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Influence of architectural style on indoor radon concentration in a radon prone area: A case study

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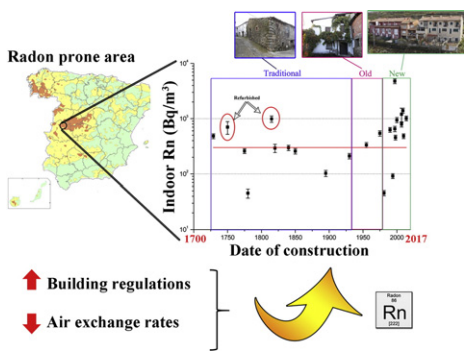
HIGHLIGHTS

- Surface radon exhalation rate from soil in itself was unable to explain indoor radon.
- Architectural style had a significant influence in the selected radon prone area.
- New dwellings have higher indoor radon concentrations than Traditional ones.
- Refurbished Traditional dwellings have higher indoor radon than Non-Refurbished.

GRAPHICAL ABSTRACT



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ABSTRACT

Indoor radon is a major health concern as it is a known carcinogenic. Nowadays there is a trend towards a greater energy conservation in buildings, which is reflected in an increasing number of regulations. But, can this trend increase the indoor radon concentration? In this paper, we selected a radon prone area in Spain and focused on single-family dwellings constructed in a variety of architectural styles. These styles ranged from 1729 up to 2014, with varying construction techniques (from local resources to almost universally standard building materials) and regulations in force (from none to the Spanish regulation in force). The ^{226}Ra concentrations in soil and surface radon exhalation rates were rather similar in this area, mean values ranging 70–126 Bq/kg and 49–100 mBq/m^2·s, respectively. Indoor radon concentration was generally greater than the contribution from soil exhalation (surface exhalation rates), especially in New dwellings (1980–2014). Its concentration in dwellings built in the Traditional style (1729–1940) was significantly lower than in the new houses. This can be consequence of the air tightness of the dwellings as a consequence of the different regulations in force. In the period covered by the Traditional style, there was no regulation in force, and dwelling had loose air tight. Whereas in recent times, there are mandatory regulations assuring a better air tightness of the buildings. Refurbishment of Traditional dwellings also seems to increase the indoor radon concentration, as they must also comply with the regulations in force.

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1. Introduction

Radon (^{222}Rn) is a radioactive gas, recognized by the World Health Organization as the second cause of lung cancer after that produced

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by tobacco smoke (WHO, 2009). Its presence in the environment depends fundamentally on the geochemical nature of the soil, which determines the ^{226}Ra soil content (Baeza et al., 1994) and the permeability of them (Neznal and Neznal, 2005). Although radon concentration in atmospheric air do not usually reach significant concentrations (Arnold et al., 2009), radon can be accumulated in dwellings and its concentration can be high. Since people usually remain a high percentage of their lives indoors, it can become a serious problem from the point of view of radiological protection (Barros et al., 2015; Torres-Durán et al., 2014). Therefore, it is extremely important to know, or better yet, to predict accurately radon levels indoors. Indoor radon concentrations depend on a large number of factors (climate, building materials and construction methods, ventilation, etc.), in addition to the characteristics of the soils where they were built, which can produce a great dispersion of results. This is why a large number of studies have been carried out, from very different perspectives, in order to know the risk posed by high concentrations of radon in the interior of homes and to design solutions to reduce it (Frutos-Vázquez et al., 2011; Bartzis et al., 2012).

In fact, many countries have developed maps identifying areas more or less prone to high levels of indoor radon. Specifically, in Spain (García-Talavera et al., 2013a, 2013b) a predictive radon map has been elaborated based on the geological characteristics of the soils and on the measurements of the gamma dose rate that by external irradiation is received from these. Other radon maps have been constructed from direct measurements of the concentrations of radon within buildings (Miles, 1997; Andersen et al., 2001; Martin, 2004; Friedmann, 2012). In some of them, dwellings have been classified according to their potential exposure to radon in different categories: low (<150 Bq/m^3); medium (between 150 and 300 Bq/m^3); and high (>300 Bq/m^3) (Martin, 2004).

Other studies have focused on whether it is possible to reduce the build-up of radon in homes. Among them, there is the European Union's RADPAR project (Bartzis et al., 2012), which concludes that in certain newly constructed and energy-efficient buildings, efforts to achieve greater energy savings are also effective in reducing the entry of radon into them. Similar results have been obtained in another study developed in Germany (Kemski et al., 2009), which confirms that the most modern buildings, built after 1995, have more moderate radon concentrations inside. The use of depressurization techniques based on underground sumps was also effective to reduce the indoor radon concentration (Frutos-Vázquez et al., 2011). However, concern about the consequences of high concentrations of indoor radon is relatively recent. In fact, in many countries such as Spain, the conclusions obtained from among others in those studies have not yet been transferred to the rules governing the construction of houses, to achieve an effective reduction of these levels in the areas that can exhale important radon activities from the soils.

One of the radon prone areas in Spain where there is a high risk that in the, measured annual mean value concentrations of indoor radon may exceed 300 Bq/m^3 (García-Talavera et al., 2013b) is located in the north of the province of Cáceres (Spain) (see Fig. 1), mainly due to the radioactive characteristics of their soils (Baeza et al., 1994). The most widespread type of housing in these regions, eminently rural, is single-family dwellings. These have been constructed, initially ignoring the existence of radon gas or its effects and therefore the need to take counter-measurements into account. At present, although there is

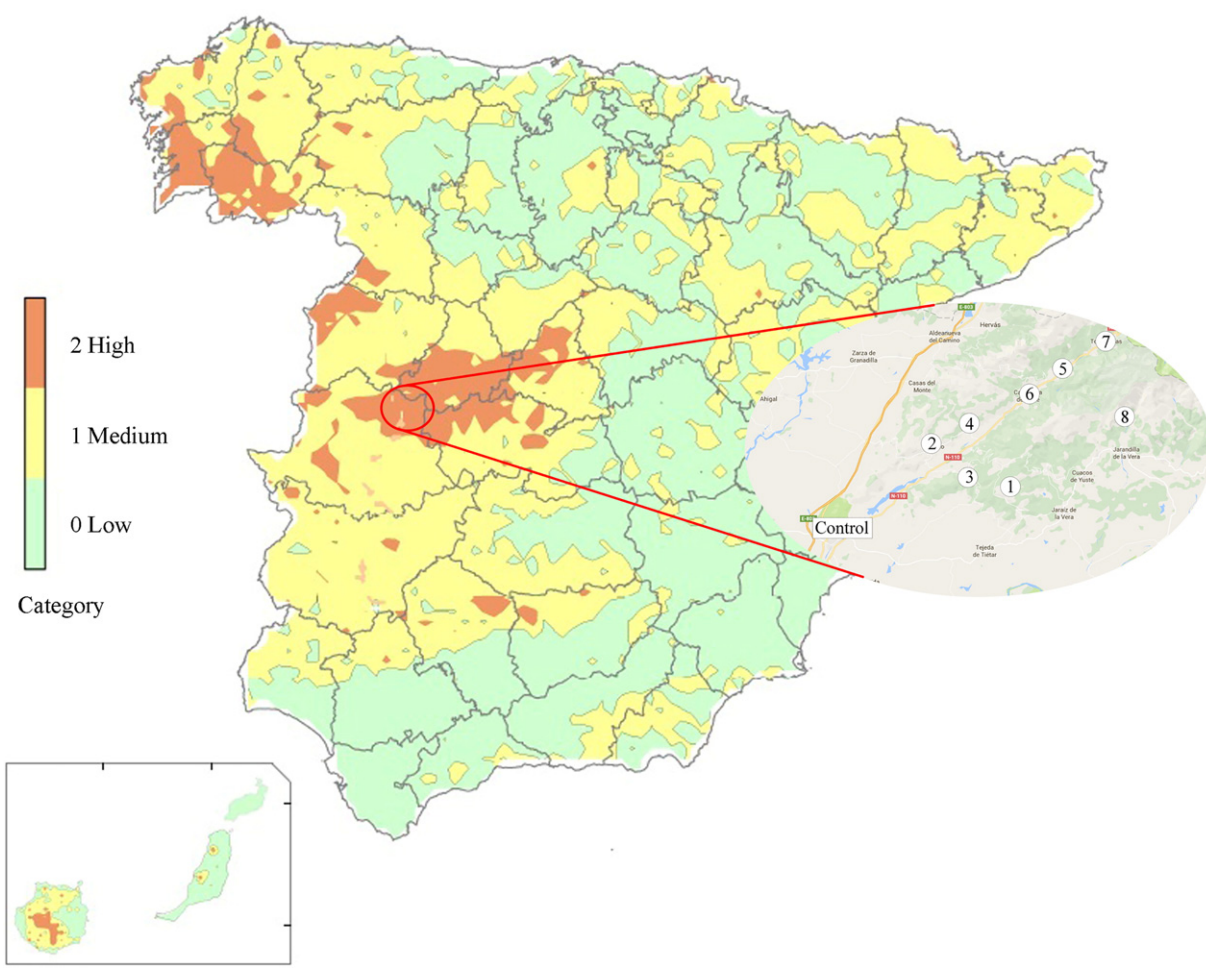

Fig. 1. Map of the selected locations. Modified from the Predictive Map of Radon Exposure in Spain (García-Talavera et al., 2013a). (Low exposure: Rn < 150 Bq/m^3; medium exposure: 150 < Rn < 300 Bq/m^3; and high exposure: Rn > 300 Bq/m^3.)

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