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Analysis of Seasonal Airborne Radon Concentration Characteristics in Public-Use Facilities

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Abstract

Purpose: The purpose of this study is to investigate the characteristics of airborne radon concentration by season in public-use facilities in South Korea. **Research design, data and methodology:** The data is provided by the public data portal, and public-use facilities nationwide where radon in the air is measured are specialized sanatorium for senior citizens, libraries, childcare facilities, postpartum care centers, medical institutions, funeral halls, underground shopping malls, and underground subway stations. **Results:** The facility with the highest radon concentration in public-use facilities was childcare facilities with an average of 50.2 ± 21.7 Bq/m^3, while the average of medical institutions was the lowest at 24.8 ± 5.7 Bq/m^3. The season with the largest difference in average radon concentration between childcare facilities and medical institutions was in the order of fall (28.6 Bq/m^3), followed by winter (28.1 Bq/m^3), spring (23.0 Bq/m^3), and summer (22.0 Bq/m^3). **Conclusions:** The main concentration levels of each public-use facility shown in this study are all below domestic and international standards, but there is a significant concentration difference between facilities. By season, winter showed the highest average concentration (40.6 ± 21.3 Bq/m^3) and summer showed the lowest average concentration (23.8 ± 14.0 Bq/m^3).

Keywords : Airborne radon, Public-use facilities, Season, Underground facilities, Concentration

JEL Classification Codes : I10, I18, I20, I31

1. Introduction

Radon (226Ra) is a gaseous material produced by the radioactive decay of uranium (238U). It is known as a natural radioactive substance and is reported to have health effects when exposed to the general public (David Bodansky et al., 1987). Radon is an odorless and colorless inert gas that easily enters the body through the human respiratory system. Once radon gas enters the human body, it undergoes decay and generates radon daughter nuclides, which are adsorbed to the bronchi and lungs, resulting in health effects (UNSCEAR, 1988).

Radon from the soil moves into indoor spaces where the pressure is lower than the external environment. It enters through cracks in interior walls, floor joints, and pipelines (US EPA, US Environmental Protection Agency, 2001). According to a report by the US EPA, radon exposure is responsible for 10-15% of all lung cancers, making it the second leading cause of lung cancer after cigarettes (US EPA, 2003). Studies have shown that higher exposure to

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radon gas in the air increases the risk of lung cancer (Lubin et al., 2004).

Indoor buildings on lower floors or in contact with the ground are more likely to be exposed to radon in the air compared to outdoor environments. It has been reported that indoor radon concentrations are generally higher than those in actual buildings (NIER, Korea National Institute of Environmental Research of Korea, 2014). The UK Health Protection Agency (UK HPA) (2009) states that new houses in the UK and Sweden should be managed at 200 Bq/m^3 or less, while existing houses should be managed at 400 Bq/m^3. The WHO (World Health Organization) applies a strict standard of 100 Bq/m^3 for indoor air. In the US, the guideline for indoor environments is set at 148 Bq/m^3, and the WHO provides necessary data and promotes safe building construction methods for radon to the general public (WHO, 2009). These efforts aim to manage radon gas concentration in indoor environments by addressing the health hazards associated with radon gas.

In Korea, the Ministry of Environment suggests 148 Bq/m^3 (Ministry of Environment of Korea, 2015) as the recommended standard, which is the same as that in the United States, under the 'Indoor Air Quality Control Act.' However, there are no specific guidelines regarding the management measures for radon risk or the characteristics, size, and region of public-use facilities, in comparison to this guideline, concerning the possible occurrence of radon in public-use facilities.

Recent studies on radon in the air among public-use facilities in Korea have primarily focused on evaluating concentrations and environmental factors for various facilities. However, there have been few studies examining the characteristics of radon concentration changes by season on a national scale. Therefore, the purpose of this study is to analyze radon concentration by season and facility in public-use facilities nationwide, evaluate the findings, and establish a foundation for radon management measures in Korea based on this data."

2. Materials and Methods

2.1. Research Subjects

The distribution of radon concentrations in public-use facilities in Korea was analyzed using data measured by the NIER, Ministry of Environment. This data is provided on the public data portal (https://www.data.go.kr/index.do), and the name of the data is NIER, National Indoor Radon Information Public-Use Facility, Ministry of Environment'.

The distribution of radon concentrations in public-use facilities was analyzed using data measured by the NIER, Ministry of Environment. These public-use facilities across the country, where radon in the air was measured, include 8 specialized sanatorium for senior citizens, libraries, childcare facilities, postpartum care centers, medical institutions, funeral halls, underground shopping malls, and underground subway stations. Table 1 shows public-use facilities, measurement areas, and the number of samples used in this data.

Table 1: Classification of Radon Sampling Areas in Public-Use Facilities in South Korea

Type	No. of sample	Sampling area
Specialized sanatorium for senior citizens	11	Gyeonggi, Gyeongbuk, Seoul, Chungbuk
Library	37	Gangwon, Gyeonggi, Gyeongnam, Gyeongbuk, Daejeon, Seoul, Jeonnam, Jeju, Chungnam
Childcare facility	17	Gangwon, Gyeonggi, Gyeongbuk, Daegu, Seoul, Jeonbuk
Postpartum care center	10	Gangwon, Gyeongbuk, Gwangju, Daegu, Daejeon, Busan, Incheon, Jeonnam, Jeonbuk, Chungnam
Medical institutions	42	Gangwon, Gyeonggi, Gyeongnam, Gyeongbuk, Gwangju, Daegu, Busan, Seoul, Ulsan, Incheon, Jeonnam, Jeonbuk, Chungnam, Chungbuk

Funeral hall	11	Gyeonggi, Gyeongbuk, Gwangju, Daejeon, Seoul, Chungbuk
Underground shopping mall	14	Gyeonggi, Gyeongnam, Daegu, Seoul, Incheon
Underground subway station	29	Gyeonggi, Gwangju, Daegu, Busan, Seoul, Incheon
Total	171	

2.2. Statistical Analysis

The statistical program used for data analysis was R-Studio (version 4.2.1). All statistical analyses were performed using a non-parametric method, and the Shapiro-Wilk test results indicated a non-normal distribution. Kruskal-Wallis test was employed to assess the significance of radon concentrations among the 8 public-use facilities (specialized sanatorium for senior citizens, libraries, childcare facilities, postpartum care centers, medical institutions, funeral halls, underground shopping malls, and underground subway stations) and the seasons of spring, summer, autumn, and winter. To determine the significance between facilities with the lowest and highest radon concentrations, the Wilcoxon signed-rank test method was used.

3. Research Results

Table 2 presents the distribution of radon concentrations in the air measured at 8 public-use facilities nationwide. Among these facilities, childcare had the highest radon concentration, with an average of 50.2 ± 21.7 Bq/m^3, while medical institutions had the lowest average of 24.8 ± 5.7 Bq/m^3.

Table 2: Distribution of Radon Concentration in Public-Use Facilities (Unit : Bq/m^3)

Type[a]	Concentrations				
	Min.	Max.	Median	Mean	S.D[b]
Specialized sanatorium for senior citizens	16.4	56.8	25.8	28.1	11.4
Library	20.9	92.7	38.8	41.7	16.5
Childcare facility	27.2	106.0	42.9	50.2	21.7
Postpartum care center	16.2	56.2	28.1	29.4	10.8
Medical institutions	16.6	41.9	24.1	24.8	5.7
Funeral hall	16.0	47.7	25.0	27.6	9.0
Underground shopping mall	17.5	45.1	24.6	26.4	7.7
Underground subway station	14.4	58.6	21.6	25.6	9.6

Note: a; Kruskal-Wallis rank sum test (< 0.001), b; Standard deviation

Fig. 1 illustrates the distribution of radon concentration in the air at public-use facilities by season across the 8 locations nationwide. Winter exhibited the highest radon concentration among the seasons, with an average of 40.6 ± 21.3 Bq/m^3, followed by spring (34.6 ± 16.6 Bq/m^3) and autumn (28.7 ± 17.3 Bq/m^3). Among the four seasons, summer had the lowest average radon concentration of 23.8 ± 14.0 Bq/m^3. The seasonal variations in radon concentrations were statistically significant ($p < 0.001$).

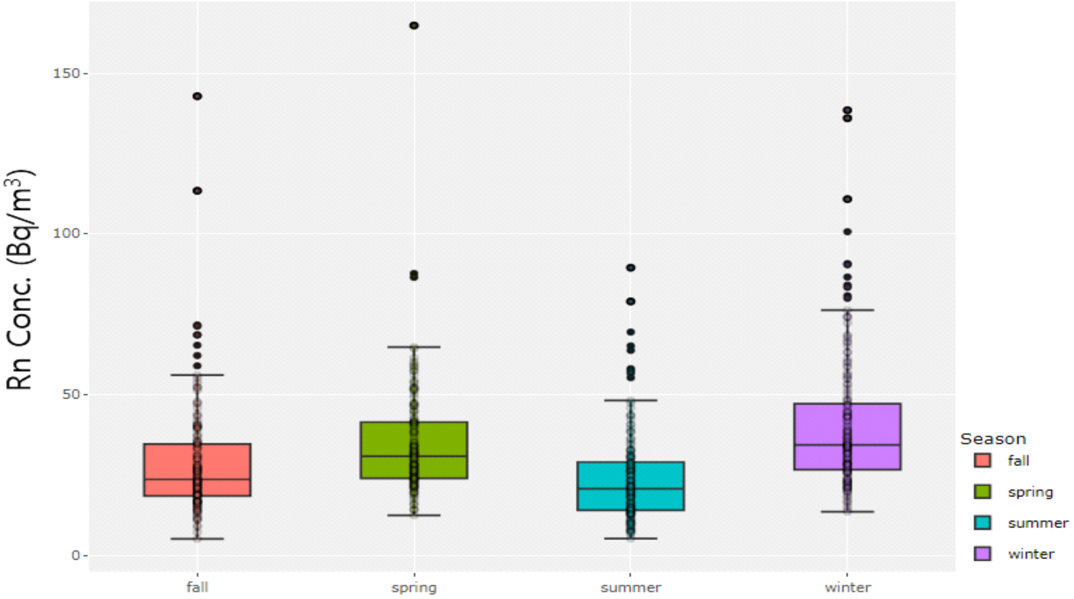

Figure 1: Distribution of Rn Concentrations by Season in Public-Use Facilities ($p < 0.001$).

Table 3 displays the distribution of radon concentrations in the air based on public-use facilities and seasons in 8 locations nationwide. Childcare facilities exhibit the highest rates among public-use facilities in all four seasons: spring (50.8 ± 13.9 Bq/m^3), summer (39.2 ± 21.6 Bq/m^3), fall (50.4 ± 31.7 Bq/m^3), and winter (60.5 ± 29.0 Bq/m^3), indicating the average radon concentrations. However, underground subway stations and medical institutions generally show low average radon concentrations.

Table 3: Seasonal Concentration of Radon in Public-Use Facilities (Unit : Bq/m^3)

Type	Mean ± Standard deviation			
	Spring	Summer	Fall	Winter
Specialized sanatorium for senior citizens	29.1 ± 10.9	19.4 ± 7.9	26.8 ± 16.3	37.2 ±15.9
Library	43.3 ± 24.8	32.8 ± 13.1	37.2 ± 14.7	53.6 ± 25.0
Childcare facility	50.8 ± 13.9	39.2 ± 21.6	50.4 ± 31.7	60.5 ± 29.0
Postpartum care center	31.2 ± 8.5	20.4 ± 7.9	28.4 ± 15.5	37.7 ± 17.3
Medical institutions	27.8 ± 9.4	17.2 ± 8.45	21.8 ± 7.7	32.4 ± 13.5
Funeral hall	31.9 ± 10.3	20.7 ± 12.6	25.4 ± 10.5	32.9 ± 14.7
Underground shopping mall	31.9 ± 9.5	21.4 ± 7.5	18.5 ± 7.1	34.0 ± 12.6
Underground subway station	29.8 ± 11.3	17.9 ± 10.3	22.2 ± 9.1	32.3 ± 13.0

Fig. 2 presents a comparison of concentrations by season between childcare facilities, which have the highest average radon concentration, and medical institutions, which have the lowest average radon concentration among public-use facilities. The season with the largest difference in average radon concentration between these two facilities is autumn (28.6 Bq/m^3), followed by winter (28.1 Bq/m^3), spring (23.0 Bq/m^3), and appeared in the order of summer (22.0 Bq/m^3).

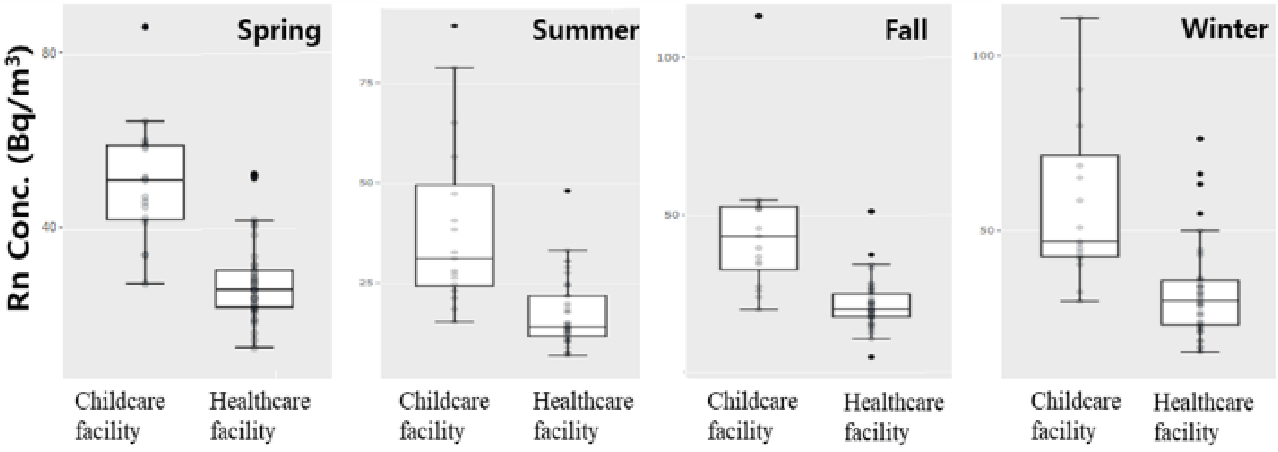

Figure 2: Distribution of Rn Concentrations in Childcare-facilities and Healthcare Facilities ($p < 0.001$)

4. Discussions

This study analyzes the characteristics of radon concentration distribution in public-use facilities by facility and season. Airborne radon was measured in 8 public-use facilities across the country: specialized sanatorium for senior citizens, libraries, childcare facilities, postpartum care centers, medical institutions, funeral halls, underground shopping malls, and underground subway stations. The average radon concentration in public-use facilities across the country was 28.1 ± 11.4 Bq/m^3 in specialized sanatorium for senior citizens, 41.7 ± 16.5 Bq/m^3 in libraries, 50.2 ± 21.7 Bq/m^3 in childcare facilities, 29.4 ± 10.8 Bq/m^3 in postpartum care centers, 24.8 ± 5.7 Bq/m^3 in medical institutions, 27.6 ± 9.0 Bq/m^3 in funeral halls, 26.4 ± 7.7 Bq/m^3 in underground shopping malls, and 25.6 ± 9.6 Bq/m^3 in underground subway stations. These radon concentration values fall below the WHO recommended international standard of 100 Bq/m^3 and the domestic "Indoor Air Quality Control Act" recommended standard of 148 Bq/m^3 (Ministry of Environment of Korea, 2015). However, the International Commission on Radiation Protection recommends reducing all radon exposures to levels well below the reasonably achievable reference levels8), regardless of the initial exposure level. The exposure standard level is defined as the "control of dose or risk level," and exposure above the standard is reported as inappropriate. The term 'exposure as low as possible' (ALARA) is also used, which is a widely used safety principle for minimizing exposure to ionizing radiation and controlling the release of radioactive materials (Gue, 2015).

As a result of comparing the concentration level of public-use facilities measured in this study with other residential indoor environments, it was found that the radon concentration in the residential environment was higher. According to the results of radon concentration in detached houses in 17 cities/provinces, the average radon concentration in Daejeon Metropolitan City was 173.1 Bq/m^3, and Chungcheongbuk-do showed a high concentration of 182.6 Bq/m^3, while Busan Metropolitan City showed a relatively low concentration of 82.6 Bq/m^3. However, compared to the average radon concentrations investigated in this study, all of them were at high levels. These results were similar to previous studies (National Institute of Environmental Research, 2012a; Zoo et al., 2015), which reported that the main cause was the effect of granite. In other words, it was reported that the ground of the house was an area with a high distribution of granite strata with high uranium content (National Institute of Environmental Research, 2012b). In order to know the level of radon concentration in public-use facilities in Korea, indoor radon concentration levels in other countries were compared. Spain's Barcelona Metropolitan Underground (21 Bq/m^3) and Tokyo Metro (11.1 Bq/m^3) (Doi & Kobayashi, 1996) showed lower radon concentrations than those reported in this study. Radon concentrations in underground facilities in Hong Kong (41.5 Bq/m^3) (Yu et al., 1996) and underground parking lots (41.8 Bq/m^3) in six states of Kuwait (Bu-Olayan & Thomas, 2016) were similar to those of this study, or at a relatively high level.

Meteorological parameters are important factors that can affect seasonal changes in radon concentrations in indoor environments (Xie et al., 2015). In northern climates, radon concentrations have been reported to be highest in winter and lowest in summer (Mose et al., 1992; Lee et al., 2017).

These results were consistent with the results of this study. In this study, the season with the highest average radon concentration in public-use facilities was winter (40.6 ± 21.3 Bq/m^3) (Fig.1). As a result, windows are often closed and sealed to minimize heat loss during heating time (Jeaon et al., 2011). Therefore, it is judged that the indoor radon concentration is increased. Due to the reason that the radon concentration is higher in winter than in other seasons, it is necessary to open the indoor door or window for a while to ventilate (Duggal et al., 2014). Also, in winter, high levels of radon gas are generated in the indoor environment because the pressure is lower than that of the outside (Sahoo et al., 2007). In addition, according to the study by Abdulrahman and Khalid (2014), indoor radon concentration was high in winter when heating appliances were mainly used, but showed a slightly higher tendency in summer when air conditioners were used. It is thought that the longer the time it is sealed in the indoor environment, the more difficult it is to dilute with clean air (air in the atmosphere), thereby affecting the radon concentration.

Another factor affecting radon concentration regardless of the season is the radon concentration generated in the semi-basement. The reason for the high level of radon in the semi-basement can be attributed to the inflow of radon due to cracks or crevices in the surrounding soil, low temperature, and high humidity in the outdoor environment (UNSCEAR, 2006). Most residential environments in Arab countries are also basement environments, and the radon concentration in the underground environment was higher than that in other above-ground environments (Abdulrahman & Khalid, 2014).

It has been reported that the radon concentration is higher in the basement compared to the second floor (Abel, 2008). However, in this study, the radon concentration in above-ground facilities was found to be higher than in underground environments such as subway stations and underground shopping malls, which are located below the semi-basement. These results can be attributed to the smooth operation and maintenance of ventilation and air conditioning systems in the underground environment (Bu-Olayan & Thomas, 2016). A previous study reported that controlling outdoor air ventilation to increase it 3 to 10 times the natural ventilation rate at home helps reduce indoor emissions (Hospodsky, et al., 2015).

Therefore, high ventilation rates are effective in reducing radon concentration levels. Another factor that can affect indoor radon concentrations is the underlying geology. A significant correlation was found between indoor radon concentrations and the geological composition of the ground (Moreno et al., 2008). Previous studies also reported that the radon concentration in underground stations based on granite areas was higher than that in underground stations based on non-granite areas (Hwang et al., 2018).

The WHO recently stressed that radon concentrations were higher indoors and in poorly ventilated areas, and high levels were seen in places such as caves and mines. According to WHO (2021), common methods of reducing radon concentration levels are frequent ventilation and sealing of cracks in floors and walls.

This study has several research limitations. First, since the measured data were not measured while directly evaluating the surrounding situation at the site, but were analyzed using public data, it is not possible to accurately determine the cause of the slight difference in the concentration of radon measured in public-use facilities for each facility. point. Therefore, to identify seasonal changes in radon concentrations in the subsurface environment, it is necessary to evaluate the impact of seasonal differences, such as during winter. In addition, it is not possible to know the properties of the building's flooring and construction materials, along with the geologic structure of the ground, such as soil type, proximity to rivers, and other indicators in the area that can affect radon concentrations (Teiri et al., 2021). Therefore, additional studies that can supplement these limitations and comparisons between meteorological parameters and radon concentrations are essential for future studies. Despite these limitations, this study is a nationwide radon evaluation study. It is possible to check the concentration distribution according to various public-use facilities and seasons, so it is possible to set up radon control measures that can be applied not only to public-use facilities but also to general housing facilities, seasons, soil distribution in geographic regions, building materials, and construction years. It is meaningful in that it can provide basic data.

5. Conclusions

The purpose of this study was to analyze the seasonal radon concentrations in spring, summer, autumn, and winter in public-use facilities nationwide and evaluate the characteristic results accordingly.

In other words, prioritization of specific management measures in public-use facilities can be applied based on basic data. Although the main concentration levels of each public-use facility in this study were below the domestic and international standards, there were significant concentration differences between facilities. By season, winter showed the highest average concentration (40.6 ± 21.3 Bq/m^3) and summer showed the lowest average concentration (23.8 ± 14.0 Bq/m^3).

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