Extremely volatile, Radon gas can seep up through cracks in a local territory. Increase the risk of lung cancer to those subjected to a long-term exposure, individuals to high risk radionuclides, and may also small pores in hollow-block walls, or sumps/drains which will the floors, floor-wall junctions, gaps around pipes/cables, or from water if it contains dissolved radon.

Radon is a natural occurring radioactive gas, chemically inert, odorless, colorless, and flavorless. During the natural decay chain of uranium and thorium in soils and rocks (which is part of a series of 14 transformations), radon is emitted. This means at every single step of this radioactive decay chain the atom nuclei emit radiation: alpha, beta particles, or gamma rays. Radon can be generated from the construction materials or from water if it contains dissolved radon. Elevated levels of radon have been found in many buildings all across South Korea. Any home, school, subway station or any type building is subject to radon threat, whether new or old buildings, well-sealed or cold drafty ones, and those with or without basement. Indeed, radon gas gets into all types of buildings. However, because most of indoor radon gases present in houses comes from the soil on which it is built in, its levels are the highest in houses’ basements since these areas are nearest to the source. The concentration level of Radon is more related to the geological nature of a regional or a local territory. Extremely volatile, Radon gas can seep up through cracks in the floors, floor-wall junctions, gaps around pipes/cables, small pores in hollow-block walls, or sumps/drains which will expose individuals to high risk radionuclides, and may also increase the risk of lung cancer to those subjected to a long-term exposure. Many sources refer to radon as the highest source of human radiation exposure [1]. Radon is also regarded as the second leading cause of lung cancer after smoking [2].

The most important route of exposure to such radiation is indoor places. Building materials are the major sources of indoor radon gas emission. Even though radon can accumulate to high levels in closed or poorly ventilated areas, a small amount of its gas will not pose a health risk in open air spaces or well-ventilated areas.

This study was carried out to evaluate various radon issues such as radon emission rate in South Korea and radon mitigation efficiency.

SICK BUILDING SYNDROME: RADON A NEW CHALLENGE
In the early 1970s, the problem of indoor pollution was clearly identified and related to the energy crisis. The situation went worse when the new construction energy-saving-regulations recommended the use of synthetic insulation materials, i.e., the use of asbestos. Asbestos fibers were widely used in the past because they are strong, durable and non-combustible, but are much less used nowadays because it appeared they can cause health risks (even during maintenance, renovation or demolition). Due to lack of epidemiological studies and insufficient public awareness about Radon [3], its environmental and health issue are less known in South Korea [4], and also less documented. For example, in United States, it has been estimated that 20,000 lung cancer deaths per year are related to radon [5], and 3 to 15% of all lung cancer patients have been identified to be due to radon [6]. While in South Korea, there is no research to confirm these US actual facts within the Korean context.

In developed and temperate countries, it is estimated that individuals spend 70% of their time in their private homes, 20% in buildings and 10% working outside or in transport [7]. So if there are flaws in the heating/ventilation and air (HVAC) systems, the occupants who naturally spend 90% of their time indoors may experience serious health effects. The expression of Sick Building Syndrome (SBS) was used to refer to any disease related to indoor air pollutants. The quality of indoor air is actually influenced by two levels: outdoor air pollution and the presence of internal sources that often produce pollution in higher levels. Various factors can contribute to the quality of the air such as the geological and climatic characteristics of the site, the building typology of the building, the materials, and the technological systems.

INDOOR AIR QUALITY AND HEALTH RISKS
Radon health risks are less known in South Korea [4], and also less documented. For example, in United States, it has been estimated that 20,000 lung cancer deaths per year are related to radon [5], and 3 to 15% of all lung cancer patients have been identified to be due to radon [6]. While in South Korea, there is no research to confirm these US actual facts within the Korean context.

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POLICY OF RADON ABATEMENT IN KOREA

In Korea, the radon mitigation political awareness is quite new. The Ministry of environment established a comprehensive indoor measurement only in 2007. The same year, measures were seized using a passive radon detector to identify areas having higher than average indoor radon concentrations (measured in Becquerel per cubic meter, Bq/m$^3$) and take accurate data during the winter term, since this is the period where buildings remains closed. There are indeed differences between the seasons. It is known that usually in winter radon levels are increased because of a not well-ventilated room. In fact, the relative humidity, building ventilation rate and building orientation will affect significantly the indoor radon concentrations in buildings. But in principle these concentrations should be much higher in winter and much lower in summer because of closing or opening the windows, this window-opening behavior of the occupied buildings influence directly the indoor air quality and its pollution concentration [9].

Since 2009, the Ministry of environment has focused on an “Indoor Air Quality radon Management Plan” for developing and promoting strategies for mitigation of radon exposure. The last survey, published in March 2015, was conducted in 6648 survey points using passive detectors producing a national radon mapping [10]. Figure 1, shows the average indoor radon concentrations in different Korean province. It was also necessary to determine whether indoor radon levels were above the Environmental Protection Agency (EPA) recommended levels. The measurements were carried out during the winter three months’ period. The results revealed that the average radon concentration of 102 Becquerel’s released per m$^3$ (102 Bq/m$^3$). This result is lower than the previous one conducted from December 2011 to February 2012 on 7885 dwellings nationally with an average concentration of 124Bq/m$^3$ [10].

![Figure 1: Radon concentration in different Korean provinces. (Adapted from: [10])](image)

Figure 2: Governmental radon management initiative

There are distinct differences by region and by the range of average exposures. But these first reported data call for government action to carry out a general study throughout the whole country, establish a control plan to the radon concentrations and protect those vulnerable to radioactivity. In order to reduce radon health risks, the Korean Ministry of the Environment (KME) has recommended that the indoor radon concentration be less than 148 Bq/m$^3$ which is the same value suggested in the United States [11]. To achieve this goal, the KME suggested some guidelines such as improving the ventilation systems. Therefore, indoor air quality in buildings is of crucial importance and so are the measures taken to establish improvements to prevent its deterioration, i.e., to prevent any kind of pollutants emitted into the air whether it comes from human activities or from natural sources [12]. So, air sealing and other energy retrofits in buildings can raise or lower radon levels, whether the building is more airtight or less airtight, it will have a significant impact on the air exchange in the space. As an example, a well heated home, equipped with energy-saving equipment, is a typical example of deterioration of indoor air quality.

MANAGEMENT OF INDOOR AIR OF MULTI-PURPOSE FACILITIES

At the end of 2015, the Korean National Assembly passed a revised bill on ‘Management of indoor air of multi-purpose facilities’ strengthening the existing policies and regulations about indoor radon mitigation [13]. With this new bill, local and imported constructions materials will follow a sick building syndrome analysis and pollution detection, preventing indoor air contamination. The government is indeed working towards an active ‘Radon management plan’. The Ministry of environment and the local authorities will investigate, advise and mitigate indoor radon gas depending on the gas concentration fig 2.

![Investigate Advise Mitigate](image)
CONCLUSION
It is clear that indoor radon concentrations depend on factors such as the soil, building materials, the ventilation habits of people, airtightness and the design of the building thus the amount of air-change between the indoor and the outdoor. Given many research findings, radon has become an emerging environmental and health issue in Korea that needs to be tackled. The basis for the action plan is the reduction of radon concentration.

The Korean government recently started supporting radon detection and management, and working towards radon mitigation. The strategic plan in South Korea should involve:

- The definition of guideline values based on the new findings on radon.
- A better understanding of the effective exposure of the population to radon; through mapping the zones at risk and the constant measurements, seen as necessary.
- An improvement in radon control through building regulations.
- The endorsement of radon-free buildings requirements: building standards and codes.
- The adoption of national policy and local ordinances. Policies for testing, mitigation for the existing building stock and new constructions.
- Promotion of Radon mitigation techniques among professionals and homeowners’ awareness.
- The involvement of Korean researchers because obviously radon-related studies in Korea are minimal compared to those in foreign countries.

ACKNOWLEDGEMENT
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REFERENCES


Table 2: Conducted Indoor radon investigations in different building types by the Ministry of Environment [14].

<table>
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