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The Influence of Internal Wall and Floor Covering Materials and Ventilation Type on Indoor Radon and Thoron Levels in Hospitals of Kermanshah, Iran

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Abstract

Background: Building materials and the ventilation rate of a building are two main factors influencing indoor radon and thoron levels (two radioactive gases which have the most important role in human natural radiation exposure within dwellings).

Objectives: This analytical descriptive study was intended to determine the relationship between indoor radon and thoron concentrations and the building materials used in interior surfaces, as well as between those concentrations and the type of ventilation system (natural or artificial).

Materials and Methods: 102 measurements of radon and thoron levels were taken from different parts of three hospital buildings in the city of Kermanshah in the west of Iran, using an RTM-1688-2 radon meter. Information on the type of building material and ventilation system in the measurement location was collected and then analyzed using Stata 8 software and multivariate linear regression.

Results: In terms of radon and thoron emissions, travertine and plaster were found to be the most appropriate and inappropriate covering for walls, respectively. Furthermore, granite and travertine were discovered to be inappropriate materials for flooring, while plastic floor covering was found suitable. Natural ventilation performed better for radon, while artificial ventilation worked better for thoron.

Conclusions: Internal building materials and ventilation type affect indoor radon and thoron concentrations. Therefore, the use of proper materials and adequate ventilation can reduce the potential human exposure to radon and thoron. This is of utmost importance, particularly in buildings with a high density of residents, including hospitals.

Keywords: Indoor Radon and Thoron, Building Material, Ventilation, Hospital, Iran

1. Background

Out of the 98% average radiation dose received by humans from natural sources, approximately 52% occurs due to inhalation of radon, thoron and their progeny in the dwellings (1). Radon (222Rn), which is considered a noble gas, is colorless, odorless, tasteless and naturally radioactive (2). When inhaled, a fraction of radon and its progeny are transported to the lungs (3) and produce severe biological damage, which could eventually lead to lung cancer (4-6); alpha decay of radon and its progeny causes this radiation damage. Even though soil is the main source of indoor radon (7), studies have shown a positive correlation between the radon exhalation rate and its concentration in building materials (8). Review of studies on the construction materials in Iran (9) indicated a high content of uranium and radium in the granite which was used for many years in construction and decoration, especially on the interior surfaces of buildings. The only other radon isotope that can be generated indoors in significant amounts is thoron (220Rn). Because of its short half-life (55.6 seconds), thoron in soil gas underneath a building, in most cases cannot survive long enough to enter the building and contribute to the indoor thoron level. Therefore, indoor thoron is typically due to the exhalation from thorium, which may be present in materials used on the interior surfaces of the building (10).

Given that distinct coating materials affect radiation emissions from radon, thoron, and their progeny (11, 12), it is expected that these concentrations will vary in places with different wall and floor covering materials. High concentrations of radon and thoron in indoor air, and poor ventilation along with prolonged exposure due to residency in the building, turn indoor radon and thoron into a potential hazard. As a result, the increase of indoor radon and thoron in Iran due to changes in construction styles and building materials is of concern in recent years. In addition, modern buildings are known for enhancing airtight construction and decreasing natural ventilation. This risk is of especially high priority in public buildings such as hospitals, due to the large populations in these places (13).

2. Objectives

This study was intended to discover the relationship between indoor radon and thoron concentrations and the construction materials used on the interior surfaces of buildings, as well as the correlation between these concentrations and the type of ventilation system (natural or artificial). In addition, the goal was to identify those factors that primarily affect indoor radon and thoron concentrations and to develop a model for describing their behavior depending on the related parameters. Accordingly, how building material and ventilation type influence indoor radon and thoron concentrations was assessed using multiple linear regression techniques.

3. Materials and Methods

In this study, which was performed as an analytical descriptive study, measurement of radon and thoron was conducted from October to December 2012 in three hospital buildings (Imam Khomeini (RA), Taleghani, and Imam Reza (AS)) in Kermanshah, a city in the west of Iran, using the RTM-1688-2 radon meter made by SARAD, Germany. This coincided with the fall season in Iran.

The places of that measurements were taken were determined based on the material used and the ventilation system; measurements were made in different parts of the buildings with various interior coverings and different ventilation systems for comparison purposes. Measurements in 34 locations, selected from different parts of three studied hospitals, were carried out three times (once per month). A total of 102 measurements were performed. After selecting the location, the device was placed at a height of 0.8 m to 2 m (3 to 6.5 feet) from the floor in the typical breathing zone, at least 50 cm (20 inches) from the ceiling and 20 cm (8 inches) from other objects so as to allow normal airflow around the detector, and approximately 40 cm (16 inches) from an interior wall or approximately 50 cm (20 inches) from an exterior wall. Additionally, the device placement was intended to avoid air currents caused by heating, ventilating and air conditioning vents, doors, fans and windows (14). In each measurement, after 150 minutes of continuous suction of the air, radon and thoron concentrations simultaneously were reported with a 95% confidence interval by the device. Information was also collected on the type of the building material and ventilation system for each measurement location.

Data obtained was analyzed using Stata 8 statistical software. To compare the average data, one-way Anova and, if needed, Kruskal-Wallis, were performed. The multivariate linear regression model was used to determine the effects of building material and ventilation type on indoor radon and thoron concentrations. In this regression analysis, $P < 0.05$ was considered significant.

4. Results

Based on the results, the average concentrations of indoor radon and thoron in the studied hospitals were 11.44 $\pm$ 4.9 Bq/m^3 and 4 $\pm$ 3.9 Bq/m^3, respectively. The highest concentrations of radon and thoron were observed in the Imam Reza (AS) hospital (Table 1).

Figure 1 presents radon and thoron concentrations in rooms with different wall coverings. As can be seen from the the the radon level in rooms with the wall coverings “granite and plaster” and then “plaster” and “PVC wall covering” was the highest, it was the lowest in those with “travertine and plaster” wall covering, and it was significantly different in the rooms (P = 0.024). Thoron concentration in rooms with walls covered with “granite” and “travertine” was the highest and it was the lowest in rooms with wall coverings “plaster covered by oil paint” and “travertine and plaster,” with significant differences (P = 0.022).

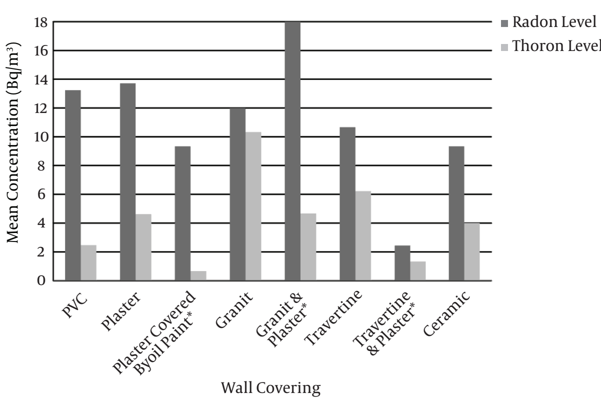
In terms of floor covering, the maximum and minimum radon concentrations were observed in granite and plastic (vinyl) floor covering, respectively (Figure 2) with a significant difference (P = 0.002). The maximum concentration of thoron was observed in rooms with floor covered with granite. Thoron concentration in rooms with various floor coverings was significantly different (P = 0.01).

Radon concentration in rooms ventilated by central air conditioning system and then in those with no ventilation

Table 1. Average Radon and Thoron Concentrations

Hospital	Radon, Bq/m^3	P Value	Thoron, Bq/m^3	P Value
Imam Khomeini (ra)	6.8 ± 4.4	0.56	2.8 ± 2.8	0.003
Taleghani	11.6 ± 3.9		3.8 ± 2.75	
Imam Reza (AS)	13.7 ± 4.3		4.64 ± 4.84	

Figure 1. Average Concentrations of Radon and Thoron in Terms of Wall Coverings



*Half of the wall surface was covered by a structure and the other half by another structure.

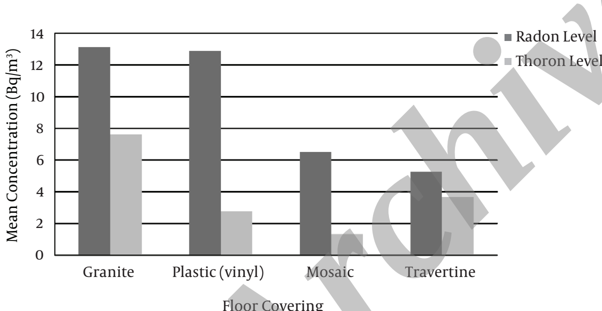


Figure 2. Average Concentrations of Radon and Thoron in Terms of Floor Coverings

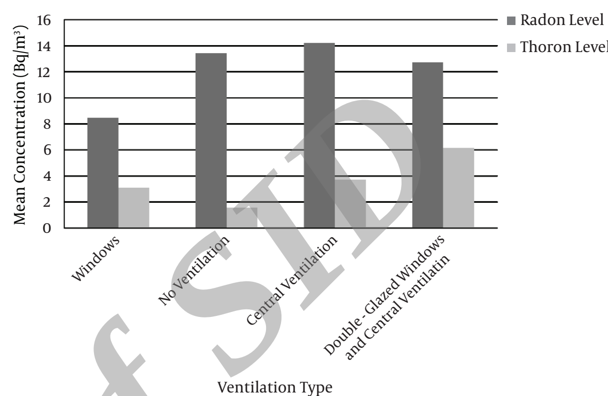


Figure 3. Average Radon and Thoron Concentrations in Terms of Different Ventilation Systems

was the highest, while it was the lowest in those ventilated by a window (natural ventilation) (Figure 3), although the difference was not statistically significant (P = 0.16). Despite the fact that thoron concentration as influenced by ventilation type did not show a significant difference (P = 0.36), it was the highest in rooms ventilated by central air conditioning system along with double-glazed windows and the lowest in rooms with no ventilation.

The multivariate linear regression model based on the effect of different wall coverings on the radon concentration (Table 2) showed that if the structure “travertine and plaster” is the basis for comparison, rooms with wall coverings “PVC” and then "plaster" had the highest concentrations and rooms with walls covered with “granite” and “travertine” had the lowest. In the case of thoron, rooms with walls covered with “granite and plaster” and “ceramic” had the highest concentrations and rooms with wall coverings “travertine” had the lowest. The results of the multivariate linear regression model also revealed that rooms with a granite floor covering contained the highest concentration and rooms with plastic (vinyl) floor covering contained the lowest. Rooms with floor covered with travertine and those with plastic floor covering contained the highest and lowest thoron concentrations, respectively. In addition, the model showed that rooms with no ventilation and those ventilated by central air conditioning system had the maximum radon concentration and rooms ventilated by windows had the minimum. Based on the model, rooms with no ventilation and those ventilated by windows (natural ventilation) had the highest concentration of thoron and those with central air conditioning system had the lowest.

5. Discussion

Based on the results, indoor radon concentration in the hospitals studied was much less than the maximum of

Table 2. Multivariate Regression Model Determining the Effects of Construction Materials and Ventilation Type on Indoor Radon and Thoron Concentrations

Variable	On Radon		On Thoron	
	Coef.	[% 95 Conf. Interval]	Coef.	[%95 Conf. Interval]
Wall covering				
Travertine and plaster		1		1
Plaster	11.7	-61.9 - 85.3	18.6	13.6 - 23.6[a]
Ceramic	1.4	-81.6 - 84.4	20.9	15.2 - 26.6[a]
Plaster covered by oil paint	0.5	-64.6 -65.7	6.5	2 - 11[a]
Granite	-8	-63.7 - 47.7	17.3	13.5 - 21[a]
PVC wall covering	13.5	-80 - 107	0.6	11.2 - 23.9[a]
Travertine	-6.9	-73.2 - 59.4	17.5	-3.9 - 5.1
Granite and plaster	4.2	-98.5 - 106.8	24.4	17.4 - 31.4[a]
Floor covering				
Travertine		1		1
Plastic floor covering	-4.2	-86 - 77.5	-17.3	-22.9 - -11.7[a]
Granite	11.2	-45.5 - 68	-11.7	-15.6 - -7.8[a]
Mosaic	1.1	-45.6 - 47.8	-0.5	-3.7 - 2.7
Ventilation system				
Window		1		1
No ventilation	12.6	-71-96.3	16.6	13.8 - 25.3[a]
Central air conditioning system	8.3	-90.9-107.5	-6.2	-13 - 0.6
Double-glazed window and central air conditioning system	4.5	-108.3-117.4	-2.8	-10.5 - 4.9

[a] Statistically significant.

100 Bq/m^3 that is recommended by world health organization (10).

Given that wall and floor covering materials, in contrast to ventilation type, made significant differences in the concentrations of indoor radon and thoron, it can be deduced that building material influenced the concentration of these gases more than the type of ventilation system.

Results obtained from measurements of radon and thoron in rooms with different wall and floor coverings, as well as different types of ventilation, differed from what was achieved based on the multivariate linear regression model. This is due to the fact that the effect of various factors on radon and thoron overlap; that is, the floor and wall coverings combine to affect radon and thoron levels in a room. Whereas in the multivariate linear regression model, the effect of different variables on the concentrations are considered together, in which case the net effect of each variable is more clearly revealed.

According to the results of the multivariate linear regression model, the maximum concentration of radon was emitted in rooms with walls covered with "PVC" and "plaster" and the maximum concentration of thoron escaped from walls covered with "granite and plaster" and "ceramic." The lowest radon concentration was emitted in rooms with walls covered with "granite" and "travertine" and the lowest thoron level was exhaled in rooms with walls covered with "travertine." It would seem that in terms of radon and thoron emissions, plaster is the most inappropriate and travertine is the most appropriate covering for walls.

Although there no radium (the source of radon) in PVC wall covering, the highest radon level was observed in rooms with PVC wall coverings. This may be explained by the fact that PVC covering has a smooth surface and therefore particles remain suspended in the air, while these particles are partly adsorbed by other coverings. On the other hand, PVC wall covering increases the airtightness of the room, which prevents radon that originates in the soil from escaping. Both of these theories should be investigated.

Based on the results of the multivariate linear regression model, the highest concentrations of radon and thoron were measured in rooms with the floor covered with granite and travertine, respectively, while the lowest radon and thoron concentrations were emitted in plastic (vinyl) floor covering rooms. Therefore it can be concluded that both granite and travertine are inappropriate materials for flooring in terms of radon and thoron emissions, and plastic (vinyl) floor covering is the best.

High emissions of radon and thoron from building materials such as granite and plaster can be attributed to the high radium and thorium content of the materials. Studies on radon activity in building materials in Iran do not recommend the use of granite and local stone from high background radiation areas (HBRAs); based on these results, the uranium and radium content in granite is high and can significantly increase radon levels in indoor areas where it is used. The use of these stones indoors is a health risk for residents and should be remedied (15-17). Evaluation of radon concentration in dwellings of the city of Mysore in India also indicated higher radon concentration in those buildings with granite floorings versus other building materials. In addition, houses with mosaic flooring showed a slightly lower radon exhalation rate than cement flooring houses (18). Similarly, results obtained from this study in Mysore showed that, in terms of radon and thoron exhalation, mosaic is suitable for floor covering. Yu et al., as observed in this study, introduced plastic as the most effective material inhibiting radon exhalation from the floor (12).

Based on the multivariate linear regression model, natural ventilation for radon and central air conditioning system for thoron had better performance. Similarly, Moura et al. showed a significant effect of natural ventilation on indoor radon concentration (19). Experimental studies in Sweden (20) and the UK (21) showed that increased natural ventilation on average can reduce indoor radon concentration by a factor of two. In another study it was shown that mechanical ventilation can be a greater risk factor for indoor radon than a balanced ventilation system. The researchers of this study have explained this result by postulating an increase in radon suction from the soil beneath due to the indoor air pressure gradient created by the mechanical ventilation system (22). Perhaps the higher efficiency of natural ventilation versus central air conditioning system in regards to indoor radon can be attributed to the increase of radon suction from the building ground. However, it should be noted that all measurements in this study were done by one device, and the duration of each measurement was long, so it was not possible to measure radon simultaneously or at the same time of the day in different parts of the hospitals.

Internal building materials and ventilation type affect indoor radon and thoron levels. Therefore, the use of proper materials and adequate ventilation can reduce the potential exposure to radon and thoron indoors, which is of utmost importance particularly in buildings with a high density of residents, including hospitals.

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This letter resulted from thesis, major of environmental health engineering.

Footnotes

Authors' Contribution: Study concept and design: Meghdad Pirsaheb, Abbas Haghparast, Kiomars Sharafi, Lida Hemati; acquisition of data: Lida Hemati; analysis and interpretation of data: Najafi, Lida Hemati; study supervision: Meghdad Pirsaheb, Abbas Haghparast; critical revision of the manuscript: Nematullah Kurd, Lida Hemati.

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