpha spectrometry, is a tremendous advantage in sniffing, or grab sampling applications.

(a) (b)

Fig. 2. (a) E-PERM system; (b) RAD 7 detector (radon in soil gas measurement configuration).

The measurement in soil gas was performed by using the "Grab" protocol a preset protocol able to return in 30 minutes a short-term measurement.

III. DISCUSSION

Indoor measurements were performed in several rooms at different floors, from theunderground floor to the 2nd floor.

Measurements were integrated over a period of three months, the minimum one according to the Italian legislation for the assessment of the radon exposure [10]. Results are reported in table 1.

Fig. 3 reports a graphical drawing of the value of the indoor radon concentrations per each floor, measured in the different environment and depicted with different colour according to the range indicated.

Table 1. Results of indoor measurements.

Floor	Description	C_{Rn} [Bq/m^3]
2nd	Bedroom	98.6
2nd	Office	154.3
2nd	Living room	130.4
2nd	Living room	199.2
2nd	Kitchen	162.1
1st	Bedroom	166.5
1st	Living room	138.1
1st	Office	92.4
1st	Living room	112.9
1st	Bedroom	263
1st	Bedroom	140.5
ground	Old restaurant	647.6
underground	deposit	585.3

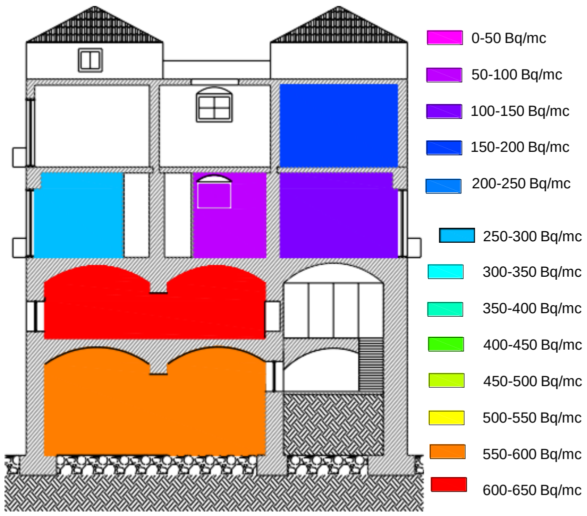

Fig.3. Graphical representation of the measurements of indoor radon activity concentrations ranged in classes.

The radon soil measurement was performed in the garden area of the building by using the RAD7 detector and according to the preset protocol, GRAB consisting in 4 cycle of 5 minutes, and two preliminary cycle of 5 minutes for grabbing and decaying. Short term tests are very useful in the inspection phase giving a good indication of the radon situation. The result shows a mean value of 39800 Bqm^{-3} which is comparable with the expected one by the RAD Campania provincial map (ranging between 1.000-30.000 Bqm^{-3} in the area as said in the previous section). The medium high value of the measurement is coherent with the geological feature of the underneath soil of the building, characterized by a lenticular pozzolanic layer on an alluvial sediment.

Table 2. Result of soil measurement.

Location	Description	C_{Rn} [Bq/m^3]
garden	Pozzolanic and alluvial soil	39800

IV. CONCLUSION

In this work an historical representative building in the town of Fisciano was investigated for monitoring radon activity concentrations in the indoor environment. Results show how, as confirmed by other studies in literature, some buildings materials and artworks made with particular kind of stone, could affect the indoor air by exhalating radon. Also, the results of this study show how radon concentrations are higher than the national average value of 75Bqm^{-3} [11]. This may be related to the fact that the buildings is constructed with a volcanic stone and direct foundations allowing radon to easily penetrate from the soil to the building environment. Most of the old buildings in the area are made of the volcanic stone tuff which is very porous and generally containing high value of the primordial radionuclide 226Ra [4]. Indoor radon concentration revealed in the upper floors could be likely attributed to the presence of building materials naturally containing radioactivity. Even if not negligible concentrations were measured, all of them are under the recent new limit defined by the current national legislations according to the ED 59/2013 [12], except for the underground and ground floor where very high concentrations were registered. But, from the radon risk assessment point of view, these concentrations do not constitute a risk since the investigated environment are not daily frequented by people (the 'old restaurant' is a local now closed to the public and the 'deposit' is a private local used to store instruments for the wine production).

Of course if the useof these environments should change, opportune mitigation measurements has to be evaluated for reducing radon concentrations.

The results of the present work highlight how the monitoring of indoor Radon in historical heritage buildings should be not neglected and extensively inspection should be performed to all environments at different floors since the massive use of building materials naturally containing radionuclide can seriously affect the indoor air. Further study will regard the assessment of the radiological hazard related to the building materials and the application of an indoor radon model for the complete assessment of the indoor environment [13].

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