CHAPTER 4

PROCESSING AND ANALYSIS

4.1 Soil-gas radon and indoor radon concentrations

In order to understand the relationship between indoor radon concentration and soil-gas radon concentration, comparison between indoor radon and soil-gas radon concentrations during different seasons and at different depths were studied. Figures 4.1 to 4.4 show winter and summer indoor radon concentrations and soil-gas radon concentration at 0.5-meter and 1.0-meter depths.

From these figures, it is clear that there is no apparent correlation between indoor radon and soil-gas radon in this study area. This finding emphasizes that soil-gas radon alone can not be used as an indoor radon indicator, especially in a small area having the same rock formation. Indoor radon in this case may depend also on other factors, such as type of house, soil-gas permeability and radon transport mechanism.

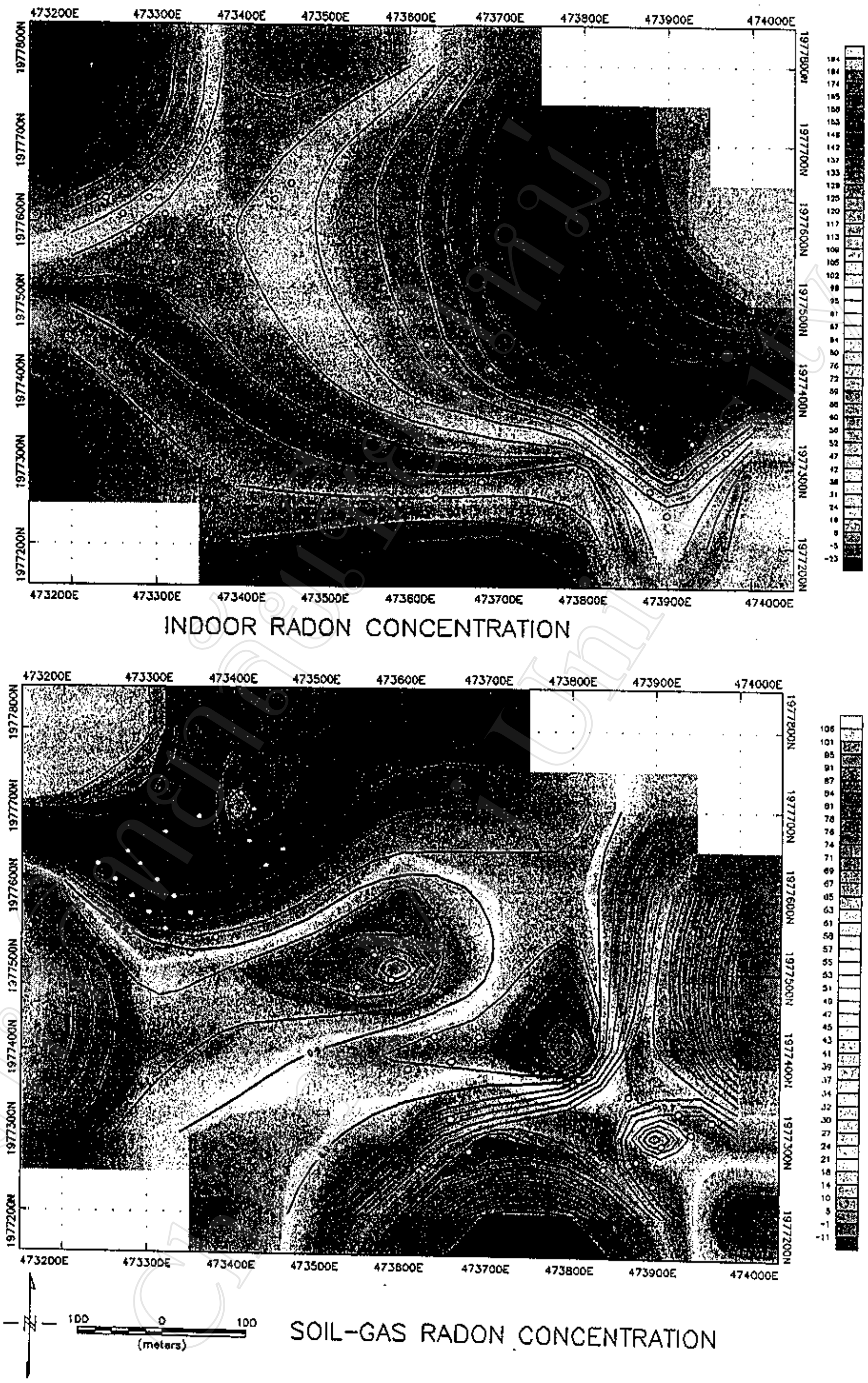


Figure 4.1 Winter indoor radon concentration and soil-gas radon concentration at a 0.5-meter depth.

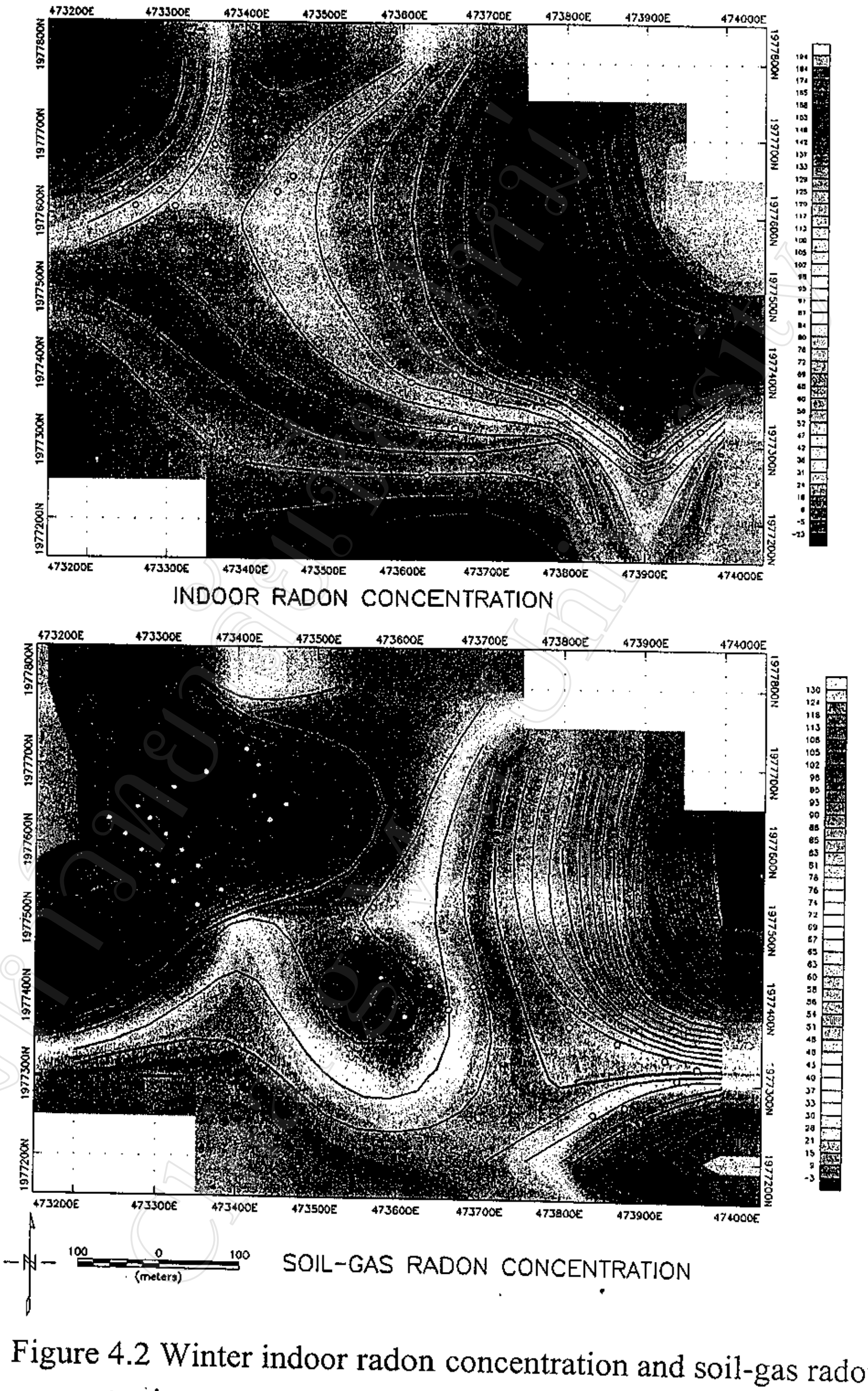


Figure 4.2 Winter indoor radon concentration and soil-gas radon concentration at a 1.0-meter depth.

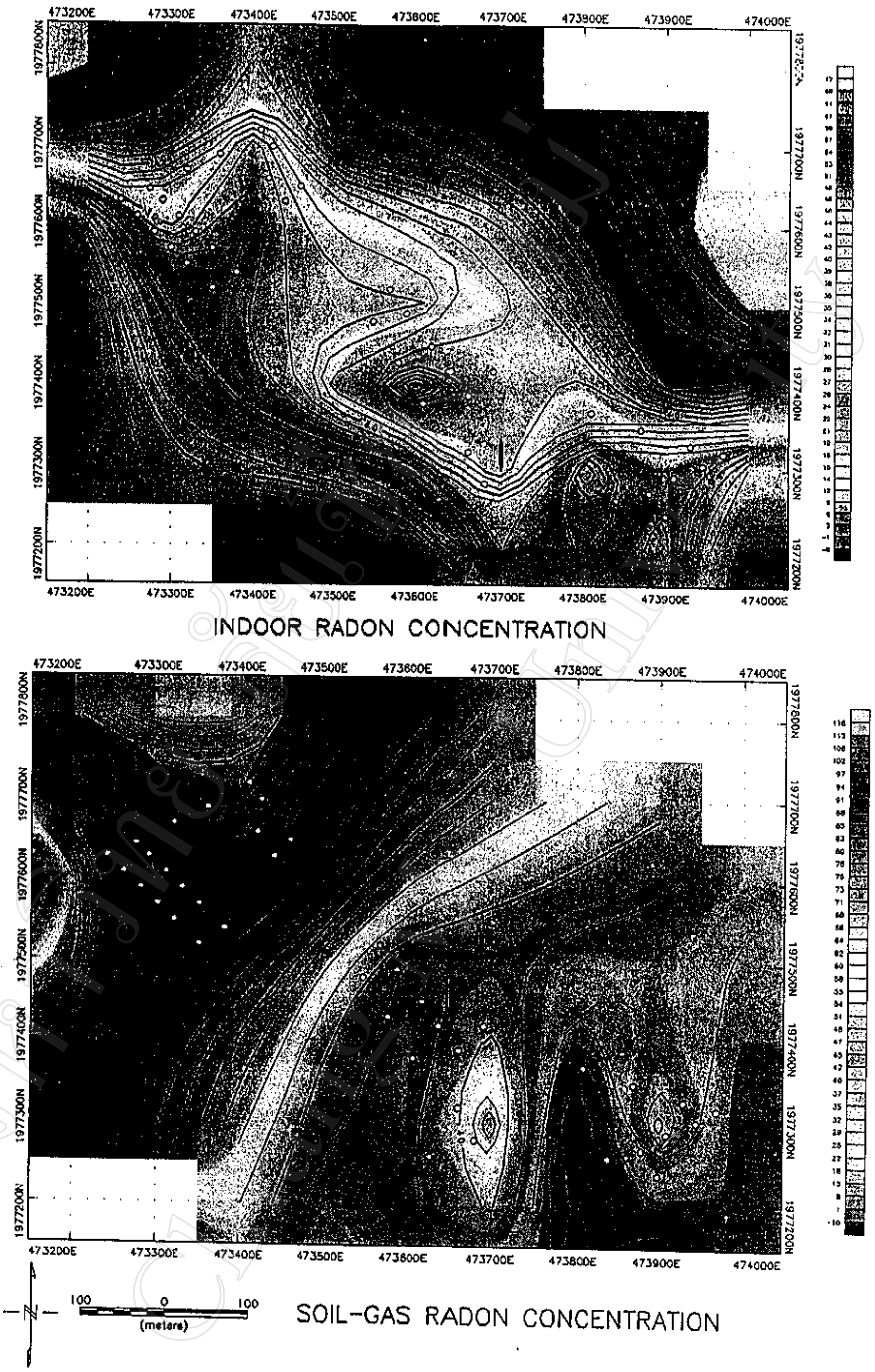


Figure 4.3 Summer indoor radon concentration and soil-gas radon concentration at a 0.5-meter depth.

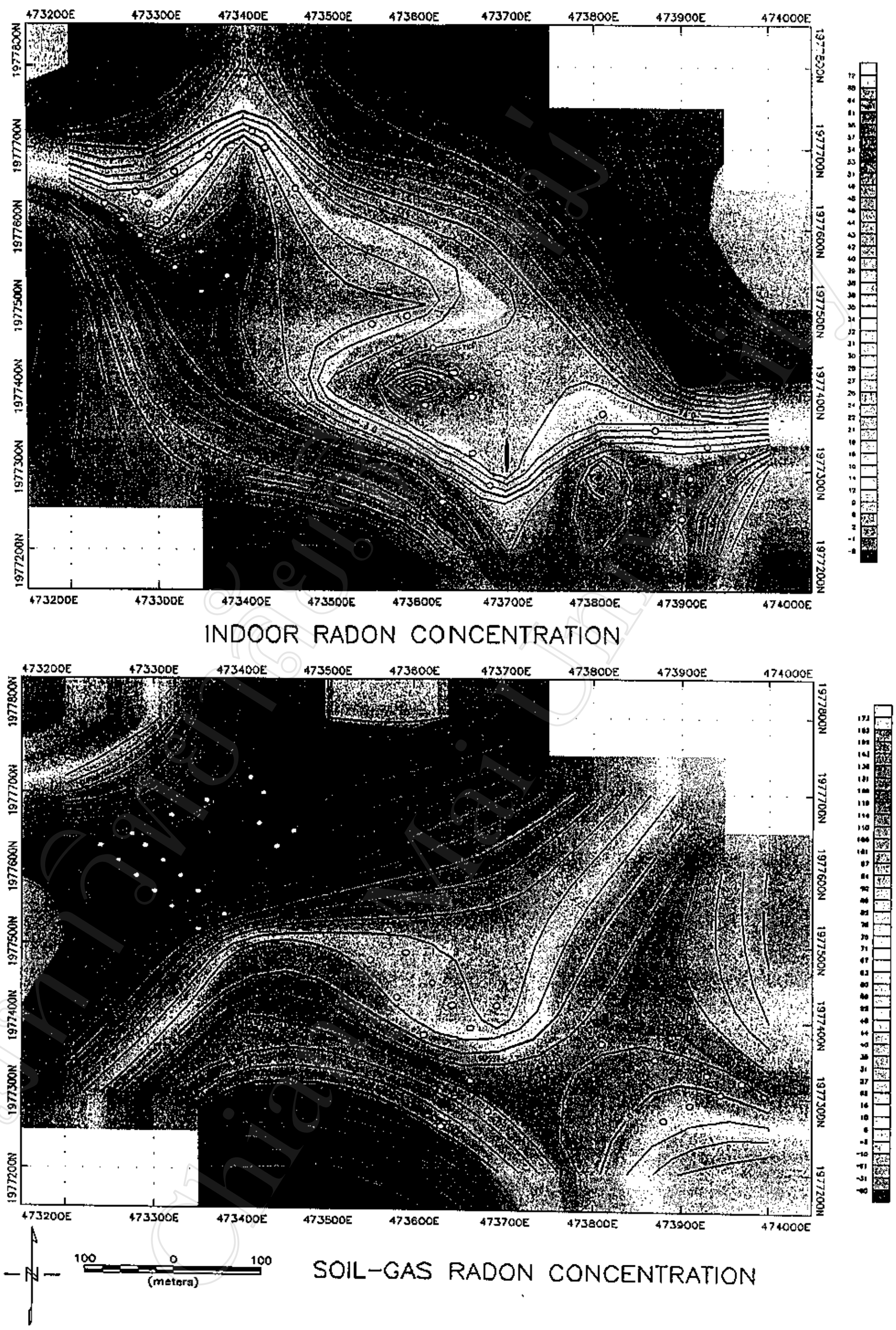


Figure 4.4 Summer indoor radon concentration and soil-gas radon concentration at a 1.0-meter depth.

4.2 House classification

Radon concentrations were measured in 40, mainly wooden houses. These houses were of four types, I, II, III, and IV. Type I houses were essentially all wooden and simply constructed. They were perched on high posts and were more than 1.8 meters above the ground. Type II houses had concrete floors on the ground surface and combined brick and timber walls. Type III houses were modern and neatly constructed with tight timber floors and walls. Type IV houses were simply constructed close to the ground surface. Their floors and walls were loosely fixed timber and had numerous ventilating slots. Figures 4.5 to 4.8 show these four house types.

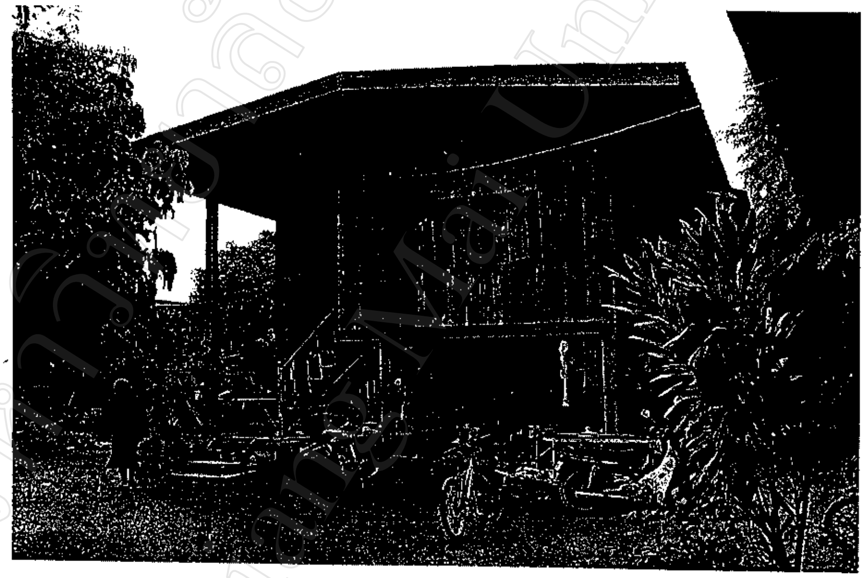


Figure 4.5 A sample of type I houses

Figure 4.6 A sample of type II houses

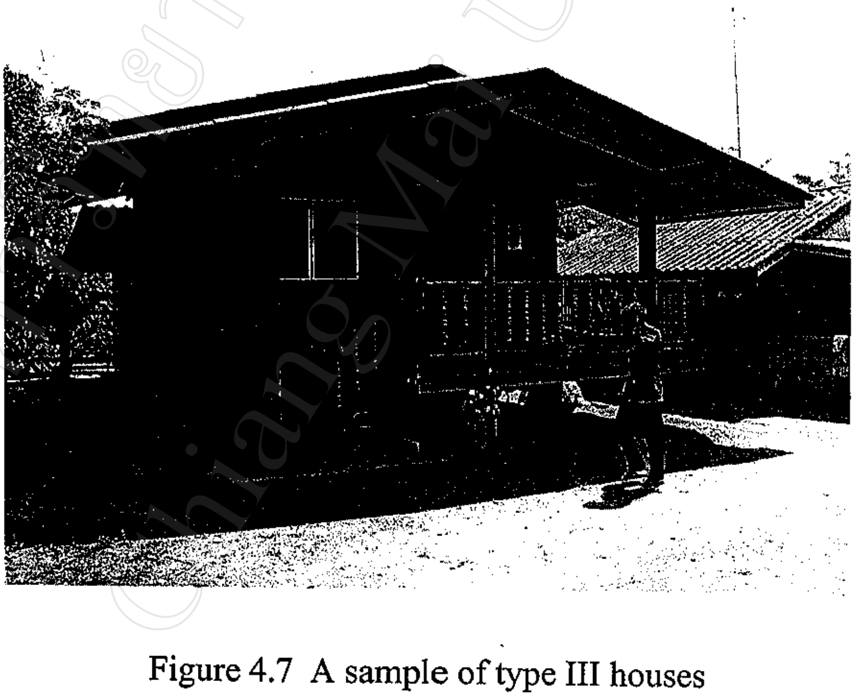


Figure 4.7 A sample of type III houses

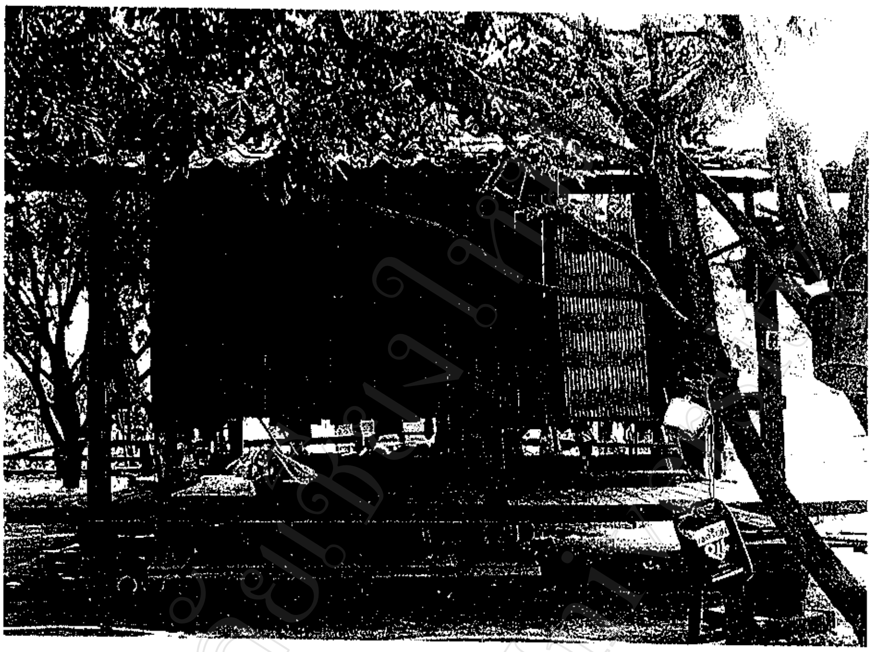


Figure 4.8 A sample of type IV houses

4.3 Indoor radon concentration and soil-gas radon concentration at 0.5-meter and 1.0-meter depths in relation to winter and summer and to house type.

4.3.1 Indoor radon concentration and soil-gas radon concentration at 0.5-meter depth in winter and summer correlated to house type.

In winter, soil-gas radon concentrations at a depth of 0.5 meter ranged from 16.21 to 88.98 kBq.m^{-3}. Their average value (avg) was 45.95 kBq.m^{-3} and their standard deviation (SD) was 22.36 kBq.m^{-3}. These values were divided into four groups:

Group 1: less than 23.59 kBq.m^{-3}. (avg – SD)
Group 2: 23.59 to 45.95 kBq.m^{-3}. (from –SD to avg)
Group 3: 45.95 to 68.31 kBq.m^{-3}. (from avg to +SD)
Group 4: greater than 68.31 kBq.m^{-3}.

The medians of these four groups are 12.41, 34.77, 57.13 and 79.49 kBq.m^{-3}, respectively. Figure 4.9 shows the correlation between median values of winter indoor radon concentration and soil-gas radon concentration at a 0.5-meter depth according to house type.

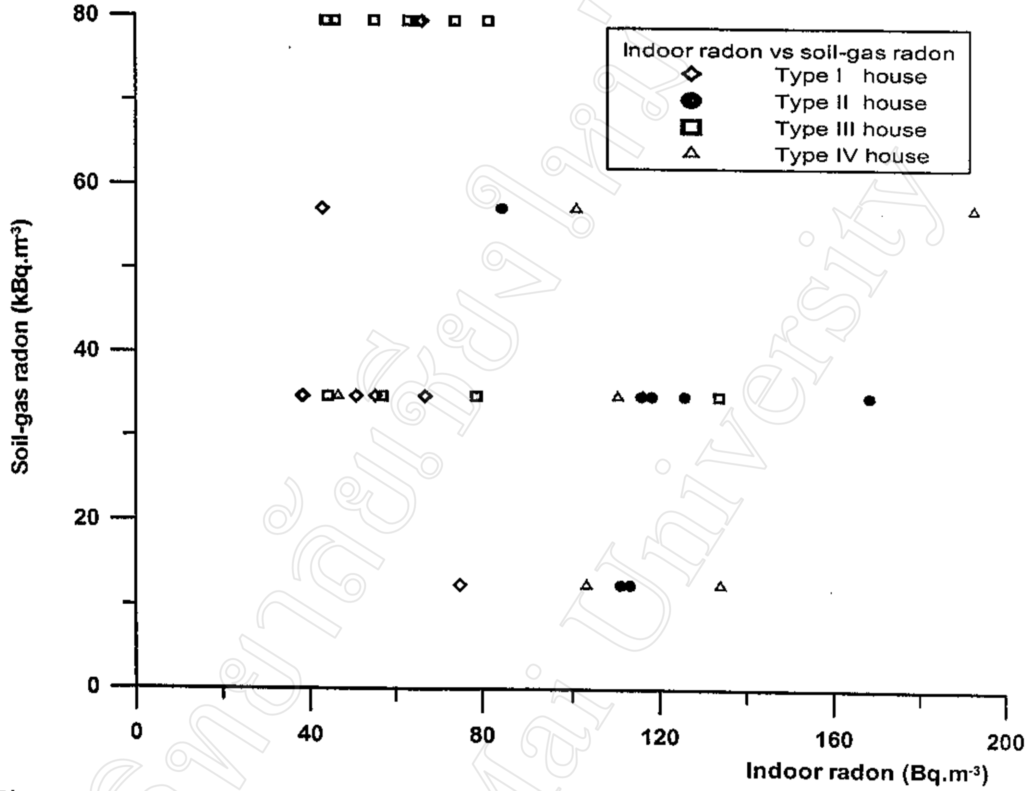


Figure 4.9 Winter indoor radon concentration versus soil-gas radon concentration at a 0.5-meter depth.

In summer, soil-gas radon concentrations at a 0.5-meter depth ranged from 10.74 to 201.02 kBq.m^{-3} and averaged (avg) 72.91 kBq.m^{-3}. Their standard deviation (SD) was 52.58 kBq.m^{-3}. These values were divided into four groups:

Group 1: less than 46.62 kBq.m^{-3}. (avg – ½SD)

Group 2: 46.62 to 72.91 kBq.m^{-3}. (from – ½SD to avg)

Group 3: 72.91 to 99.20 kBq.m^{-3}. (from avg to + ½SD)

Group 4: greater than 99.20 kBq.m^{-3}.

The medians of these four groups are 33.47, 59.76, 86.05 and 112.35 kBq.m^{-3}, respectively. Figure 4.10 shows the correlation between median values of summer indoor radon concentration and soil-gas radon concentration at a 0.5-meter depth according to house type.

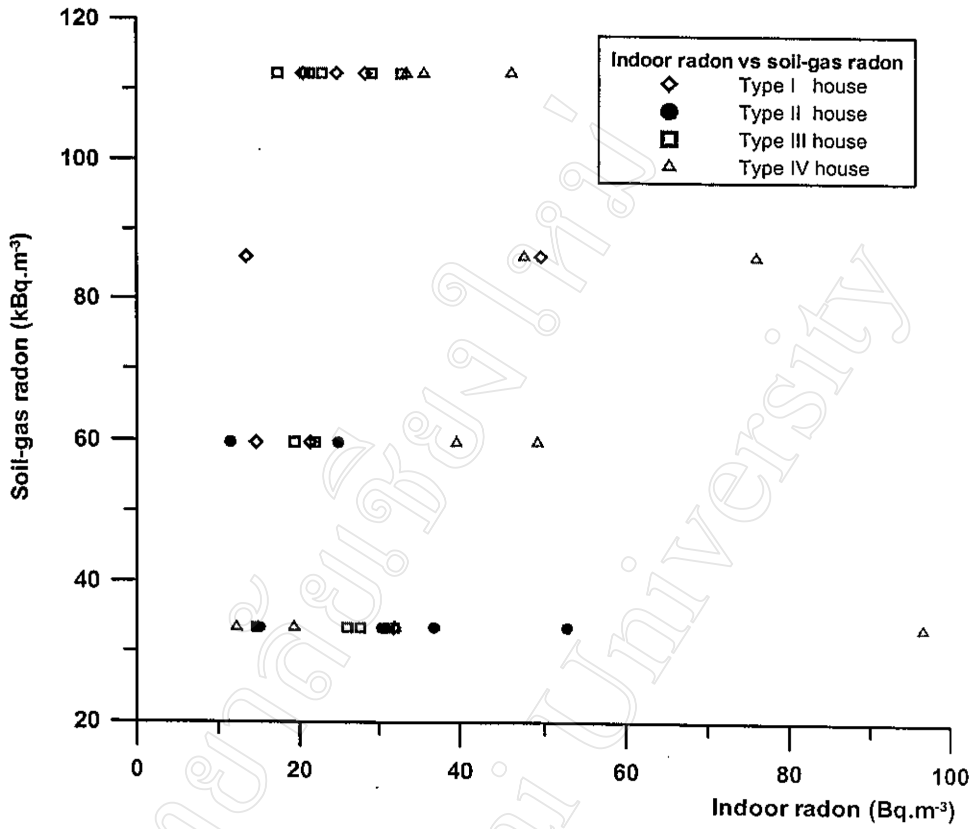


Figure 4.10 Summer indoor radon concentration versus soil-gas radon concentration at a 0.5-meter depth.

4.3.2 Indoor radon concentration and soil-gas radon concentration at 1.0-meter depth in winter and summer correlated to house type.

In winter, soil-gas radon concentrations at a 1.0-meter depth ranged from 21.09 to 212.04 kBq.m^{-3}. They averaged 91.14 kBq.m^{-3} and their standard deviation was 39.24 kBq.m^{-3}. These values were divided into four groups:

Group 1: less than 51.90 kBq.m^{-3}. (avg – SD)
Group 2: 51.90 to 91.14 kBq.m^{-3}. (from –SD to avg)
Group 3: 91.14 to 130.38 kBq.m^{-3}. (from avg to +SD)
Group 4: greater than 130.38 kBq.m^{-3}.

The medians of these four groups are 32.28, 71.52, 110.76 and 150 kBq.m^{-3}, respectively. Figure 4.11 shows the correlation between median values of winter indoor radon concentration and soil-gas radon concentration at a 1.0-meter depth according to house type.

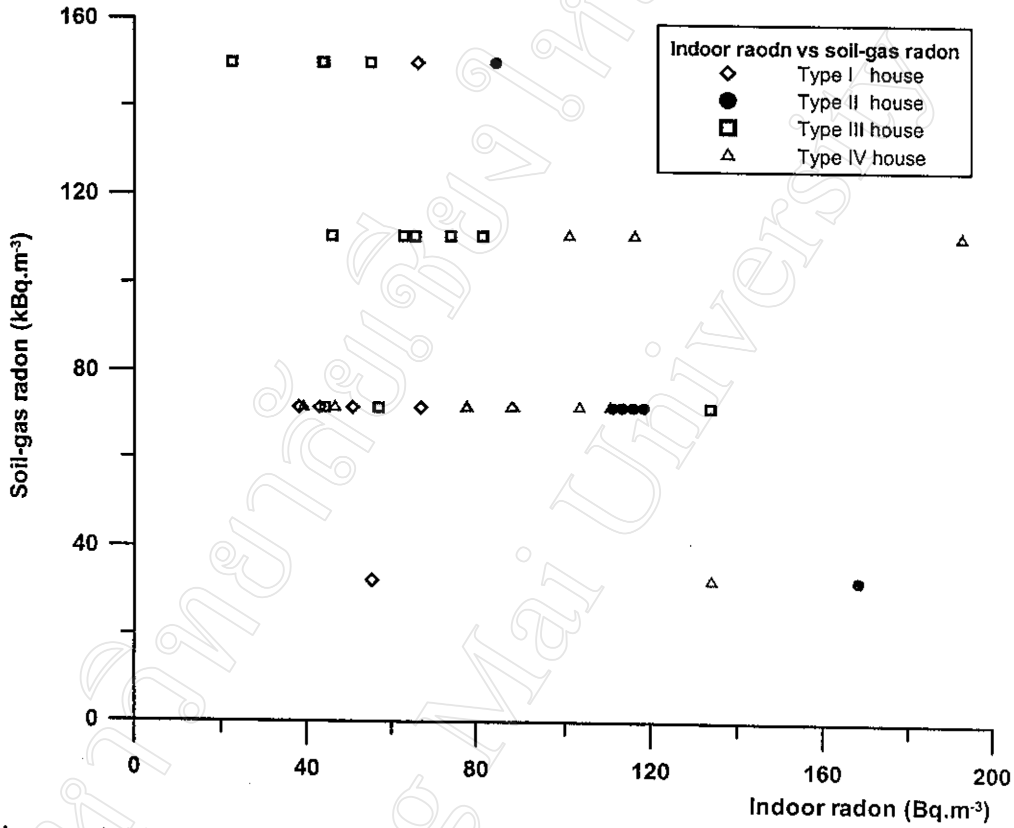


Figure 4.11 Winter indoor radon concentration versus soil-gas radon concentration at a 1.0-meter depth.

In summer, soil-gas radon concentrations at a depth of 1.0 meter ranged from 9.13 to 242.99 kBq.m^{-3} and averaged 100.91 kBq.m^{-3}. Their standard deviation was 66.63 kBq.m^{-3}. These values were divided into four groups:

Group 1: less than 67.59 kBq.m^{-3}. (avg – ½SD)

Group 2: 67.59 to 100.91 kBq.m^{-3}. (from – ½SD to avg)

Group 3: 100.91 to 134.23 kBq.m^{-3}. (from avg to + ½SD)

Group 4: greater than 134.23 kBq.m^{-3}.

The medians of these four groups are 50.93, 84.25, 117.57 and 150.89 kBq.m^{-3}, respectively. Figure 4.12 shows the correlation between median values of summer indoor radon concentration and soil-gas radon concentration at a 0.5-meter depth according to house type.

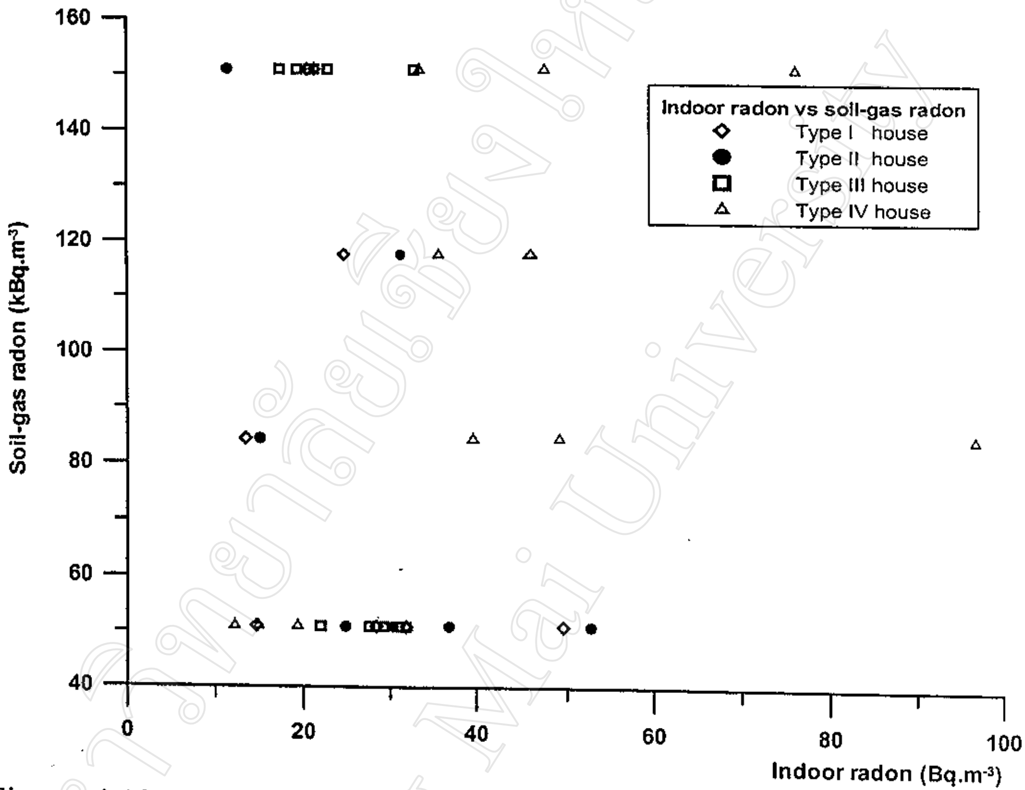


Figure 4.12 Summer indoor radon concentration versus soil-gas radon concentration at a 1.0-meter depth.

Figures 4.9 to 4.12 show that for type IV houses winter and summer indoor radon concentrations seem to increase when soil-gas radon concentrations at both 0.5-meter and 1.0-meter depths increase, but there is no clear trend for this. For some type IV houses in lowest range of soil-gas radon had higher indoor radon concentration than the others which sit on the higher range of soil-gas radon concentrations. For type I, II, and III houses, winter and summer indoor radon concentrations, in general, did not increase when soil-gas radon concentrations at depths of 0.5 meter and 1.0 meter increased.

Figure 4.13 shows the least square fits of the four house types. This figure describes all situations. Generally, the slopes of these fits are negative, though there are a few positive slopes. And these positive slopes given very low r-squared values, the low r-squared values were indicated very poor relationships between indoor radon and soil-gas radon concentration.

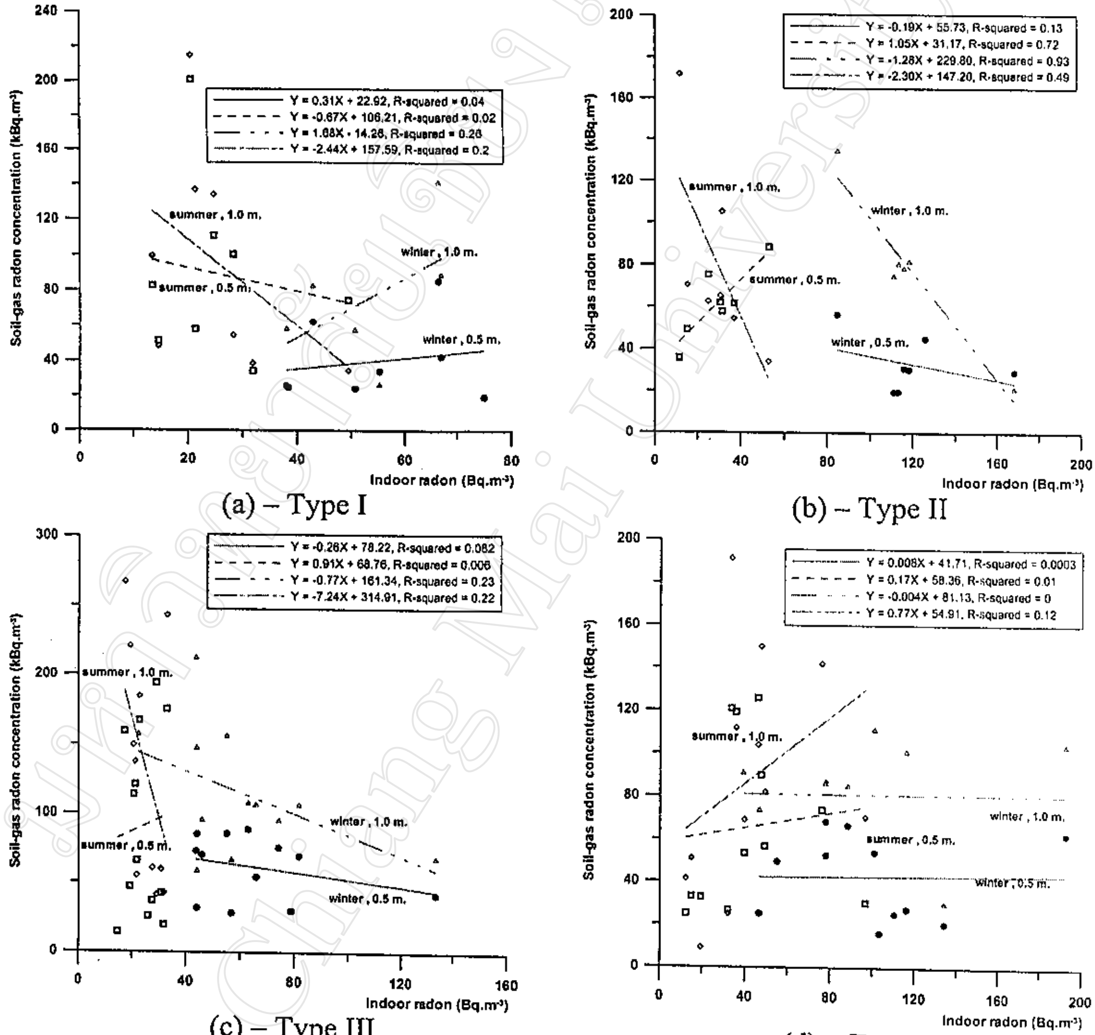


Figure 4.13 Indoor radon versus soil-gas radon concentration in winter and summer

4.4 Winter and summer indoor radon concentrations and soil-gas permeability at 0.5-meter and 1.0-meter depths in relation to house type.

4.4.1 Winter and summer indoor radon concentrations and soil-gas permeability at a 0.5-meter depth correlated with house type.

The winter range of soil-gas permeability at a 0.5-meter depth was 4.14×10^{-12} to 7.40×10^{-11} m^2. The average permeability was 1.99×10^{-11} m^2 and the standard deviation was 1.62×10^{-11} m^2. These values were divided into four groups:

Group 1: less than 1.18×10^{-11} m^2. (avg – ½SD)

Group 2: 1.18×10^{-11} to 1.99×10^{-11} m^2. (from – ½SD to avg)

Group 3: 1.99×10^{-11} to 2.80×10^{-11} m^2. (from avg + ½SD)

Group 4: greater than 2.80×10^{-11} m^2.

The medians of these four groups are 7.70×10^{-12}, 1.58×10^{-11}, 2.40×10^{-11}, and 3.21×10^{-11} m^2, respectively. Figure 4.14 shows the correlation between median values of winter indoor radon concentration and soil-gas permeability at a 0.5-meter depth according to house type.

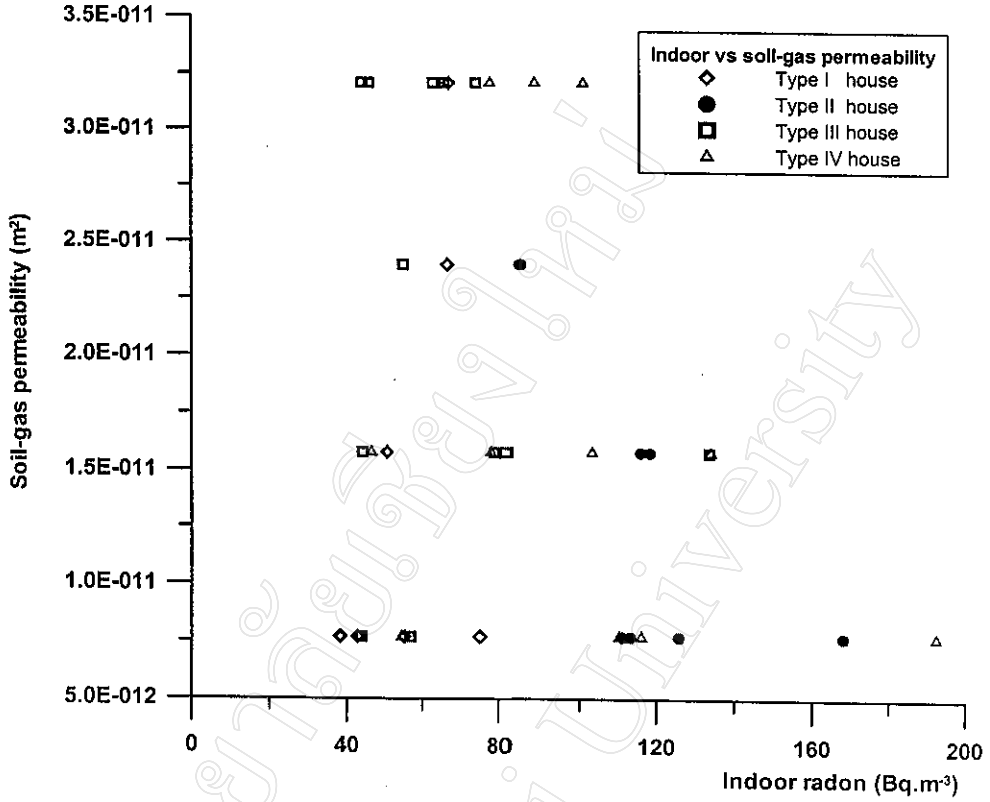


Figure 4.14 Winter indoor radon concentration versus soil-gas permeability at a 0.5-meter depth.

The summer soil-gas permeability at a 0.5-meter depth ranged from 1.99×10^{-12} to 6.47×10^{-11} m^2 and averaged 2.16×10^{-11} m^2. Its standard deviation was 1.6×10^{-11} m^2. These values were divided into four groups:

Group 1: less than 1.36×10^{-11} m^2. (avg – ½SD)
Group 2: 1.36×10^{-11} to 2.16×10^{-11} m^2. (from – ½SD to avg)
Group 3: 2.16×10^{-11} to 2.96×10^{-11} m^2. (from avg + ½SD)
Group 4: greater than 2.96×10^{-11} m^2.

The medians of these four groups are 9.60×10^{-12}, 1.76×10^{-11}, 2.56×10^{-11}, and 3.36×10^{-11} m^2, respectively. Figure 4.15 shows the correlation between median values of summer indoor radon concentration and soil-gas permeability at a 0.5-meter depth according to house type.

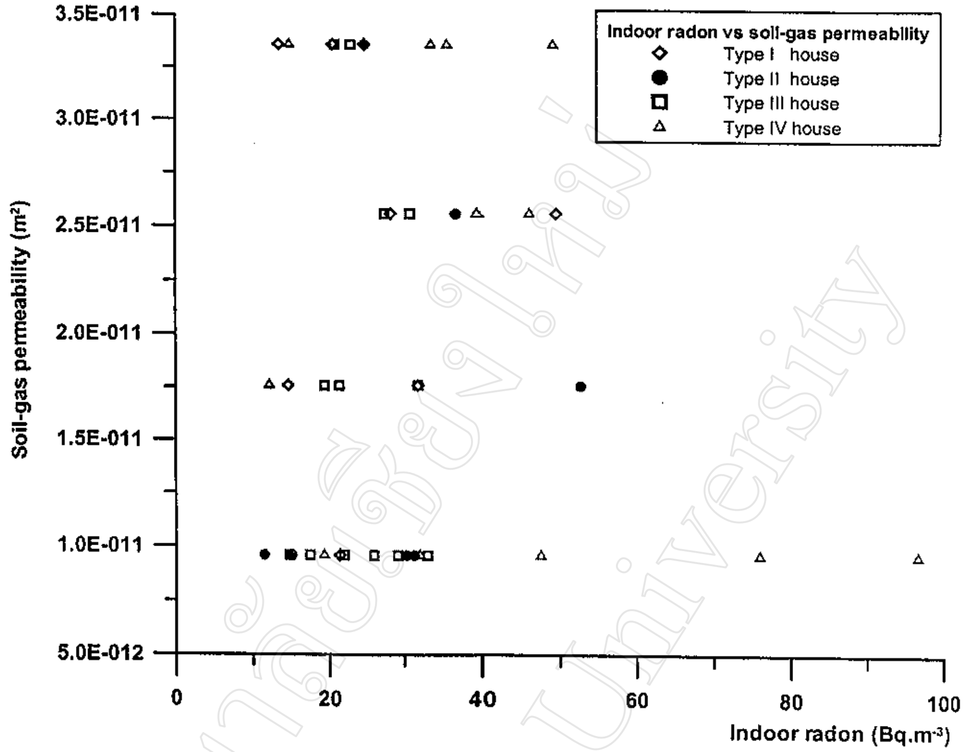


Figure 4.15 Summer indoor radon concentration versus soil-gas permeability at a 0.5-meter depth.

4.4.2 Winter and summer indoor radon concentration and soil-gas permeability at a 1.0-meter depth correlated with house type.

The winter range of soil-gas permeability at a 1.0-meter depth was 3.96×10^{-12} to 1.59×10^{-10} m^2. This permeability averaged 2.76×10^{-11} m^2 and its standard deviation was 2.96×10^{-11} m^2. These values were divided into four groups:

Group 1: less than 1.28×10^{-11} m^2. (avg – ½SD)

Group 2: 1.28×10^{-11} to 2.76×10^{-11} m^2. (from – ½SD to avg)

Group 3: 2.76×10^{-11} to 4.24×10^{-11} m^2. (from avg + ½SD)

Group 4: greater than 4.24×10^{-11} m^2.

The medians of these four groups are 5.40×10^{-12}, 2.02×10^{-11}, 3.50×10^{-11}, and 4.98×10^{-11} m^2, respectively. Figure 4.15 shows the correlation between median values of winter indoor radon concentration and soil-gas permeability at a 1.0-meter depth according to house type.

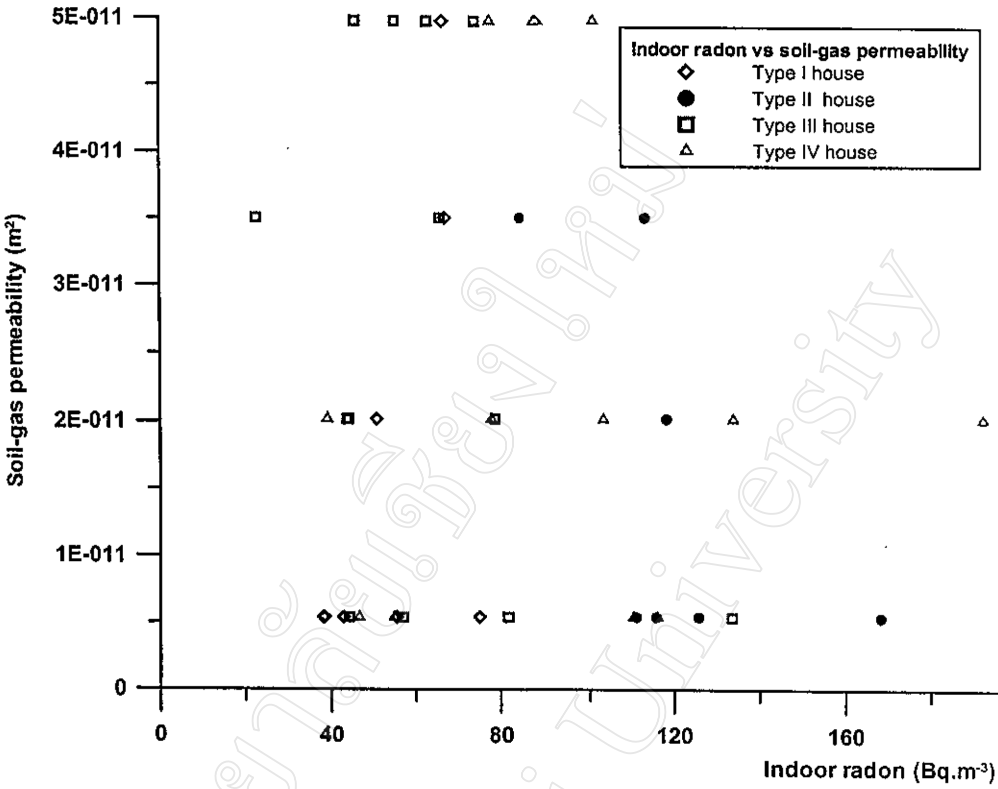


Figure 4.16 Winter indoor radon concentration versus soil-gas permeability at a depth of 1.0 meter.

The summer range of soil-gas permeability at a 1.0-meter depth was 3.65×10^{-12} to 8.91×10^{-11} m^2. This permeability averaged 2.79×10^{-11} m^2 and its standard deviation was 1.99×10^{-11} m^2. These values were divided into four groups:

Group 1: less than 1.79×10^{-11} m^2. (avg – ½SD)

Group 2: 1.79×10^{-11} to 2.79×10^{-11} m^2. (from – ½SD to avg)

Group 3: 2.79×10^{-11} to 3.79×10^{-11} m^2. (from avg + ½ SD)

Group 4: greater than 3.79×10^{-11} m^2.

The medians of these four groups are 1.29×10^{-11}, 2.29×10^{-11}, 3.29×10^{-11}, and 4.29×10^{-11} m^2, respectively. Figure 4.17 shows the correlation between median values of summer indoor radon concentration and soil-gas permeability at a 1.0-meter depth according to house type.

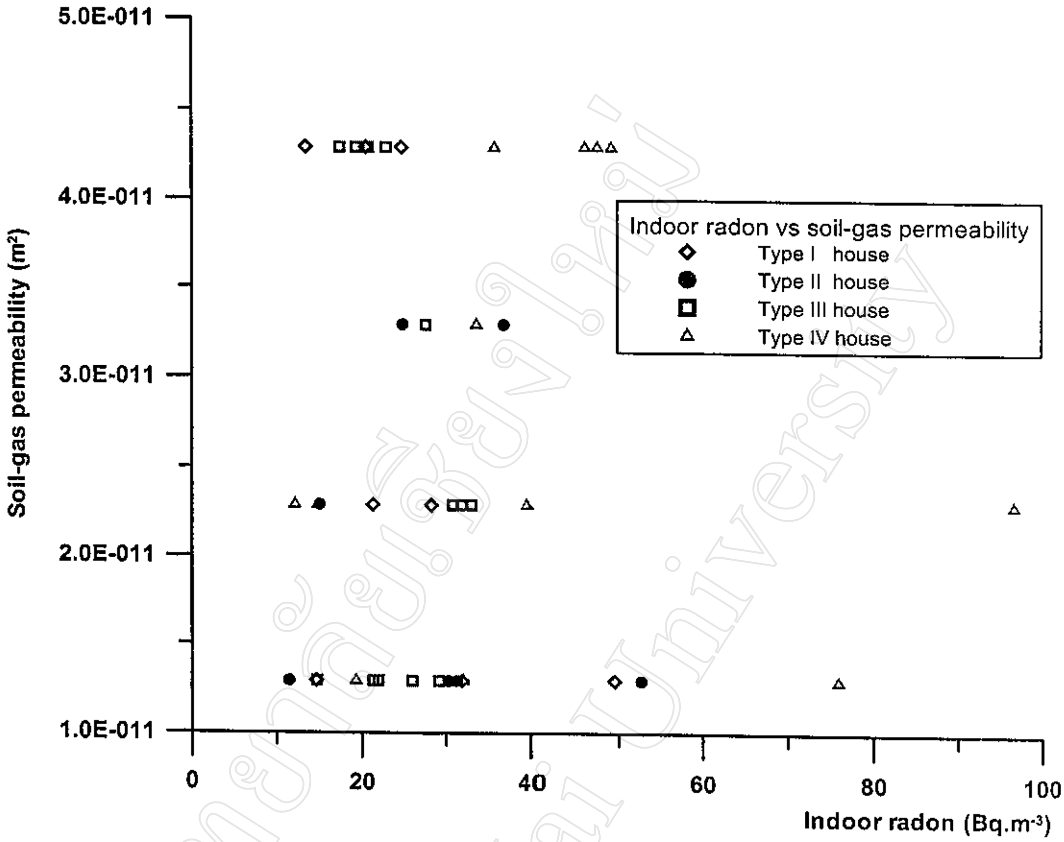
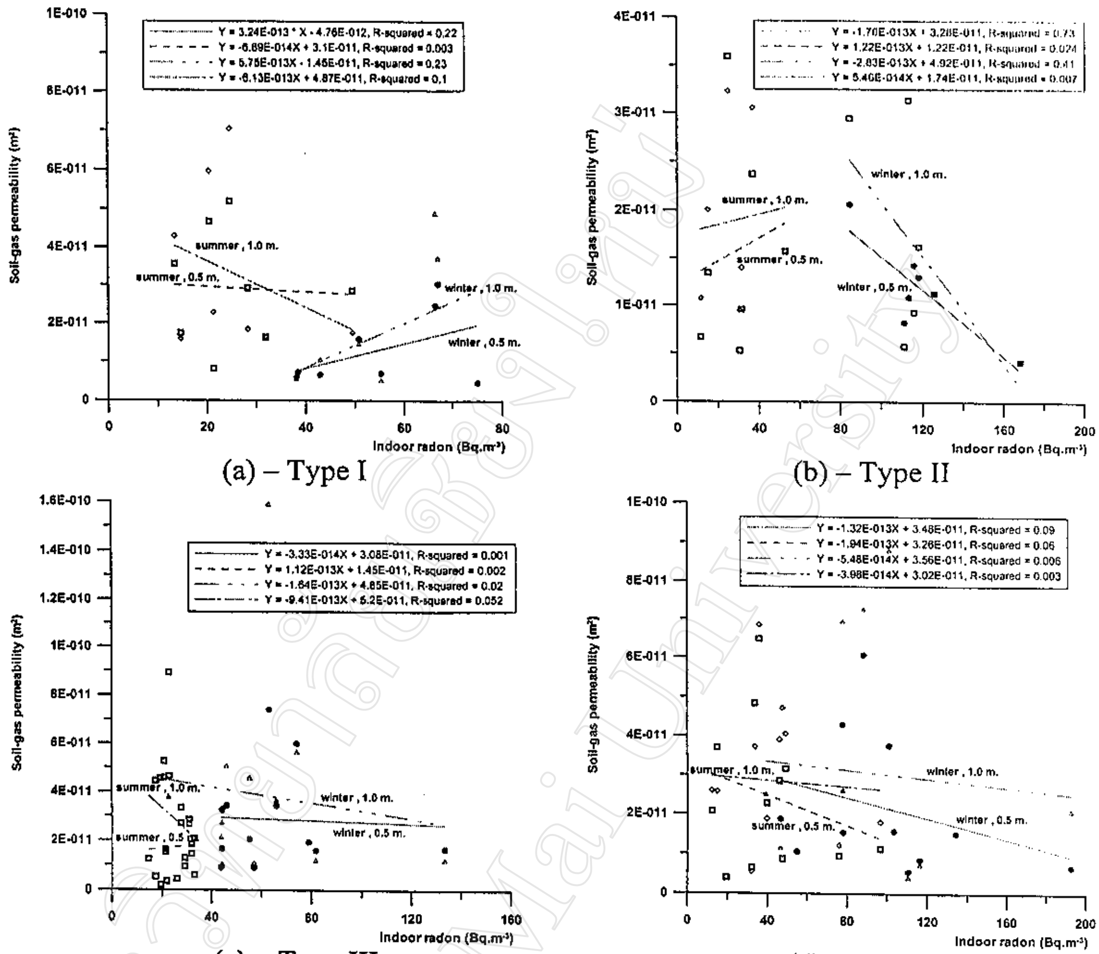


Figure 4.17 Summer indoor radon concentration versus soil-gas permeability at a 1.0-meter depth.

Figures 4.14 to 4.17 show that for all house types, there was no general correlation between winter and summer indoor radon concentrations and increased soil-gas permeability at either 0.5-meter or 1.0-meter depths, indoor radon concentrations generally stayed about the same or decreased slightly with increased soil-gas permeability.

Figure 4.18 represents the least squared relationships between indoor radon concentration and soil-gas permeability for the four house types. Almost all house types have negative slopes, there being only a few positive slopes. The r-squared values for all house types are low and indicate poor relationship between indoor radon concentration and soil-gas permeability.



(a) – Type I (b) – Type II

(c) – Type III (d) – Type IV

Figure 4.18 Indoor radon versus soil-gas permeability in winter and summer

4.5 Winter and summer indoor radon concentration and product of soil-gas radon concentration times soil-gas permeability at 0.5-meter and 1.0-meter depths in relation to house type.

4.5.1 Winter and summer indoor radon concentration and product of soil-gas radon concentration times soil-gas permeability at a 0.5-meter depth correlated with house type.

In winter, soil-gas radon concentration times soil-gas permeability at a depth of 0.5 meter ranged from 9.16×10^{-8} to 6.58×10^{-6} Bq.m^{-1} and averaged 1.12 x 10^{-6} Bq.m^{-1}. Its standard deviation was 1.40 x 10^{-6} Bq.m^{-1}. These values were divided into four groups:

Group 1: less than 4.20 x 10^{-7} Bq.m^{-1}. (avg – ½SD)

Group 2: 4.20 x 10^{-7} to 1.12 x 10^{-6} Bq.m^{-1}. (from – ½SD to avg)

Group 3: 1.12 x 10^{-6} to 1.82 x 10^{-6} Bq.m^{-1}. (from avg + ½SD)

Group 4: greater than1.82 x 10^{-6} Bq.m^{-1}.

The medians of these four groups are 7.00 x 10^{-8}, 7.70 x 10^{-7}, 1.47 x 10^{-6}, and 2.17 x 10^{-6} Bq.m^{-1}, respectively. Figure 4.19 shows the correlation between median values of winter indoor radon concentration and the product of soil-gas radon concentration times soil-gas permeability at a 0.5-meter depth according to house type.

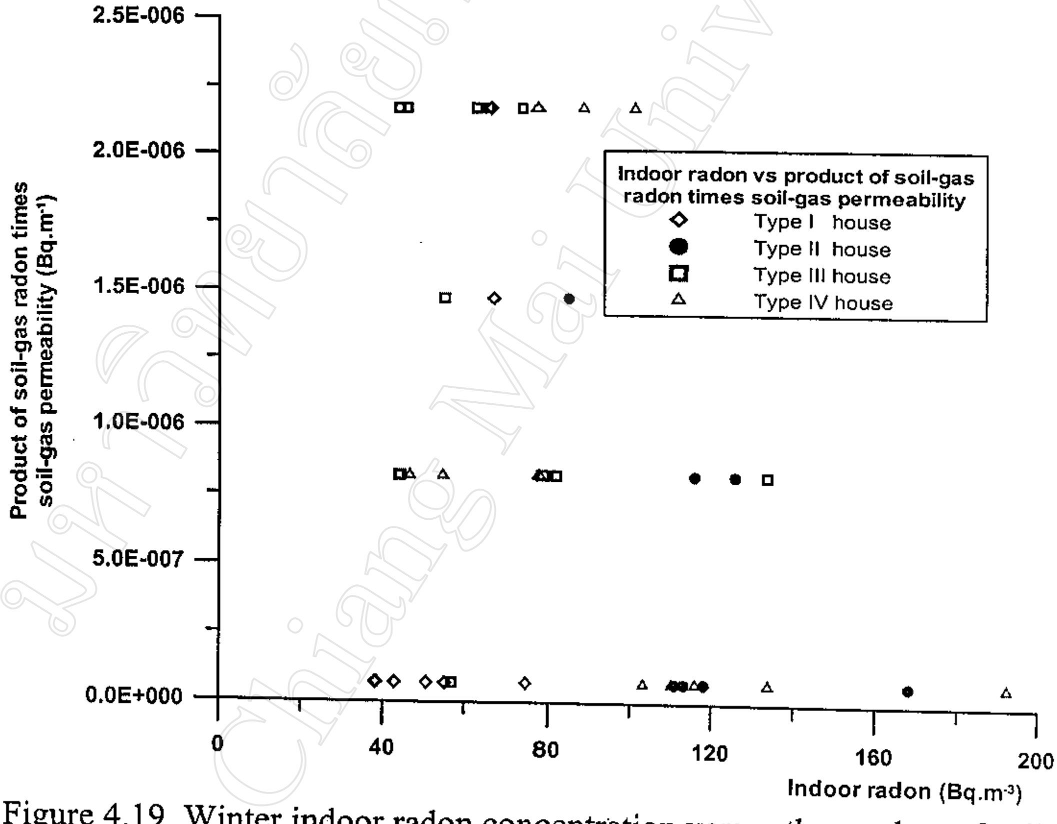


Figure 4.19 Winter indoor radon concentration versus the product of soil-gas radon concentration times soil-gas permeability at a 0.5-meter depth.

The product of summer soil-gas radon concentration times soil-gas permeability at a 0.5-meter depth ranged from 5.65 x 10^{-8} to 9.39 x 10^{-6}

Bq.m^{-1}. The average was 1.89 x 10^{-6} Bq.m^{-1} and the standard deviation was 2.38 x 10^{-6} Bq.m^{-1}. These values were divided into four groups:

Group 1: less than 1.29 x 10^{-6} Bq.m^{-1}. (avg – ½SD)

Group 2: 1.29 x 10^{-6} to 1.89 x 10^{-6} Bq.m^{-1}. (from – ½SD to avg)

Group 3: 1.89 x 10^{-6} to 2.49 x 10^{-6} Bq.m^{-1}. (from avg + ½SD)

Group 4: greater than 2.49 x 10^{-6} Bq.m^{-1}.

The medians of these four groups are 1.00 x 10^{-6}, 1.59 x 10^{-6}, 2.19 x 10^{-6}, and 2.79 x 10^{-6} Bq.m^{-1}, respectively. Figure 4.20 shows the correlation between median values of summer indoor radon concentration and the product of soil-gas radon concentration times soil-gas permeability at a 0.5-meter depth according to house type.

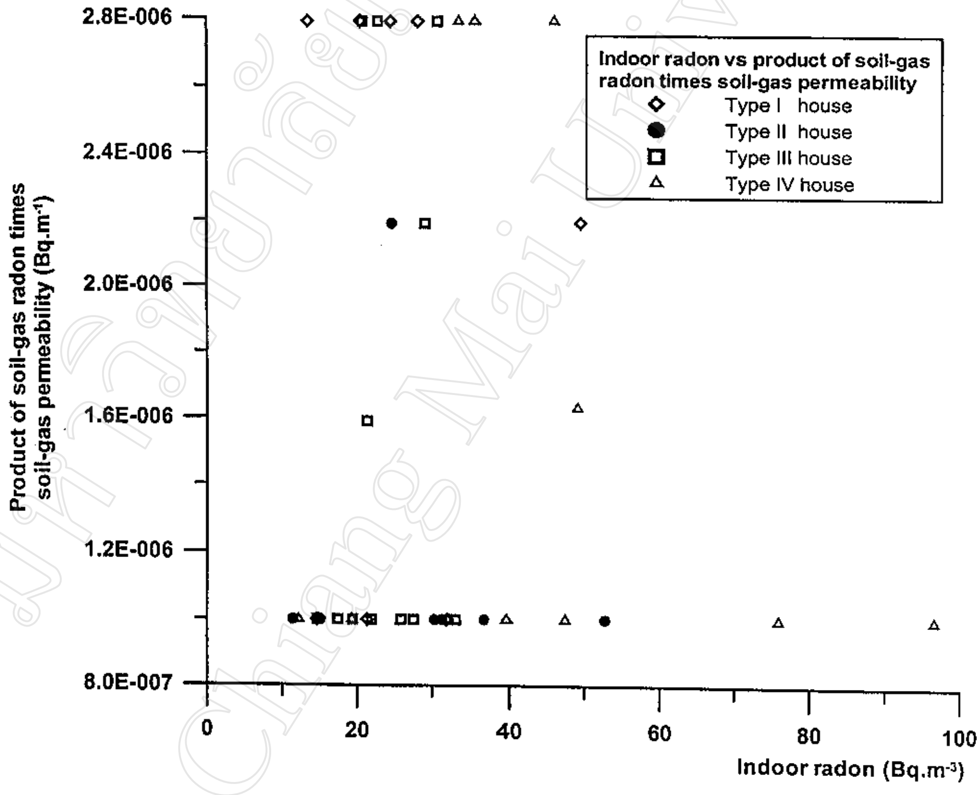


Figure 4.20 Summer indoor radon concentration versus the product of soil-gas radon concentration times soil-gas permeability at a 0.5-meter depth.

4.5.2 Winter and summer indoor radon concentration and product of soil-gas radon concentration times soil-gas permeability at a 1.0-meter depth correlated with house type.

In winter, the product of soil-gas radon concentration times soil-gas permeability at a 1.0-meter depth ranged from 8.74 x 10^{-8} to 1.71 x 10^{-5} $Bq.m^{-1}$, averaged 3.12 x 10^{-6} $Bq.m^{-1}$, and had a standard deviation of 3.48 x 10^{-6} $Bq.m^{-1}$. These values were divided into four groups:

Group 1: less than 1.38 x 10^{-6} $Bq.m^{-1}$. (avg – ½SD)

Group 2: 1.38 x 10^{-6} to 3.12 x 10^{-6} $Bq.m^{-1}$. (from – ½SD to avg)

Group 3: 3.12 x 10^{-6} to 4.86 x 10^{-6} $Bq.m^{-1}$. (from avg + ½SD)

Group 4: greater than 4.86 x 10^{-6} $Bq.m^{-1}$.

The medians of these four groups are 5.1 x 10^{-7}, 2.25 x 10^{-6}, 3.84 x 10^{-6}, and 5.58 x 10^{-6} $Bq.m^{-1}$, respectively. Figure 4.21 shows the correlation between median values of winter indoor radon concentration and the product of soil-gas radon concentration times soil-gas permeability at a 1.0-meter depth according to house type.

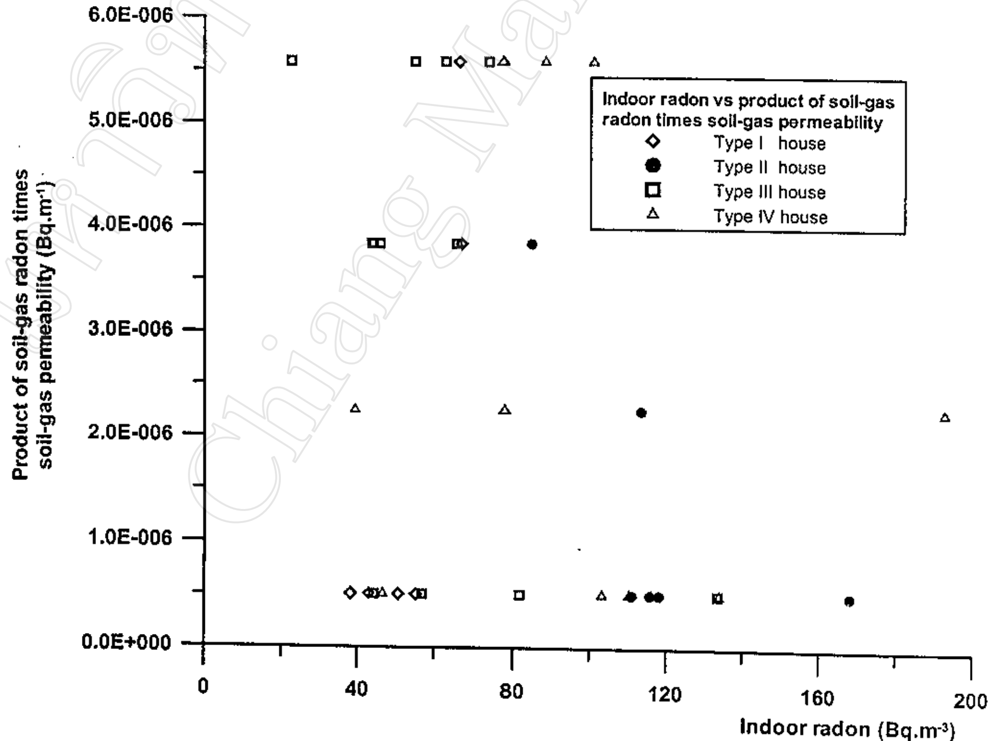


Figure 4.21 Winter indoor radon concentration versus the product of soil-gas radon concentration times soil-gas permeability at a 1.0-meter depth.

The summer product of soil-gas radon concentration times soil-gas permeability at a 1.0-meter depth ranged from 3.72 x 10^{-8} to 1.64 x 10^{-5} Bq.m^{-1}, averaged 3.60 x 10^{-6} Bq.m^{-1}, and had a standard deviation of 4.08 x 10^{-6} Bq.m^{-1}. These values were divided into four groups:

Group 1: less than 1.56 x 10^{-6} Bq.m^{-1}. (avg – ½SD)

Group 2: 1.56 x 10^{-6} to 3.60 x 10^{-6} Bq.m^{-1}. (from – ½SD to avg)

Group 3: 3.06 x 10^{-6} to 5.64 x 10^{-6} Bq.m^{-1}. (from avg + ½SD)

Group 4: greater than 5.64 x 10^{-6} Bq.m^{-1}.

The medians of these four groups are 5.40 x 10^{-7}, 2.58 x 10^{-6}, 4.62 x 10^{-6}, and 6.66 x 10^{-6} Bq.m^{-1}, respectively. Figure 4.22 shows the correlation between median values of summer indoor radon concentration and the product of soil-gas radon concentration times soil-gas permeability at a 1.0-meter depth according to house type.

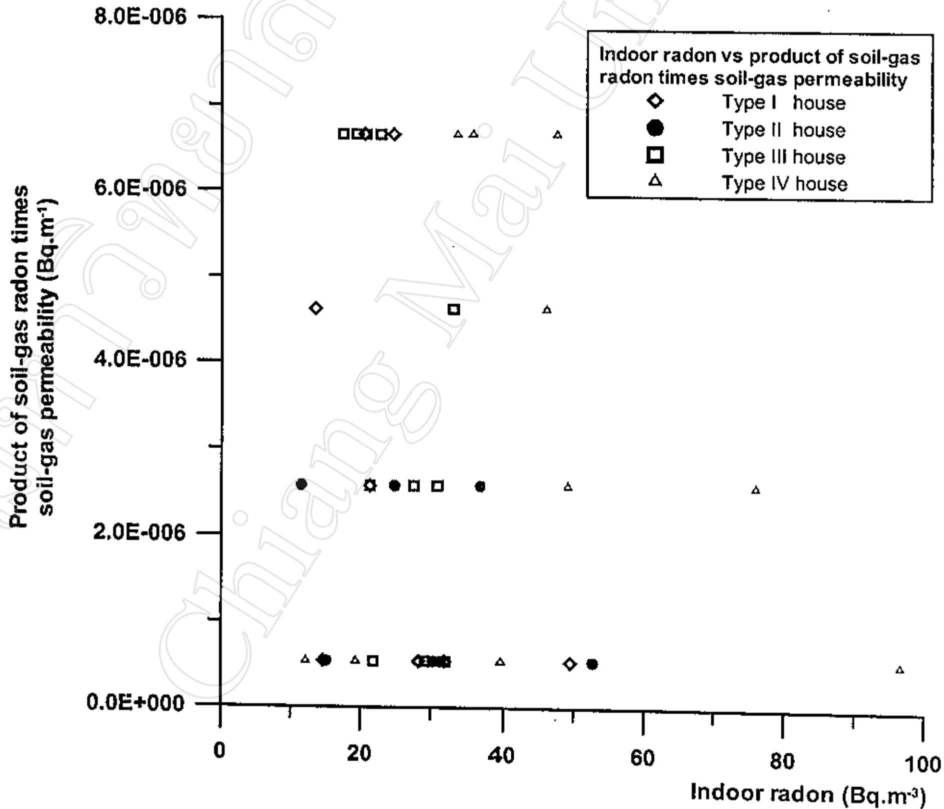


Figure 4.22 Summer indoor radon concentration versus the product of soil-gas radon concentration times soil-gas permeability at a 1.0-meter depth.

Figures 4.19 to 4.22 show that the influence of the product of soil-gas radon times soil-gas permeability on indoor radon concentration is very small for the four house types. The indoor radon concentration generally fluctuates for all house types when the product of soil-gas radon times soil-gas permeability increases. These situations are more clearly represented on Figure 4.23, which is least-square plots for the four house types. For all house types, the slopes are normally negative. These negative slopes indicate a poor relationship between indoor radon concentration and the product of soil-gas radon concentration times soil-gas permeability.

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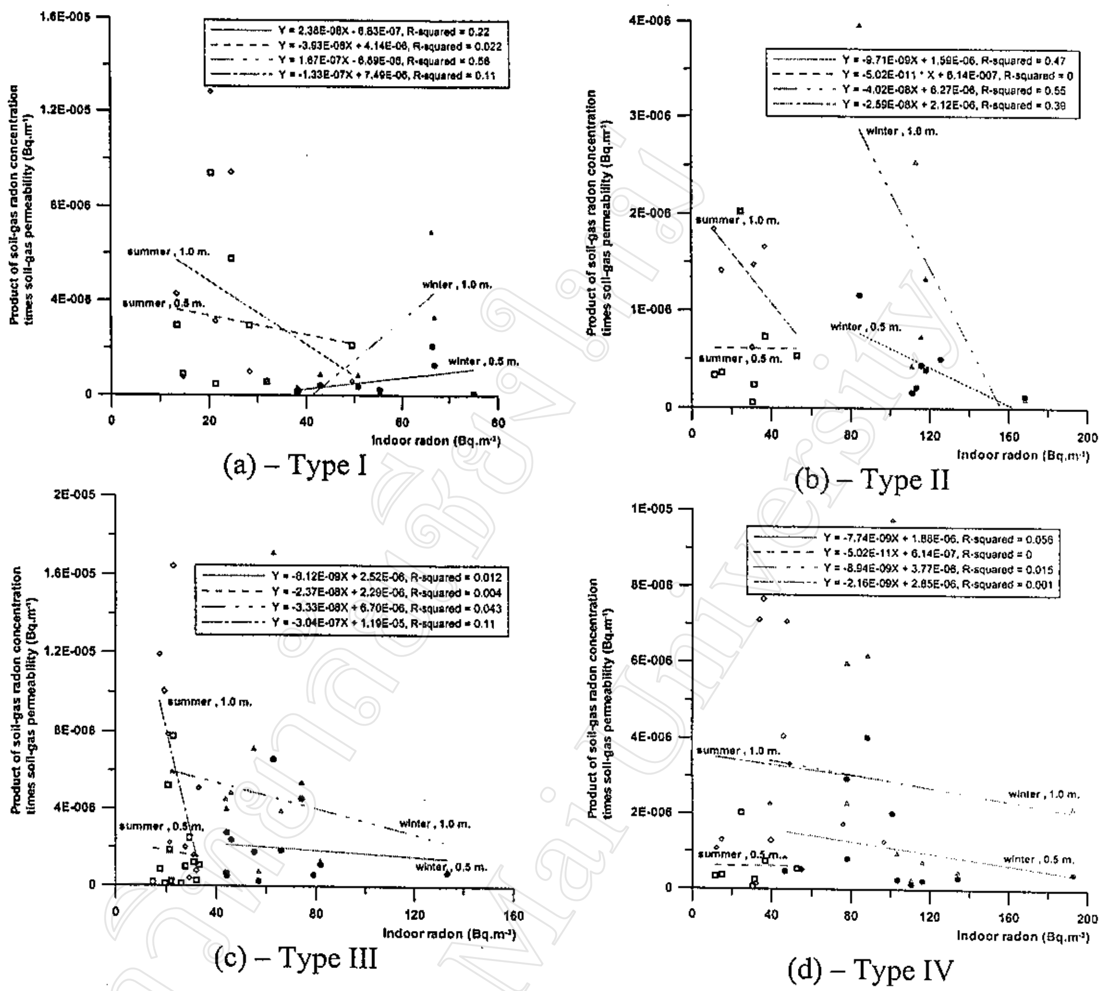

Figure 4.23 Indoor radon versus product of soil-gas radon concentration times soil-gas permeability in winter and summer

4.6 Winter and summer indoor radon concentration and thoron/radon ratio at 0.5-meter and 1.0-meter depths in relation to house types.

4.6.1 Winter and summer indoor radon concentration and thoron/radon ratio at a 0.5-meter depth correlated with house type.

The winter thoron/radon ratio at a 0.5-meter depth ranged from 0.09 to 0.88, averaged 0.29 and had a standard deviation of 0.15. These values were divided into four groups:

Group 1: less than 0.14. (avg –SD)

Group 2: 0.14 to 0.29. (from –SD to avg)

Group 3: 0.29 to 0.44. (from avg +SD)

Group 4: greater than 0.44.

The medians of these four groups are 0.065, 0.22, 0.37, and 0.52, respectively. Figure 4.24 shows the correlation between median values of winter indoor radon concentration and thoron/radon ratio at a 0.5-meter depth according to house type.

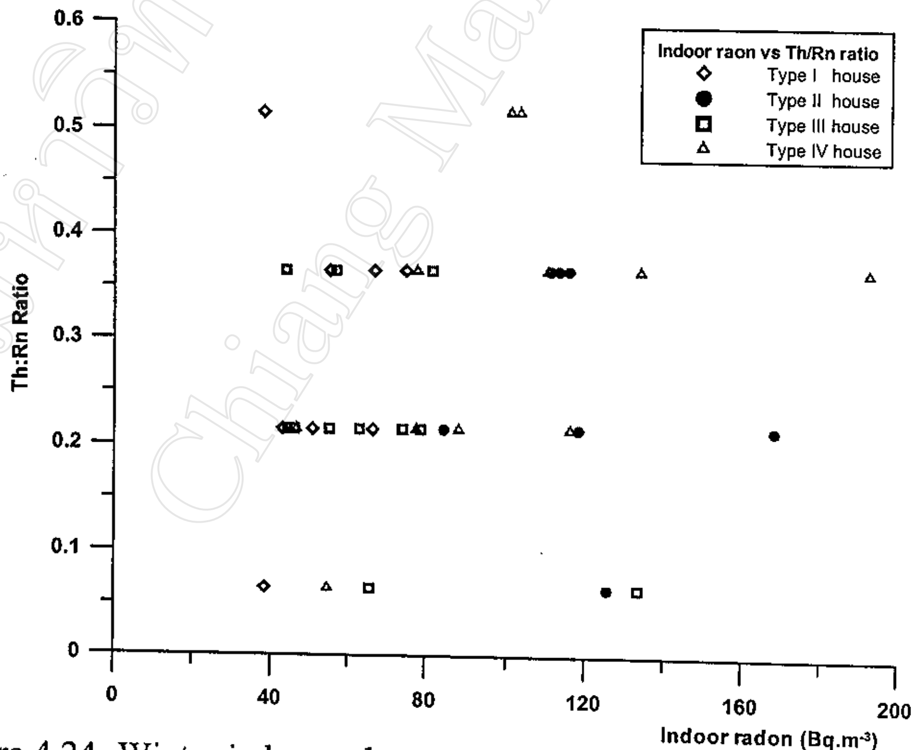

Figure 4.24 Winter indoor radon concentration versus thoron/radon ratio at a 0.5-meter depth.

The summer thoron/radon ratio at a 0.5-meter depth ranged from 0.0091 to 0.417, averaged 0.21, and had a standard deviation of 0.10. These values were divided into four groups:

Group 1: less than 0.11. (avg –SD)

Group 2: 0.11 to 0.21. (from –SD to avg)

Group 3: 0.21 to 0.31. (from avg +SD)

Group 4: greater than 0.31.

The medians of these four groups are 0.06, 0.16, 0.26, and 0.36, respectively. Figure 4.25 shows the correlation between median values of summer indoor radon concentration and thoron/radon ratio at a 0.5-meter depth according to house type.

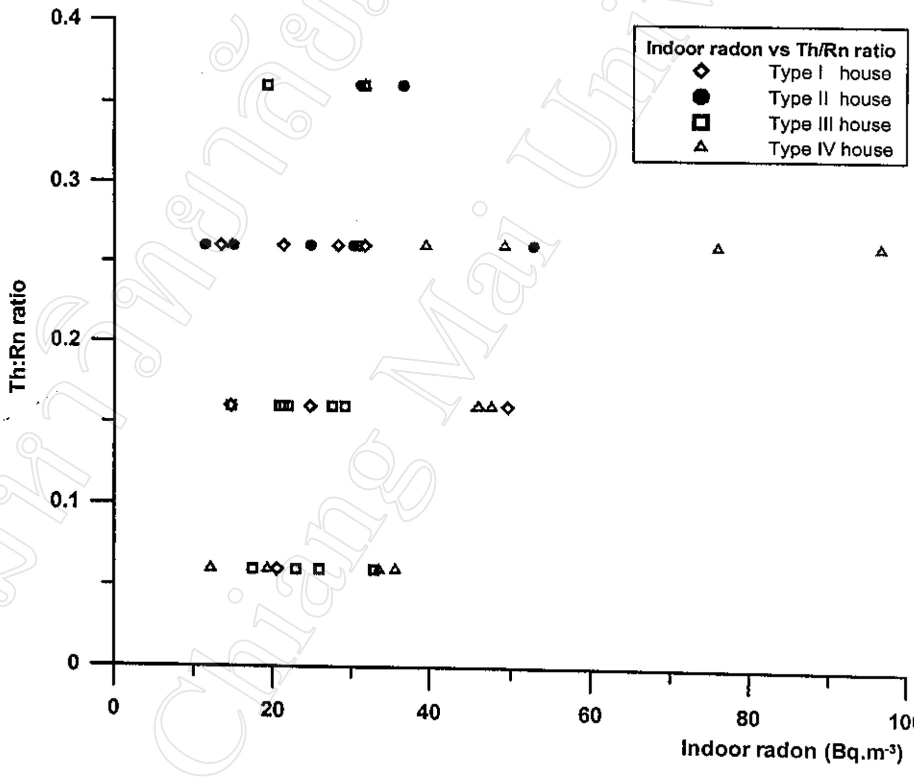

Figure 4.25 Summer indoor radon concentration versus thoron/radon ratio at a 0.5-meter depth.

4.6.2 Winter and summer indoor radon concentration and thoron/radon ratio at a 1.0-meter depth correlated with house types.

The winter thoron/radon ratio at a 1.0-meter depth ranged from 0.019 to 0.289, averaged 0.12, and had a standard deviation of 0.06. These values were divided into four groups:

Group 1: less than 0.06. (avg –SD)
Group 2: 0.06 to 0.12. (from –SD to avg)
Group 3: 0.12 to 0.18. (from avg +SD)
Group 4: greater than 0.18.

The medians of these four groups are 0.03, 0.09, 0.15, and 0.21, respectively. Figure 4.26 shows the correlation between median values of winter indoor radon concentration and thoron/radon ratio at a 1.0-meter depth according to house type.

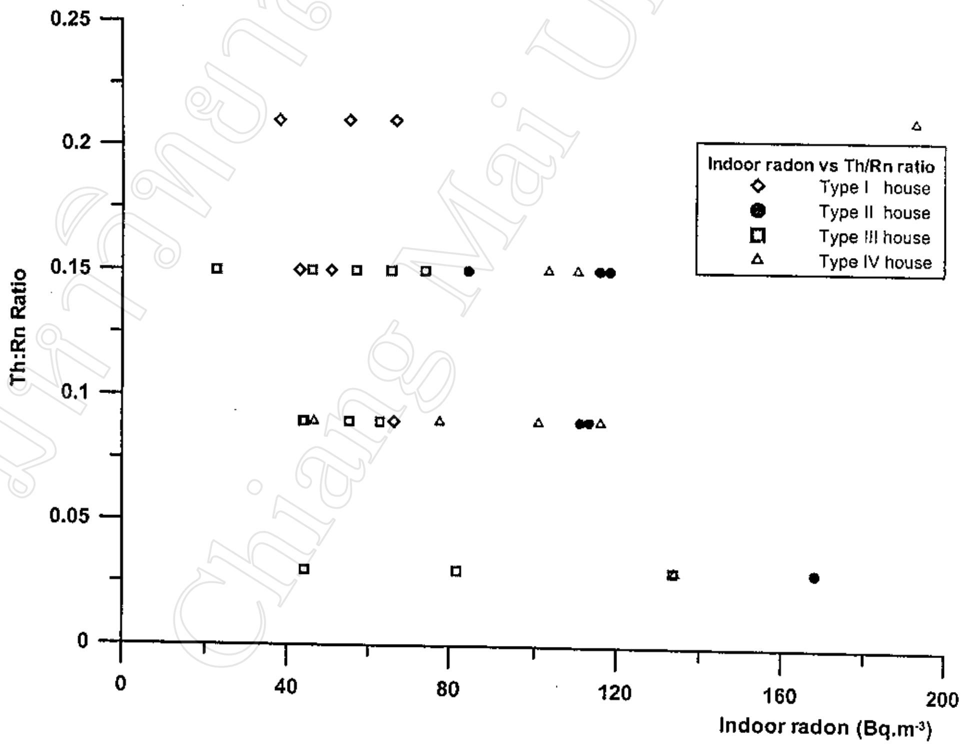

Figure 4.26 Winter indoor radon concentration versus thoron/radon ratio at a 1.0-meter depth.

The summer thoron/radon ratio at a 1 .0-meter depth ranged from 0.038 to 0.33, averaged 0.12, and had a standard deviation of 0.06. These values were divided into four groups:

Group 1: less than 0.06. (avg –SD)

Group 2: 0.06 to 0.12. (from –SD to avg)

Group 3: 0.12 to 0.18. (from avg +SD)

Group 4: greater than 0.18.

The medians of these four groups are 0.03, 0.09, 0.15, and 0.21, respectively. Figure 4.27 shows the correlation between median values of summer indoor radon concentration and thoron/radon ratio at a 1.0-meter depth according to house type.

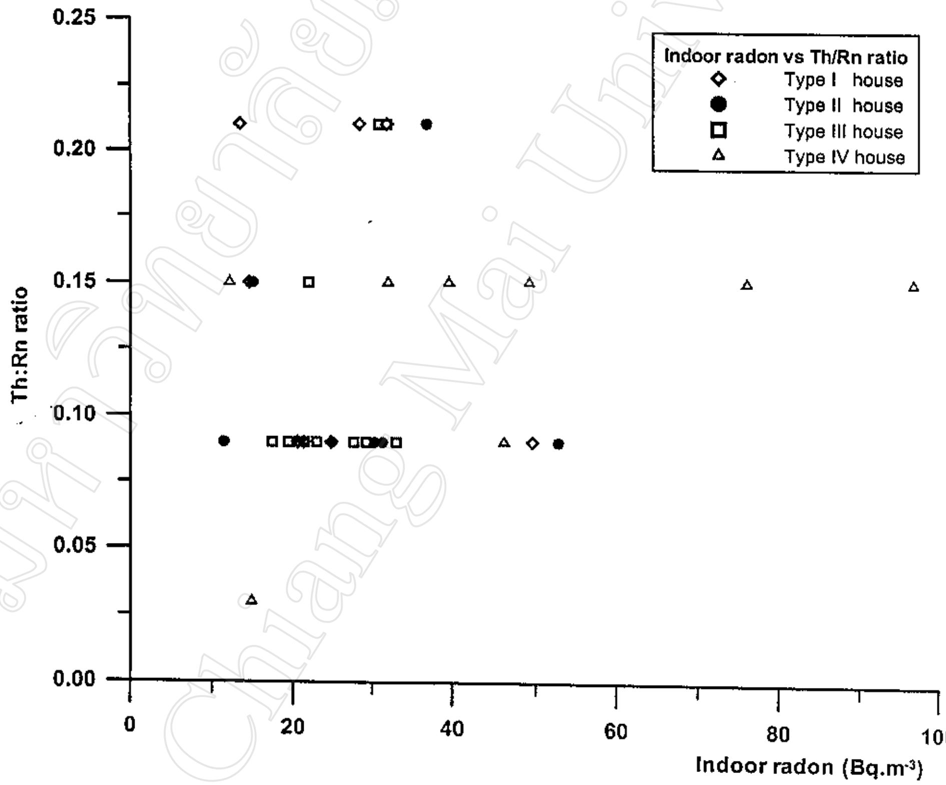

Figure 4.27 Summer indoor radon concentration versus thoron/radon ratio at a 1.0-meter depth.

Figures 4.24 to 4.27 show that for type IV houses, both winter and summer indoor radon concentration increased when thoron/radon ratios increased. For type I, II, and III houses, increased thoron/radon ratio caused either no increase in indoor radon concentration or a slight decrease or only a slight increase-decrease fluctuation.

Figure 4.28 is least squared plots of the four house types. Figure 4.28 (d) shows that there is a weak correlation between indoor radon concentrations and thoron/radon ratios in winter and summer and at 0.5-meter and 1.0-meter depths of type IV houses. Also the least squared fits are positive for both seasons and depths, though the r-squared values are small. Figure 4.28 (a), (b) and (c) do not show such correlation for the three other house types the least squared fits for these house types are both positive and negative and, like type IV houses, r-squared are low.

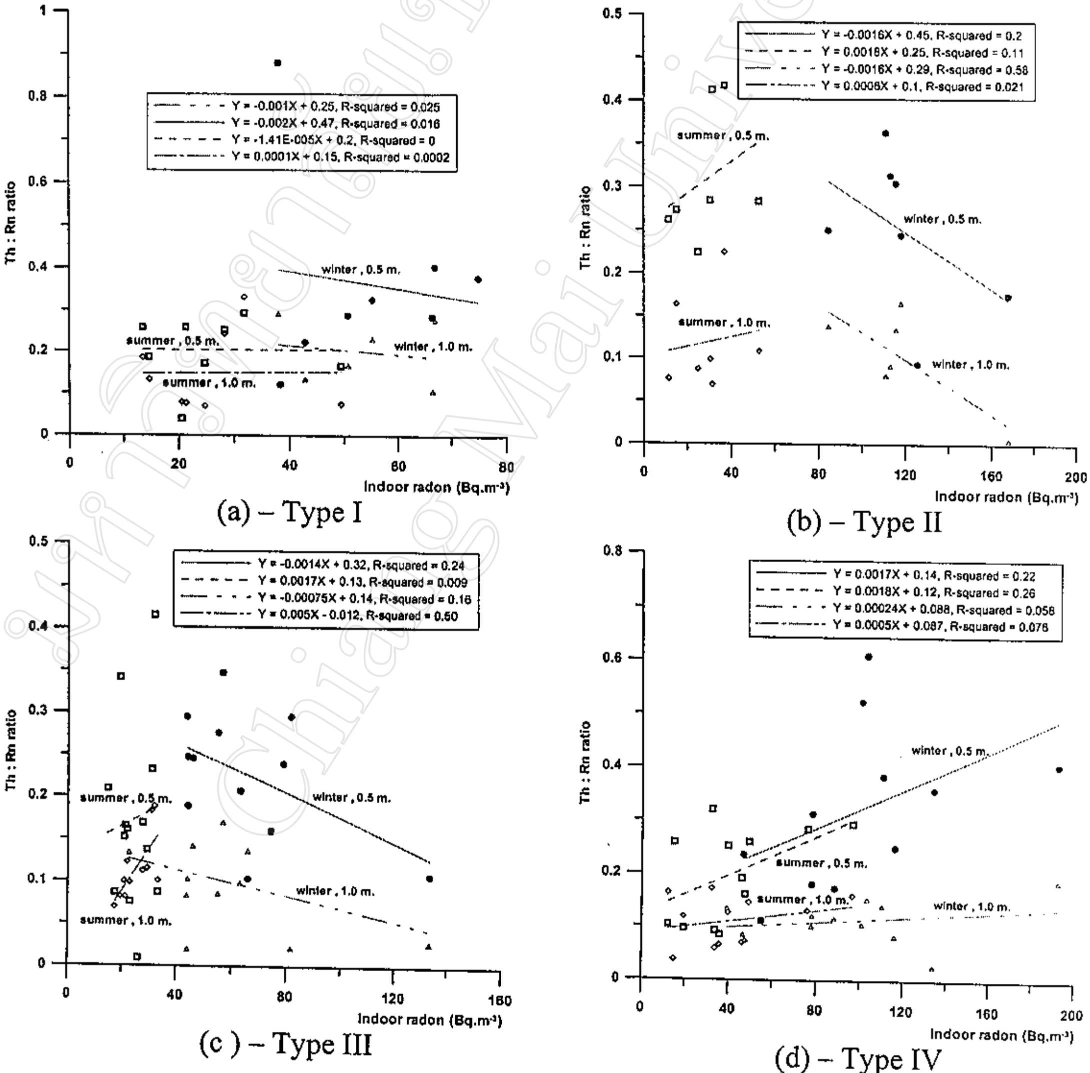

Figure 4.28 Indoor radon versus thoron/radon ratio in winter and summer

4.7 Correlation between soil-gas radon concentration and soil-gas permeability for indoor radon prediction.

Based on Surbeck's studies, an estimation of radon risk for a house can be made by combing soil-gas radon concentration with soil-gas permeability. This is done by plotting logarithmic values of soil-gas radon concentration versus soil-permeability. The product of soil-gas radon concentration times soil-gas permeability is called soil-gas availability. The winter radon risk diagram at a 0.5-meter depth is shown in Figure 4.29 and that of the summer risk in Figure 4.30. The winter and summer risks at a 1.0-meter depth were show in Figures 4.31 and 4.32, respectively.

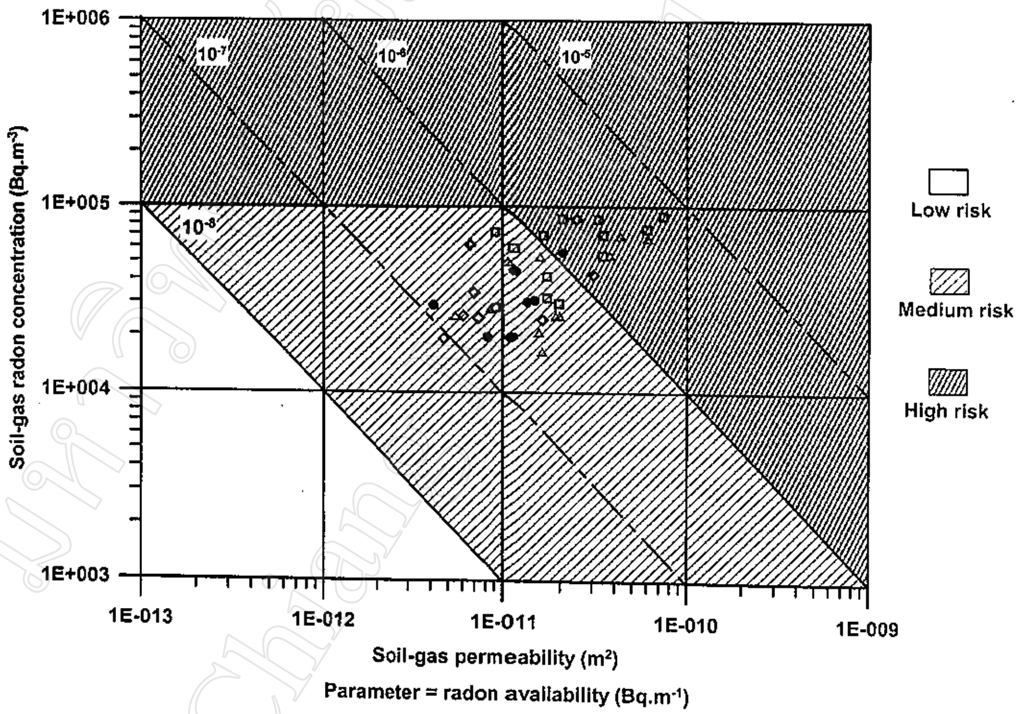

Figure 4.29 Radon risk diagram of 0.5 meters depth in winter

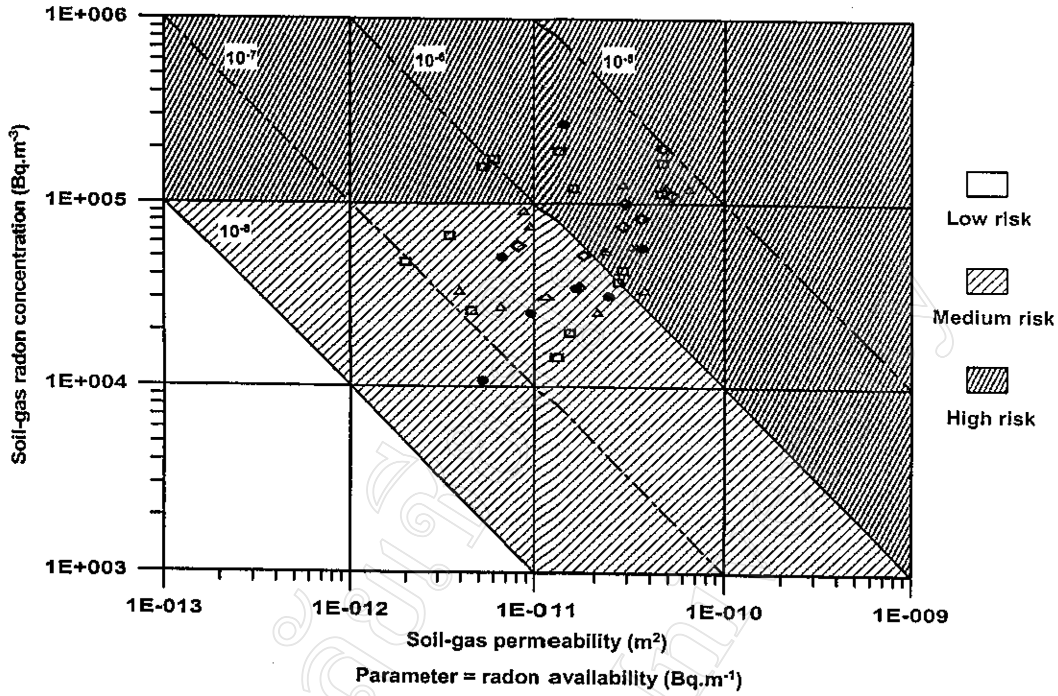

Figure 4.30 Radon risk diagram of 0.5 meters depth in summer

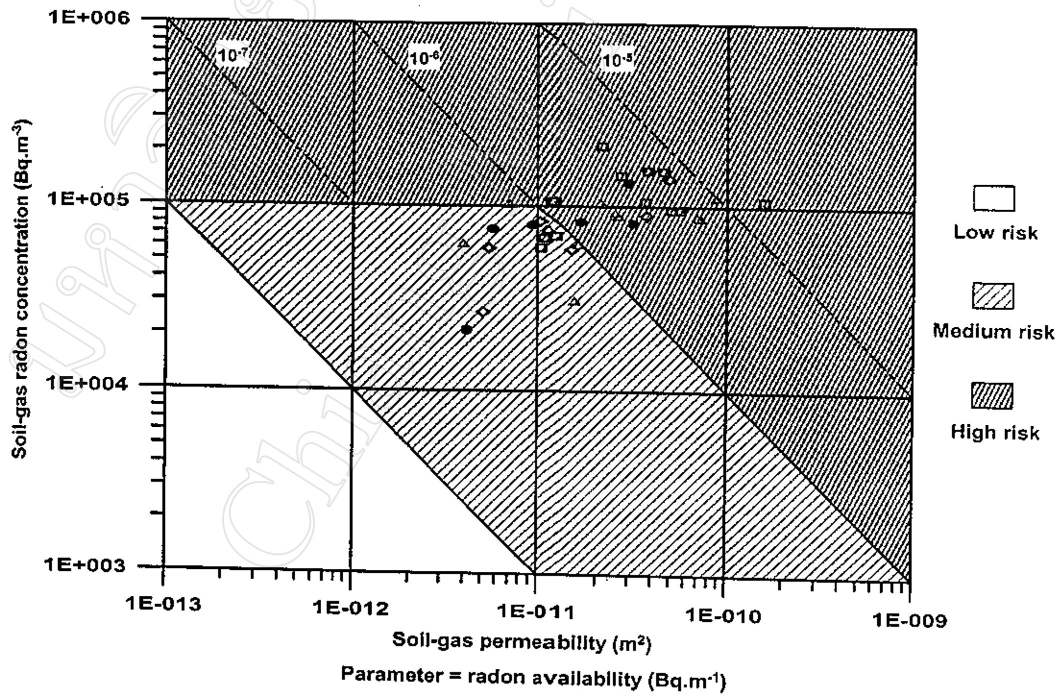

Figure 4.31 Radon risk diagram of 1.0 meters depth in winter

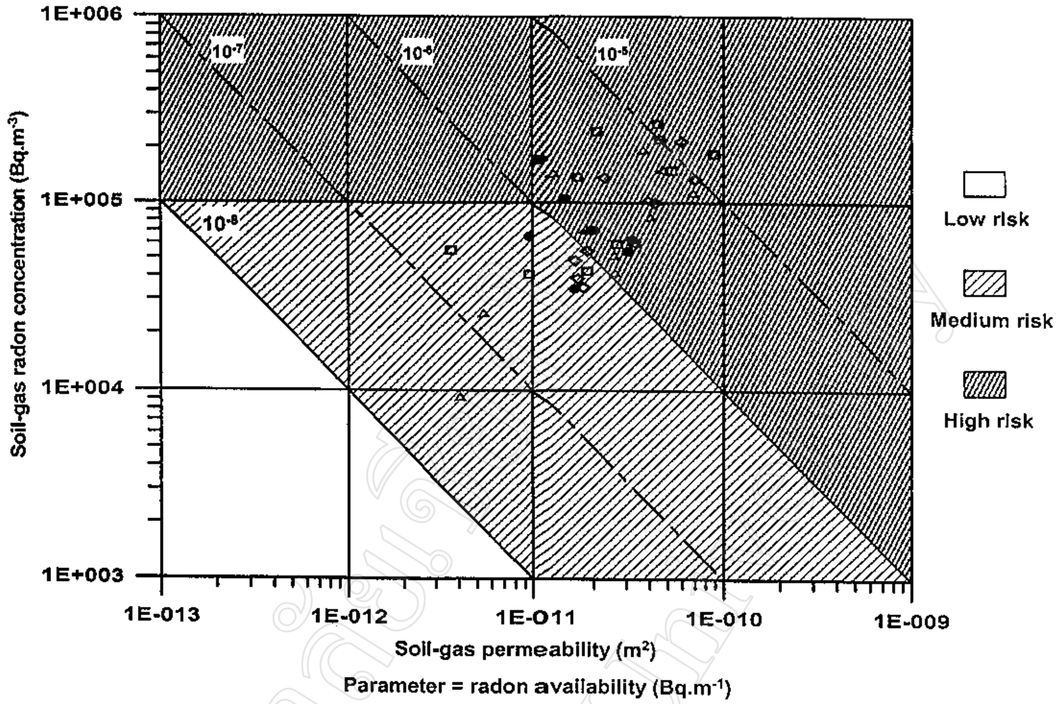

Figure 4.32 Radon risk diagram of 1.0 meters depth in summer

Figures 4.29 to 4.32 show that all houses are located in medium risk and high risk zones, regardless of season and depth of soil-gas origin. Table 4.1 shows number of houses for each house type according to depth, season and risk zones. The numbers of houses of each type were different from depth to depth and from season to season. This result indicates that radon risk diagram obtaining from plots of soil-gas radon and soil-gas permeability can not be used to estimate indoor radon risk in this small study area that has the same rock formation. This is because the values of indoor radon concentrations from house to house, in this area, vary from 38.12 to 192.41 Bq.m^{-3} in winter, 11.44 to 96.57 Bq.m^{-3} in summer and 16.18 to 64.10 Bq.m^{-3} in rainy season, with year-round average ranging from 21.12 to 101.91 Bq.m^{-3}. These values should not be high or medium risk values, especially for summer and rainy seasons, since the action level for indoor radon given by the U.S. Environmental Protection Agency is 148 Bq.m^{-3}.

Depth and season	Medium risk				High-risk			
	Type I	Type II	Type III	Type IV	Type I	Type II	Type III	Type IV
0.5 m., winter	6	6	6	9	2	1	7	3
0.5 m., summer	3	5	7	6	5	2	6	6
1.0 m., winter	6	3	3	5	2	3	9	6
1.0 m., summer	3	2	3	2	5	5	8	10

Table 4.1 Table of the number of houses in radon risk diagram

4.8 The correlation between year-round average indoor radon and some of soil parameters at 0.5-meter in summer season for type IV houses

On the basis of house type classification, type IV houses should have the strongest relationship between radon flux coming out of the ground underneath each house and indoor radon concentration in each house compared to houses of other types. Therefore, in an area where soil radon and thoron production rates are constant, if indoor radon concentration is plotted against other soil parameters the graph will be like that shown in Figure 4.33 for this type of houses. The radon flux in this figure could also be representative of indoor radon concentration.

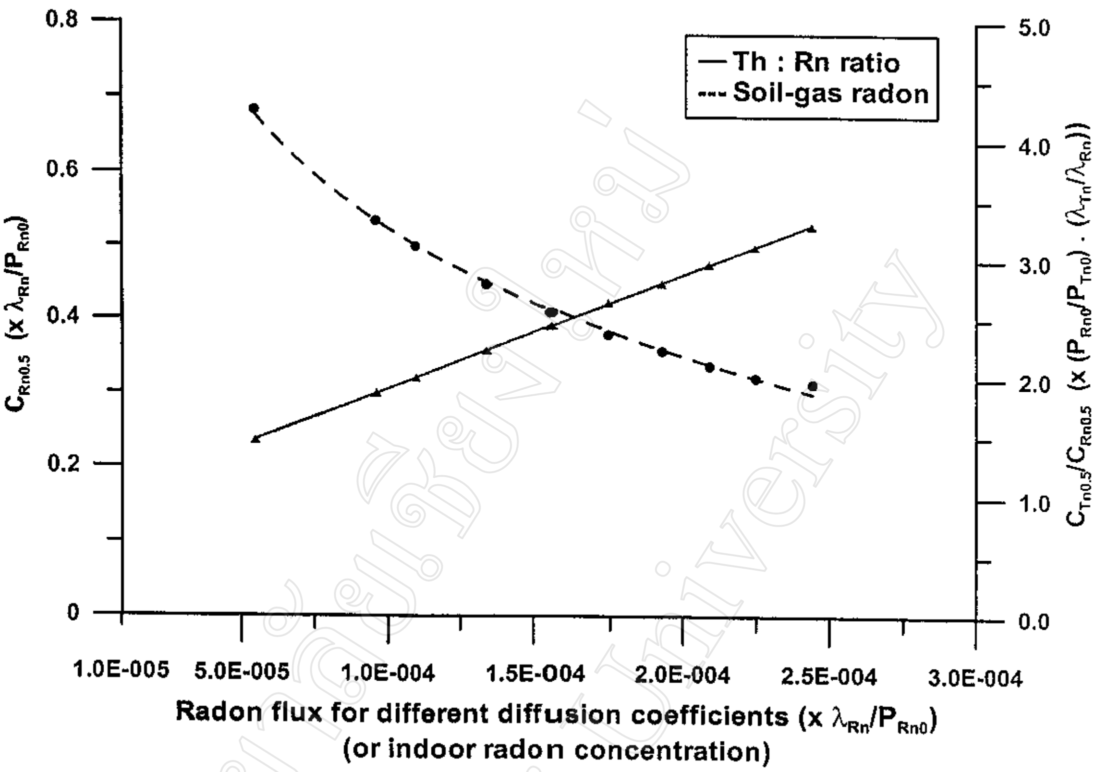

Figure 4.33 Soil-gas radon concentration and soil thoron/radon ratio versus radon flux (or indoor radon) for a set of diffusion coefficients

From the investigated data, indoor radon concentration values in winter were higher than the values in summer whereas soil-gas radon concentrations in winter were smaller than the values in summer. These may be seen already from Figure 4.33 where it is obvious that when soil-gas radon concentrations were high, radon flux were normally low.

In order to further explain results against this theory, such a graph will be plotted. However, since section 3.2 shows that soil-gas variation at a 0.5-meter depth in a base house is smallest during summer, soil radon and thoron summer values at the 0.5-meter depth will be used in these plots. This will reduce the variation of soil radon and thoron concentrations due to other factors rather than measurement positions. Also, year-round average indoor radon concentrations will be used instead of the values for each season. This will reduce the uncertainty of the indoor radon value for each house.

The plots of year-round average indoor radon concentration values versus soil-gas radon concentration are shown in Figure 4.34. Figure 4.35 shows the plots of year-round average indoor radon concentration versus soil thoron and radon ratio.

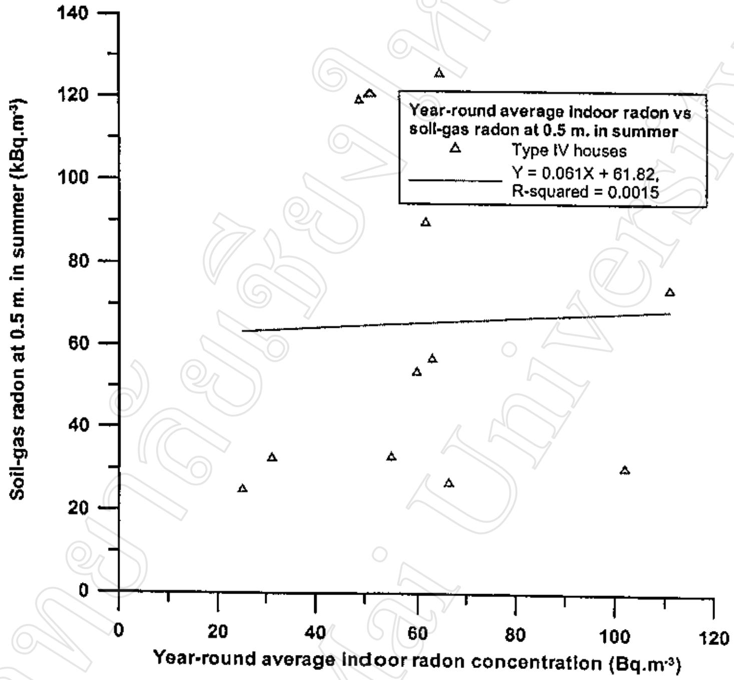

Figure 4.34 Year-round average indoor radon concentration versus soil-gas radon at 0.5-meter in summer

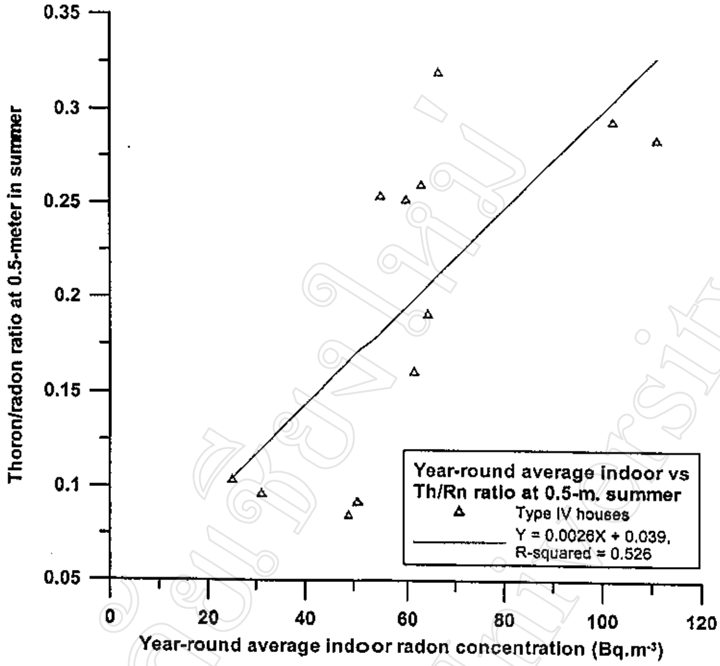

Figure 4.35 Year-round average indoor radon concentration versus thoron/radon at 0.5-meter in summer

Figure 4.34 is the least squared plot of type IV houses. It shows no correlation between year-round average indoor radon concentration and soil-gas radon concentration at a 0.5-meter depth in summer, since its r-squared value is only 0.0015. However there is a weak correlation between year-round average indoor radon concentration and thoron/radon ratio at the same depth and season shown in Figure 4.35. In Figure 4.35 the least squared plot is positive and its r-squared value is 0.526.

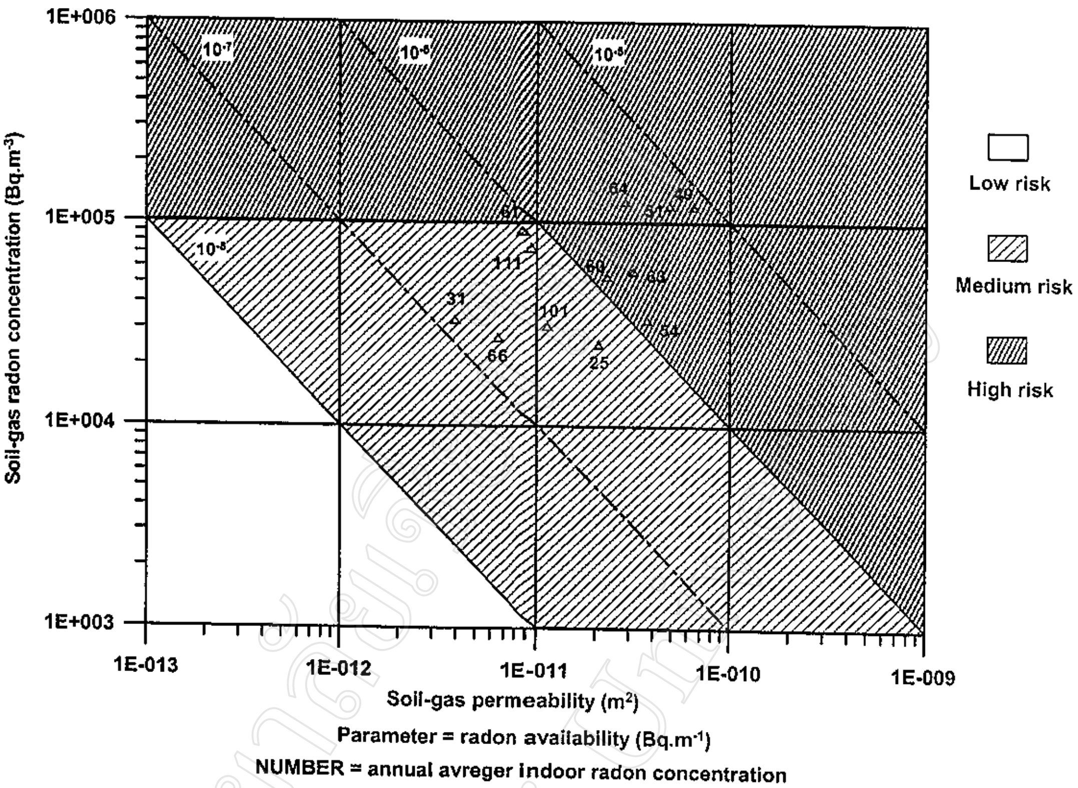

Figure 4.36 Radon risk diagram of type IV houses. Data are summer values from 0.5-meter depth; number is year-round indoor radon indication.

Figure 4.36 shows the logarithmic correlation between soil-gas radon concentration and soil-gas permeability and also indicates the year-round average indoor radon concentration for each type IV house. This correlation still fluctuates within the medium and high risk zones. Also, there is no correlation between soil-gas radon concentration, soil-gas permeability, and indoor radon concentration, i.e. lower indoor radon concentration values can occur in the high risk zone but higher indoor radon concentration can occur in medium risk zone.