Chapter Four Results and Discussion

4.1 Introduction

In this chapter the results of radon concentration, among other radiation data conducted in a multi-storey residential building is presented. The location chosen was Abdullah Hukum Apartment, a high density dwelling in Kuala Lumpur. The method chosen was LR-115 type II films placed in a canister for collecting radon, thoron, and potential alpha energy concentrations. These data were collected and analysed in sixty different units representing the whole building. These data were also analysed based on the floor levels to allow for an understanding of radiation diffusion as a function of floor levels of a multi-storey building. Additionally surveys were carried out to address for any likely variations in the measured concentration that may arise due to characteristics of household fixtures and furnishings.

4.2 Radon Concentration Variations as a Function of Floor Level

Figure 4.1 and Table 4.1 outline the results of the indoor radon concentration in a multi storey apartment. In Figure 4.1, the graph depicts the first floor of the apartment with the maximum concentration (42.21 Bq/m^3) of all floor levels. Second floor indoor radon concentration is second highest (26.18 Bq/m^3), albeit drastically reduced by thirty-eight percent (38%). Incidentally the tenth floor (26.01 Bq/m^3) spiked again in the indoor radon concentration and is the third highest.

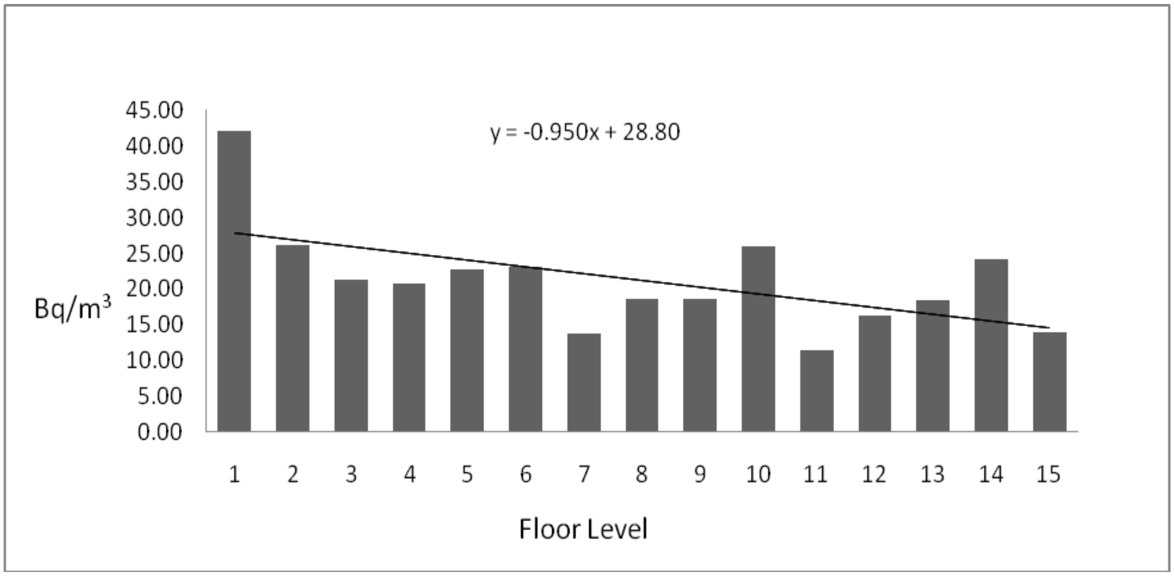


Figure 4.1 Radon concentration variations as a function of floor level

For the third (21.32 Bq/m^3), fourth (20.88 Bq/m^3), fifth (22.81 Bq/m^3), sixth (23.20 Bq/m^3), and fourteenth (24.12 Bq/m^3) floors, the indoor radon concentration are measuring above 20 Bq/m^3. Three major dips occur at seventh (13.77 Bq/m^3), eleventh (11.45 Bq/m^3), and fifteenth floors (14.04 Bq/m^3). The seventh (13.77 Bq/m^3), eighth (18.70 Bq/m^3), ninth (18.73 Bq/m^3), eleventh (11.45 Bq/m^3), twelfth (16.23 Bq/m^3), thirteenth (18.42 Bq/m^3), and fifteenth floors (14.04 Bq/m^3), all measured values are below 20 Bq/m^3.

The minimum and the maximum range is found between 11.45 Bq/m^3 and 42.21 Bq/m^3 (arithmetic mean values), with an average of 21.2 Bq/m^3, and standard deviation of 0.51. The gradient ratio of the trend line for radon concentration is -0.95, and intercept the y-axis at 28.81 Bq/m^3. This value indicates for a probable ground site radon concentration. The trend line specifies for space variation of radon concentration in the multi-storey building.

The decreasing trend line is reflective and confirms of a hypothesis stating that soil radon diffusion indoor reduces as the floor level goes higher above ground level.

Table 4.1 Measured values of PAEC, Tn, Rn, DE and EDE. AM-Arithmetic Means, GM- Geometric Means, STDEV-Standard Deviation.

			mWL	Thoron Concent	Bq/m3	Radon Concentr	Bq/m3	mSv/y (DE)	mSv/y (EDE)
1	AM		4.0		0.1		42.2	1.1	2.7
	GM		3.8		0.1		42.1	1.1	2.7
	STDEV		1.3		0.1		2.7	0.1	0.2
2	AM		2.4		0.2		26.2	0.7	1.7
	GM		2.4		0.2		25.7	0.7	1.6
	STDEV		0.5		0.2		5.2	0.1	0.3
3	AM		5.7		0.2		21.3	0.6	1.4
	GM		5.6		0.1		21.2	0.6	1.3
	STDEV		1.1		0.2		2.3	0.1	0.1
4	AM		3.2		0.3		20.9	0.6	1.3
	GM		2.4		0.2		20.0	0.5	1.3
	STDEV		2.5		0.3		5.7	0.2	0.4
5	AM		2.8		0.1		22.8	0.6	1.4
	GM		2.4		0.1		22.7	0.6	1.4
	STDEV		1.6		0.0		2.4	0.1	0.2
6	AM		2.9		0.1		23.2	0.6	1.5
	GM		2.8		0.1		22.4	0.6	1.4
	STDEV		0.8		0.1		5.6	0.1	0.4
7	AM		6.0		0.3		13.8	0.4	0.9
	GM		4.2		0.2		13.8	0.4	0.9
	STDEV		4.7		0.2		0.3	0.0	0.0
8	AM		1.9		0.1		18.7	0.5	1.2
	GM		1.8		0.1		17.7	0.5	1.1
	STDEV		0.7		0.1		6.2	0.2	0.4
9	AM		2.0		0.4		18.7	0.5	1.2
	GM		2.0		0.2		17.6	0.5	1.1
	STDEV		0.6		0.3		6.5	0.2	0.4
10	AM		2.6		0.2		26.0	0.7	1.7
	GM		2.3		0.2		25.1	0.7	1.6
	STDEV		1.2		0.2		6.3	0.2	0.4
11	AM		4.1		0.5		11.4	0.3	0.7
	GM		3.2		0.3		11.0	0.3	0.7
	STDEV		2.6		0.3		3.3	0.1	0.2
12	AM		1.2		0.1		16.2	0.4	1.0
	GM		1.2		0.1		15.6	0.4	1.0
	STDEV		0.3		0.0		4.5	0.1	0.3
13	AM		1.6		0.1		18.4	0.5	1.2
	GM		1.4		0.1		17.3	0.5	1.1
	STDEV		0.9		0.2		6.4	0.2	0.4
14	AM		2.5		0.1		24.1	0.6	1.5
	GM		2.3		0.0		23.9	0.6	1.5
	STDEV		1.0		0.0		2.9	0.1	0.2
15	AM		4.3		0.1		14.0	0.4	0.9
	GM		3.6		0.0		12.0	0.3	0.8
	STDEV		2.2		0.0		7.6	0.2	0.5

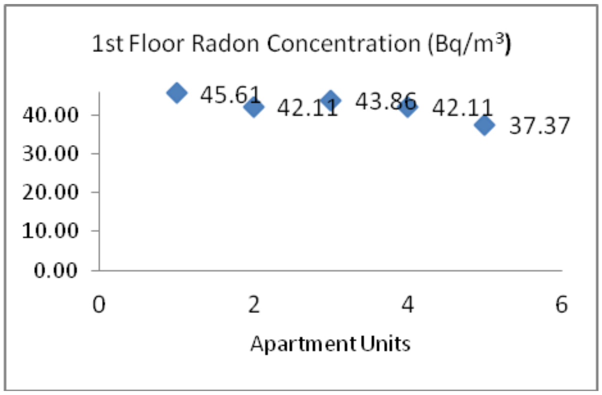
4.3 Floor Level Variation of Radon Concentration

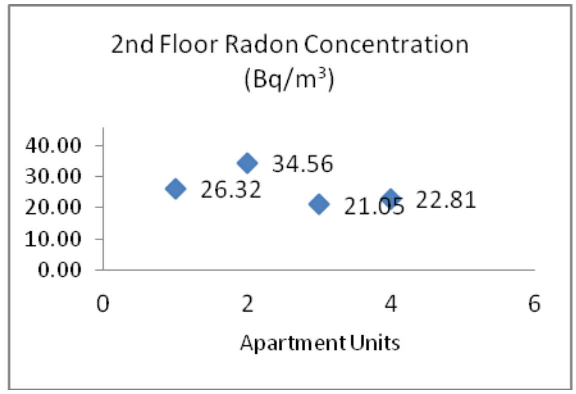
The mean radon concentration in the dwellings of every floor level is depicted in Figure 4.2. In each floor, the measurements were taken in four, five or six different apartment units.

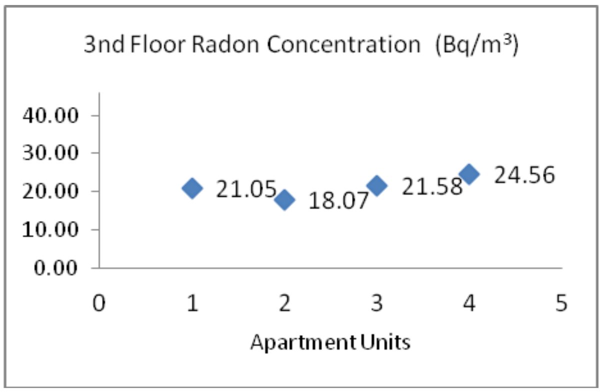
Accordingly, apartment units in the first floor of the building accumulated the highest indoor radon concentration. The minimum value measured was 37.37 Bq/m^3, while the maximum was at 45.61 Bq/m^3.

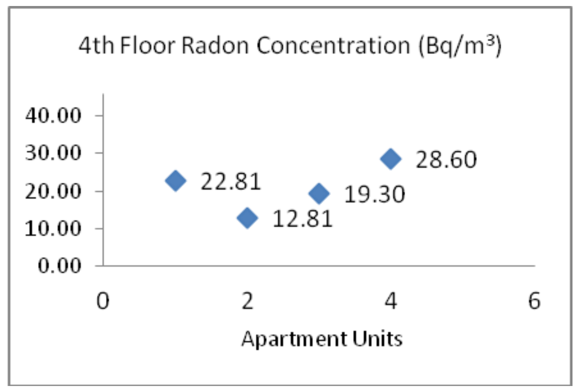
The second floor gives 34.56 Bq/m^3 as the maximum reading and 21.05 Bq/m^3 the minimum. Two units at the tenth floor gives out maximum reading at 31.58 Bq/m^3 each. One unit measures at 24.56 Bq/m^3 while the one other unit gives out the floor's minimum reading at 16.32 Bq/m^3. The tenth floor measurements combined ranked third highest in Figure 4.2. One apartment unit reached 22.81 Bq/m^3, whereas other units measured well below 20 Bq/m^3.

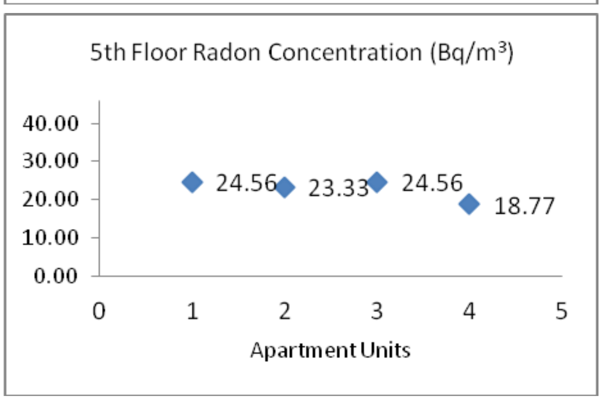
The lowest measurement in a unit occurred on the fifteenth floor. It reads 5.26 Bq/m^3. The only other unit that gives single digit measurement is 8.25 Bq/m^3 on the eleventh floor. A chart in Table 4.1 contains the data by floor level of which provides for the discussion throughout the section.

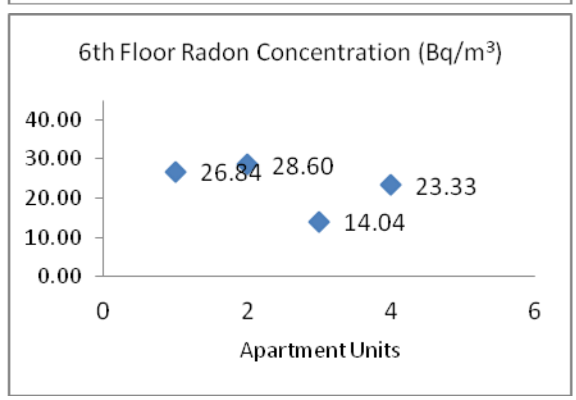

1st Floor Radon Concentration (Bq/m^3)
45.61
42.11
43.86
42.11
37.37
40.00
30.00
20.00
10.00
0.00
0
2
4
6
Apartment Units

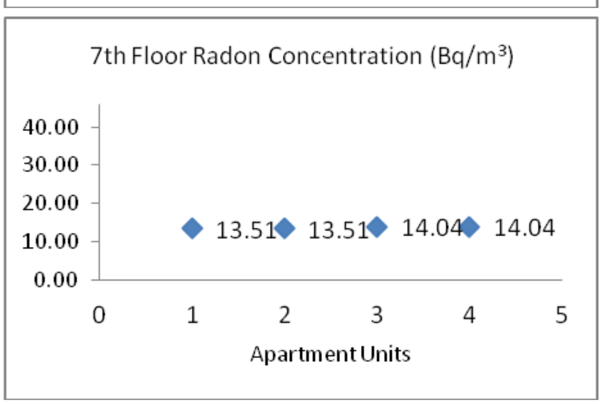

2nd Floor Radon Concentration (Bq/m^3)
34.56
26.32
21.05
22.81
40.00
30.00
20.00
10.00
0.00
0
2
4
6
Apartment Units

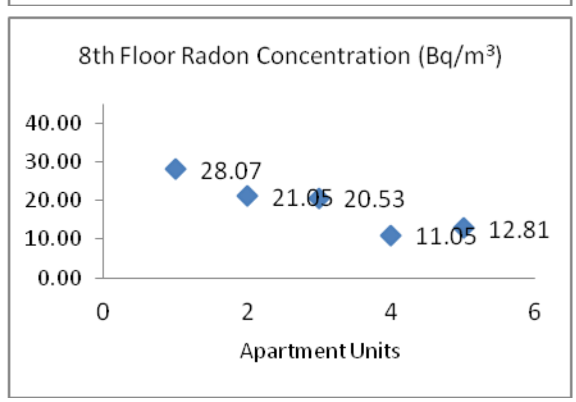

3nd Floor Radon Concentration (Bq/m^3)
21.05
18.07
21.58
24.56
40.00
30.00
20.00
10.00
0.00
0
1
2
3
4
5
Apartment Units


4th Floor Radon Concentration (Bq/m^3)
22.81
12.81
19.30
28.60
40.00
30.00
20.00
10.00
0.00
0
2
4
6
Apartment Units


5th Floor Radon Concentration (Bq/m^3)
24.56
23.33
24.56
18.77
40.00
30.00
20.00
10.00
0.00
0
1
2
3
4
5
Apartment Units


6th Floor Radon Concentration (Bq/m^3)
26.84
28.60
14.04
23.33
40.00
30.00
20.00
10.00
0.00
0
2
4
6
Apartment Units


7th Floor Radon Concentration (Bq/m^3)
13.51
13.51
14.04
14.04
40.00
30.00
20.00
10.00
0.00
0
1
2
3
4
5
Apartment Units


8th Floor Radon Concentration (Bq/m^3)
28.07
21.05
20.53
11.05
12.81
40.00
30.00
20.00
10.00
0.00
0
2
4
6
Apartment Units

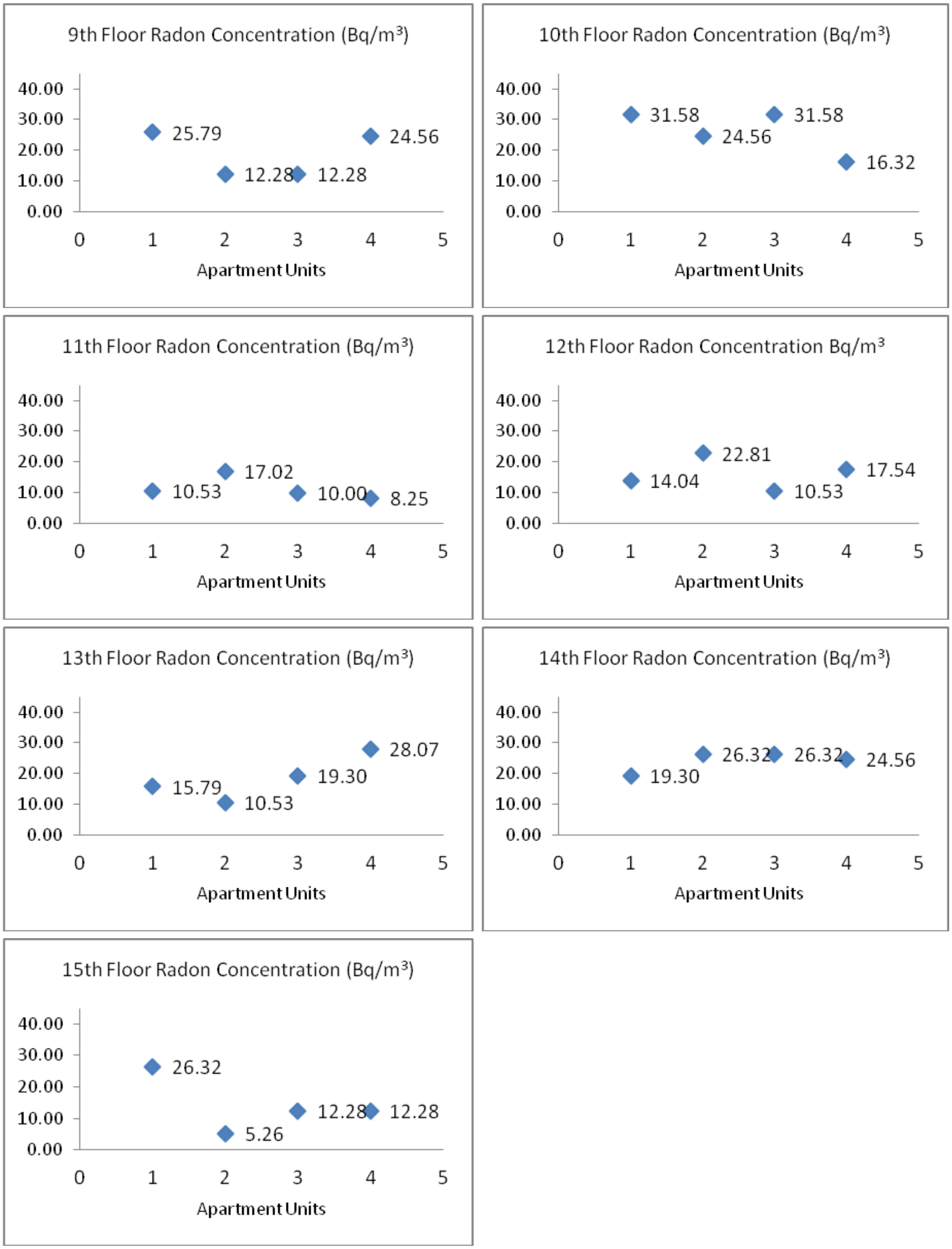


Figure 4.2 Total Charts for Radon Concentration in Bq/m^3 for individual floors in a multi-storey building

4.4 Thoron Concentration

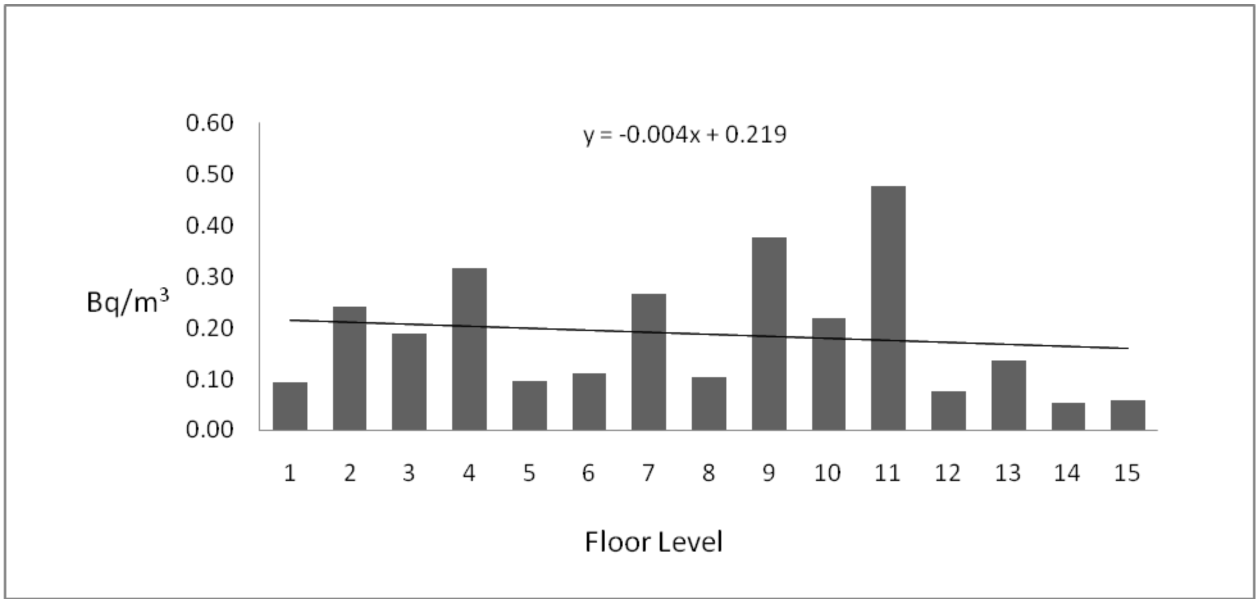


Figure 4.3 Thoron Concentration Variations in between Floors

The range of indoor thoron measurement in the multi-storey apartment reads between 0.05 Bq/m^3 (minimum) on the fourteenth floor, and 0.48 Bq/m^3 (maximum) on the eleventh floor. In terms of any meaningful ranking, the highest indoor thoron concentration occurred on the eleventh floor (0.48 Bq/m^3), fell next on ninth floor (0.38 Bq/m^3), and then the fourth floor (0.32 Bq/m^3). These three floors measured well above 0.30 Bq/m^3. As for the lowest measurements of thoron at the apartment, fourteenth floor (0.05 Bq/m^3) is followed by fifteenth floor (0.06 Bq/m^3), then twelfth floor (0.08 Bq/m^3), then first floor (0.09 Bq/m^3). These four floors measured below 0.10 Bq/m^3.

The minimum and maximum range is found between 0.05 Bq/m^3 and 0.48 Bq/m^3 (arithmetic mean values), with an average of 0.2 Bq/m^3, and standard deviation of 0.02.

The gradient ratio for thoron concentration is -0.004. The y-intercept is 0.219 Bq/m^3, therefore indicating a probable ground site thoron concentration at 0.219 Bq/m^3.

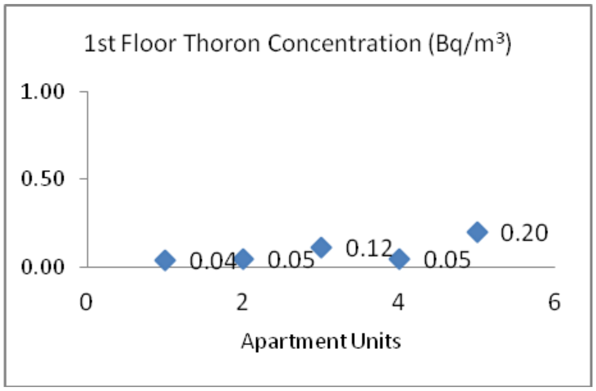
There is unpredictability in relating floor level to indoor thoron concentration due to irregular spikes as observed in Figure 4.3. Though in summary, thoron concentration at the apartment is absolutely low overall.

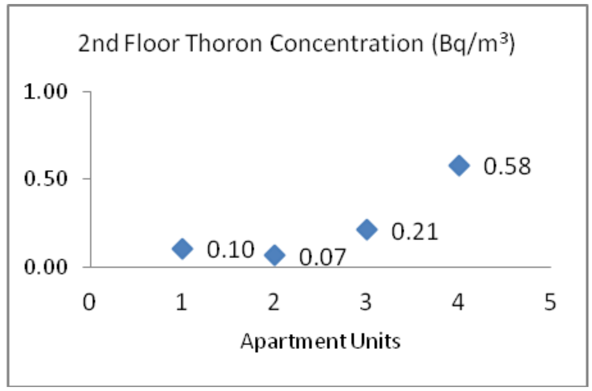
4.5 Floor Level Variation of Thoron Concentration

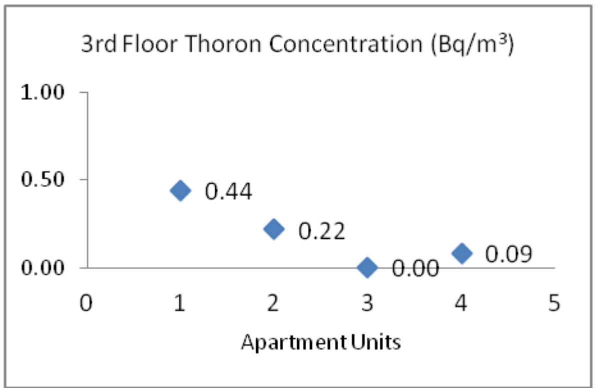
An apartment unit with the highest measured indoor thoron reads 0.86 Bq/m^3 on the fourth floor, followed by a dwelling unit on the eleventh floor 0.76 Bq/m^3. Accordingly in Figure 4.4, the highest indoor thoron does not measure above 1.00 Bq/m^3 in any apartment unit measured.

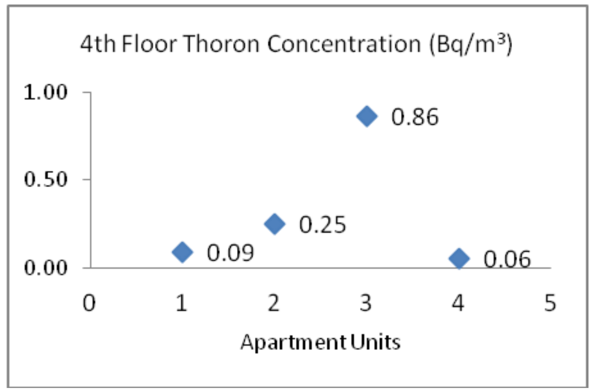
An apartment unit on the third floor reads 0.00 Bq/m^3. On the thirteenth floor, fourteenth floor, and fifteenth floor, each contained units that read only 0.01 Bq/m^3. According to Figure 4.4, indeed apartment units are measuring towards the very low end of the scale that is below 0.2 Bq/m^3. This is in compatibility with Figure 4.3 that shows an overall low thoron concentration at all floors that is not exceeding 0.50 Bq/m^3.

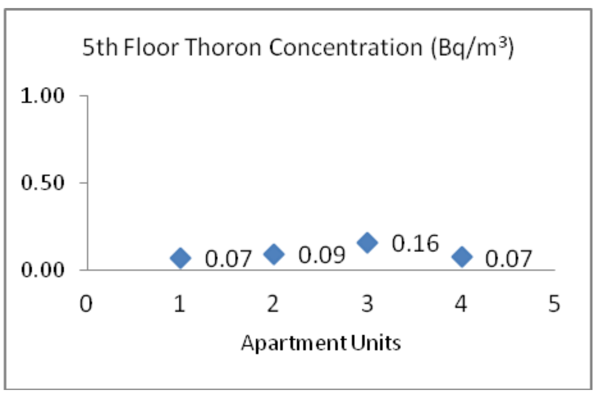
The research project was carried out within the two year after the completion of the apartment. By assuming that radon and thoron were generated during the construction process, then thoron concentration would have been significantly depleted.

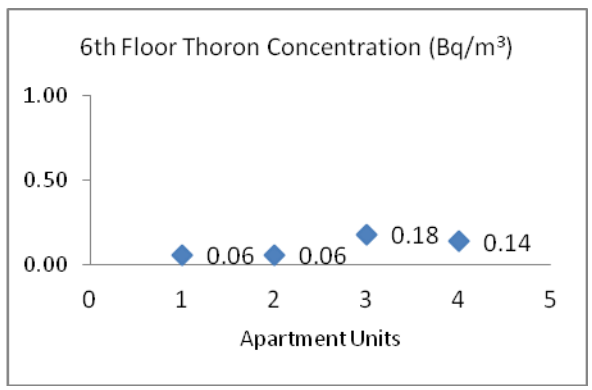

1st Floor Thoron Concentration (Bq/m³)
1.00
0.50
0.00
0.04
0.05
0.12
0.05
0.20
0
2
4
6
Apartment Units

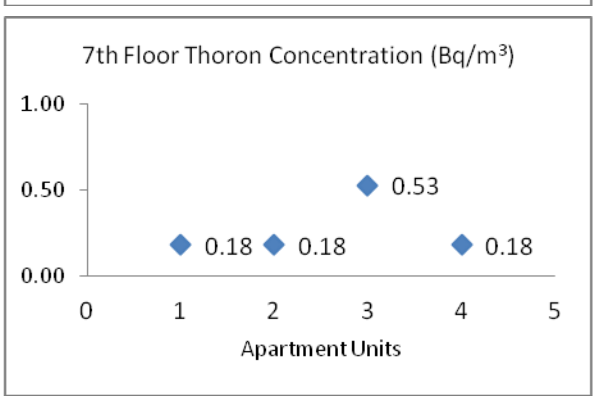

2nd Floor Thoron Concentration (Bq/m³)
1.00
0.50
0.00
0.10
0.07
0.21
0.58
0
1
2
3
4
5
Apartment Units

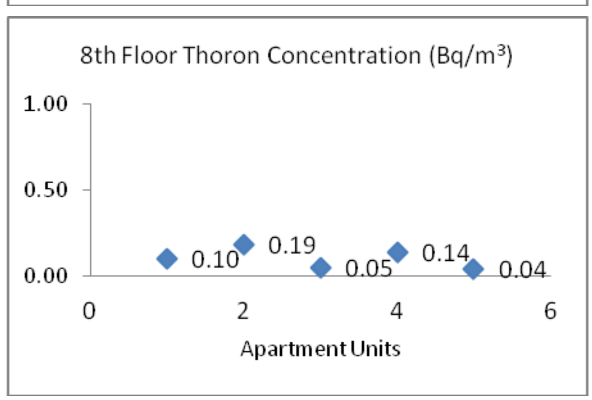

3rd Floor Thoron Concentration (Bq/m³)
1.00
0.50
0.00
0.44
0.22
0.00
0.09
0
1
2
3
4
5
Apartment Units


4th Floor Thoron Concentration (Bq/m³)
1.00
0.50
0.00
0.09
0.25
0.86
0.06
0
1
2
3
4
5
Apartment Units


5th Floor Thoron Concentration (Bq/m³)
1.00
0.50
0.00
0.07
0.09
0.16
0.07
0
1
2
3
4
5
Apartment Units


6th Floor Thoron Concentration (Bq/m³)
1.00
0.50
0.00
0.06
0.06
0.18
0.14
0
1
2
3
4
5
Apartment Units


7th Floor Thoron Concentration (Bq/m³)
1.00
0.50
0.00
0.18
0.18
0.53
0.18
0
1
2
3
4
5
Apartment Units


8th Floor Thoron Concentration (Bq/m³)
1.00
0.50
0.00
0.10
0.19
0.05
0.14
0.04
0
2
4
6
Apartment Units

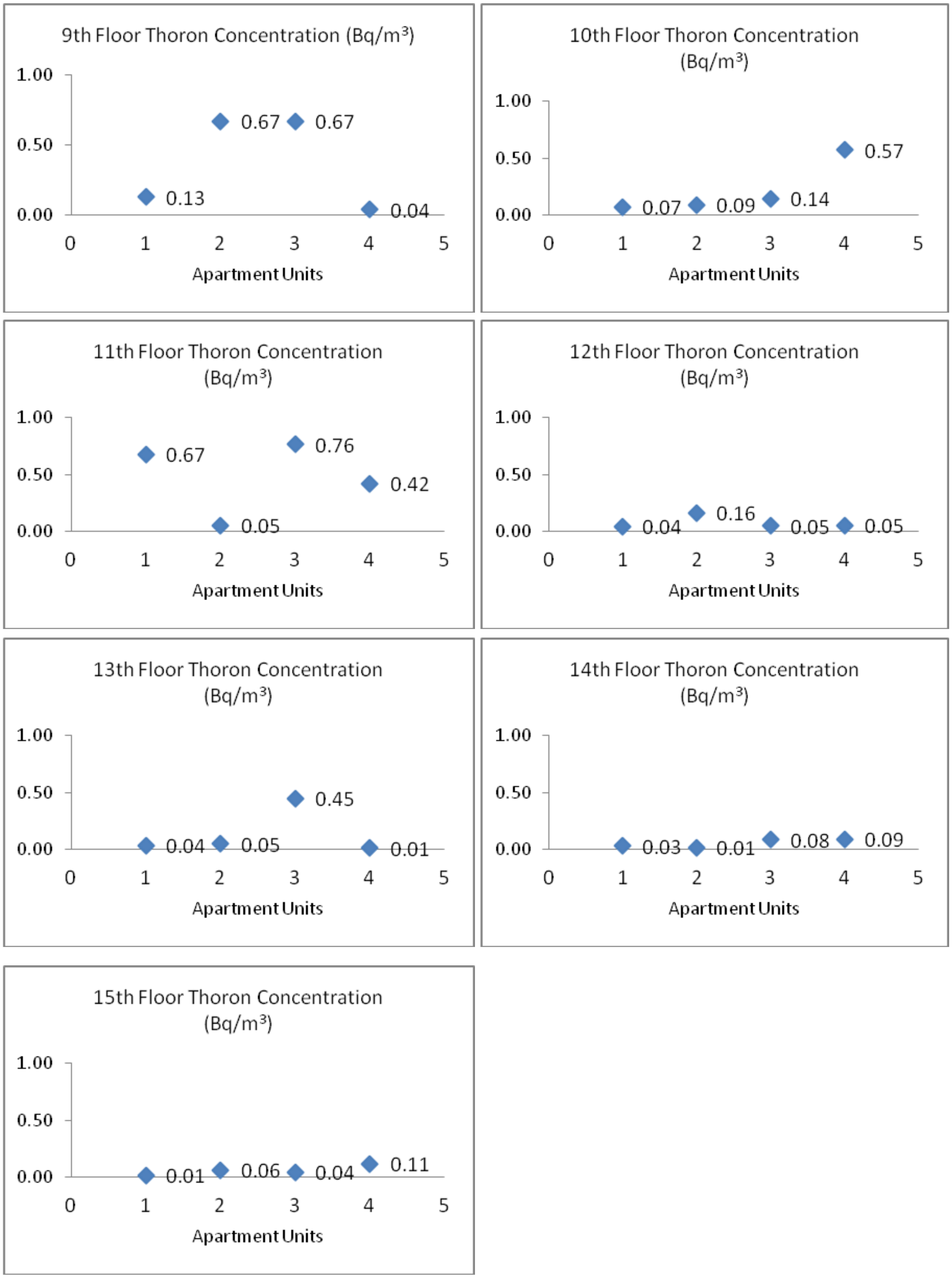


Figure 4.4 Total Charts for Thoron Concentration in Bq/m3 for individual floors in a multi-storey building

4.6 Effective Dose Equivalent (EDE)

Based on the concentrations of radon and thoron, Figure 4.5 depicts a calculated and not device-measured annual effective dose equivalent in mSv/y on human residents, at all floor levels. It is to account for inhalation dose impact and the variation is observed to exhibit similar patterns to Figure 4.1.

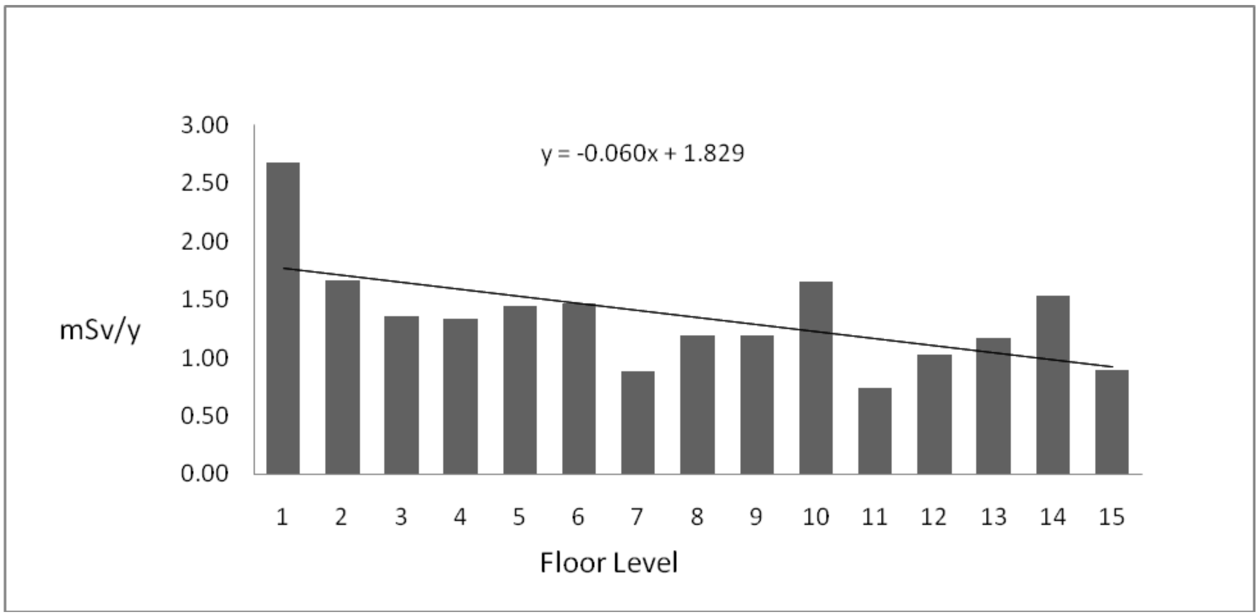


Figure 4.5 Variation of EDE between Floor Levels

The estimated effective dose equivalent in the first floor is about 2.68 mSv/y which is notably slightly higher than the world average of 1.00 mSv/y (UNSCEAR 2000). Second floor is the second highest in EDE although the value fell to 1.66 mSv/y. On the tenth floor it measures 1.65 mSv/y.

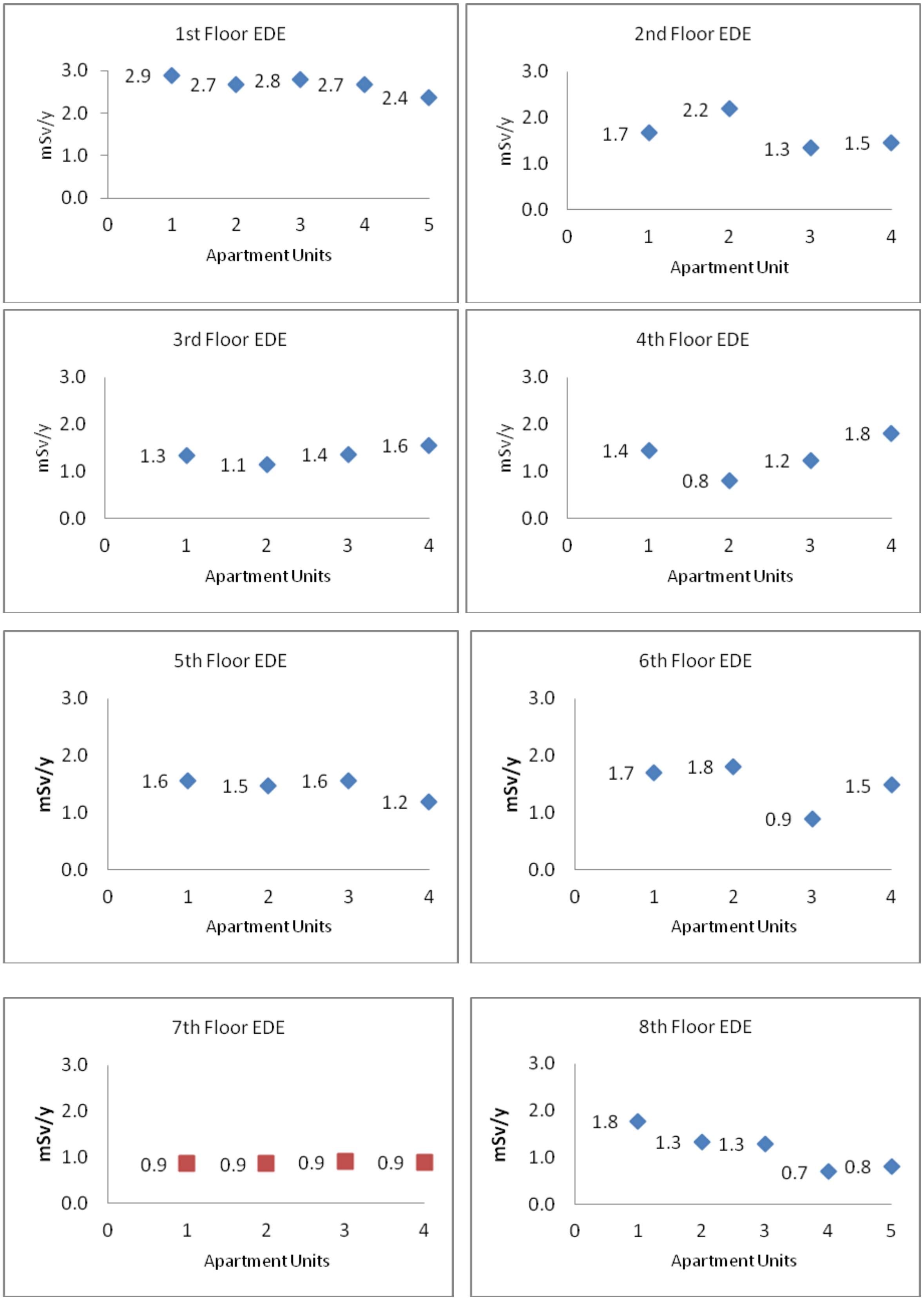
For eleventh floor, the EDE is lowest (0.74 mSv/y), followed by the seventh floor (0.88 mSv/y), and the fifteenth floor (0.89 mSv/y). These three floors measure below the 1.00 mSv/y, the recommended threshold level (UNSCEAR 2000). The results showed eighty percent of the building units with EDE level higher than 1.00 mSv/y.

The second floor to the fifteenth floor level EDE values obtained do not show any pattern. At this point, seventh, eleventh and fifteenth floor level of EDE provide no plausible reason of observation, though these results can be assessed in more details when we look into the household survey data in section 4.10.

There is a gradation in the inhalation dose attributable to radon from the first floor to the upper levels. Some irregularities seen in the apartment building are the result of individual ventilation. In the tenth floor level, windows are rarely opened. There are observed construction and traffic activities in the area that bring dust in the breeze from nearby resulting in modest ventilation for that floor level.

4.7 Floor Level Variation in Effective Dose Equivalent

The effective dose equivalent in mSv/y to every resident in the fifteen floor dwellings is similarly depicted in the fifteen charts in Figure 4.6.


1st Floor EDE
mSv/y
3.0
2.0
1.0
0.0
2.9
2.7
2.8
2.7
2.4
0
1
2
3
4
5
Apartment Units
2nd Floor EDE
mSv/y
3.0
2.0
1.0
0.0
1.7
2.2
1.3
1.5
0
1
2
3
4
Apartment Unit
3rd Floor EDE
mSv/y
3.0
2.0
1.0
0.0
1.3
1.1
1.4
1.6
0
1
2
3
4
Apartment Units
4th Floor EDE
mSv/y
3.0
2.0
1.0
0.0
1.4
0.8
1.2
1.8
0
1
2
3
4
Apartment Units
5th Floor EDE
mSv/y
3.0
2.0
1.0
0.0
1.6
1.5
1.6
1.2
0
1
2
3
4
Apartment Units
6th Floor EDE
mSv/y
3.0
2.0
1.0
0.0
1.7
1.8
0.9
1.5
0
1
2
3
4
Apartment Units
7th Floor EDE
mSv/y
3.0
2.0
1.0
0.0
0.9
0.9
0.9
0.9
0
1
2
3
4
Apartment Units
8th Floor EDE
mSv/y
3.0
2.0
1.0
0.0
1.8
1.3
1.3
0.7
0.8
0
1
2
3
4
5
Apartment Units

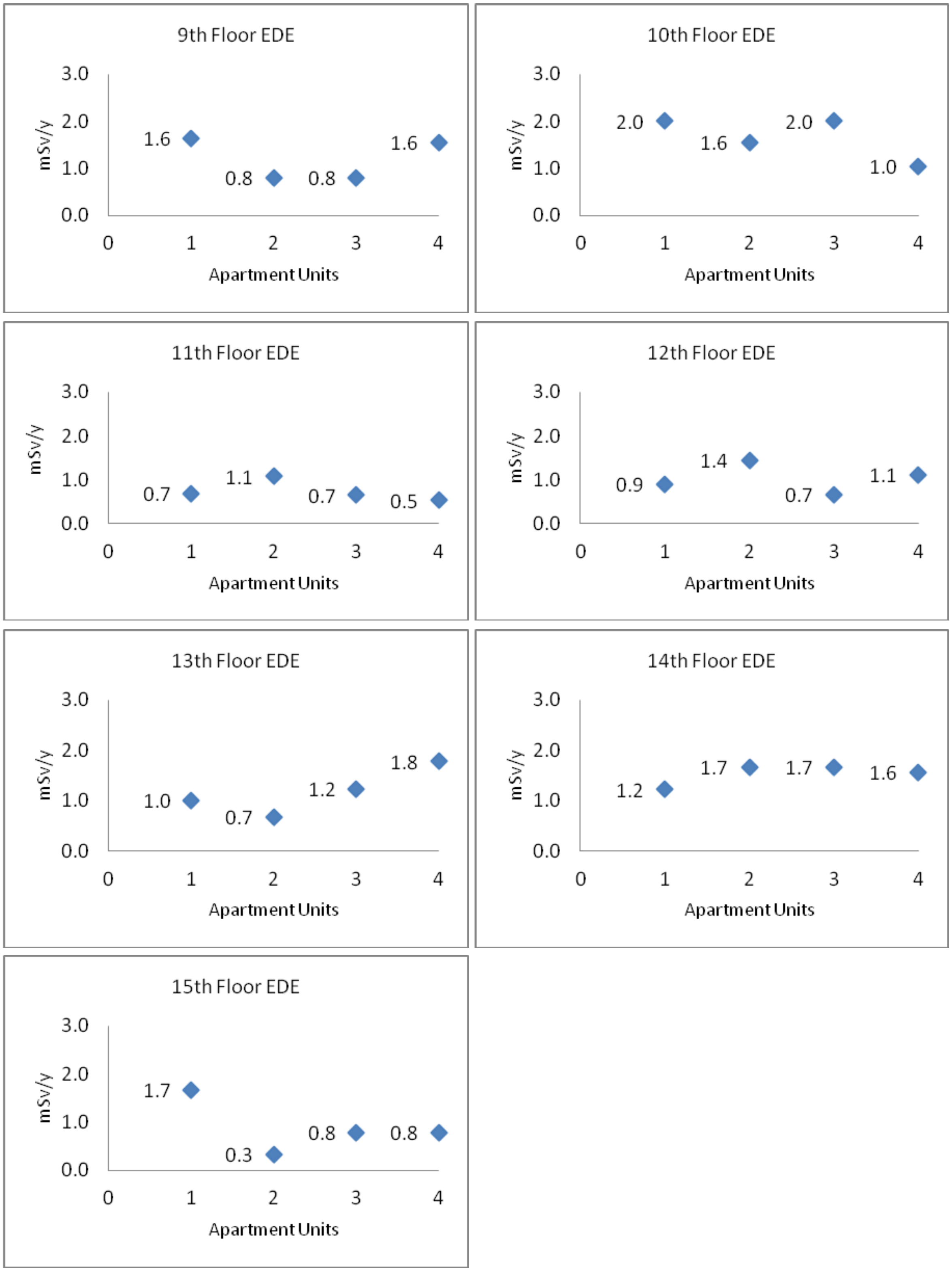


Figure 4.6 Total charts for effective dose equivalent in mSv/y for individual floors in a multi-storey building

1.00 mSv/y is an important reference level in effective dose equivalent study (UNSCEAR 2000). The maximum reading on the first floor is 2.9 mSv/y, which is also the highest reading for the entire study. The first floor apartment units read highly in the EDE and it is the only floor where EDE read above 2.00 mSv/y for all units studied.

The maximum on the second floor read 2.2 mSv/y. The second floor read EDE above 2.00 mSv/y in one unit and above 1.00 mSv/y in three units. The apartment units in third, fifth, fourteenth floor, read EDE between 1.00 mSv/y and 1.99 mSv/y.

The apartment units in fourth, sixth, eighth, ninth, eleventh, twelfth, thirteenth, fifteenth floor, read EDE right about 1.00 mSv/y, that is some units read above 1.00 mSv/y (but below 2.00 mSv/y), while some units went below 1.00 mSv/y already.

Incidentally on the seventh floor, all apartment units give equalised EDE at 0.9 mSv/y. On the fifteenth floor, the minimum EDE occurred at 0.3 mSv/y in one apartment unit, this is also the lowest reading for the entire study.

4.8 Potential Alpha Energy Concentration (PAEC)

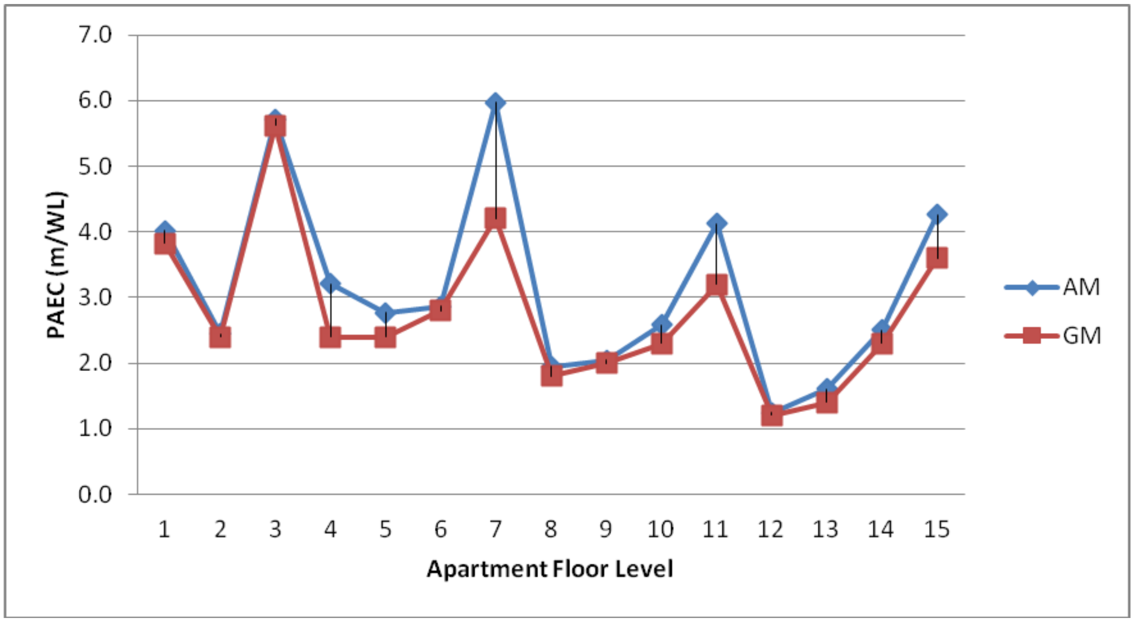


Figure 4.7 Variation of PAEC between Floor Levels

The PAEC is a radiation study independent of radon and thoron measurements. Figure 4.7 showed variation in PAEC as a function of floor levels. The arithmetic mean (A.M.) values of the PAEC are shown as diamond point in Figure 4.7. The first floor read 4.0 mWL. The highest floor on level fifteenth read 4.3 mWL. The fluctuation in between ranged from 1.2 mWL (twelfth floor) to 6.0 mWL (seventh floor).

The variation of the geometric mean (G.M.) of the PAEC is shown as square points in Figure 4.7. The geometric mean values do not move away from the exact trends of the arithmetic mean values except that these values are read slightly lower, and coincided only on the few floor levels of the second, ninth, twelfth floor.

The values of the arithmetic mean and geometric mean of the PAEC for the different floor levels, and the exposure time in days is tabulated in Table 4.2.

Table 4.2 Summary of arithmetic mean and geometric mean of PAEC as a function of floor level.

Floor Level	PAEC values (AM)	PAEC values (GM)	Exposure Time (Average Number of Days
1	4.0	3.8	45
2	2.4	2.4	55
3	5.7	5.6	51
4	3.2	2.4	57
5	2.8	2.4	61
6	2.9	2.8	54
7	6.0	4.2	58
8	1.9	1.8	56
9	2.0	2.0	51
10	2.6	2.3	58
11	4.1	3.2	46
12	1.2	1.2	51
13	1.6	1.4	52
14	2.5	2.3	49
15	4.3	3.6	54

Details of the actual data collected which included tract measurements of individual units within a level is shown in Table 4.4 (page 68). The plots of the variation in PAEC values between units within the same floor level are also shown in Fig.4.8. Table 4.3 is a full reading chart to the raw data collected on the SSNTD track intensity, PAEC level, and time in the number of exposure days for each apartment unit measured.

Table 4.3 Tabulation Sample of Raw Data Collected: Track Intensity, PAEC Level, and Number of Exposure Days (Time)

			Days Exposed
Codes	Tr/cm2	PAEC(mWL)	
			38
00N--B	74	6.06	
00S--B	62	5.08	49
00E20B	38	3.11	50
00W35B	35.7	2.92	60
00W30B	35.4	2.90	30
AM		**4.01**	58
GM		**3.82**	
STDEV		**#NAME?**	
01N01B	24.3	1.99	63
01S10B	25.3	2.07	55
01E28B	29	2.38	48
01W30B	41	3.36	53
AM		**2.45**	48
GM		**2.39**	49
STDEV		**#NAME?**	
02W35B	56.7	4.64	46
02S01B	90.7	7.43	62
02E28B	72	5.90	48
02W29B	59.7	4.89	47
AM		**5.71**	89
GM		**5.62**	48
STDEV		**#NAME?**	
03W38B	23	1.88	53
03S11B	12.7	1.04	55
03W39B	92	7.53	63
03W34B	29	2.38	56
AM		**3.21**	56.75
GM		**2.43**	
STDEV		**#NAME?**	
04N01B	20	1.64	57
04S11B	22.7	1.86	57
04N04B	24	1.97	61
04W32B	68.3	5.59	68
AM		**2.76**	60.75
GM		**2.41**	
STDEV		**#NAME?**	
05W40B	23	1.88	48
05E20B	47.3	3.87	53
05E27B	28.3	2.32	57
05W38B	41.3	3.38	57
AM		**2.86**	53.75
GM		**2.75**	
STDEV		**#NAME?**	
06N05B	33	2.70	58
06W39B	16	1.31	55
06E28B	78	6.39	62
06W30B	164.7	13.49	58
AM		**5.97**	77
GM		**4.18**	
STDEV		**#NAME?**	
07N08B	38	3.11	53
07S18B	26	2.13	48
07E19B	16	1.31	85
07W38B	12.3	1.01	48
07W37B	26.7	2.19	48
AM		**1.95**	73
GM		**1.80**	
STDEV		**#NAME?**	

Table 4.3 (Continue)

08N10B	38	3.11	51
08S18B	20.7	1.70	50
08N15B	21.3	1.74	51
08W33B	20	1.64	50
AM		**2.05**	73
GM		**1.97**	72
STDEV		**#NAME?**	31
09N--B	17	1.39	
09S08B	18	1.47	58
09W35B	49.7	4.07	
09W39B	41.3	3.38	58
AM		**2.58**	58
GM		**2.31**	
STDEV		**#NAME?**	
10E28B	18	1.47	50
10S16B	81.7	6.69	32
10E25B	19	1.56	52
10W35B	82.7	6.77	50
AM		**4.12**	46
GM		**3.19**	
STDEV		**#NAME?**	
11W36B	10.7	0.88	52
11W29B	19	1.56	52
11W35B	14	1.15	52
11W22B	17	1.39	48
AM		**1.24**	51
GM		**1.21**	
STDEV		**#NAME?**	
12N03B	15.3	1.25	48
12S11B	13	1.06	53
12E20B	38	3.11	50
12W--B	12	0.98	58
AM		**1.60**	52.25
GM		**1.42**	
STDEV		**#NAME?**	
13N09B	15.7	1.29	48
13S11B	33	2.70	48
13S13B	25	2.05	51
13W37B	48.7	3.99	48
AM		**2.51**	48.75
GM		**2.31**	
STDEV		**#NAME?**	
14N09B	20	1.64	50
14S15B	77	6.31	58
14N02B	30.7	2.51	48
14W30B	80.7	6.61	58
AM		**4.27**	47
GM		**3.62**	
STDEV		**#NAME?**	

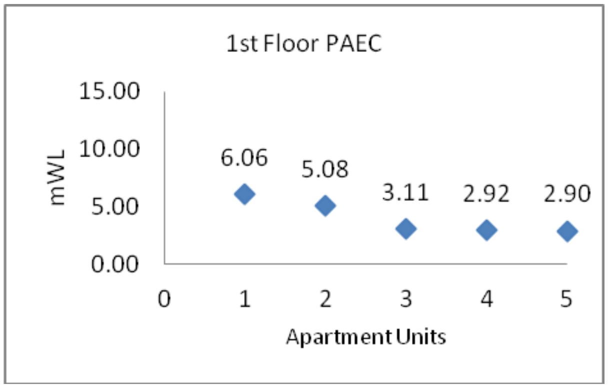
4.9 Floor Level Variation of PAEC

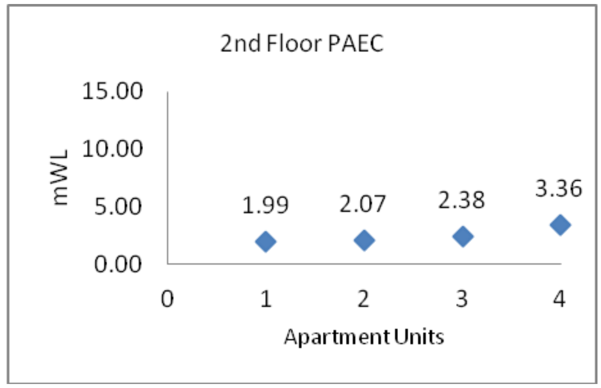
First floor PAEC did not seem evenly spread as all units here measured a different PAEC. Its highest was measured at 6.06 m/WL, lowest at 2.90 m/WL. Second floor PAEC was less erratic with highest PAEC measured at 3.36 m/WL, lowest at 1.99 m/WL. Third floor PAEC seemed to jump to the higher side with 7.43 m/WL highest measured, lowest at 4.64 m/WL Fourth floor PAEC had 7.53 m/WL highest, lowest at 1.04 m/WL, a big gap observed for units within a single floor level.

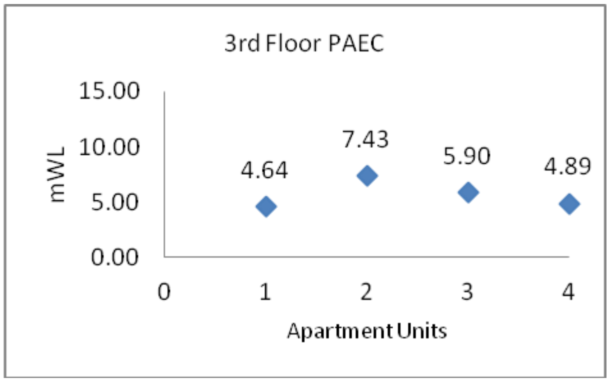
Fifth floor PAEC measured highest at 5.59 m/WL, lowest at 1.64 m/WL. Sixth floor PAEC highest measured at 3.87 m/WL, lowest at 1.88 m/WL. Seventh floor PAEC was all different for each of the unit measured. Highest at 13.49 m/WL, lowest at 1.31 m/WL, biggest gap observed thus far. Eight floor highest measured at 3.11 m/WL, lowest at 1.01 m/WL, quite a stable floor in terms of PAEC readings. Same stability in ninth floor, highest measured at 3.11 m/WL, lowest at 1.64 m/WL. Tenth floor highest measured at 4.07 m/WL, lowest measured at 1.39 m/WL. Eleventh floor PAEC had highest at 6.77 m/WL, lowest at 1.47 m/WL.

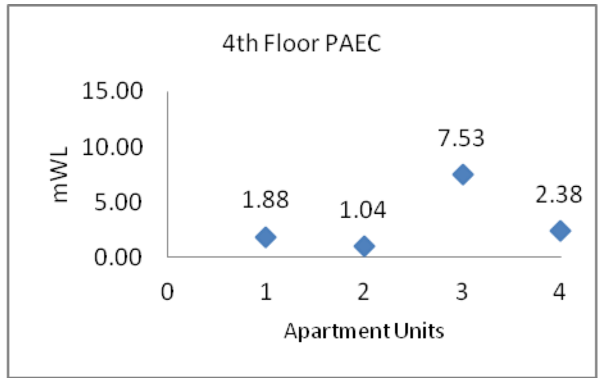
Twelfth floor PAEC were low in general, it went from 1.56 m/WL to 0.88 m/WL. Thirteenth floor highest measured at 3.11 m/WL, lowest at 0.98 m/WL. Fourteenth floor highest PAEC measured 3.99 m/WL, lowest at 1.29 m/WL. Highest floor at the fifteenth was also giving erratic readings, highest measured at 6.61 m/WL, lowest measured at 1.64 m/WL.

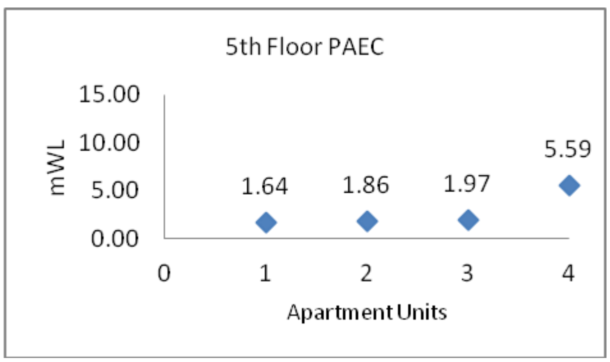
An overview conclusion would be erratic PAEC readings occurred at first, third fourth, seventh, tenth, eleventh, and fifteenth floor level.

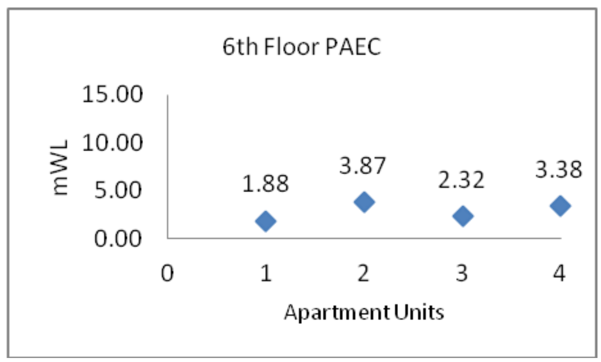

1st Floor PAEC
mWL
15.00
10.00
5.00
0.00
6.06
5.08
3.11
2.92
2.90
0
1
2
3
4
5
Apartment Units

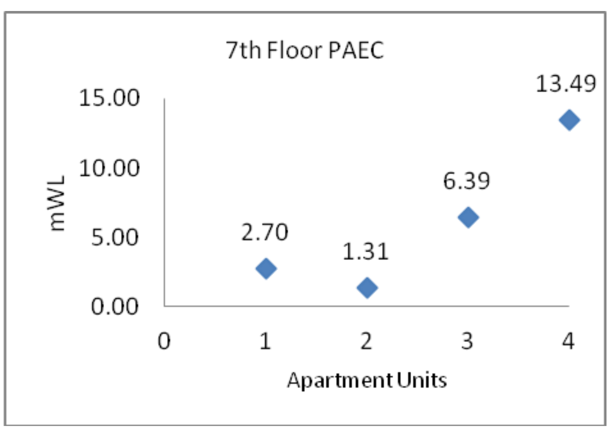

2nd Floor PAEC
mWL
15.00
10.00
5.00
0.00
1.99
2.07
2.38
3.36
0
1
2
3
4
Apartment Units

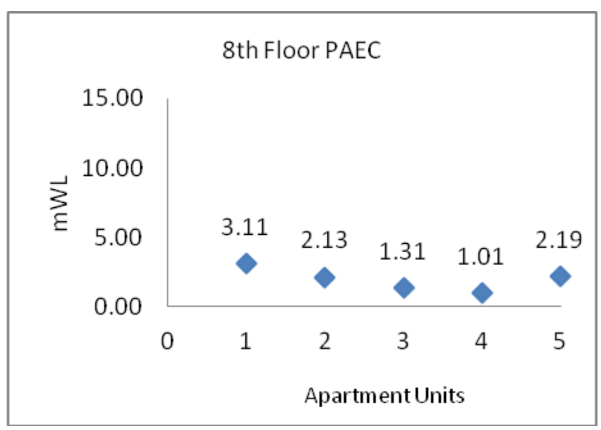

3rd Floor PAEC
mWL
15.00
10.00
5.00
0.00
4.64
7.43
5.90
4.89
0
1
2
3
4
Apartment Units


4th Floor PAEC
mWL
15.00
10.00
5.00
0.00
1.88
1.04
7.53
2.38
0
1
2
3
4
Apartment Units


5th Floor PAEC
mWL
15.00
10.00
5.00
0.00
1.64
1.86
1.97
5.59
0
1
2
3
4
Apartment Units


6th Floor PAEC
mWL
15.00
10.00
5.00
0.00
1.88
3.87
2.32
3.38
0
1
2
3
4
Apartment Units


7th Floor PAEC
mWL
15.00
10.00
5.00
0.00
2.70
1.31
6.39
13.49
0
1
2
3
4
Apartment Units


8th Floor PAEC
mWL
15.00
10.00
5.00
0.00
3.11
2.13
1.31
1.01
2.19
0
1
2
3
4
5
Apartment Units

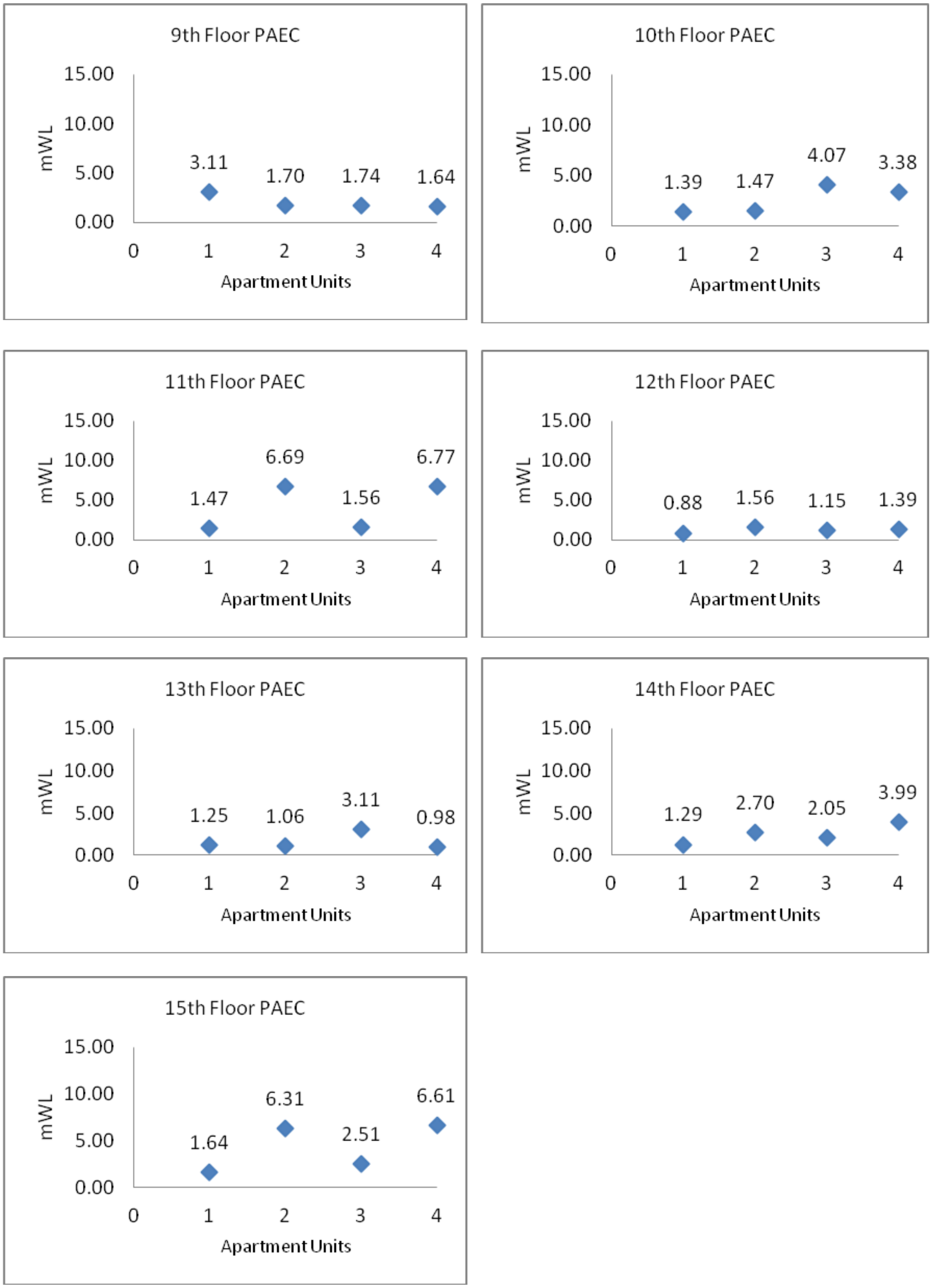


Figure 4.8 Total Charts for PAEC in mWL for individual floors in a multi-storey building

4.10 Results on Household Survey

An additional descriptive survey with the households was conducted on the variation in the condition of apartment units on a floor by floor basis. The affected variations were expected in ventilation in the master bedrooms, floor finishing and wall finishing. The household survey allowed a description and impression on the indoor quality of the apartment building.

As presented beforehand in Figure 4.5, the EDE on 2nd, 10th, 14th floors are above the value 1.5 mSv/y. The EDE on 7th, 11th, 15th floors on the other hand are observed below the value 1.00 mSv/y. The discussions below will observe for any peculiarity in the household survey data on these floors.

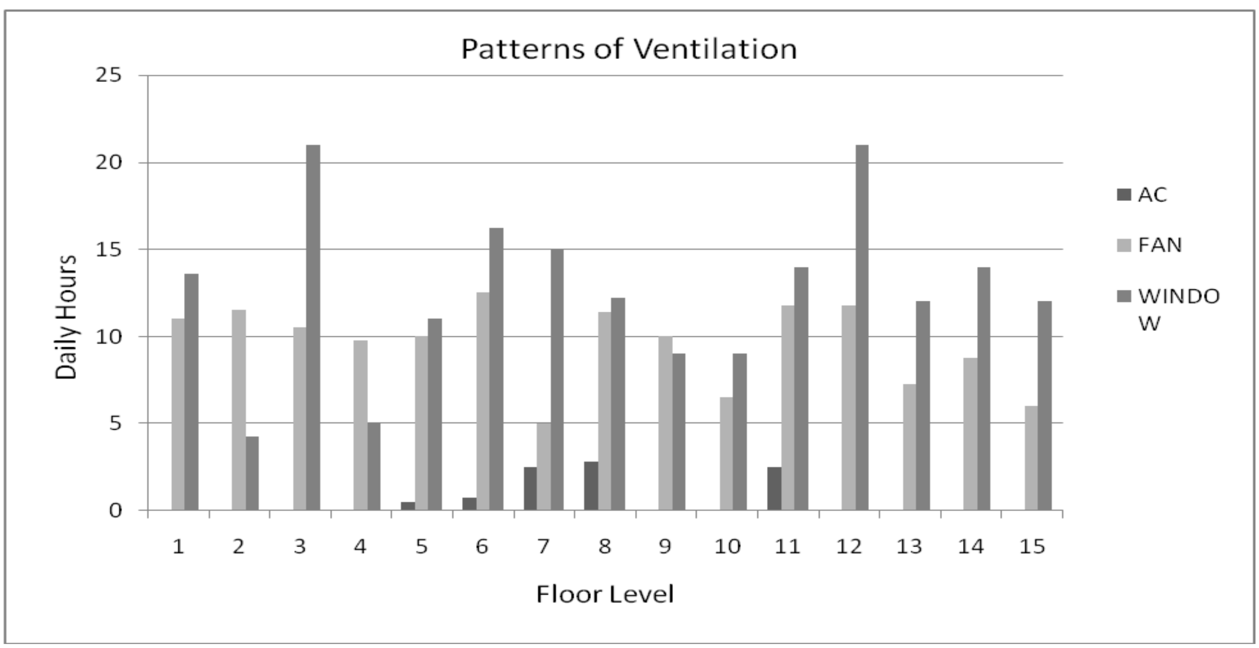


Figure 4.9 Patterns of ventilation in master bedrooms

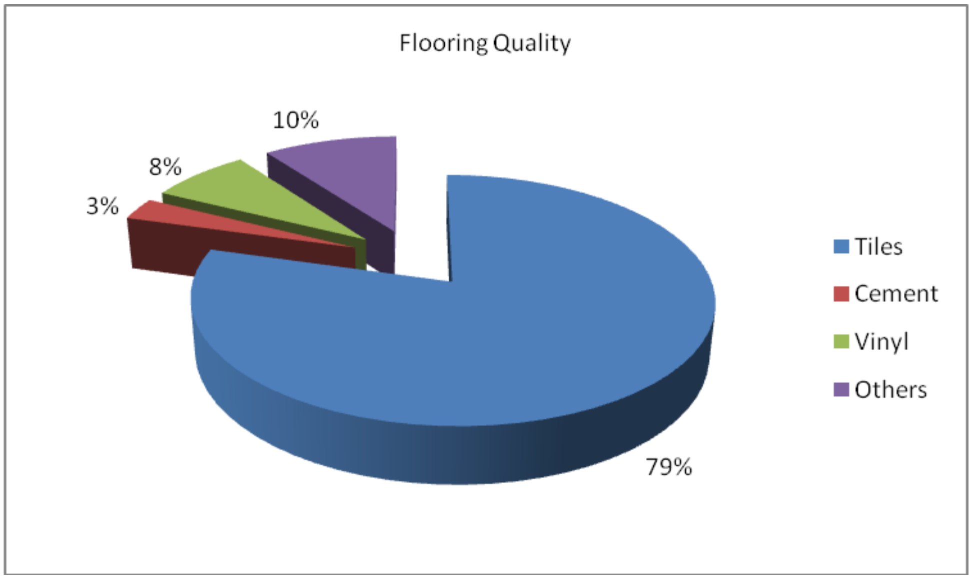
Figure 4.9 shows the arithmetic mean of ventilation patterns at the various floor level of the multi-storey building. The daily mean hour usage of air-conditioner is low and occurred only in floor level fifth (5^{th}), sixth (6^{th}), seventh (7^{th}), eighth (8^{th}), and eleventh (11^{th}). Compared to fan, a cheaper alternate mechanical ventilation method, fan is widely adopted at all apartment units on all floor level in this multi-storey apartment building.

Natural ventilation to facilitate for environmental comfort, by way of opening windows is the most common method here. Proper ventilation dilutes indoor concentration of radon and thoron from piling up. According to the chart, it is most frequent in floor level third (3^{rd}), twelfth (12^{th}), sixth (6^{th}), seventh (7^{th}), eleventh (11^{th}), fourteenth (14^{th}), thirteenth (13^{th}) and fifteenth (15^{th}). It is not frequently adopted at the second and fourth floor level (under five daily hours) presumably to avoid stench. There seemed to be no correlation between ventilation patterns in this Figure 4.9 with the concentration of thoron or radon as shown in Figure 4.1 and Figure 4.3. Varying types of ventilation method added to some disability at quantification for good or bad ventilation. Opening windows too is a difficult if not arduous gauge to ventilation as this relies on wind direction and speed information.

The seventh floor (7^{th}) has good opened-window ventilation, and therefore low EDE results it would seem. The eleventh (11^{th}) floor comparing to tenth (10^{th}) floor also have better ventilation from longer opened-window hours and fan ventilation hours. We will recall also fourteenth (14^{th}) floor comparing to 13^{th} or 15^{th} floor experienced a higher level of EDE too in Figure 4.5 and Figure 4.6 (on page 50 and 53). However, the fourteenth (14^{th}) floor comparing to 13^{th} or 15^{th} floor was showing better ventilation hours according to tabulation in Figure 4.9.

4.10.1 Indoor Built Materials

Figure 4.10 shows the distribution of indoor built materials preferences. Figure 4.10 (a) refers to the building in whole; Figure 4.10 (b) shows it for tiles, cement, vinyl and others. A complete illustration is provided in Table 4.4 (page 67).



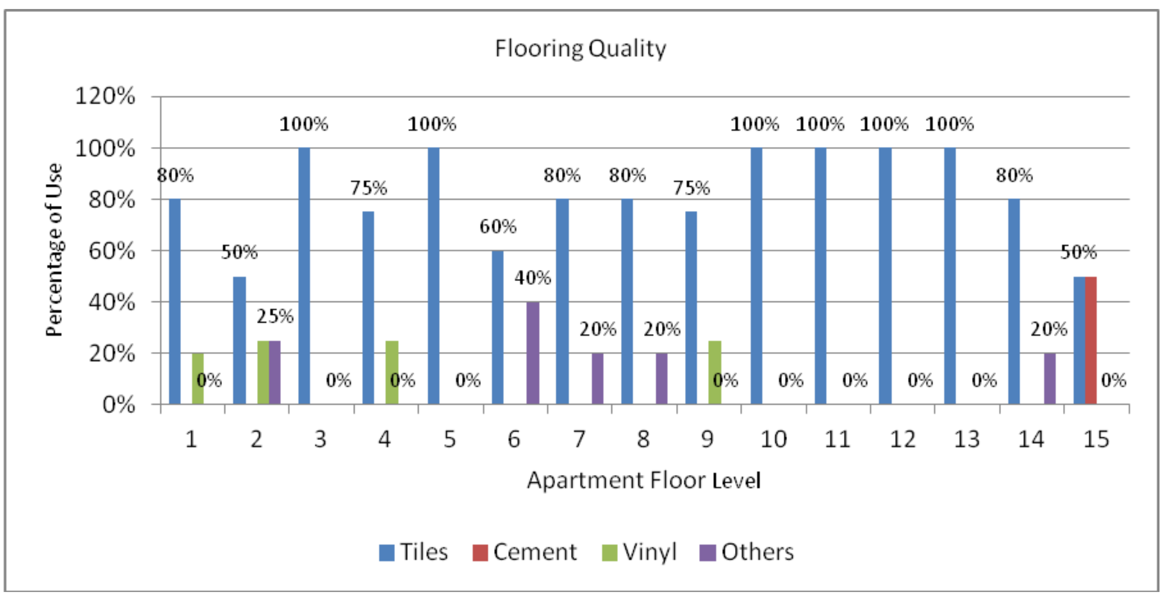


Figure 4.10 Patterns of Flooring Quality (a) for the whole building (b) by floor level.

Figure 4.10 (a) reveals the flooring quality for the entire multi-storey building. Seventy-nine percent of the households apply tiles to their indoor floor. Ten percent remained cement-rendered, which is the original condition of the apartment units. Eight percent used vinyl which is a type of plastic mat to cover the cement-rendered floor. And three percent in the “others” category had specified wool carpets, marble tiles, and laminated wood flooring as the current condition of their indoor flooring. Details of these variations have been summarized in Table 4.4 (end of this chapter on page 67) containing also measured concentration for PAEC, thoron, radon for comparison.

First floor EDE is high as the subsoil radon penetration is most apparent. Even though it is seventy-nine percent tiled-up, it does not prevent a high EDE outcome on the first floor. The tenth and eleventh floor are tiled up, both floors are higher up from the ground, the similarities here however resulted in differing EDE outcomes (as tenth has higher EDE than eleventh floor, page 49, Figure 4.5). The results obtained from the fourteenth (14th) and fifteenth (15th) floor do not follow the notion that flooring quality affects indoor radon concentration, especially since they are on higher floor level. Higher EDE is observed on fourteenth which have more tiled up units than the fifteenth floor. The fifteenth floor exhibited lower EDE though some of its units are observed to be in cement-rendered condition only.

4.10.2 Wall

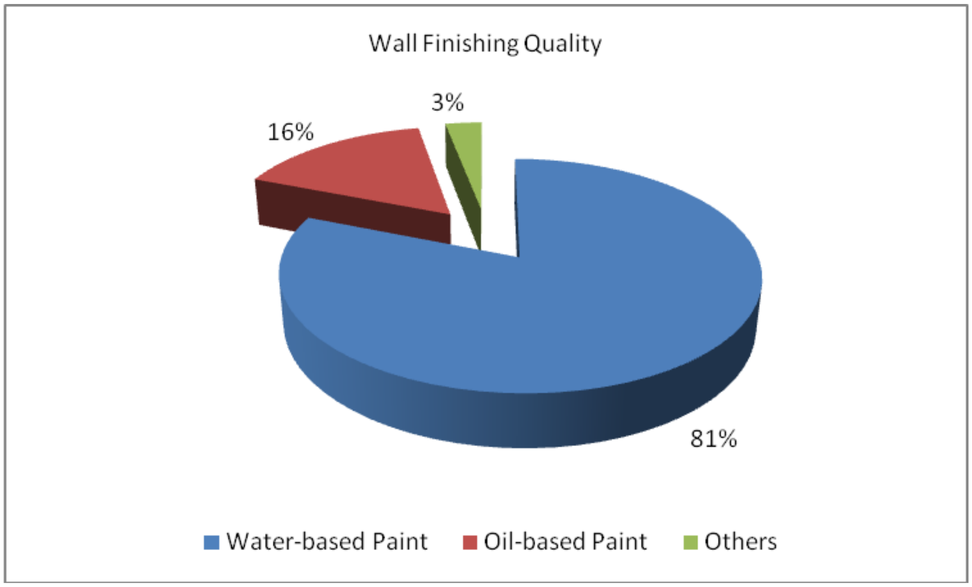


Figure 4.11 Wall finishing quality

Eighty-one percent of the households used water based paint for their indoor walls. Sixteen percent used oil based paint. Three percent for others category consists of one household that put a large size decorative carpet on their wall, and one other household that has expended on wallpaper for improved decorative effect.

A conclusion on the *Household Survey* would be that, with the scientific experiments being conducted in an inhabited apartment building, varying preferences are observed in terms of indoor finishing types. There is no evidence thereafter from the derived chart to determine if the decreasing trend in radon and thoron concentrations in the fifteen floor levels may have been impacted by indoor finishing type usage.

Table 4.4 presents a summary chart of the percentages of indoor finishing type usage, i.e. wall finishing quality and floor finishing quality, against the indoor radon and thoron concentration in Bq/m^3 by floor level. Outputs presented in this chart have formed the basis for discussions throughout the earlier sections of this chapter.

Table 4.4: Summary of PAEC, Thoron Concentration, Radon Concentration, Wall Finishing Quality and Floor Finishing Quality

			mWL	Thoron Concentration (Bq/m3)	Radon Concentration (Bq/m3)		Wall Finishing Quality			Floor Finishing Quality			
							Water-based	Oil-based	Others	Tiles	Cement	Vinyl	Others
1	AM		4.0	0.1	42.2								
	GM		3.8	0.1	42.1								
		%					100%	0%	0%	80%	0%	20%	0%
2	AM		2.4	0.2	26.2								
	GM		2.4	0.2	25.7								
		%					75%	25%	0%	50%	0%	25%	25%
3	AM		5.7	0.2	21.3								
	GM		5.6	0.1	21.2								
		%					75%	25%	0%	100%	0%	0%	0%
4	AM		3.2	0.3	20.9								
	GM		2.4	0.2	20.0								
		%					75%	25%	0%	75%	0%	25%	0%
5	AM		2.8	0.1	22.8								
	GM		2.4	0.1	22.7								
		%					100%	0%	0%	100%	0%	0%	0%
6	AM		2.9	0.1	23.2								
	GM		2.8	0.1	22.4								
		%					75%	25%	0%	60%	0%	0%	40%
7	AM		6.0	0.3	13.8								
	GM		4.2	0.2	13.8								
		%					50%	25%	25%	80%	0%	0%	20%
8	AM		1.9	0.1	18.7								
	GM		1.8	0.1	17.7								
		%					80%	20%	0%	80%	0%	0%	20%
9	AM		2.0	0.4	18.7								
	GM		2.0	0.2	17.6								
		%					80%	20%	0%	75%	0%	25%	0%
10	AM		2.6	0.2	26.0								
	GM		2.3	0.2	25.1								
		%					50%	50%	0%	100%	0%	0%	0%
11	AM		4.1	0.5	11.4								
	GM		3.2	0.3	11.0								
		%					60%	20%	20%	100%	0%	0%	0%
12	AM		1.2	0.1	16.2								
	GM		1.2	0.1	15.6								
		%					75%	25%	0%	100%	0%	0%	0%
13	AM		1.6	0.1	18.4								
	GM		1.4	0.1	17.3								
		%					100%	0%	0%	100%	0%	0%	0%
14	AM		2.5	0.1	24.1								
	GM		2.3	0.0	23.9								
		%					100%	0%	0%	80%	0%	0%	20%
15	AM		4.3	0.1	14.0								
	GM		3.6	0.0	12.0								
		%					100%	0%	0%	50%	50%	0	0%

Chapter 5 Conclusions

A study on the radon and thoron concentrations in a high-rise apartment building has been conducted. Variations of radon and thoron concentrations as a function of different units within the same floor and between different floors have been analysed. Influences from conditions of the apartment units have also been studied.

Measurable variation of indoor radon concentration was observed when measurements of the different levels were compared. The pattern of radon concentration was overall decreasing from the bottom floor level to the higher floor levels. This was very likely due to the entry of radon into indoor atmosphere via subsoil sources impacting on the bottom floor level the most.

Presumably much radon and thoron were generated during a construction process of the apartment building, and this research project was attempted and carried out within the two year timeframe of completion and move-in. The thoron concentration would have been low (half-life of thoron is 55.6 seconds) and significantly depleted after incurring many half-lives since. Therefore when compared to radon concentration there is no sharp decrease in thoron concentration as a function of floor level, they are both physically different in nature.

Measurement results further showed variation in the figure for thoron concentration per floor level, it had shown some fluctuations which could be due to thoron being short-lived, and some thoron may have decayed before being caught in the atmosphere by the measurement device. Take note though thoron concentration is absolutely low overall in the building. There may be little thorium trace in the building materials or the local soil. The lowest reading occurs on the fourteenth and fifteenth floor. As the fifteen charts for indoor thoron concentrations are low and do not standardise at each floor level, this just reflects an overall small concentration of thoron as a source of indoor radiation.

The radiation level due to radon and thoron level measured in all the units were well below the safety requirement levels. In summary, the radon concentration measured was between 42.21 Bq/m^3 (Max_{flr}) and 11.45 Bq/m^3 (Min_{flr}). The thoron concentration measured from 0.48 Bq/m^3 (Max_{flr}) to 0.05 Bq/m^3 (Min_{flr}). The effective dose equivalents were between 2.68 mSv/y (Max_{flr}) and 0.74 mSv/y (Min_{flr}). The potential alpha energy concentration ranged from 6.0 m/WL (Max_{flr}) to 1.2 m/WL (Min_{flr}).

Some floor levels were observed to have erratic pattern of radon concentration. This could be due to the fact, trapping mechanism of radon exist in these floors, or orientation of the apartment unit, or differing usage, changing ventilation conditions, and differing post-renovation condition of apartments at the floor levels. However, all these reasons could also occur simultaneously.

There is no certainty from the derived survey data to assess radon or thoron concentration variation arising from impact of indoor built materials in apartment units of the building studied. This is attributed to the homogeneity of the varying units in their preferences for indoor built materials used (seventy-nine percent is tiled up). In the post occupancy renovation, flooring quality and wall finishing quality of units in the building had been highly standardized.

These experiments being conducted in an apartment building, varying preferences are observed in terms of indoor finishing types. There is no evidence thereafter from the derived chart to determine, if the decreasing trend in radon and thoron concentrations in all fifteen floor levels may have been impacted by indoor finishing type usage. The ventilation patterns were difficult to quantify as wind direction and speed information were not available, and so correlation and contribution to concentration of radiation was arduous.

As far as ventilation might be an impact in some studies, tenth floor may have suffered higher radon concentration due to poorer means of accessing ventilation, there were observed construction and traffic activities in the area that brought dust in the breeze from nearby resulting in modest ventilation for that floor level.

The summary understanding of indoor radiation levels here were observed to be low and within the recommended safety level. It was a conclusive radiation monitoring outcome conducted in a multi-storey apartment building in the Klang Valley. No distinctive pattern in space variation of measurements are observed in this study owing to individual indoor activity, except the bottom floor level compared to other floor levels in the building. All apartment dwellings studied are safely below the upper value reference level for radon gas of 300Bq/m^3. At the Health Protection Agency (HPA, 2013) of the UK, it recommends a lower level of 200 becquerels per cubic metre (Bq/m^3) in homes. However, a closer look at the values for radon and thoron must be taken every now and then so that the inhabitant can be sure; or they can raise the alarm if they reach the maximum limit.

APPENDIX 1

Household Survey Questionnaire