

Mechanical ventilation as radon reduction strategy: methodologies for calculating flow rates and field experiences

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Abstract. Radon is a naturally radioactive gas that represents a health risk when it accumulates indoors. Controlled Mechanical Ventilation (VMC) is an effective strategy for mitigating radon concentrations, improving indoor air quality, and reducing occupant exposure. The principle on which it is based is the dilution of pollutants, which may include radon. Numerous scientific articles, regulations, and technical documents address the topic of VMC as a strategy for reducing radon concentrations. This study presents a detailed review to highlight critical issues and strategies in the design and management of VMC systems against radon. In addition to the correct determination of flow rates, an important design aspect is the assessment of their imbalance, aimed at creating slight overpressure in the rooms. This article explores methodologies for calculating the ventilation flow rates required for radon remediation, integrating theoretical models with practical field experience. Case studies that illustrate the practical application of these methodologies in real contexts, highlighting the benefits and challenges encountered during implementation, are described. The results show that proper design and management of VMC can significantly reduce radon levels, helping to create healthier and safer indoor environments.

Key words: Radon, Controlled Mechanical Ventilation, IAQ.

1. Introduction

Controlled Mechanical Ventilation (VMC) is a well-established technology that allows air to be exchanged in rooms through a system of fans and ducts, even of reduced length. It is a solution that must be carefully planned in line with the overall plant design of the building. The principle on which it is based is the dilution of air pollutants, which may include radon.

VMC is a technology that allows the air renewal rates to be precisely measured according to the requirements determined during the design phase: it is no coincidence that one of the mottos for sustainable design is “build tight, ventilate right” (i.e. build without infiltration and ventilate correctly).

For school buildings and offices, the logic is to extract and introduce air into the same room but at a distance to allow for proper air exchange (i.e. to replace the air throughout the entire volume of the room). In residential buildings, on the other hand, the extraction is carried out in the bathrooms and kitchen, and the air is fed into the bedrooms and living room.

Many articles address the topic of VMC as a strategy for reducing radon concentrations (as well as other pollutants). Among these, the most relevant have been selected and are discussed in detail in Table 1 below. Further details are summarised in “Quaderno ISPRA 27/23” “Indoor air quality and radon risk in Italy and comparable situations: regulations, scientific literature, energy certifications” produced by ISPRA with funding from MASE [1].

Table 1. Scientific articles on VMC and radon.

Title	Authors	Year	Approach to analysis and solutions analysed	Results
Comparison of Indoor Radon Reduction Effects Based on Apartment Housing Ventilation Methods [2]	Choi et al.	2022	Active measurements (RAD 7 Radon Detector). Various ventilation solutions.	With VMC, the radon reduction rate was equal to or less than 70% in all conditions.
Experimental Study on CO ₂ and Radon Mitigations in an Apartment Using a Mechanical Ventilation System [3]	Jeong and Cho	2023	Active measurements (AlphaGuard), blower door, dose assessment. VMC with various flow rates.	VMC as a radon removal strategy, input on how to regulate it and ventilation rate.
Radon Investigation in 650 Energy Efficient Dwellings in Western Switzerland: Impact of Energy Renovation and Building Characteristics [4]	Yang et al.	2019	Passive measurements. VMC, insulation, fixtures.	New homes with VMC have lower radon concentrations. Thermal adaptation of windows, roofs, external walls and floors was associated with higher radon levels.

There is very little scientific literature exploring the issue of pressure differences related to VMC systems. Among the most notable articles are those in Table 2.

Table 2. Scientific articles on VMC and radon with focus on pressure differences.

Title	Authors	Year	Approach to analysis and solutions analysed	Results
Ventilation approaches and radon control in Canadian houses [5]	Gaskin et al.	2025	Monitoring of the pressure differential between the environment and the ground and between the environment and the outside.	The sustained operation of mechanical exhaust ventilation devices increased the depressurization and the indoor radon concentration. Indoor radon concentrations observed at -5 Pa were higher than those at -10 and -20 Pa.

Decentralised ventilation efficiency for indoor radon reduction considering different environmental parameters [6]	Altendorf et al.	2022	Monitoring of the pressure differential and radon concentration in apartment with decentralized mechanical ventilation.	A moderate positive differential pressure of approximately 2–3 Pa is recommended to prevent radon intrusion into buildings.
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To ensure a slight positive pressure inside the building, such that the indoor air pressure is kept a little higher than the pressure in the underlying soil and outdoor air, so that air flows outward through leaks and openings and radon-contaminated soil gas is prevented from entering. Maintaining this overpressure is closely linked to multiple variables such as air tightness, the pressure differential related to temperatures, and the use of the rooms.

2. Technical standards and legislative references on VMC and radon

The UNI 10339:1995 [7] standard has been withdrawn without replacement. The UNI EN 16798-1:2019 [8] standard is the reference for the design of ventilation systems (it addresses many issues, including acoustics, comfort, etc.). It has been translated into Italian to facilitate its application, and its national Annex [9] was published in 2025. The standard is referred to in the CAM [10], updated in 2025 and due to come into force in February 2026. The CAMs prescribe VMC for all public buildings (schools, offices, public housing), for which the reference level is 200 Bq/m³.

Regarding radon, the main legislative references are:

- D.Lgs. 101, 2020 (Implementation of Directive 2013/59/Euratom, which lays down basic safety standards for protection against the dangers arising from exposure to ionising radiation) [11]
- DPCM 11 January 2024. Adoption of the National Radon Action Plan 2023–2032 (PNAR) [12]: The plan describes radon prevention and remediation measures. Regarding VMC, the PNAR indicates that these solutions must be carefully planned in line with the overall plant design of the building.

There are no European and Italian technical standards detailing how to calculate ventilation rates to reduce radon in school buildings. An important German standard is DIN/TS 18117-1:2021 [13].

The assessment for redevelopment work aimed at reducing radon is based on the following parameters:

- Ventilation rate of the rooms;
- Average annual radon concentration (for existing buildings in which a measurement has been taken using a dosimeter).

The link between these two parameters is of fundamental importance because it describes and characterizes the building and its ability to reduce radon.

When the source of radon is the ground (but also if the source is materials), in addition to correctly determining the flow rates, an important design aspect is the assessment of their imbalance, aimed at creating a slight overpressure in the rooms. Determining the correct ratio between the flow rate introduced and the flow rate extracted is complex and closely linked to the airtightness of the building. A building with low airtightness will require a greater imbalance, which will also lead to a reduction in heat exchange efficiency.

3. A new calculation methodology for ventilation flow rates

Understanding the dynamics and evaluating the flow rates can be approached with a new methodology described below.

The analysis consists of determining the slope of the radon increase based on active measurement data and then defining the ventilation rate of the VMC. Great importance must be given to the choice of curve, as the slope can vary greatly depending on all the parameters involved. One strategy may be to extend monitoring over several days and average the data. A second strategy may be to consider a period when the environment is unoccupied (e.g., weekends for offices), so that there is no air exchange component from occupants. For residential buildings, the night-time period may be selected or a holiday period, in the absence of natural or mechanical air exchange. The analysis should be carried out during the most critical period of the year, which is usually winter (there are cases where the most critical period is summer, which should be assessed differently). Radon testing must be carried out under controlled conditions, with no ventilation of any kind and no people who could activate or deactivate components that could alter pressure and air exchange (activation of extraction hoods). The minimum monitoring period is approximately one week, during which several curves can be selected, with a minimum time of 12 hours to average the data collected. The curve to be selected will be the steepest one, i.e., the curve that represents the most critical situation. The proposed calculation method does not directly quantify pressure effects, which remain highly building-specific, weather-dependent, etc. An example of how the methodology is applied is shown in Figure 1. Dividing the slope found by the target concentration determines the ventilation rate required to dilute the radon (Equation 1). This value can be chosen between 100 or 150 Bq/m³, as it represents the peak value, while the average (annual) value will be lower due to natural air exchange (if present) and seasonal dynamics.

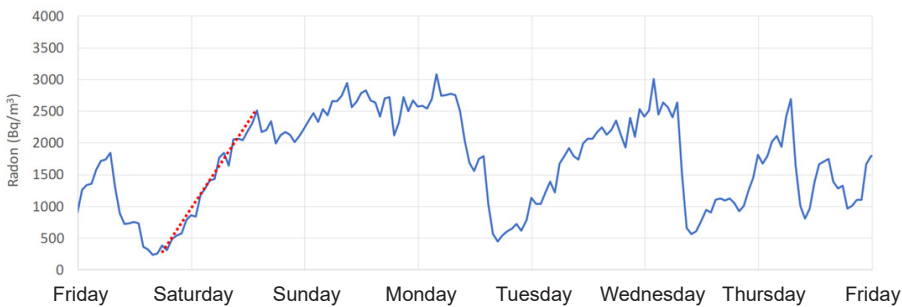


Fig. 1. Radon concentration prior to remediation in an office building on the ground floor [14]

$$n = (C_f - C_i) / (C_0 \cdot \text{time}) = (2500 - 220) / (100 \cdot 22) = 1 \text{ vol/h} \quad (1)$$

Where:

C_f Final radon concentration (end of red dotted line): 2500 Bq/m³

C_i Initial radon concentration (Saturday, office closed): 220 Bq/m³

time Radon growth time: 22 hours

C_0 Target radon concentration: 100 Bq/m³.

The target concentration can also be chosen according to the project categories listed in the UNI EN 16798-1 standard, National Annex [9], as shown in Table 3.

Table 3. Recommended design values for radon in indoor environments.

Category	Radon yearly average values
I	100 Bq/m ³
II	150 Bq/m ³
III	200 Bq/m ³

4. Application of the methodology to a case study in a building in the Province of Bolzano

The building consists of several floors with different uses. On floor -1 there are offices and a library, on the ground floor there is a primary school. The building is located approximately 1,256 meters above sea level. The ventilation rate calculated using the method described above varied between 1 and 2 vol/h. It was therefore decided to calculate the flow rates for all rooms with a ventilation rate of 2 vol/h.

During the summer of 2025, four ventilation units were installed. The ventilation units were switched on Monday, 8 September 2025, at a flow rate of 170 m³/h, equal to 28% of the maximum flow rate (600 m³/h). On 3 October 2025, the ventilation flow rates of the two units on the ground floor were increased from 28% to 50%.

Radon concentration was measured using a Radon Scout Professional (Sarad GmbH, Germany), a continuous radon monitor based on an alpha-spectroscopic detection of radon progeny. The instrument records time-resolved radon activity concentration with an integration time of 1 h, and stores data in an internal memory for later download. It provides a measurement range suitable for typical indoor and soil-gas applications and includes sensors for atmospheric pressure, temperature and relative humidity, allowing basic environmental parameters to be logged together with radon concentration.

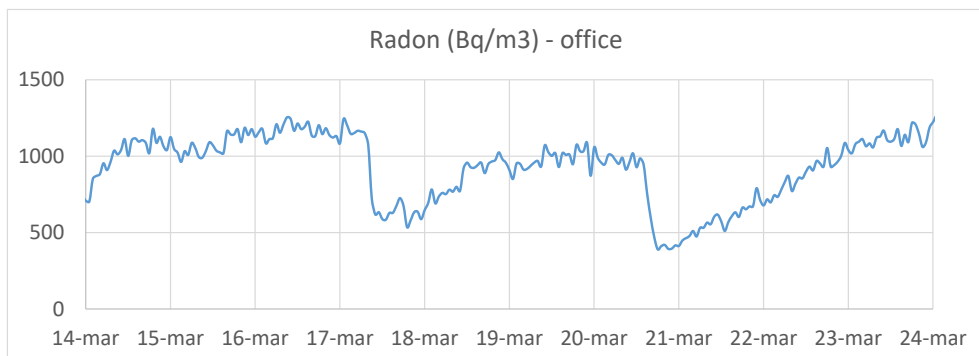


Fig. 2. Radon concentration prior to remediation in an office building.

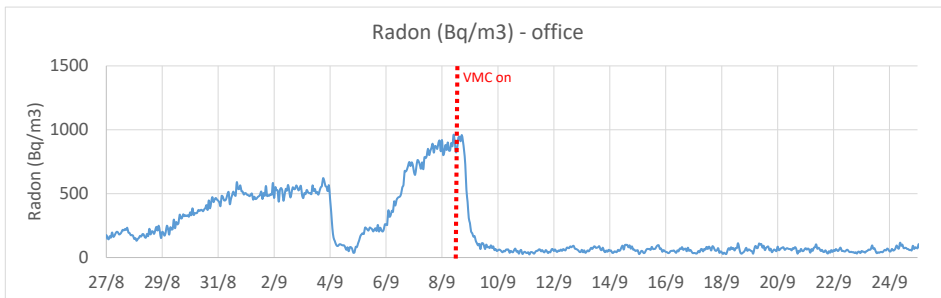


Fig. 3. Radon concentration after the installation of a VMC system in an office building.



Fig. 4. VMC system installed in the office building. In the photo on the right: distribution system.

Table 4. Radon mean concentration during March and September–October period and % of variation.

	March, without mechanical ventilation	September–October, with VMC	% variation
Library, floor -1	2154 Bq/m ³	104 Bq/m ³	-95%
Office 1, floor -1	957 Bq/m ³	102 Bq/m ³	-89%
Office 2, floor -1	471 Bq/m ³	41 Bq/m ³	-91%
Classroom 1, ground floor	1039 Bq/m ³	115 Bq/m ³	-89%
Classroom 2, ground floor	1188 Bq/m ³	153 Bq/m ³	-87%

Table 4 shows the average radon concentration data before and after switching on the VMCs and the relative percentage reduction.

5. Conclusions

The study confirms that Controlled Mechanical Ventilation (VMC) is an effective strategy for radon mitigation, if it is based on specific design. The proposed methodology, based on the analysis of the concentration growth slope, allows the necessary flow rates to be calibrated much more accurately than nominal exchange rates, ensuring compliance with regulatory targets.

In the future, research and industry should focus on the optimisation of overpressure: it is a priority to conduct studies aimed at identifying the minimum effective overpressure necessary to counteract the entry of radon, whether it comes from the soil, building materials or ducts and pipes. Defining this value is essential to limit radon concentrations (pressure counteraction) without exceeding the energy load for ventilation (dilution counteraction).

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