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Prediction of Radon Concentration after 24 Hours using Multiple Linear Regression Analysis

Deog-Gyeong Yoon[1], Jai-Won Chung[2], Tae-In Hyon[3], Gyu-Sik Kim[2]

[1]Department of Electrical Engineering, Chuncheon Campus of Korea Polytechnic Colleges, Chuncheon, Korea
[2]Department of Electrical and Computer Engineering, University of Seoul, Seoul, Korea
[3]LINC+ Industry University Cooperation Group, Jeonju University, Jeonju, Korea

ABSTRACT

In this paper, we propose the model for predicting radon concentration after 24 hours using multiple linear regression analysis. If the proposed predictive model predicts the concentration of radon after 24 hours, simple methods such as using a ventilator or opening a window can greatly reduce the concentration of radon that can be exposed.

KEYWORDS: *radon concentration, temperature, humidity, prediction, multiple linear regressions*

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I. INRODUCTION

Radon is an inert gas produced by radium decay. Also, its colorless, odorless and tasteless characteristics prevent the human sensory organs from recognizing it and reaches the lungs through breathing. Long-term exposure to radon can lead to lung cancer. According to the US Environmental Protection Agency (EPA), more than 10 percent of Americans' annual lung cancer deaths, about 20,000, are due to cumulative exposure of radon progeny, more than 10 times higher than death from air pollution [1]. The World Health Organization lists radon as the second leading cause of lung cancer after smoking [2]. The International Agency for Research on Cancer, a subsidiary of the WHO, has also identified radon as a definite carcinogen [3].

At standard conditions (STP: 0 ° C, 1 atm), radon is 9.73 g / L, about eight times heavier than air (1.217 g / L). Because of this property, radon can be easily accumulated indoors and one can be exposed to radon continuously without being aware of it [4]. The pathways of radon into the interior are soil and the connections, cracks, drains, etc. at the lower floors of the building [5]. The main inflow driving force is driven by the flow of air from high pressure to low pressure [6].

In the case of indoor radon, studies have shown that it is related to temperature and humidity inside and outside the room. Seftelis et al. reported that radon concentrations were highest in the morning of the day when the temperature was low and the relative humidity was the highest, and that the minimum was in the afternoon when the relative humidity decreases as the temperature increases [7]. Marley's analysis of the influence of meteorological variables on radon concentration in the basements of buildings showed that water vapor pressure was a major determinant of short-term variability in radon concentrations, and that air pressure was a major determinant of long-term variability in radon concentrations. Both water vapor and pressure were found to be related to room temperature [8]. Lee Seung-chan et al. measured indoor radon concentration continuously for 35 days and reported that radon concentrations were proportional to humidity and air pressure, but inversely proportional to temperature [9].

If the radon concentration is high, simple ventilation of the room can greatly reduce the radon concentration [6]. Therefore, if the temperature and humidity, which is related to indoor radon concentration, and the current radon concentration are used to estimate radon concentration in 24 hours, simple ventilation methods such as using a ventilator or opening a window can greatly reduce radon concentration that can be exposed. However, no studies have been reported on how future radon concentrations can be predicted.

In this paper, multiple linear regression analysis was performed on indoor, outdoor temperature and relative humidity measurements and indoor radon concentration measurements to derive multiple regression models to predict indoor radon concentrations after 24 hours. A multiple regression model using indoor temperature and relative humidity and a multiple regression model using outdoor temperature and relative humidity were derived, respectively, and the two predictive models were compared based on R^2 and root mean square error (RMS) values.

II. Main Results

2.1. Experiment method and result

Figure 1 shows the temperature, humidity, and radon concentration meters used in the experiment. The temperature and humidity meter is a DATA LOGGER CSD-1 (CAS) model that can measure and store the data. The measurement error is ± 0.2 ° C in the temperature range of -40 ° C to 105 ° C, and the relative error is ± 2% at 25 ° C in the relative humidity range of 0% to 100%. The temperature and humidity meter was set to measure temperature and relative humidity at 1 minute intervals. The radon concentration meter stores values every hour, and thus the temperature and relative humidity values were averaged over one hour. Indoor radon concentration was measured with RandonEye (RD200) model. The measuring range is 0.37 to 3700 Bq/m^3 and the measuring error is within ± 10%. Radon concentration values were measured and stored on an hourly basis.

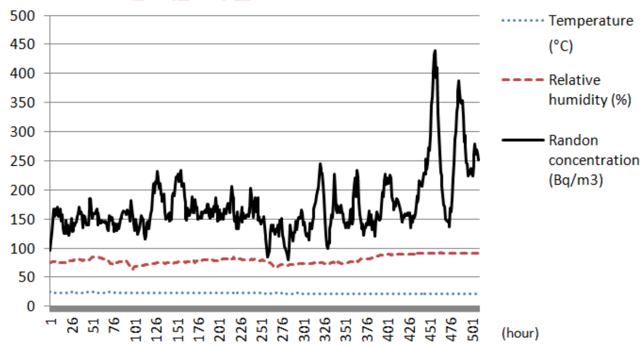
(a) DATA LOGGER Temperature and humidity meter (b) RandonEye(RD200) Radon concentration meter

Fig.1. Temperature / radon concentration meter

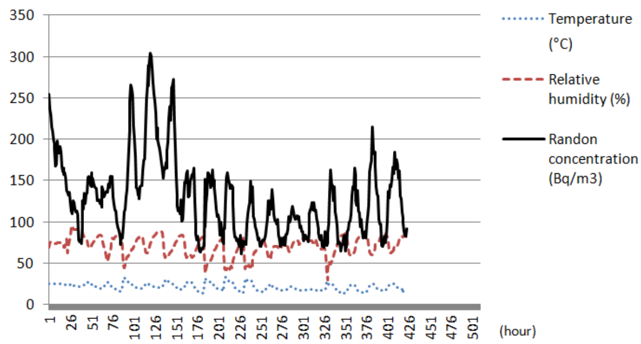
Figure 2 shows the installation of the experimental equipment. The experiment was conducted in the multipurpose room at an University, Gangwon-do, Korea. The site of the experiment is a building carved from a hillside and is on the first floor from the western entrance, but it is semi-underground in the east side. The two windows are sealed and the entrance is opened at a frequency of 0.5 times / day. The horizontal, vertical and height dimension measured 8.6 [m], 2.4 [m] and 2.5 [m], respectively, with an area of 51.6 [m^3]. Five radon concentration meters were installed radially at the center of the room, and one temperature and humidity meter was installed on the outdoor wall.

Fig.2. Installed experiment equipment

Figure 3 shows the temperature, relative humidity, and radon concentration measured during indoor and outdoor temperature and radon concentration measurement experiments. It was analyzed by measuring indoor temperature, relative humidity, and radon concentration at intervals of one hour for a total of 509 hours, outdoor temperature, relative humidity, and indoor radon concentration for a total of 424 hours, also at intervals of one hour. For radon concentration, the measured radon concentration values were averaged over a total of five radon concentration meters. EPA recommends that indoor radon concentration measurements should be held under closed conditions 12 hours prior to the measurement, and since the prediction of radon concentration after 24 hours is intended, data up to 24 hours prior to the final measurement was used[10]. Table 1 shows the mean and standard deviation of the data used in the analysis.



(a) Indoor temperature and humidity measurement experiment (n=509)



(b) Outdoor temperature and humidity measurement experiment (n=424)

Fig. 3. Temperature, relative humidity, and radon concentrations measured in indoor and outdoor temperature and radon concentration experiments

Table1. Data characteristics used in the analysis (mean ± standard deviation)

Experiment	Temperature (° C)	Relative humidity (%)	Radon concentration (Bq/m^3)
Indoor temperature and humidity measurement experiment (n=473)	22.73 ± 0.76	79.39 ± 6.69	168.09 ± 48.05
Outdoor temperature and humidity measurement experiment (n=388)	21.16 ± 4.31	70.44 ± 12.28	125.92 ± 48.51

2.2. Analysis and Discussion

Table 2 shows the results of a multi-linear regression analysis for estimating radon concentration after 24 hours for indoor temperature and humidity measurement experiments. In the multi-linear regression analysis, the temperature, relative humidity, and radon concentration of the room were used as independent variables and radon concentration after 24 hours as a dependent variable. Standardized beta values for room temperature, indoor relative humidity, and radon concentration were -0.113, 0.34 and 0.198, respectively, which greatly affected the radon concentration after 24 hours in the order of indoor relative humidity, radon concentration and room temperature, and indicated that indoor relative humidity and radon concentration had a positive correlation with the dependent variable while the indoor temperature had a negative correlation with the dependent variable. In the derived multiple linear regression model, the modified coefficient of determination R^2 was 0.264, which is low in explanatory power, but the p-value was smaller than 0.001, indicating that the model was statistically significant, and the RMSE value was 46.65 Bq/m^3.

Table2. Results of a multi-linear regression analysis for estimating radon concentration after 24 hours for indoor temperature and humidity measurement experiments (n=473)

Independent variable	Regression coefficient			Regression model		
	Beta	Standar-dized beta	P-value	Modified R^2	P-value	RMSE (Bq/m^3)
(Constant term)	98.794	-	0.223	0.264	< 0.001	46.65
Indoor temperature	-8.048	-0.113	0.007			
Indoor relative humidity	2.789	0.343	< 0.001			
Radon concent-ration	0.224	0.198	< 0.001			

Equation 1 is a formula that can predict the radon concentration after 24 hours through the room temperature, relative humidity, radon concentration derived using the beta value of the regression coefficient in Table 2. In the expression, x represents the indoor radon concentration, v represents the indoor temperature, w represents the relative humidity of the room, and c represents the radon concentration after 24 hours predicted by the multi-linear return model.

$$c = 0.224x - 8.048v + 2.789w + 98.794 \quad (1)$$

Table 3 below shows the results of multiple linear regression analysis for the prediction of radon concentration after 24 hours of outdoor temperature and humidity measurement experiments. In the multiple linear regression analysis, outdoor temperature, relative humidity and radon concentration were used as independent variables, and radon concentration after 24 hours was used as a dependent variable. For the independent variables outdoor temperature, outdoor relative humidity, and radon concentration, the standardized beta values were 0.217, 0.102, and 0.558, respectively, which greatly influenced radon concentration after 24 hours in order of radon concentration, outdoor temperature, and outdoor relative humidity. In addition, it can be seen that all the independent variables have a positive correlation with the dependent variables. The modified determinant coefficient R^2 of the derived multiple linear regression model is 0.443, which is not high in the explanatory power of the model, but the P-value is less than 0.001, which is statistically significant, and the RMSE value is 36.25 Bq/m^3.

Table3. Results of a multi-linear regression analysis for estimating radon concentration after 24 hours for outdoor temperature and humidity measurement experiments (n=329)

Independent variable	Regression coefficient			Regression model		
	Beta	Standardized beta	P-value	Modified R^2	P-value	RMSE (Bq/m^3)
(Constant term)	-25.04	-	0.381	0.443	< 0.001	36.25
Outdoor temperature	2.44	0.217	0.002			
Outdoor relative humidity	0.40	0.102	0.088			
Radon concentration	0.55	0.558	< 0.001			

Equation 2 is a formula that can predict the radon concentration after 24 hours through the outdoor temperature, relative humidity, and indoor radon concentration using the beta value of the regression coefficient. In the expression, x represents the indoor radon concentration, y represents the outdoor temperature, z represents the outdoor relative humidity, and c represents the radon concentration after 24 hours predicted by the multiple linear regression model.

$$c = 0.559x + 2.449y + 0.405z - 25.041 \quad (2)$$

III. Conclusion

In this paper, we propose a multiple linear regression model that can predict indoor radon concentration after 24 hours using indoor and outdoor temperature and relative humidity and indoor radon concentration measurements. Comparing the multiple linear regression model derived using indoor temperature and humidity and the multiple linear regression model derived using outdoor temperature and humidity, it was confirmed that a higher R^2 and lower RMSE models could be derived when outdoor temperature and humidity are used.

When the radon concentration after 24 hours is predicted using the proposed prediction model, the radon concentration that one can be exposed to could be significantly reduced by ventilating in advance. However, the relationship between radon concentration after 24 hours and the current radon concentration, temperature and relative humidity may vary depending on the measurement site or environment [11, 12]. Therefore, further research in various places and environments is needed.

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