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An indoor radon mitigation method by heterogeneous nucleation of H_2O vapor on Rn favored by Peltier cooling

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This work presents a novel method for mitigating indoor radon, which consists of four steps: a) nucleation of water vapor around Rn atoms and Rn progenies, b) condensation of the mentioned clusters favored by a Peltier cooling process, c) accumulation of the resulting solution, and d) discharging of the liquid outside. This system was proved in an underground cave in Mexico City with fixed microclimate conditions: 80% relative humidity, 798-800 mbar atmospheric pressure, 20°C temperature, and an almost constant indoor Rn activity of 890 Bq/m^3. The proposed method takes advantage of the natural formation of a system of Radon-Water ($Rn-H_2O$) complexes induced by van der Waals interactions. We have observed that by reducing the relative humidity by Peltier cooling, from 80% to 52% , a removal of radon is produced, from 607 Bq/m^3 to 165 Bq/m^3, which is a very remarkable mitigation effect. Experimentally, the operation of the mitigation system in relative humidity environments between 30% and 80%, and between 40 Bq/m^3 and 1500 Bq/m^3, is certified, always obtaining control of the desired intramural radon activity (100 Bq/m^3), in less than 12 hours. This surpasses most of today's commercial radon mitigation methods in efficiency, cost, time and ease, specifically in conditions where ventilation is not a reliable option.

Keywords: Radon mitigation; thermoelectric devices; water condensation.

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1. Introduction

The major part of the exposure to natural ionizing radiation is attributed to Radon, with a contribution around 50% of the average natural background radiation dose that receive the population [1]. Radon gas enters buildings from the ground or from the walls material and travels through cracks and porosity of concrete, and can mix with indoor air and water vapor, and part of it could be inhaled. In closed places, Radon accumulates, and its concentration rises, causing a significant health hazard [2].

International institutions, principally: ICRP (International Commission on Radiological Protection), WHO (World Health Organization), USEPA (United States Environmental Protection Agency), UK-HSE (United Kingdom-Health and Safety Executive), have been created action levels and specific regulations for Radon concentration in houses, work places, buildings and more recently, places where children and babies stay for many hours. These institutions have worked in actions and methods to mitigate indoor Radon using forced ventilation systems, sealing of entry routes, filtration [3], heat recovery ventilators [4], basement pressuriza-

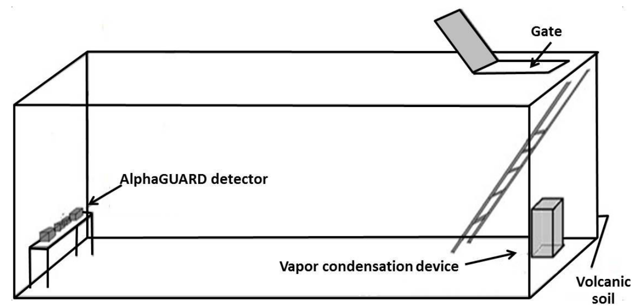

FIGURE 1. Cellar with the AlphaGUARD® detector, the water vapor condensation device and monitor of relative humidity.

tion and sub slab depressurization [5, 6]; however, most of them are expensive and involve structural modification on the buildings.

As it is well known, Radon is a good tracer in liquid water [7, 8]. The H_2O molecules have significant dipole momenta, which favor their surrounding around Rn and Rn progenies [9].

2. Methodology

2.1. The site

The present research was done in an underground closed room (cellar) inside a house. The location area is part of an ecosystem formed by the lava spills of volcano Xitle in the Southern part of Mexico City (19°29’ 52” N, 99°7’ 37” W) at 2380 m over the sea level. The room has a volume of 30.36 m^3 with one gate at the roof of 0.62×1 m, which is generally closed. A scheme of the cellar with the experimental setup is shown in Fig. 1.

2.2. Radon activity measurements in the cellar and in liquid water

The ^{222}Rn activity and relative humidity were measured by using the radon monitor AlphaGUARD® PQ 2000. The monitor was calibrated by the manufacturer, whose specifications indicate reliable management in temperatures ranging from 10°to 50°, under pressures from 700 mbar to 1100 mbar, and 0% to 99% relative humidity. The instrument is insensitive to vibrations. The Radon activity was also measured in the liquid water that resulted from the condensation of the humidity. This was done using the additional equipment AquaKIT® Dynamic System, which determines the Radon concentration directly through the AlphaGUARD® detector. The system used is based on the aeration method in a closed loop cycle in such a manner that Radon equilibrium is achieved between Radon dissolved in water and Radon flushed into the air entering the dynamic detector [10].

2.3. Control of the relative humidity

In order to control the relative humidity, a programmable humidity condenser by Peltier effect was designed [11]. The system is a typical dehumidifier, whose scheme is shown in Fig. 2. The cooling stage is formed by 6 Peltier cells size $4 \times 4 \times 0.4$ cm^3, and the whole system draws 330 watts. We assigned 10 different control set points for the relative humidity values in the range 52% to 79%, in a period of two months.

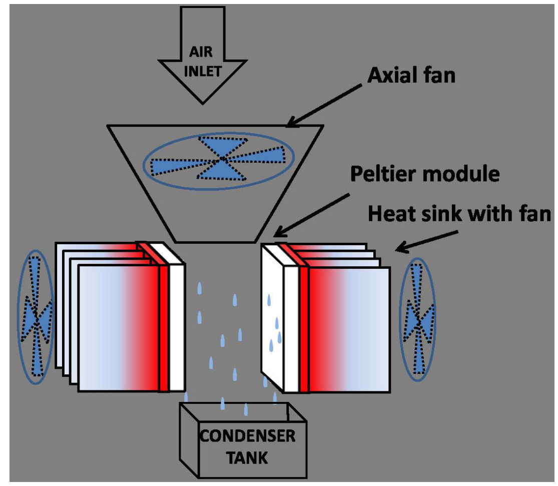

FIGURE 2. A scheme of the dehumidifier system.

The condenser tank has a capacity of 5 liters of water, which are collected in 5 days. The liquid water was separated into samples of 100 ml for the Rn activity measurements in the condensed water.

3. Results and discussion

3.1. Experimental results

In Fig. 3, the ^{222}Rn activity evolution without any humidity control during a four-month period is shown. When the gate is open, radon accumulation diminishes. Once the gate is closed, Radon has the chance to return to the previous levels. The average Radon concentration was 6636 ± 135 Bq/m^3,

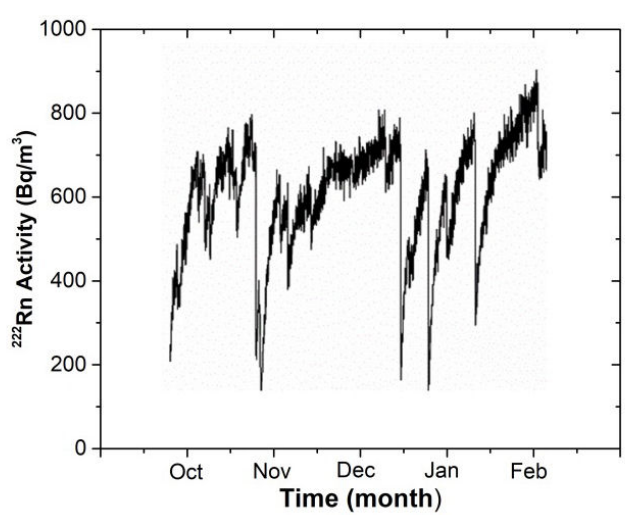

FIGURE 3. Evolution of ^{222}Rn activity during four months.

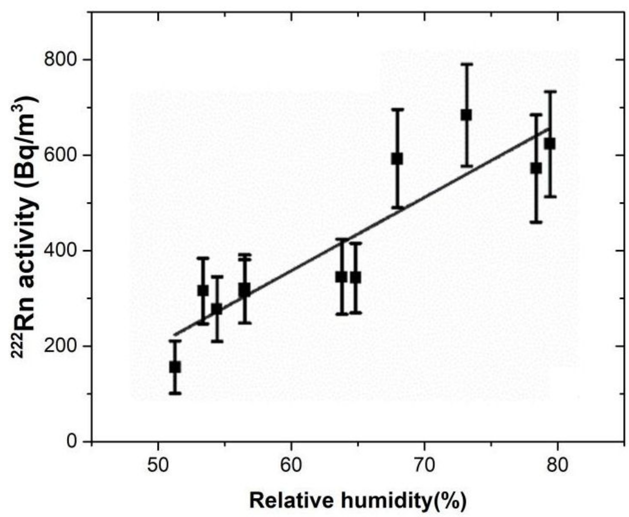

FIGURE 4. Radon activity as a function of the controlled relative humidity.

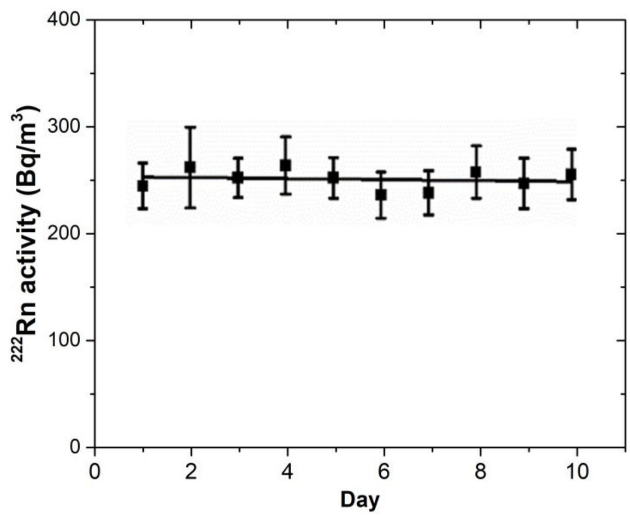

FIGURE 5. Radon activity in different days, for a controlled relative humidity value of 54%.

at an average temperature of 20 ± 0.8°C, relative humidity of 64 ± 9.7% and atmospheric pressure of 799.3 ± 2.8 mbar. The maximum value of Radon concentration was 936 Bq/m^3 at constant environmental conditions of temperature and atmospheric pressure, nevertheless the relative humidity parameter also has reached to a maximum 82.7 ± 2.4%.

A controlled decrease in the ambient relative humidity induces a reduction of the Radon activity, as shown in Fig. 4, in which a linear behavior with a positive slope is observed. A change from 79% to 52% of the relative humidity produces a change of the radon concentration from 607 Bq/m^3 to 165 Bq/m^3, representing a radon mitigation of 73%. In addition, it is interesting to observe in Fig. 5 that when the relative humidity is fixed to a specific value, in this case 54% relative humidity, the Radon concentration is maintained at the same value. Thus the rate of trapped radon in water molecules is constant, corresponding to a constant Rn exhalation rate from the walls and floor of the cellar.

3.2. Discussion

It has been reported that Rn measurements is significantly influenced by water, in the form of humidity [12]. When a radon nucleus decays, the passage of the alpha and recoiling polonium ions produce a substantial number of ions along their tracks. These ions can then act to induce the formation of nuclei at supersaturation values below those that would be necessary for homogeneous nucleation [13].

Once we observe a linear behavior of the Radon concentration as a function of the ambient relative humidity, it is interesting to verify the entrapment of Radon by the water molecules. Thus we determined the Rn activity in the liquid water obtained from the condensation of the humidity. By monitoring the radioactivity concentration during five days, it was verified that ^{222}Rn is the radioisotope responsible for the radiological activity of the accumulated water samples. The half-life of 3.8 days was experimentally determined.

3.3. Dehumidifier operation

To account for the underlying microscopic mechanisms of this mitigation process we must consider the data available in the literature. The air entering the condenser is cooled below the saturation point, and consequently the moisture (H_2O) molecules start to condense. Since each Radon atom can be surrounded by up to six water molecules [14], they act as natural seeds for the nucleation of the water droplets, which in turn precipitate to the collection tray. The whole process thus works as a very efficient mechanism for trapping Rn. The amount of condensed water is regulated by setting the internal temperature below the appropriate dew point, and afterwards the air is reheated to the room temperature before leaving the dehumidifier. The amount of trapped Radon is then roughly proportional to the volume of removed liquid water. At $T = 20$°C the relative humidities of 85% and 45% correspond, respectively, to 0.014714 kg and 0.00779 kg of water per cubic meter [15]. This means that 0.21 kg of water is removed from the whole room of 30.36 m^3 during this drying process. However, the moisture, as well as the Radon itself, keeps seeping from the walls, ceiling and floor of this room. The reported maximum solubility of Radon in water (which we were unable to measure) is roughly 42 Bq/L [16], so given a constant water removal rate, we get the linear expression

$$[Rn] = 11 * rH - 280, \quad (1)$$

after adjusting for the operational efficiency, where $[Rn]$ is the Radon activity in Bq/m^3 and rH is the setting for percentage relative humidity in the dehumidifier. Of course, the applicability of this formula is limited to the humidity range under consideration.

4. Conclusion

A novel and inexpensive method to mitigate Rn concentration and progenies was shown. It consists in the use of a condensation system based on the thermoelectric effect. It was found that the decrease of Rn in the ambient provoked by the condensation of water vapor corresponds to the appearance of Rn dissolved in the water tank of the condenser. Thus the water vapor in the ambient participates in an entrapment process of Rn atoms.

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