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Effects of buildings' refurbishment on indoor air quality. Results of a wide survey on radon concentrations before and after energy retrofit interventions

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ABSTRACT

Energy regulation, policy and targets enhance energy retrofit in buildings with a wide distribution in Europe and Switzerland. These actions are mainly aimed at reducing heat dispersion through the envelope. The interventions affect the permeability of the envelope influencing indoor air quality. Focusing on radon concentration, this study reports the results of a survey on 154 buildings measuring the radon concentrations before and after energy remediation. The buildings were located in the southern part of Switzerland (Canton Ticino), a region with measurements of radon concentration in more than half of the buildings (over 55,000 building in 2018), within a population of approximately 355,000. These figures make this region an area with an exceptionally high number of radon measurements, performed in 2005–10 upon mandate of the local public health authorities. The survey reveals the increasing of radon concentrations, in particular where windows were replaced with more performant ones. Results underline the need of considering energy saving and indoor air quality at the same time, in the frameworks of orienting public and private investment towards improving long-term public health. Adequate techniques for improving ventilation could be very helpful to that end.

1. Introduction

Energy saving measures within the built environment (e.g. energy retrofit of existing buildings) represent an important institutional strategy of governments committed to the need to decrease fossil fuels utilization in the implementation of climate change national policies. Several programs and regulations at global and local level document this issue. However, since energy saving and indoor air quality (IAQ) are the two sides of the same coins, the impacts of the interventions have to be evaluated both in terms of energy performance improvement and in terms of indoor comfort preservation. Energy saving should be accomplished by proper measures in order to guarantee also healthy IAQ. When energy retrofit is improperly implemented, it can worsen IAQ, especially if energy saving measures are not accompanied by appropriate means of air exchanger between indoors and outdoors. Doors and windows that are not hermetically sealed can contribute to air change per hour (ACH) in a significant way. Because energy saving measures normally change the permeability of the building envelope and consequently decrease the ventilation rate, it is important to carefully evaluate this issue before energy retrofit is undertaken.

Regarding IAQ, many aspects and parameters can be considered; the research here presented focus on radon concentration. Radon has an enormous impact on the health of the occupants, being the second cause of lung cancer after smoke according to the World Health Organization. The dramatic effects of exposure to radon on human health are well known and documented (World Health Organization (WHO, 2009). According to a recent study (Milner et al., 2014), the effect of energy retrofit can increase the exposure to radon and risk of lung cancer. The implications of energy retrofit in terms of possible decrease of ACH "need to be carefully evaluated to ensure that the desirable health and environmental benefits of home energy efficiency are not compromised by avoidable negative impacts on indoor air quality".

For example, in Switzerland, where the problem is more serious than in other European countries (Vienneau et al., 2017), attention is payed to radon measurements and mitigation in homes and dwelling (Federal Office of Public Health (FOPH, 2011) and three official radon competence centers have been operating since 2008 in the different linguistic areas of the country, including the Italian part (see also: *Centro Competenze Radon – CCR* Radon Competence Centre). The Swiss

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federal programs and activities carried out by CCR makes Canton Ticino (that is a radon prone area with the most part of the territory with a medium radon risk, an important part with a high radon risk and a negligible part with a low radon risk[1]), the region with the highest density of residential measurements worldwide, to our knowledge, accounting for measurements in 55,440 buildings for a population of roughly 355,000 people. This data, referred to the state of the art in 2013, are available in Excel-format at www.ch-radon.ch.

Radon concentrations in buildings depend on different factors such as the amount of radon-producing uranium-238 in the underlying rocks and soils, the permeability of soils, the routes available for its infiltration into the buildings and the rate of exchange between indoor and outdoor air. Infiltration and diffusion of radon from the soil to the indoor air is promoted by differential pressure caused by the temperature differences between outdoor and indoor air, which itself is significantly influenced by the degree of tightness of the building envelope. A research (Collignan, Le Ponner, & Mandin, 2016) explained that the most important parameters affecting indoor radon concentration are: the nature of the ground and the soil air permeability and presence of cracks; some building characteristics, such as the type of foundation and the ventilation rate also affect the indoor radon concentration. In addition, they stressed that the improvement of building envelope airtightness primarily refers to the part of the dwelling shell that is above the floor. The floor in contact with the ground is generally not included. As a result, pressure differentials between indoors and outdoors could be accentuated and enhance the radon infiltration in the dwelling through the floor. Considering this phenomenon, along with a possible reduction of the ventilation rate, higher indoor radon concentrations can be expected in thermally retrofitted dwellings (Collignan et al., 2016).

An interesting study about multi-storey building construction underlines that in buildings constructed meeting new requirements on energy efficiency, radon concentration exceeds the average level in early-constructed buildings (Vasilyev, Yarmoshenko, & Zhukovsky, 2015). Authors conclude their experiment research stressing that the main factor that leads to higher radon concentrations indoors is low ventilation rates.

A recent research (Collignan & Powaga, in press) states that the parameters affecting the indoor radon activity concentration are indoor depressurization of a building and its ventilation rate and underline the importance of a correct management of ventilation as key factor in this filed. They provide a numerical tool adapted to the assessment of radon concentration as a function of the prevailing parameters. They compare different ventilation systems in relation to the French context and without taking into account the impact of occupant behavior (windows opening) and conclude stressing the need to install and to maintain an efficient ventilation system in new airtight buildings in order to prevent radon risks on health.

A research (Milner et al., 2014) found that increasing the air tightness of dwellings (without compensatory purpose-provided ventilation) heightened mean indoor radon concentrations by 56.6%, from 21.2 Bq/m^3 to 33.2 Bq/m^3. Fitting extraction fans and trickle ventilators to restore ventilation will help offset the additional burden, but only if the ventilation related energy efficiency gains are lost. Mechanical ventilation systems with heat recovery may lower radon levels while maintaining the advantage of energy efficiency for the most airtight dwellings, but there is potential for a major adverse impact on health if such systems fail. The authors stressed that the problem needs much research and debate before undertaking the planned large scale program of housing investments that may embed health problems for many years to come.

This paper focuses on the effects of buildings' refurbishment on indoor air quality and presents results of a wide survey on radon measurements performed in buildings before and after energy saving measures promoted by the government through its national energy policies. In particular, we referred to the Federal Program for energy retrofit launched from the Federal Office of Energy (available at www.dasgebäudeprogramm.ch).

The aim of the research is to give an answer to the following questions:

- Are radon concentrations inside buildings influenced by energy retrofit interventions?
- How much does radon concentration vary inside buildings due to these interventions?
- Which type(s) of interventions have the most influence on indoor air radon concentrations?

Therefore, suggestions about to plan and to monitor properly energy efficiency together with IAQ could be derived.

The innovation of this research is given by the large sample size: 154 buildings. Due to the difficulty of sampling buildings characterized both by radon measurement and energy retrofit interventions, most studies deal with a much smaller sample size, considering a limited number of buildings. In other words, although the question seems to be simple, the evidence-based answer is more difficult because radon measurements prior to remediation are quite rare. Thanks to a widespread measurement campaign performed in the last decade in the southern part of Switzerland, we were able to access a large amount of radon data collected from buildings before they underwent energy remediation. By crossing data from the National Radon Database (Federal Office of Public Health (FOPH, 2013) and data from energy-retrofit of buildings, it was possible to select a sample of 154 buildings with radon measurements data related to the situation before and after different types of energy retrofit interventions.

Information on which type of energy measures was performed in the different buildings was made available from the cited federal program launched from the Federal Office of Energy for improving buildings energy performance. This data availability permits to analyze the type of retrofit measures as well as their influence on IAQ.

Considering the systematic nature of the campaigns for the prevention of radon exposure in Switzerland and the representativeness of the sample of buildings analysed during the survey, the achieved results can represent a valid support to the decisions also in other territories exposed to the same problem.

2. Materials and methods

The Swiss Federal Office of Public Health (FOPH) provided documents, data and programs in order to monitor radon concentration in buildings and reduce the health risks derived by radon exposure in Switzerland.[2] The guideline value for dwellings defined in the Swiss Radiological Protection Ordinance (the so-called *Strahlenschutzverordnung* no. 814.501) is 300 Bq/m^3.

Radon concentrations can be easily measured using passive dosimeters. In our survey, radon measurements before and after energy retrofit were performed using Radtrak Radonova dosimeters[3]. The duration of exposure ranged from 1 to 3 months. The uncertainty of this measurement was estimated as $+/-$ 12%. Concentrations were expressed in Bq/m^3.

Regarding the measurement, in each building, one dosimeter was positioned in the lower occupied room of the building during the winter season when space heating is in operation and windows are less open. At the end of the period of measurement, the dosimeters were sent to the CCR.

[1] See also the map of radon risk in Switzerland (source: www.ch-radon.ch).

[2] This information are downloadable at www.ch-radon.ch.

[3] Former Landauer Nordic Gammadata; Uppsala, Sweden.