Radon concentration control by ventilation, and energy efficiency improvement

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ABSTRACT

Radon gas is a pathological agent confirmed by World Health Organization in terms of increasing the risk of lung cancer generation when it is inhaled by human in high concentration. This gas comes from soils with uranium content (i.e. granite terrain) and penetrates through the building envelope, such, as floors or basement walls. Its accumulation in indoor spaces increases the radon concentration level, constituting a health problem for occupants. This can be handled by rehabilitation actions in buildings that reduce indoor concentration to acceptable levels.

Ventilation technique can contribute for the same purpose. The gas dilution, by exchanging indoor and outdoor air is an effective mechanism. A priori, this easy to implement and low cost alternative can be recommended when other architectonic options are not feasible. However, the aspects that can compromise energy efficiency in ventilated spaces should also be evaluated. In order to reduce radon concentration from 900 Bq/m3 to 200 Bq/m3, an additional 30000 kWh/year can be needed for achieving indoor thermal comfort. This is showed in some cases where the air change rate required to reduce this concentration is 5ac/h,

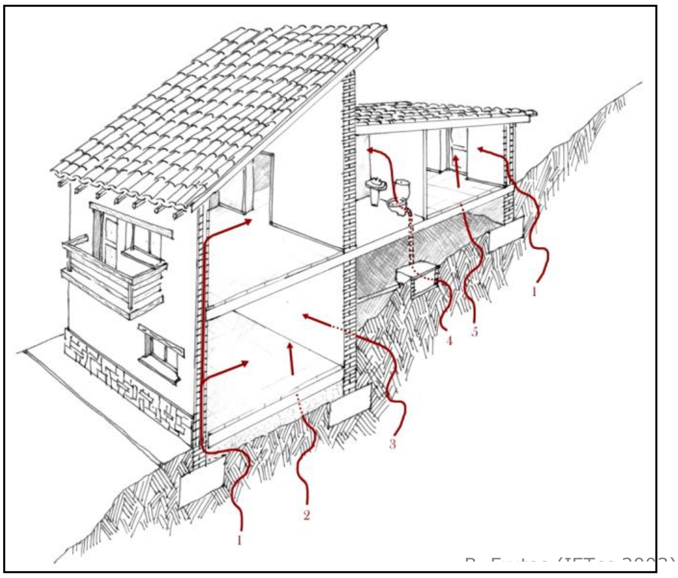
This paper presents an approach for understanding radon mitigation by ventilation, the energy lost in the process, and how to reduce such loss by implementing energy efficiency measures.

KEYWORDS

Radon mitigation; Ventilation; Heat recovery, Energy efficiency.

1 INTRODUCTION

Radon gas (hereinafter referred to isotope of radon, Rn-222) is a radioactive element that is generated in areas with high radio content in soils (granitic terrain for example).
Its high degree of mobility allows it to penetrate from the ground into buildings through the enclosure (porosity of materials, fissures, cracks and joints) and to accumulate inside, where it can be inhaled in high concentrations. Figure 1 shows a schematic of the usual ways of radon entry into buildings.



sFigure 1:Common ways of radon entry into buildings. (1-Cavity walls, 2 - Through the floor slab, 3 - Through the basement walls, 4 - Through sanitation pipes, 5 - Through the floor slab)

In Europe, maximum concentration levels permitted in dwellings (*2013/59/EURATOM)* are expressed both for existing and new buildings:

300 Bq/m^3 for existing Dwelling. Level of action.
200 Bq/m^3 for new dwelling. Design Level.

With the aim of reducing the concentration levels to this reference benchmark, some architectural remediation options can be proposed. The intervention design depends on the initial concentration, the effectiveness required to reduce levels below recommended limits, and building configuration. They can be classified in two basic strategies (figure 2):

a) Barrier systems: Those that base their effectiveness in providing greater tightness of the building envelope in contact with the ground.

b) Extraction systems: Those that evacuate the gas from the ground, reducing its entry into the building.

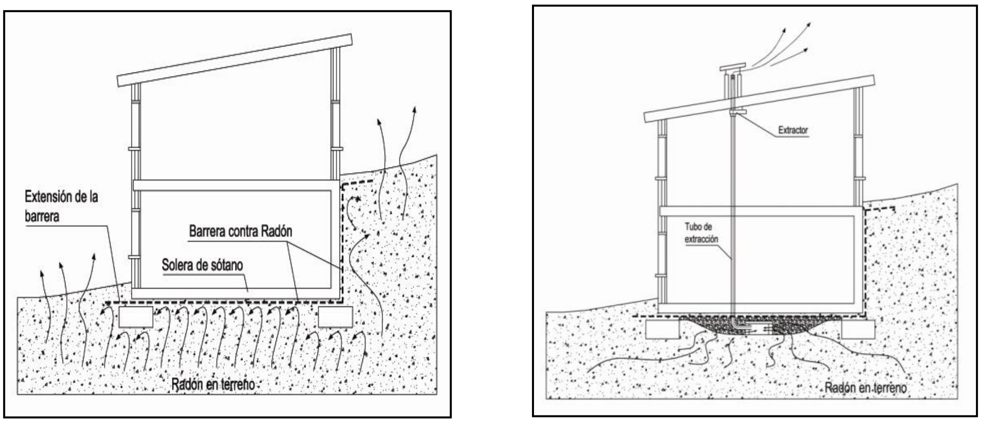


Figure 2: Examples of barrier systems (a) and extraction system (b)

Some of them have been tested in a housing prototype building placed in a high radon area in Spain, with a good effectiveness classification (Frutos, 2011).

Another type of action can be taken into account:

c) Natural or forced ventilation of indoor living spaces for diluting radon concentration. These are attractive measures as they do not involve excessive cost of execution and cause low constructive impact. This strategy has to be deeply studied for its optimization.

This paper will show relevant aspects around this ventilation protection strategy and its relation to energy efficiency.

2 VENTILATION AS A RADON CONTROL TECHNIQUE.

Dilution of the gas exchanging indoor and outdoor air (not usually exceed 20 Bq/m^3) will reduce radon concentration inside. Depending on the ventilation rate needed, this can be achieved naturally or forced with a fan (figure 3).

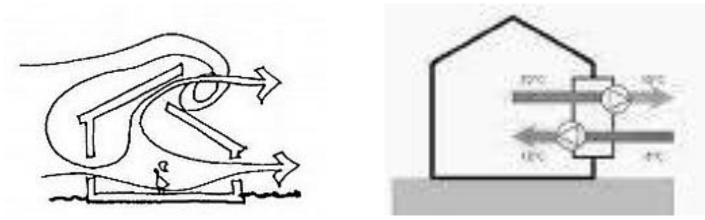


Figure 3:Ventilation strategies: natural and forced.

On the other hand, this action will produce a change in the state of internal pressures, that can modify the entry gas flow rates from the soil. When air is supplied from the outside, internal pressure usually increases, and the flow rate of radon entry gets lower than when air exchange is produced by extraction (figure 4).

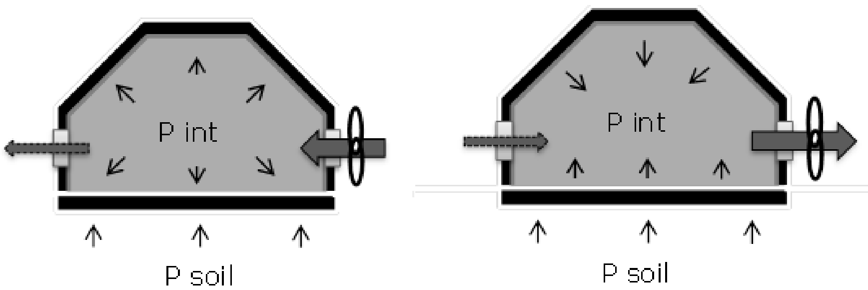


Figure 4: Supply or extract air.

However, there are some factors that should be considered before undertaking rehabilitation against radon by using this strategy, such as:

- Infiltration rates.
- Air change rate needed for reducing radon concentration

- Impact on energy efficiency.

This communication addresses, from a technical point of view, the different variants of this type of action, and the study of associated energy cost.

3 INFILTRATION RATES OF THE BUILDING.

The airtightness of a building, understood as the permeability of the envelope, can beobtained by the blow door test (EN 13829:2002).It plays an important role in outside air exchange. It is estimated that homes before 1950 may have a permeability rate of 1.5 h^{-1} (1.5 changes of the whole air volume per hour are produced). In modern homes, the airtightness is estimated at 0.25 h^{-1}, and lower, according to energy efficiency European directives(DIRECTIVE 2012/27/EU). This value depends primarily on windows permeability, building envelopes, fissures and cracks.

As shown in some studies (Lembrechts 2001) the tightness levels of current building have increased in part due to the improvements in joinery windows and doors, and sealed with waterproof sheets. This also involves an increase in indoor radon levels. See Figure 5.

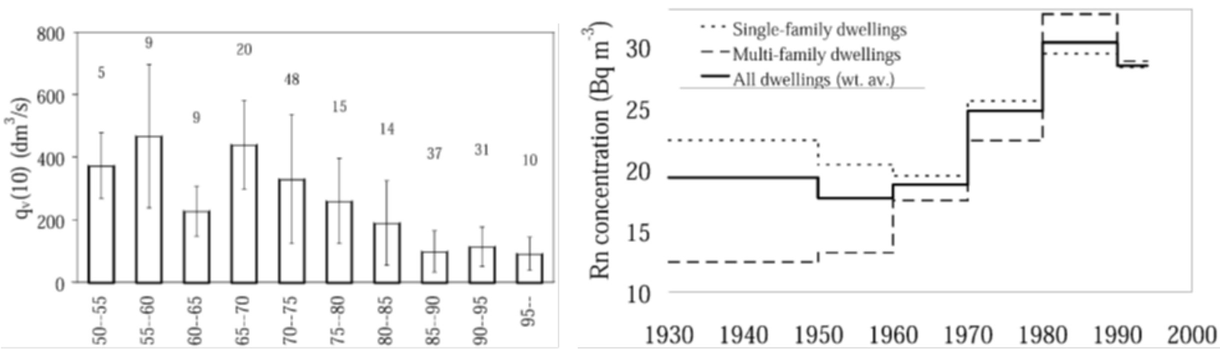


Figure 5:Evolution of infiltration rates and their impact on indoor radon levels. (Lembrechts 2001)

To determine the degree of affectation that permeability of a house has in the final radon concentration, next expression can be used for simulating.

$$C=R/V.\lambda t \qquad (1)$$

where:
R: Exhalation rate Bq/h
λt (h^{-1}) (λd decay radon constant (0,00756)+ λh air tightness)
V Volume (m^3)

This estimation is useful for knowing the impact of energy rehabilitation measures reducing airtightness of a building, in indoor radon concentration. Next figure 6 shows the variation in indoor radon concentration due to variations in the permeability of the envelope, for the same starting condition and same radon entry rate into the building. Indoor radon concentration goes from 200 Bq.m^{-3} in an old building with a 1.5h^{-1}permeability rate to 1000 Bq.m^{-3} in a new one with a 0.25 h^{-1}permeability rate.

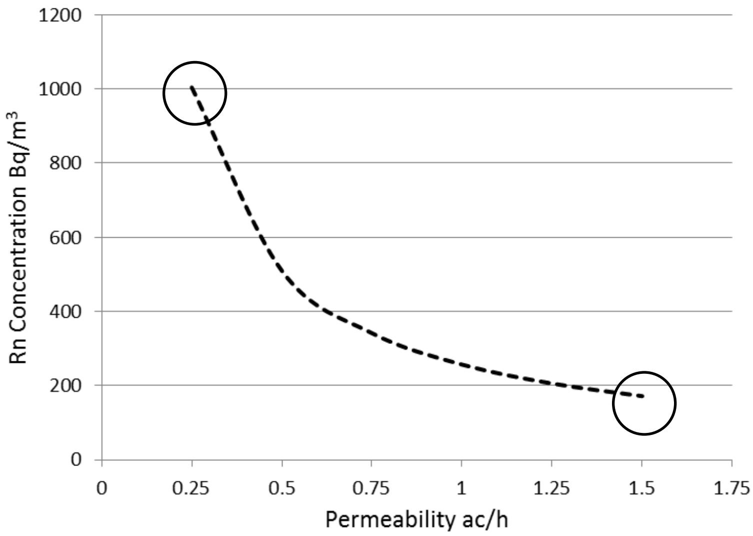


Figure 6: Permeability / Rn concentration

4 AIR CHANGE RATE NEEDED FOR REDUCING RADON CONCENTRATION. A CASE STUDY

An example of a building prototype has been studied on the capacity of the ventilation technique in reducing radon. Its main characteristics are:

- Building: 3 floors, 690 m^3 air volume, heavy construction with thermal transmittance U=0.35 W/m^2K

Air change rates for reducing radon concentration, can be achieved by exchanging outdoor air with a lower concentration. It can be simulated using next expression:

$$C=R/V.\lambda_{total} \quad (2)$$

where:
λ_{total} (h^{-1}): (λ_d disintegration const. + λ_h initial air tightness + λ_r air change rate /h)
The following studies have been accomplished: Study 1 with four different cases of initial radon concentration, while maintaining the rate of initial airtightness (1 ac//h), and Study 2 where airtightness is varying while maintaining the initial radon concentration (900 Bq/m^3).Results are shown in figure 7.

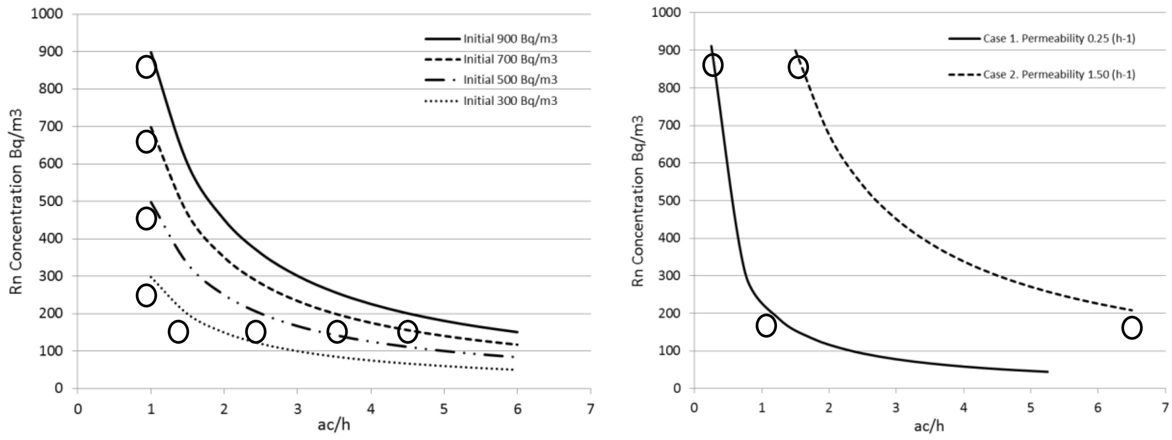


Figure 7: Study 1 (Different initial permeability) and Study 2 (Different initial concentration)

Taking into account 200 Bq/m^3 as the goal of effectiveness, next aspects can be discussed:

In study 1 the air change rate needed increases from 1.5ac/h to 4.5ac/h according to the initial radon concentration from 300 Bq/m^3 to 900 Bq/m^3.

In study 2 the air change rate needed for reducing radon concentration depends on initial air tightness. It can be seen that buildings with less initial permeability need less exchange air for reducing radon concentration than those which more permeability. Note that for the reaching the same initial radon concentration, with more permeability condition (from 0.25 to 1.5), more radon entry rate is considered.

Finally, for defining the air exchange rate as a method for reducing radon, next study is carried out in a standard house with these initial conditions:

- Building: 3 floors, 690 m^3 air volume, heavy construction (U=0.35 W/m^{2}K)
- Radon concentration: The hypothetical radon concentration in ground floor has been set in 900 Bq/m^3
- Ground: the exhalation radon rate from soil into the building: 175Bq/s.
- Airtightness rate of the building: 1 h-^{1}

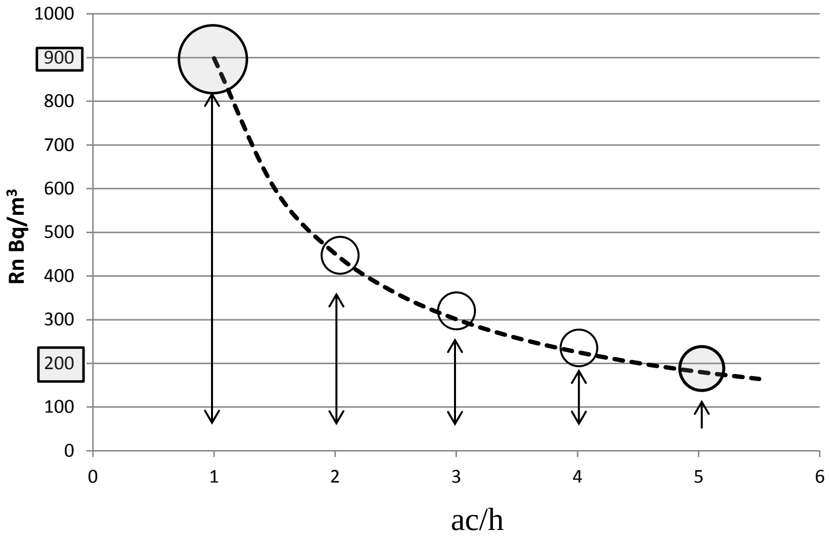


Figure 8: Air change rate vs. radon concentration.

As shown in figure 8, five air changes per hour are needed to reach 200 Bq/m^3. Notice that just dilution is considered and not other effects as pressure state changes.

This high rate can only be reached by forced ventilation in most cases (Cavallo, 1996), and so:
- Forced ventilation implies energy consumption in fans
- High air change rate implies losses of thermal comfort in many types of climates that has to be supported with heating or cooling systems.

5 IMPACT ON ENERGY EFFICIENCY.

Next energy efficiency analysis is made with the prototype house showed in the previous section, taking into account the energy needed for fans, heating and cooling when changing from 1 to 5 air change rate.

The study has been carried out using thermal performance software (Design Builder, V.4.2.0.034). The model is located in Madrid, Spain, as the reference climate. (range of temperatures: -4ºC; 36ºC).

Next figure 9 shows the energy consumption, in the whole year period, when five air changes per hour is implemented. Note that in colder months, heating is needed for maintaining temperatures in a comfort standard of 20 ºC, and in hotter months, cooling is necessary for 25 ºC standard.

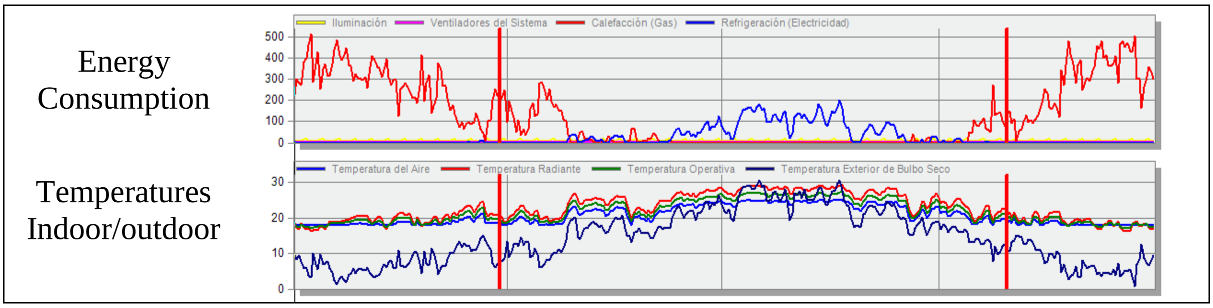


Figure 9: Daily energy consumption for maintaining comfort condition in one year period.

The HVAC annual balance simulation, changing from 1 to 5 air changes, increases the heating loads and slightly lowers cooling loads as shown in figure 10:

Figure 10: Energy consumption (kWh/year) simulated for one year in Madrid with 1 and 5 air changes per hour . (Red colour: energy for heating; Blue colour: energy for cooling)

To ensure 5 air changes per hour, as continuous ventilation for reducing radon levels, it is necessary to implement a forced ventilation system. For the study of energy consumption associated with such measures it has also been considered electricity consumption of the fans and the ability to install or not a heat recovery. The results are shown in the table below:

Table 1: Summary of energy and radon concentrations in the three case studies.

Case study	Permeability/ Ventilation (ac/h)	Rn concentration (Bq/m^3)	Heat recovery	Electricity consumption FANS (kWh/year)	Energy consumption HEATING (kWh/year)	Energy consumption COOLING (kWh/year)
A. Dwelling without forced ventilation.	1 ac/h	900 Bq/m^3	NO	No fans. Ventilation by natural convection	4879	17994
B. Dwelling with forced ventilation	5 ac/h	200Bq/m^3	NO	3267	38305	14688
C. Dwelling with forced ventilation	5 ac/h	200 Bq/m^3	SI	9636	9461	11398

Taking case A as the base case study, it can be observed the different energy consumption with strategies, B and C, depending on whether or not using of a heat recovery system. In B less electricity for fans is used, but the HVAC system needs more energy, while in C, with more electricity consumption in fans, the HVAC energy need is reduced.

For options B and C, the increase of the total energy from initial case A, is:

Initial. Case A: Total 22873 kWh/year
Remediation. Case B: Δ 33387kWh/year
Remediation. Case C: Δ 7622kWh/year

6 LIMITS OF THE STUDY

- The study has been carried out considering ventilation techniques, acting just by dilution without modifying indoor pressures state. This consideration is important because no modification of gas flow penetration rate from soil has been taken into account.
- Madrid climate has low and high extreme temperatures. In other climates, energy consumption has to be analyzed.
- Heating and cooling systems are relevant in final energy consumption. In this case, heating pump and gas boiler has been selected.
- A 0,37 kW fan, has been selected for moving 5 air changes per hour, without heat recovery.
- Two 0,55kW fans have been implemented in the heat recovery, in case C, for treating 5 air changes per hour.

7 CONCLUSIONS

The paper has shown the relation between permeability, ventilation, energy use, and indoor radon levels in a building. Some aspects show up:

- Airtightness retrofitting, according to energy efficiency standards, can have a relevant impact on indoor radon concentration.
- Ventilation technique can be considered as a solution for reducing radon concentration by dilution, but attention must be paid when high radon levels are measured because of the high air change rate required.
- Energy impact, especially in colder climates, can be excessive in order to maintain indoor comfort temperatures when ventilation strategies are implemented
- This impact can be reduced with a heat recovery system.

8 ACKNOWLEDGEMENTS

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9 REFERENCES

Cavallo, A. (1996). *Comparison of natural and forced ventilation for radon mitigation in houses*.Environment International, Vol. 22, Suppl. 1, pp. SlO73-S1078.

COUNCIL DIRECTIVE 2013/59/EURATOM *of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation.*

DIRECTIVE 2012/27/EU *OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency*

EN 13829:2002.*Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method.*(ISO 9972:1996, modified)

Frutos, B; Olaya, M; Quindós, L. S.; Sainz, C.; Fuente, I.(2011).*Experimental study of effectiveness of four radon mitigation solutions, based on underground* *depressurization, tested in prototype housing built in a high radon area in Spain.* Journal of Environmental Radioactivity 102, 378-385.

Lembrechts, J; Janssen, M; Stoop, P. (2001)..*Ventilation and radon transport in Dutch dwellings: computer modelling and field measurements.* The Science of the Total Environment 272, 73-78.

WHO (2009).*Handbook on Indoor Radon.A public health perspective*.World Health Organization.