TECHNICS FOR PREVENTION AND MITIGATION OF RADON INFLOW IN BUILDINGS

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Abstract:

Radon (Rn) is a radioactive gas that has no color, smell or taste and that can be found in soil as a result of the radioactive decay of naturally present elements such as uranium and radium. Radon can be present as well in building materials and water, but concentrations derived from them are usually lower than those derived from radon from soil.

Radon is the greatest natural source of ionizing radiation and exposure of population to high levels of concentration of Rn during prolonged periods can become a public health problem. According to the World Health Organization (WHO), radon exposure is, in many countries, the second cause of lung cancer (after tobacco) for smokers and the first cause for nonsmokers, also having a predominant incidence in cases of childhood leukemia. For this reason, WHO recommends an annual average indoor radon level of 100 Bq/m3.

Radon may enter buildings by convection through cracks in the envelope or by diffusion through the envelope itself when it is porous; and attain concentrations over the recommended reference levels, which values may vary according to the legislation of each country. The reference value of 300 Bq/m3 was established in The Council Directive 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to incising radiation. This level is usually established as the legal indoor Rn maximum annual average for residential buildings and workplaces in most EU countries. The most usual methods to prevent or mitigate radon inflow in buildings include protection barriers, ventilation and sub-slab depressurization. However, the effectiveness of these methods is variable so they may need to be combined to increase overall efficiency in cases with high risk of radon concentration.
In this communication, the factors that influence radon level and most usual methods to prevent or mitigate radon are presented and discussed as part of the training programme being developed to provide technical qualification for radon mitigation professionals, within the scope of the LeaRn4LIFE project.

A reference to products and materials used for radon protection is also referred. Finally, recommendations are presented to guarantee the success of radon protection measures.

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1 | Introduction: overview of main prevention and remediation solutions

Radon protection solutions aim to limit people´s exposition to indoor radon, reducing radon concentration at least in the spaces where people spend longer periods, such as habitable rooms. This objective can be achieved protecting directly these habitable rooms or indirectly, protecting non-habitable rooms placed underneath the habitable rooms to be protected.

There is a set of solutions that used alone or in combination, depending of the radon potential risk or the measured radon concentration, in new or existing buildings, respectively, allow minimizing the concentration of radon inside buildings

Radon protection solutions can be classified according to the way of action [3]:

- Insulating habitable rooms from the soil
- Reducing radon concentration before it enters the building
- Reducing radon concentration within the areas to be protected

The solutions leading to the insulation of buildings are as follows.

- Application of radon proof barriers (membranes) on the building envelope (building elements in contact with the ground (slab or wall) or a non radon protected building area that enclose habitable rooms and isolate them from radon).
- Sealing the building envelope
- Positive pressurization of habitable rooms
- Airtight doors in openings in the building envelope

The solutions leading to the reduction of radon concentration before it enters the building, are the following:

- Installation of a ventilation system in a containment space (crawl space or non habitable room such a garage, placed between the soil and the room to be protected)
- Installation of a sub-slab depressurization system

As an additional or complementary way to improve indoor air quality and reduce radon concentration within the areas to be protected, the use of natural or mechanical ventilation of habitable rooms can also be considered.

In existing buildings, protection solutions are similar to those above mentioned, but with the limitations than can suppose the presence of existing building elements, the scope of the intervention, available budget, etc. In addition to these solutions, other solutions can be used to reinforce their effectivity or to replace them when they cannot be used [3].

2 | Factors influencing radon potential

Indoor radon concentration can fluctuate enormously depending on many factors. The main driving factor is the type of soil, but climatic conditions can also be very relevant inducing changes in radon concentration in the same building, as well as building characteristics may strongly cause variability between different buildings in the same location [3]. In this section, only soil and building characteristics will be described.

2.1 Type of soil

The main variable associated with indoor radon concentration is geogenic radon content. For instance, soils mostly composed of granite rocks have a large content of radon.

But the exhalation of radon from the soil is also determined by the gas mobility through the soil, which is governed by its permeability. In fractured soils the gas moves faster, reaching the outside or surroundings more easily. Gas mobility is influenced as well by soil water content, because radon diffusion coefficient in water is lower than that in air.

Therefore, the greater the compaction and saturation of the soil, the less easy it is for the gas to propagate. This way, if the soil under the building is dry and the surrounding soil is saturated , the gas tends to take the easiest route and enters the building instead of flowing outwards .

2.2 Type of ground floors

The concentration of radon is usually higher in spaces located close to the soil, ground floors, basements and semi-basements generally used as cellars, pantries, utility rooms, storerooms and garages, that is, as non-habitable spaces with little occupancy.

For the purposes of assessing the risk of exposure to radon, buildings are generally classified according to the type of construction, with emphasis on the type of building envelope (basements, semi-basements, ground floor concrete slabs laid directly on the ground, or floors above crawl space [1].

The larger is the surface of the envelope in contact with the soil, the bigger the risk to radon penetration. Therefore, the biggest concentration of radon usually occur in basements.

When there is a gap between the building and the soil, the risk is lower, such in the case of floors above crawl space.

Some types of ground floor ”pavements” in existing buildings do not offer restriction to the flow of radon gas from the ground into the respective space, namely:

- compacted terrain or smoothed rocky materials
- a layer of poor concrete laid directly on the ground or over a rockfill
- a layer of stone (which may be granite) laid directly on the ground or over a screed, with or without underlying rockfill.

In such cases, it may be necessary to replace the existing “pavement” by another one whose permeability to radon gas is substantially lower, thus being a barrier to the passage of radon from the ground.

2.3 Type of basement walls

In the worst-case scenario, the walls are made up of the rock itself where the cellars of the buildings were excavated, with no barrier to radon entry [1].

In the intermediate scenario, the basements have stone or brick walls, built without barriers to protect against the passage of radon, even if plastered with cement/lime and sand mortars (painted or not) or plastered. Due to the permeability of these walls, aggravated by the probable existence of cracks in the wall itself and/or in the respective coatings, radon gas easily penetrates through them [1].

The presence of moisture on the walls accelerates the aging process of the materials, giving rise to anomalies, such as cracking, which are yet another contribution to facilitating the passage of radon into buildings.

2.4 Type of intermediate floors

The floor that separates the cellar or basement from the immediately overlying floor is as well important as it is large the possibility of a high concentration of radon in them.

Wooden floors, or their derivatives, are usually supported on joists of the same material. The joints between the planks or wooden planks are the most critical points for the passage of radon gas from the lower space to the upper one [1].

When floors are made up of stone (granite, limestone or other) or ceramic elements, generally forming arches with different configurations (for example, vaults), they offer greater resistance to the flow of radon coming from the lower floor, but radon emissions from the materials themselves must also be considered [1].

Finally, in more recent constructions, the most common intermediate flooring solution consists of solid or lightened reinforced concrete slabs, or lightened slabs with prefabricated elements (for example, joists and vaults). With these solutions the permeability of the radon flux is reduced. It should be noted that, in these cases, the most critical points are the joints resulting from the crossing of the slab by various pipes, the openings made in them and the cracking of the constituent materials of the floor [1].

False ceilings do also little to reduce the flow of radon, if they are not completely watertight (as is the case with plasterboard sheets, applied continuously, creating an overlying airtight air box).

2.5 Ventillation

Natural ventilation in dwellings is traditionally performed through the openings in the interior bathrooms, the kitchen fume traps, or infiltration through the gaps around the blind boxes or the joints within the window and exterior door frames and, of course, sporadically, by opening windows, which is not a permanent solution that can be considered to contribute to the reduction of radon concentration [1] [3].

Hybrid ventilation systems are becoming very common in dwellings, where fresh air enters through air inlets placed in windows or façade walls of dry rooms (bedrooms and living-dining rooms) and stale air is exhausted through ventilation shafts in wet rooms (bathrooms and kitchens) equipped with hybrid fans.

Furthermore, mechanical ventilation systems are spreading among dwellings in low and nearly-zero energy buildings, with the aim of controlling energy losses due to ventilation.

The obstruction of cooker hoods, or bathrooms ventilation shafts substantially reduces the amount of air drawn from the interior of the dwellings. [1]. In the same way, the obstruction of air inlets causes a reduction of the fresh air drawn to the interior. All these actions reduce, therefore, the efficiency of the natural ventilation [3].

However, it is important to remark that increasing ventilation should not be conducted without a previous detailed assessment of each case, because in some situations it can be counterproductive, causing a depressurization that draws radon indoors though cracks and deficiently sealed joints in the envelope [3].

In addition to this, increasing ventilation usually supposes a rise in energy demand, so this aspect must be also assessed [3].

In other type of buildings, ventilation is usually performed via air conditioning systems, introducing fresh air into the circuit.

2.6 Type of openings between spaces

Openings between the basement and the upper floor play an important role in the transport of radon. These openings can be doors to basements such as garages, which are generally communicated via interior stairs, particularly in high-rise buildings [1]; or hatches to crawl spaces.

The worst scenario corresponds to the situation in which openings are insufficiently airtight ,[1]. The floor between the protected and non-protected areas may be radon proof, but this opening poses a highway to radon.

3 | Specificity of different solutions

3.1 Radon barrier

Radon barrier is any continuous element that is placed between the space that needs to be protected and the soil and that constitutes a protective barrier to the passage of radon from the ground and whose effectiveness can be demonstrated (See Fig. 1).

Fig. 1 Radon barrier

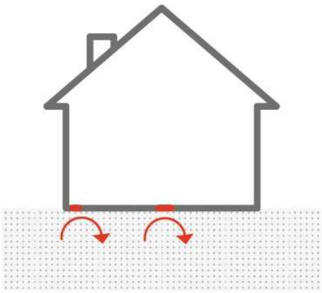


Fig. 2 Sealing

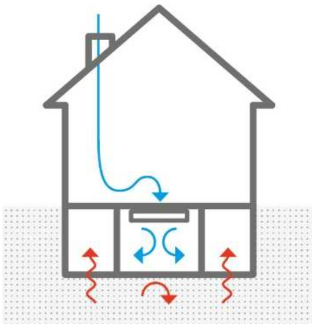


Fig. 3 Positive pressure

Source: Guía de rehabilitación frente al radón [3]

Most common radon barriers are membranes. A membrane is a laminar element in flexible plastic material or composite. The membranes for radon protection can also contribute as a barrier against the capillary rise of ground water [1], [2].

The membranes used as a barrier to the passage of radon into buildings must allow a limited exhalation of radon, which is a function of both its radon diffusion coefficient and thickness. Some regulations estimate that exhalation of radon is adequate when the radon diffusion coefficient if lower than 10 x 10^{-11} m^2 / s and the thickness is larger than 2 mm [4]. In addition to this main characteristic of radon barriers, they must be sufficiently resistant to the actions they will be subjected to, namely the mechanical actions of puncturing sharp elements.

This solution, by itself, is generally sufficient to guarantee significant obstruction to the passage of radon gas when the concentration of radon in soil is lower than 600 Bq/m3, as long asit is guaranteed continuity of the membrane over the whole envelope, particularly under the internal walls. Encounters of the envelope with construction elements (pillar, façade or pipe crossing) and the existence of expansion joints facilitate the radon entry into the interior of buildings, so they must be adequately sealed.

When the concentration of radon in soil is bigger than 600 Bq/m3, the action of radon proof barriers must be complemented with other solutions, such as sub-slab depressurization or a ventilated containment space [3] [4].

3.2 Sealing

In renovations of existing buildings, if it is not possible to place a radon protection membrane and the envelope does not show widespread cracking or is porous such as a wooden floor, an effort should be made for floors and walls conforming the envelope to function themselves as a radon protection barrier. For this purpose, sealing fissures, cracks, encounters and joints of these elements is a way to reduce inflow of radon in buildings (See Fig. 2).

This solution has effectiveness up to radon levels of 600 Bq/m^3 but requires complementary measures such as the improvement of the ventilation of habitable spaces [1], sub-slab depressurization or a ventilated containment space [3].

3.3 Positive pressurization

A positive pressurization system consists of creating a difference in pressure between the air inside the building and the underlying ground, so the natural pressure difference is reversed. This is usually produced by a ventilation unit located in the attic, which is used to blow filtered fresh air into the main rooms (bedrooms and living rooms) of the house. The increase in pressure throughout the building reduces the possibility of radon admission and causes the radon gas to be diluted and leaked out, which nevertheless enters the building [1], [5].

In dwellings, the use of this solution must be carefully assessed because it has been observed that in some cases has caused condensations.

This solution can also be used to protect small habitable areas located in large areas that are not protected, such as, for example, surveillance cabins in garages [3], [4] (See Fig. 3).

The effectivity of this solution greatly depends on the airtightness of the building envelope or the room to protect, which needs to be high.

The effectivity of this solution is usually adequate when the radon concentration is lower than 600 Bq/m^3. For higher concentrations, it is recommended to use it in combination with other solutions such as radon barrier or sealing [3].

3.4 Airtight access doors and hatches

It is important to create mechanisms that allow reducing the air flow from the containment space to the upper floor, reducing the air permeability of the access doors between them.

Fig. 4 Access door to basement

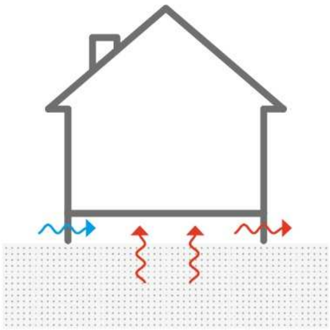


Fig. 5 Ventilated containment space

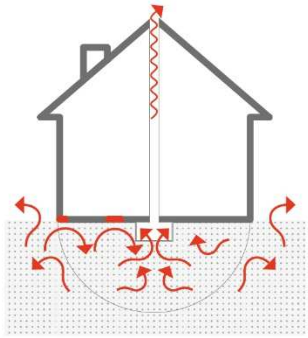


Fig. 6 Sub-slab depressurization

Source: Guía de rehabilitación frente al radón [3]

In more recent buildings, or in other older ones subject to retrofitting works, the air tightness of the access doors between floors can already be sufficiently guaranteed if the provisions regarding fire safety have been adopted (Fig. 4). This is an important contribution to especially preventing the passage of radon from the cellars, basements or ground floors of these buildings to the upper floors, which will already be reduced if the walls and floors of these basements or ground floors are made up of elements of reinforced concrete [1].

Doors with air permeability class C or D according to EN 12207 are adequate way from the point of view of airtightness [3].

In the case of improving an existing door, limiting air permeability can be achieved by [3]:

- Placing a self-closing door mechanism
- Placing an elastic joint in the whole perimeter
- Blocking existing ventilation grills

In the case of hatches, the solution depends of the frequency of its use. When it is seldom used, it better to seal it completely. When it is used regularly, the solution will be similar to those of doors.

In all cases, such a solution is not effective enough on its own and should be complemented with other mitigation methods such as radon barrier, sealing or ventilated containment space [3].

3.5 Installation of a ventilated containment space

Ventilated spaces such as a crawl space, a cavity wall, an underfloor space or a basement or cellar, may be used to dilute radon that fills this space making difficult the diffusion of radon towards habitable rooms of the building, performing as containment spaces (Fig. 5).

The crawl space is a space between the floor and the natural ground, where various services (plumbing, drainage and cables for electrical circuits and telecommunications) or other equipment can be installed.

In new buildings, it is always recommended to install a ventilated crawl space or at least an aerated floor whenever possible [2].

In building renovations, an aerated floor can replace completely an existing floor or can be placed over existing slabs if a higher finished floor elevation can be accommodated.

In new buildings´ basements, cavity walls ventilated with outdoor air can be constructed. In buildings renovations, such cavities can be added to an existing basement wall when there is enough room for it and it is possible to connect it to the exterior

3.6 Installation of a sub-slab depressurization system

One of the most widespread and successful protection techniques used to reduce the flow of radon into buildings is soil depressurization, which consists of a single underground sump or multiple sumps, into which exhaust pipes are inserted aiming to suck out the radon-laden air existing in the land, immediately below the ground floor of a building, discharging it harmlessly into the atmosphere [1], [2], [6]. A sump is an underfloor space or cavity. Extraction can be passive, relying on natural stack effect and wind action, or active, with the use of an electric fan, which is a more effective system (fig- 6)

The effectiveness of this solution depends to a large extent on the permeability of the substrate in contact with the building (fill layer) and the tightness of the enclosure in contact with the ground.

For optimal effectiveness, the permeability of the substrate and the tightness of the enclosure must be high. This way, the presence of negative pressure fields is favored by high permeable backfill material, such as gravel, but is hindered using compact natural soil. Sub-slab obstacles, such as the presence of foundations within the substrate, should affect the level of efficacy of this solution. When the floor slab is not sufficiently airtight, pressure field restrictions also occur.

Sumps can be prefabricated or constructed on-site. Instead of sumps, perforated pipe networks can be used as well. Increasing the number of sumps or suction points in perforated pipes is more effective than increasing the power of the extraction fan.

The pipes that pass through the façade connecting sub-slab pipework with external vertical ducts have no perforations. Pipes diameter can vary from 60 to110 mm) .

The best location for the exhaust outlet for dissipating radon away from the building is on the roof. Other low-level location is possible when there is no possibility of re-entry of radon into the building

The centrifugal fan must have an adequate power (usually 70 W) and must be located at an intermediate point of the vertical external duct; containing a by-pass to prevent condensation or seepage water from coming into contact with it. In the case of an internal duct, the fan must be placed close to the exhaust outlet to ensure all internal pipework is under pressure. This way, in case of leakage, the chance of radon-laden air entering the building is limited.

For the design of this solution, the number of fans needed and their location must be considered, and the reduction of problems associated with the installation, such as noise, aesthetic effects, efficiency, maintenance, etc. must be taken into account [1], [2], [3].

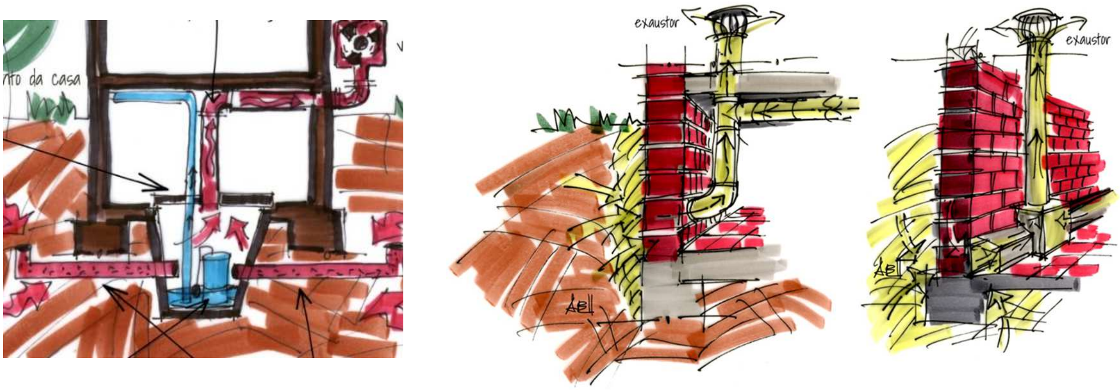
3.7 Use of drainage systems

In complement, drainage systems can be used to reduce radon intake in new or in existing buildings, according to one of the following methodologies, [1], [2]:

— Placement of a ventilation duct connected to a fan inserted in a tank for collecting and pumping rainwater from the ground (Fig. 7a), installed in the basement, exhausting it to an outlet located above the roof of the building, ensuring that the water tank cover can be removed, when necessary, namely to allow maintenance of the water pump installed in the tank.

— Connection of perforated drain pipes, installed under the ground floors, for water drainage, to a ventilation system consisting of ventilation ducts (including exhaust ducts) and mechanical fans, ensuring that any emergency points of this duct on the ground surface, installed for inspection, are closed by valves so as to allow the fan to build up a low pressure while allowing the water to drain.
— Radon aspiration system through the depressurization of the lower area of buried walls formed by perforated bricks (Fig. 7b) or blocks (Fig 7c).

Active systems are more effective than passive systems. The degree of effectiveness of this solution may be like that of underground depressurization systems.



a) b) c)

Fig. 7 Examples of radon aspiration systems using rainwater drainage pipes and underground storage (a), or through the openings in the bricks (b) or perforated blocks of buried walls (c)

3.8 Ventilation of habitable spaces

Indoor ventilation improves indoor air quality of habitable spaces and may reduce radon gas concentration. Ventilation will have to be greater the greater the degree of occupancy; that is, it should be duly proportional to the number of occupants considering the volume of the space to be ventilated.

In new buildings, ventilation rates have to comply with IAQ regulations, which usually specify minimum ventilation rates depending on the use of the space or building. Additionally, ventilation rates should be in accordance with energy saving regulations, so energy loss due to ventilation is within an adequate threshold. A balance must be found between both requirements [3].

In existing buildings, this solution can be used when ventilation is poor and does not comply with the minimum requirements specified in the IAQ regulations.

In existing buildings, when ventilation is adequate and complies with the minimum requirements specified in the IAQ regulations, an assessment in relation to energy saving and IAQ must be carried out to determine the viability of increasing ventilation rates [3].

In the case of mechanical ventilation, a depression could be produced favouring the entry of radon from the ground through gaps and cracks To avoid this effect is recommended to implement ventilation of double-flow (balancing the extraction flow and supply of air) or increment the air intake openings [1].

In general, ventilation of habitable spaces is effective for radon concentrations lower than 600 Bq/m3, particularly when is close to 300 Bq/m3. It is recommended to complement it with other mitigation methods such as radon barrier, sealing or ventilated containment space [3].

4 | Materials and products

4.1 Sumps

There are several types of underground sumps, namely prefabricated solutions, which can be easily and quickly installed under the ground floor of new buildings [2]. Prefabricated sumps are generally made up of plastic material (Fig. 5a). Sumps can also be built on site (Fig. 5b) using, for example, perforated bricks (or not) arranged in a honeycomb pattern, so as to build a box around the end of the exhaust pipe, leaving the vertical joints open and applying mortar only in the horizontal ones.

a) b)

Fig. 5 sumps: a) prefabricated; b) built on site

4.2 Fans

There are three main types of fans used for moving air, axial, centrifugal (also called radial) and cross flow (also called tangential).

Centrifugal fans are considered the most efficient and versatile to move air. The scroll housing in a centrifugal fan accelerates the air and changes the flow direction twice, a total of 90 degrees, before exiting the housing.

Exhaust fans can be plastic, composite or metal.

Plastic fans are better than metal ones as they have lighter blades and smooth edges, which ensure safety during installation and also do not overload the motor. In addition to this they are more energy efficient, and corrosion and weather resistant.

PVC fans (with polypropylene blades) provide good protection for many applications in corrosive environments. However, they are more brittle and their strength decreases with increasing temperature. PVC/polypropylene fans normally do not have metallic parts in contact with the air stream and are suitable up to temperatures of 60ºC. Both polymers are able of withstanding slightly higher temperatures when formulated with flame retardants. These plastics are resistant to many acids, caustic, and inorganic saline products used in labs.

Fans made up of fiber reinforced plastic (FRP) are highly durable, have a higher strength-to-weight ratio and are lighter than metal fans. However, they are generally used in corrosive environments and at extremely low temperatures or reasonably higher than the ambient temperature (up to 120ºC).

In contrast with FRP fans, PVC/polypropylene fans often are a more economical option. Thus, for radon extraction, and not being necessary to work in extremely corrosive environments, with hot fumes or aggressive vapours, PVC or PP fans ares better.

4.3 Exhaust pipes

The exhaust system is usually made up of plastic, usually polyvinylchloride, polyethylene or polypropylene, or composite pipes, because these materials are suitable for radon exhaust as well as for humid environments where metals perform worse.

Plastic and composite materials are also an excellent choice for caps.

Likewise, plastic and composite materials can be used successfully in noise attenuators for air streams containing condensation products.

All joints within the pipework, with sumps and other elements shall be fully sealed.

4.4 Drainage systems

The perforated drainage pipes are commonly made up of plastic materials. Underground water reservoirs, which can also be used to extract radon, are also preferably made up of plastic and composite materials, which are more resistant to corrosion in humid environments.

4.5 Barriers

Most common radon barriers membranes are made up of plastic, bitumen and composite materials that are also suitable as methane gas and water vapour barrier:

- thermoplastic polyolefins (high or low-density polyethylene) with smooth or textured surfaces, consisting of single layer or multilayer.low-density polyethylene that can include metal (generally aluminum) or plastic layers, bituminous membranes modified with atactic polypropylene (APP) or styrene butadiene styrene (SBS), with internal or external reinforced layers.

There are also strips or membrane profiles specifically suitable for sealing construction elements with angular areas or those whose geometry is difficult to circumvent.

Another possible solution consists of liquid gasproofing membranes.

5 | Main remarques and conclusions

Many of radon protection measures listed can be routinely installed in new buildings during construction but are more difficult to implement in existing buildings [1], [2].

However, these solutions are not suitable for all types of buildings, nor for all levels of radon concentration, and in specific cases, it is necessary to adopt more than one solution to solve the problem of high concentration of radon inside buildings.

When there are several types of foundation in the same building, it may be also necessary to apply a combination of radon mitigation techniques to levels converging with the reference level.

Sealing and improving the interior ventilation of habitable spaces in buildings have a limited effectiveness up to radon levels of 400 Bq/m^3 [1].

Radon protection membranes on its own only provide protection against radon entry up to radon levels of 600 Bq/m^3 [3], [4]. In existing buildings, they are more often used when it is necessary to replace the floor. The effectiveness of this solution depends on the radon permeability of the membranes [1], [3]. In areas with more than 600 Bq/m^3, this measure must be complemented with other solutions such as sub-slab depressurization [4], which can be activated with a fan if the radon level is high [1], [2].

Improvement of ventilation below the ground floor is effective up to radon concentrations of 700 Bq/m^3 (passive) or 850 Bq/m^3 (active), in some cases making it possible to achieve success up to 1200 Bq/m^3 [1]. Some regulations allow the use of this system on its own only up to 600 Bq/m^3. From this level of radon up, this system must be combined with a radon barrier [4].

Positive pressurization systems (air insufflation) present a degree of effectiveness up to radon concentrations of 700 Bq/m^3, allowing, in some cases, success up to 1000 Bq/m^3 [1]. When installing this solution in dwellings a careful assessment must be conducted to prevent the occurrence of condensations [3].

The installation of an active system for sub-slab depressurization with or without radon barriers, usually provides a guaranteed level of effectiveness of up to 2000 Bq/m^3, or even higher than this value in some cases, provided the soil is sufficiently permeable [1], [2], [7].

The use of drainage systems, often also used in conjunction with sub-slab depressurization systems, have the same degree of effectiveness.

Although active systems (mechanical ventilation) are more effective than passive systems (natural ventilation), in new buildings it is always recommended to install a passive system and later, if necessary, convert it into an active system by installing a fan in the exhaust duct [2].

Finally, the installation of ventilation systems in the building should be foreseen, in order to guarantee ventilation and indoor air quality in common spaces and basements of the building [1], [2]. However, adequate ventilation rates should be established after an assessment that takes into account IAQ and energy saving requirements, as well as possible depressurization that could draw radon-laden air from soil to the building [3].

6 | Future challenges

At materials level, some new findings may be expected to reduce radon inflow in buildings:

- Developments for inclusion of nanomaterials as improvement to reduce radon diffusion in barriers or outdoor coatings.
- Development of solutions based on reverse osmosis, due the fact that exterior paints must prevent radon from entering while interior paints should allow the escape of gas and vapors which in the meantime are concentrated in the interior environment, in particular in the case of double walls with an air gap.
- Development of prefabricated composite sumps with higher resistance

- Minimizing radioactive components in construction materials, through new compositions.
- Development of more energy efficient solutions, including the use of lighter and more efficient construction materials, either used in fans or in energy recovery systems.
- Increasing the use of recycled and more environmentally friendly materials in protection systems.

7 | Recommendations

The most relevant strategic measures, to reduce radon problems, may be classified at various levels, as is summarized below:

a) Economic incentives:

- creating financial assistance programs for testing and mitigation;
- creating favorable financing conditions for the construction of radon-resistant buildings;
- stimulating continuous investment in innovation for radon protection technologies;
- promoting and rewarding pioneering innovation on radon technologies;
- reducing VAT for radon products and technologies.

b) Regulation and legislation:

- creating regulations to mandate that all new buildings be built using radon-resistant new construction practices, particularly in radon prone areas;
- supporting radon policy activities;
- supporting the development of indicators of protection efficiency and performance in the construction sector;

c) Research and technological development

- encouraging research and technological development in the area of radon technologies, particularly in the field of depressurization, range of action of sumps, design and sizing of the system, etc.;
- compiling environmental product declaration data for selected building construction materials and radon protection products.

d) Training and creation of publications

- promoting training and training actions, providing workers with knowledge on radon protection systems and how to install them;
- promoting multifaceted communications and public awareness campaigns to improve awareness of radon;
- implementing or increasing radon education at schools.

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