Int. J. Environ. Res., 9(4):1233-1236, Autumn 2015
ISSN: 1735-6865

Parameter Ranking System of Indoor Radon Concentration in South Korea, Case Studies: Dokdo Island, Yang Pyeong and Nae Gi

Sedighian, S.[1*], Kim, S. H.[2], Cho, S.Y.[2], Kim, M. J.[2], Kim D. H.[2], Cha, D. W.[2]

[1]Graduate Faculty of Environment, University of Tehran, Tehran, Iran

[2]Department of Environmental Engineering, Yonsei University, Wonju, South Korea

Received 8 July 2015; Revised 6 Sep. 2015; Accepted 8 Sep. 2015

ABSTRACT: Indoor Radon concentration (IRC) is among the emerging environmental and health issues in Republic of Korea. Due to lack of epidemiological studies and insufficient public awareness about Radon, effective parameter ranking system is required to establish protocols for future field sampling and settlement construction. This research propose the IRC parameter ranking system based on field measurements and laboratory experiments. Dokdo Island, Yang Pyeong and Nae Gi were selected as the case studies in South Korea. The Radon transport equations and statistical analyses are modelled with Simulink and Matlab. IRC model accounts for exhalation of Radon from soil, building material and outdoor air and also considers the major mitigation methods like ventilation, air cleaners and filtration. The PAWN sensitivity analysis method has been applied to determine the sensitivity of each parameter. The results indicates that soil gas radon concentration, radium concentration, emanation coefficient and ventilation rate have the most dominant role on IRC. Based on these results, field sampling patterns and indoor mitigation strategies can be established for restricted access areas and probabilistic studies.

Keywords: Indoor Radon Concentration, Parameter Ranking System, Radioactivity, PAWN method

INTRODUCTION

Epidemiological studies introduce radon (^{222}Rn) as the first and second reason for lung cancer among non-smokers and smokers, respectively (Pressyanov *et al.,* 2015). While radon is a naturally occurring noble gas and exists in the air, its concentration can be enhanced indoors as a result of construction methods and building materials (Field, 2011). Clearance levels should be derived for building materials contain radioactive elements (Sedighian *et al.,* 2015).

The main purpose of conducting sensitivity analysis (SA) on indoor radon concentration is to investigate the model and determine the influence of each parameter. This can be used to further application of calibration, optimization and uncertainty analysis (Song *et al.,* 2015). Various methods are available to perform GSA including: regression, screening, variance-based, meta-model (Tian, 2013) and PAWN (Pianosi and Wagener, 2015). PAWN method is a simple and efficient method for GSA based on cumulative distribution functions (ECDF) which has many advantages over the variance-based methods.

The main goal of this research is to develop the IRC ranking system with emphasis on Korean dwellings. IRC mathematical equations have been modelled with MATLAB and Simulink based on compartment modelling principals (Little, 2012, Sedighian *et al.,* 2014). SA has been conducted with PAWN method. Three locations were selected as case studies in this paper and SA parameters were taken from them.

MATERIALS & METHODS

Hypothetical house designed for SA only consists of one floor and doesn't have any basement. Effective areas which radon are exhaled from include three walls and ground area of the house. For each parameter an interval has been defined based on data from field trips (Dokdo Island, Yang Pyeong and Nae Gi) and experiments conducted by the authors. Mathematical relation are directly taken from (Sextro, 1994). Summary of input parameters and their values are presented in Table 1.

Indoor, outdoor and soil gas radon concentrations were measured using RAD7. Indoor and ambient radon

*Corresponding author E-mail:siavashsedghian@ut.ac.ir

Table 1. Summery of parameters and their interval values

Parameter	Description	Range [min max]	Parameter	Description	Range [min max]
Cs (Bq/m^3)	soil gas radon concentration	[1000 25000]	L (m)	length	[2 10]
C_{Ra} (Bq/kg)	radium concentration	[10 150]	W (m)	width	[2 10]
E (-)	emanation coefficient	[0.01 0.3]	H (m)	height	[2 4]
? (-)	porosity	[0.01 0.3]	*T* (^{o}C)	temperature	[0 40]
ρ (kg/m^3)	density	[1500 2500]	C_o (Bq/m^3)	outdoor radon concentration	[5 20]
m (-)	moisture content	[0 0.1]	λ_v (1/h)	ventilation rate	[0.3 1.5]
z_f (m)	floor thickness	[0 1,1.2]	λ_r (1/h)	removal rate	[0 0.1]
z_w (m)	wall thickness	[0.2 0.5]			

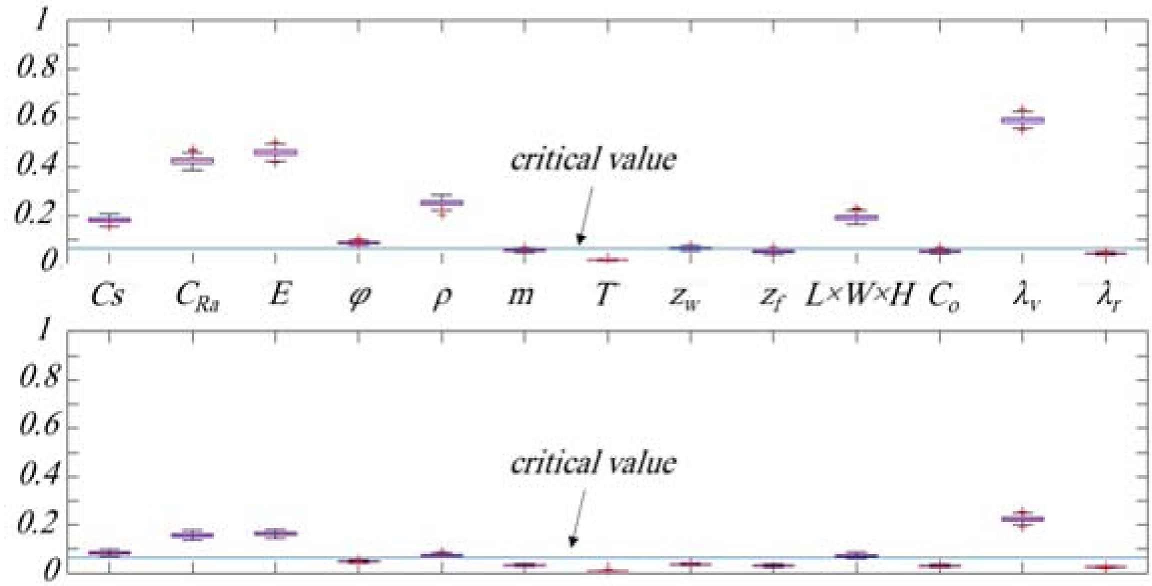

Fig. 1. Parameter ranking system

Table 2. Parameter ranking system for IRC

Ranking criterion	**Rank**	**Parameters**
Maximum PSI > critical value Median PSI > critical value	Tier 1 Highly Sensitive	Soil gas radon concentration Radium concentration Emanation coefficient Ventilation rate
Maximum PSI < critical value Median PSI > critical value	Tier 2 Mildly sensitive	Density Porosity House dimension
Maximum PSI < critical value Median PSI < critical value	Tier 3 Non sensitive	Moisture content Temperature (wall, floor) Thickness (wall, floor) Outdoor radon concentration Removal rate

concentration was measured on 1.2 meters high from the ground level, and soil gas radon concentration was measured on 0.7 meters depth using RAD7 accessories. Measurements were undertaken according to U.S. EPA protocol (USEPA, 1993). To obtain emanation coefficient, each sample was stored in Marinelli beakers for 30 days until the radioactive equilibrium condition was achieved. The counts when the beaker is sealed and opened were measured by gamma spectrometry. Flow through method was also used to double check the emanation coefficient (Ishimori, 2013). Porosity and density measurements were carried out using optical microscopy and Archimedes' principle, respectively. Physical characteristics of the buildings were directly measured for each location and ventilation rate was estimated based on interview with house owners.

RESULTS & DISCUSSION

Fig. 1 indicates the parameter ranking system while Table 2 classifies each parameter according to its PAWN Sensitivity Index (PSI).

Tier 1 group is the most sensitive and has the highest impact on IRC. Any variation in tier 1 parameters has dramatic effect on IRC. Tier 2 parameters are recognized as mildly influential. Their effect on IRC can be significant but not as much as tier 1. Tier 3 class is recognized as the least important among all the classes.

In order to identify the effect of each parameters on IRC, semi-partial correlation coefficients have been calculated between conditional parameters and their associated IRCs. The sign of these coefficients indicates whether increasing the conditional parameter has direct (positive) or inverse effect (negative) on IRC. Values closer to ±1 suggest more correlation (linear relation) between conditional parameter and IRC. Table 3 indicates semi-partial correlation coefficients for tier 1 and tier 2 parameters.

Table 3. Semi-partial correlation coefficients for tier 1 and tier 2 parameters

Parameter	Semi-partial correlation coefficient (tier 1)	Parameter	Semi-partial correlation coefficient (tier 2)
Cs	1	ρ	1
C_{Ra}	1		-0.2
E_d	0.9	House dimension	-0.77
λ_v	-0.84		

CONCLUSIONS

When it comes to the restricted access areas and probabilistic studies, measuring tier 1 parameters has the highest priority for the research team. This ranking system could be useful to design the optimum sampling plan considering the budget and time. The IRC ranking system would also be a helpful tool in controlling and mitigation of IRC for currently constructed houses. According to this ranking system, increasing ventilation rate is the easiest and most accessible way to reduce the IRC in any house.

ACKNOWLEDGMENT

This subject is supported by Ministry of Environment Republic of Korea as "The Environmental Health Action Program".

REFRENCES

Field, R. W. (2011). Radon: An Overview of Health Effects. In: NRIAGU, J. O. (ed.) Encyclopedia of Environmental Health. Burlington: Elsevier.

Ishimori, Y., Lange, K., Martin, P., Mayya, Y. S. and Phaneuf, M. (2013). Measurement and Calculation of Radon Releases from NORM Residues. International Atomic Energy Agency, Vienna.

Little, K. W. (2012). Environmental Fate and Transport Analysis with Compartment Modeling, New York, CRC Press Taylor & Francis Group.

Pianosi, F. and Wagener, T. (2015). A simple and efficient method for global sensitivity analysis based on cumulative distribution functions. Environmental Modelling & Software, **67,** 1-11.

Pressyanov, D., Dimitrov, D. and Dimitrova, I. (2015. Energy-efficient reconstructions and indoor radon: the impact assessed by CDs/DVDs. Journal of Environmental Radioactivity, **143,** 76-79.

Sedighian, S., Abdoli, M. A., Niksokhan, M. H., Kim, M. J. and Cho, S. Y. (2014). Radiological dose assessment of naturally occurring radioactive materials generated by the petroleum industry in wildlife: A case study of chinkaras of Lavan Island, Iran. Journal of Advances in Environmental Health Research, **2,** 8.

Sedighian, S., Abdoli, M. A., Niksokhan, M. H., Kim, S. H. and Cho, S. Y. (2015). A New Approach to Derive Clearance Levels for Wastes Containing Naturally Occurring Radioactive Materials (NORM) (Case Study: Lavan Island, Iran). Nature Environment and Pollution Technology, **14,** 283-290.

Sextro, R. G. (1994). Radon and the natural environment. Radon: Prevalence, Measurements, Health Risks and Control. Philadelphia, PA: American Society for Testing and Materials, 9-32.

Song, X., Zhang, J., Zhan, C., Xuan, Y., Ye, M. and Xu, C. (2015). Global sensitivity analysis in hydrological modeling: Review of concepts, methods, theoretical framework, and applications. Journal of Hydrology, **523,** 739-757.

Tian, W. (2013). A review of sensitivity analysis methods in building energy analysis. Renewable and Sustainable Energy Reviews, **20,** 411-419.

US-EPA (1993) Protocols for radon and radon decay product measurements in homes. EPA 402-R-92-003. United States Environmental Protection Agency. Office of Air and Radiation;