Assessing Radon Exhalation Rates from Building Tiles: Implications for Sustainability and Indoor Air Quality

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Received: 13 June 2024 | Revised: 26 June 2024 | Accepted: 30 June 2024

 DOI: https://doi.org/10.48084/etasr.8120

ABSTRACT

This study evaluates the radon-222 (^{222}Rn) exhalation rates from building tiles commonly used in Duhok, Iraq. Eighteen samples of tiles used for flooring and walls were collected and analyzed using the Airthings radon detector to measure the ^{222}Rn levels. Surface exhalation (E_A) and mass exhalation (E_M) rates were calculated based on the measured radon concentrations. The results showed that ^{222}Rn levels in the tile samples ranged from 2.96 to 46.99 Bq/m³, which is below the limit of 100 Bq/m³ recommended by the World Health Organization (WHO) for indoor air environments. Indian Pink Granite exhibited the highest radon emission rates among the tested materials, with an E_A of 97.9 mBq/m²h and an E_M of 9.79 mBq/kgh. These findings highlight the importance of considering both average radon concentrations and emission rates when selecting building materials. Although the immediate radon levels of these tiles are within safe limits, materials such as Indian Pink Granite, which have high emission rates, could potentially increase indoor radon levels over time. This underscores the need for comprehensive evaluations to ensure long-term safety. Identifying materials with high emission rates enables informed decision-making, supporting the sustainable selection of building materials. This approach helps mitigate indoor radon accumulation, improves air quality, and protects public health.

Keywords-Radon-222 exhalation; building materials; airthings radon detector; public health

I. INTRODUCTION

Sustainable construction is at the intersection of design aesthetics and functional durability, aiming to create structures that are not only visually appealing but also safe, sustainable, and conducive to human health [1]. The selection of building materials is a crucial aspect of this discipline, as it affects the structural integrity, environmental footprint, and indoor air quality of built environments [2, 3]. Recently, the emphasis has increasingly shifted toward sustainable building practices that support environmental protection and human well-being [4]. One significant but often overlooked factor in selecting building materials is their potential contribution to indoor air pollution through radon exhalation [5]. Radon, a naturally occurring radioactive gas, emanates from certain building materials and can accumulate to dangerous levels indoors, posing serious health risks [6]. Inhalation of radon and its decay products is the second leading cause of lung cancer worldwide, highlighting the critical importance of monitoring and controlling radon levels in residential and commercial buildings [7, 8]. Building tiles, commonly used for flooring, wall coverings, and countertops, are among the materials that can emit radon [9]. Given their widespread use and substantial surface area, tiles can significantly influence indoor radon concentrations [10]. Assessing radon exhalation rates from building tiles is essential to ensure safe indoor air quality and align with sustainable architectural practices [11].

One significant health risk associated with building materials is the exhalation of ^{222}Rn [12]. Radon is a colorless, odorless radioactive gas that originates from the decay of uranium present in various natural materials, including certain types of building tiles [13, 14]. When these tiles are used in construction, radon can spread to indoor environments, leading to elevated concentrations that pose serious health risks [15]. Prolonged exposure to high levels of radon and its decay products is the second leading cause of lung cancer after smoking, making it a critical factor to consider in material selection [16]. Assessing radon exhalation rates from building tiles involves measuring the amount of radon gas released from the tile surface over a specific period [17]. This process includes using specialized detection equipment and controlled environmental conditions to ensure accurate results [18]. Factors that influence radon exhalation rates include the type of raw materials and the manufacturing process of tiles [19]. Understanding these factors allows manufacturers to modify production techniques to reduce radon emissions and builders to make informed decisions that prioritize indoor air quality and human health. Such assessments enable regulatory bodies to establish appropriate safety standards and guidelines, ensuring that only materials with acceptable levels of radon emission are used in construction [20].

Sustainable architecture seeks to minimize the environmental impact of buildings while improving the health and comfort of the occupants [21]. This approach requires evaluating all potential health hazards associated with building materials, including radon exhalation. By incorporating radon assessment into the material selection process, architects and engineers can make informed decisions that support both environmental sustainability and human health. Understanding the radon exhalation rates from various materials allows for better design strategies that mitigate indoor air pollution, ensuring safer living and working environments. This holistic approach advances sustainable construction practices and aligns with public health goals, ultimately fostering eco-friendly and health-conscious buildings [22, 23]. This study assesses the ^{222}Rn exhalation rates from commonly used building tiles in Duhok, Iraq. This assessment is critical for identifying tiles that meet aesthetic and structural requirements to ensure low radon emissions, thus supporting healthy indoor environments. By evaluating the radon exhalation characteristics of these tiles, the study aims to provide valuable information that can guide the selection of safer and more sustainable building materials in the region.

II. MATERIALS AND METHODS

A. Sample Collection and Experimental Design

The materials considered include ceramic, marble, and granite, which are commonly used in Duhok, Iraq. Eighteen samples of various building tiles used for floors and walls were collected to represent the wide variety of tiles that are widely used in Duhok's residential and commercial structures. The collecting procedure ensured that the samples were representative of the products often found in local markets.

Various methods and detection devices are employed to assess radon concentration [24, 25]. This study selected the Airthings radon detector due to its user-friendly design, which allows individuals to measure radon levels independently. This hands-on approach contrasts with the traditional reliance on contractors for the detection of this odorless gas. The Airthings device provides both long-term and short-term readings, enhancing the precision of the measurements. The digital radon detector improved the reliability of concentration measurements throughout the study. In the experimental setup, each of the 18 samples was enclosed within a sealed plastic container, simulating a closed room environment. Within this confined space, both the sample and an Airthings radon detector device were placed for a continuous period of seven days. The detector made measurements at 24-hour intervals, providing detailed readings of the radon gas emitted from the various materials under investigation. This approach allowed for the assessment of the radon gas emission levels from the sampled materials. For comparative analysis, multiple samples were included in the study to ensure consistency in test conditions. Each sample was standardized to a mass of 1 kg and a uniform condition was maintained for all samples using a plastic container with a volume of 5000 cm³ (5 l). This standardization ensured consistency and uniformity in the experimental procedure, as illustrated in Figure 1.

Fig. 1. Sample preparation and ^{222}Rn measurement process.

B. Radon-222 Exhalation Rate

The radon exhalation rate is a critical parameter in understanding the emission of radon gas from the surface of material samples [27, 28]. In this study, radon exhalation was divided into two components: surface exhalation (E_A) and mass exhalation (E_M) rates [29]. These rates provide insights into the potential radon exposure risks associated with the samples studied. E_A represents the flux of radon released per unit area from the surface of material samples [30]. E_A is influenced by several factors, including the surface roughness, porosity, and radon content of the material. Accurate measurement of E_A is crucial for evaluating potential health risks in indoor environments where these materials are used. Methods to determine E_A typically involve sealing the sample in a chamber and measuring the radon concentration over time, allowing for the calculation of the rate of radon release per unit area. E_M refers to the amount of radon emitted per unit mass of the material. This parameter is essential to understand the intrinsic radon generation capability of the material, regardless of its surface characteristics. E_M is particularly useful when comparing different types of granite or other materials, as it normalizes the release of radon to the mass of the material. E_A and E_M are critical for a comprehensive risk assessment and management of radon exposure from building materials. By analyzing these rates, researchers can better predict the contribution of granite and similar materials to indoor radon levels and develop appropriate mitigation strategies to ensure safe indoor air quality.

$$E_A = \frac{C\times V\times\lambda}{A\times(1-e^{-\lambda\times T})} \quad (1)$$

$$E_M = \frac{C\times V\times\lambda}{M\times(1-e^{-\lambda\times T})} \quad (2)$$

where C represents the radon concentration in Bq/m³, V denotes the volume of the radon chamber (9.61×10^{-4}m³), λ signifies the decay constant of radon (0.18145 day^{-1}), A stands for the surface area of the sample in m², T indicates the time in days, and M represents the mass of the sample in kg.

III. RESULTS AND DISCUSSION

The Airthings radon detector was used to measure ^{222}Rn levels in various tile samples over seven days. Measurements were averaged to determine the radon concentration for each sample. Table I presents the results of selected materials, including ceramics, marble, and granite, which are widely used in Duhok, Iraq. The materials are organized by their geographical origin and composition and include the corresponding average radon concentrations, measured in Bq/m³. The WHO recommends that indoor radon concentrations should not exceed 100 Bq/m³. This assessment is crucial to understanding the potential hazards associated with different construction materials and their implications for sustainability and indoor air quality. By comparing the radon exhalation rates of these materials, this study provides insights into how material selection can influence indoor air quality and sustainability practices. Identifying materials with higher radon emissions helps inform safer and more sustainable building practices that prioritize both environmental and occupant health protection.

TABLE I. AVERAGE ^{222}RN CONCENTRATIONS IN BUILDING TILES IN (BQ/M^3)

Sample	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Average
KRG, Sulamaniyah Marble	0.77	3.7	3.33	4.81	3.33	7.4	13.69	5.92
Mosul Shirqat Granite	0.78	3.7	5.92	0.74	0.74	7.77	8.88	4.81
Spanish Marble	0.64	4.81	3.7	0.037	3.7	4.81	5.92	2.96
Chinese Granite	0.71	0.74	14.8	3.7	10.73	6.66	6.66	7.77
Turkish Marble Antalya	0.74	7.77	4.81	10.73	7.77	5.92	13.69	7.77
Turkish Marble Kıvan	0.54	4.81	6.7	9.99	2.96	0.74	10.73	4.81
Iranian Marble	0.74	3.7	4.81	1.85	9.99	3.7	8.88	4.81
Iranian Granite No. 1	0.24	1.01	1.85	1.85	7.77	9.99	11.84	6.66
Iranian Granite No. 2	0.38	1.85	7.77	5.92	4.7	3.7	8.88	4.81
Iranian Granite No. 3	0.82	6.66	7.77	3.7	8.88	14.8	5.92	7.77
Iranian Wall Ceramic	0.51	6.66	14.8	10.73	6.66	17.76	5.92	11.84
Iranian Floor Ceramic	0.44	8.88	3.7	3.7	5.92	7.77	6.66	7.77
Indian Granite	0.37	5.92	3.7	0.74	12	15.91	4.81	6.66
Indian Wall Ceramic	0.28	1.85	3.7	1.85	5.92	5.92	6.66	4.81
Indian Pink Granite	0.91	32.93	37	50.69	43.66	33.67	33.67	46.99
Dark Green Indian Marble	0.17	0.14	13.69	14.8	9.99	4.81	8.88	9.99
Dark Brown Indian Granite	0.49	56.98	48.84	28.86	32.93	33.67	23.68	37.74
Dark Green Indian Granite	0.34	17.76	14.8	4.81	11.84	15.91	13.69	12.95

Over 7 days, the measured ^{222}Rn levels in the tile samples ranged from 2.96 Bq/m³ to 46.99 Bq/m³, well below the WHO recommended limit of 100 Bq/m³. Although below the threshold, the variability observed among different material types and their geographical origins provides valuable insights into relative risks. Granite, recognized for its higher natural radioactivity, exhibited a wide spectrum of ^{222}Rn levels. For example, Mosul Shirqat Granite showed a relatively low level of 4.81 Bq/m³, while Chinese Granite and Iranian Granite No. 3 recorded higher levels of 7.77 Bq/m³. Indian Pink Granite stood out with a notably high level of 46.99 Bq/m³, indicating an increased potential risk compared to other granite samples. Noteworthy variations within the granite category included Iranian Granite No. 1 and Indian Granite, each at 6.66 Bq/m³, and Dark Brown Indian Granite at 37.74 Bq/m³. Marble samples generally exhibited more moderate levels of ^{222}Rn.

Spanish Marble recorded the lowest level at 2.96 Bq/m³, contrasting with Dark Green Indian Marble, which had the highest level at 9.99 Bq/m³. Turkish Marble from Antalya and Iranian Marble showed higher levels at 7.77 Bq/m³ and 4.81 Bq/m³, respectively. Turkish Marble from Kivan also exhibited a similar level of 4.81 Bq/m³. Ceramic tiles also demonstrated a range of ^{222}Rn levels. Iranian Wall Ceramic displayed the highest level at 11.84 Bq/m³, while Iranian Floor Ceramic and Indian Wall Ceramic ranged from 7.77 Bq/m³ to 4.81 Bq/m³, respectively. These values generally ranged between marble and granite samples, indicating a moderate risk profile.

The elevated ^{222}Rn levels observed in granite can be attributed to its higher natural radioactivity, primarily due to uranium in its mineral composition. Granite is formed from magma rich in these radioactive elements, which undergo decay processes that release radon gas. This geological origin leads to significant variability in radon exhalation rates among different granite types, including Indian Pink Granite and Dark Brown Indian Granite. In contrast, marble and ceramic tiles show lower radon levels due to their different mineral compositions and lower concentrations of uranium and thorium. Thus, the inherent geological characteristics of granite contribute to its higher radon emissions than other building materials.

Although all measured ^{222}Rn levels were below the WHO recommendation limit of 100 Bq/m³, the significant variation observed among different materials and their sources underscores the critical importance of meticulous selection and testing of building materials. This becomes especially crucial in mitigating the risk of indoor radon exposure, particularly in settings where multiple radon-emitting materials are used concurrently, potentially leading to cumulative effects.

In addition to the average ^{222}Rn concentrations measured over seven days, the emission rates of radon from these materials were also evaluated. Table II shows the radon surface exhalation rates (E_A) in mBq/m²h and the radon mass exhalation rates (E_M) in mBq/kgh for each sample. This dual approach provides a more comprehensive understanding of the radon emission potential of each material, which is crucial for assessing their implications for sustainability and indoor air quality. By analyzing both concentration and exhalation rates, this study highlights the importance of considering multiple metrics when evaluating building materials for safe and sustainable construction practices.

TABLE II. RESULTS OF MASS AND SURFACE RADON EXHALATION

Sample	E_A (mBq/m²h)	E_M (mBq/kgh)
KRG, Sulamaniyah Marble	12.33	1.23
Mosul Shirqat Granite	10.02	1
Spanish Marble	6.17	0.62
Chinese Granite	16.19	1.62
Turkish Marble Antalya	16.19	1.62
Turkish Marble Kıvan	10.02	1
Iranian Marble	10.02	1
Iranian Granite No. 1	13.88	1.39
Iranian Granite No. 2	10.02	1
Iranian Granite No. 3	16.19	1.62
Iranian Wall Ceramic	24.67	2.47
Iranian Floor Ceramic	16.19	1.62
Indian Granite	13.88	1.39
Indian Wall Ceramic	10.02	1
Indian Pink Granite	97.9	9.79
Dark Green Indian Marble	20.81	2.08
Dark Brown Indian Granite	78.63	7.86
Dark Green Indian Granite	26.98	2.7

Among the evaluated materials, Indian Pink Granite exhibited notably high radon emission rates, characterized by an E_A of 97.9 mBq/m²h and an E_M of 9.79 mBq/kgh. This substantial emission rate is closely correlated with the elevated average ^{222}Rn observed in Indian Pink Granite, indicating a significant potential for radon release into indoor environments. Similarly, Dark Brown Indian Granite and Dark Green Indian Granite also showed high radon emission rates, with E_A values of 78.63 mBq/m²h and 26.98 mBq/m²h, and E_M values of 7.86 mBq/kgh and 2.7 mBq/kgh, respectively. In contrast, marble samples generally exhibited lower radon emission rates. For instance, Spanish Marble demonstrated an E_A of 6.17 mBq/m²h and an E_M of 0.62 mBq/kgh, the lowest among the tested materials. Other marble samples, including KRG Sulamaniyah Marble and Turkish Marble Antalya, showed slightly higher emission rates but remained significantly lower than those of granite, with E_A values around 12.33 mBq/m²h and 16.19 mBq/m²h, respectively. Ceramic tiles showed moderate radon emission rates, with Iranian Wall Ceramic recording the highest among ceramics at 24.67 mBq/m²h E_A and 2.47 mBq/kgh E_M, whereas Iranian Floor Ceramic and Indian Wall Ceramic exhibited lower rates more akin to marble samples.

Linear regression analysis can be used to find the linear relationship between E_M and E_A radon rates. This analysis can help to determine how well E_A predicts E_M by calculating the coefficient of determination (R^2), which indicates the strength and direction of the relationship as shown in Figure 2.

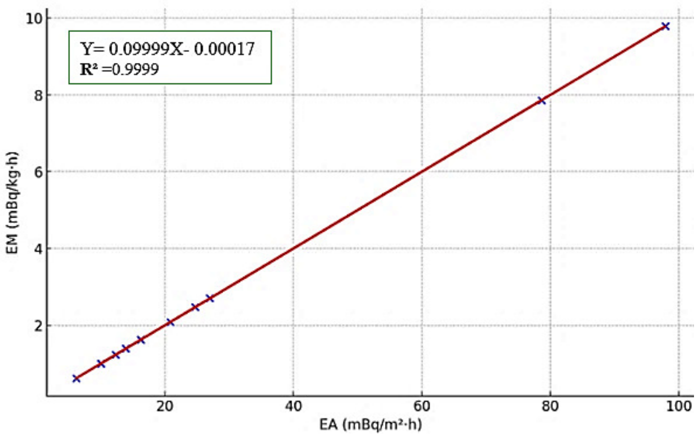

Fig. 2. Mass and surface radon exhalation relationship.

This analysis revealed a strong correlation, with a coefficient of determination (R^2) of 0.9999, indicating an almost perfect linear relationship between E_A and E_M. The slope of the regression line suggests that for every increase of 1 mBq/m²h in E_A, E_M increases by approximately 0.09999 mBq/kgh. The near-zero intercept implies that the relationship between E_A and E_M starts at or near the origin. This robust correlation underscores the reliability of surface exhalation rates to predict mass exhalation rates for the building materials evaluated in this study. A more detailed understanding of the factors influencing radon exhalation rates, such as material composition, porosity, and environmental conditions, remains crucial to effectively manage indoor air quality and minimize radon exposure risks in construction and renovation projects.

These findings highlight the importance of considering both average radon concentrations and emission rates when assessing the suitability of building materials for construction purposes. Materials with high radon emission rates can contribute significantly to indoor radon levels, potentially exceeding safe thresholds over time, even if their initial concentrations are within acceptable limits. Therefore, the selection of building materials should involve examining both parameters to effectively mitigate the risk of radon exposure.

IV. CONCLUSION

This study investigated ^{222}Rn exhalation rates from commonly used building tiles in Duhok, Iraq, using the Airthings radon detector to analyze 18 tile samples. The results consistently showed ^{222}Rn levels well below the WHO-recommended limit of 100 Bq/m³, indicating that the tested tiles are generally safe for construction from a radon exposure perspective. However, the identification of notably higher rates of radon emission in Indian Pink Granite underscores the variability in radon levels between different building materials. Indian Pink Granite exhibited the highest emission rates, with a surface exhalation rate (E_A) of 97.9 mBq/m²h and a mass exhalation rate (E_M) of 9.79 mBq/kgh. These findings highlight the importance of considering both average radon concentrations and emission rates when selecting building materials. Although the immediate radon levels of these tiles are within safe limits, materials such as Indian Pink Granite, which have high emission rates, could potentially increase indoor radon levels over time. The findings underscore the critical importance of conducting comprehensive assessments of building materials to ensure long-term safety and environmental sustainability. By integrating radon monitoring into material selection processes, engineers and stakeholders can make informed decisions to promote structural integrity and indoor air quality. Specifically, identifying materials with elevated radon emissions, such as Indian Pink Granite in this study, allows proactive measures to minimize indoor radon buildup and protect public health. Monitoring and evaluation of building materials should be prioritized to maintain safe indoor environments and mitigate the potential health impacts of radon exposure.

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