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^{222}Rn, ^{220}Rn and their progeny concentrations in offices in Hong Kong

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Abstract

An active sampling system using charcoal canisters and an HPGe γ-spectrometer was employed to survey ^{222}Rn and ^{220}Rn concentrations in 65 offices in Hong Kong, and a traditional method was used to record simultaneously the potential α-energy concentrations (PAEC) of ^{222}Rn and ^{220}Rn progeny at the same sites. The mean values of gas concentration, PAEC and equilibrium factor for ^{222}Rn were 48 ± 32 Bq m^{-3}, 5.2 ± 5.1 mWL and 0.38 ± 0.13, respectively, and the corresponding values for ^{220}Rn were 14 ± 7 Bq m^{-3}, 2.7 ± 2.1 mWL and 0.050 ± 0.016. These values were in general higher than those in dwellings in Hong Kong, which was due to the poorer fresh air exchange in offices. Factors affecting the concentrations of ^{222}Rn, ^{220}Rn and their progeny were also studied. The type of air conditioners and the indoor and outdoor temperature difference show some effects on ^{222}Rn, ^{220}Rn and progeny concentrations, while rainfall and relative humidity affect only the progeny concentrations. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: ^{222}Rn; ^{220}Rn; Progeny; Offices

1. Introduction

Research and surveys on the behavior of ^{220}Rn progeny have been carried out (Steinhäusler, Hofmann & Lettner, 1994 and references therein, Yu, Young, Stokes, Guan & Cho, 1997a; Yu, Cheung, Guan, Young, Mui & Wong, 1999), but data on the

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^{220}Rn concentration are still scant since its measurement is difficult. Recently, Yu et al. (1999) employed the system proposed by Yu, Guan, Young and Stokes (1998a), which modified the Rn counting system introduced by United States Environmental Protection Agency (USEPA) and incorporated an HPGe detector, for simultaneous active measurements of concentrations of ^{222}Rn and ^{220}Rn in 62 residences in Hong Kong.

Yu, Young, Stokes and Tang (1998b) showed that the concentrations of ^{222}Rn and its progeny in offices in Hong Kong were very different from those in residences. Therefore, it is pertinent to investigate the concentrations of ^{220}Rn and its progeny in offices in Hong Kong as well. In the present study, the concentrations of ^{222}Rn, ^{220}Rn and progeny in 65 offices in Hong Kong were surveyed using the system mentioned above. The potential α-energy concentrations (PAEC) of ^{222}Rn and ^{220}Rn progeny were also simultaneously recorded at the same sites using a traditional technique.

Factors affecting the concentrations of ^{222}Rn, ^{220}Rn and progeny are discussed; they are (1) building characteristics including the type of air conditioners employed and ages of the buildings; and (2) meteorological parameters including rainfall, relative humidity, and indoor and outdoor temperature difference.

2. Experimental

The sampling system used in the present study was described in detail by Yu et al. (1998a,1999). The commercialized standardized charcoal canisters with a diameter of 4″ recommended by USEPA were modified, with 25 holes of diameter 4 mm drilled over the bottom, an extra layer of temperature resistant permeable filter placed to cover the inside of the entire bottom (which could resist the high temperature during reactivation of the charcoal canister), and the weight of charcoal increased from the original 70–80g. Before and after sampling, the charcoal canister was covered with an original metal top lid and an extra plastic bottom; during air sampling, both lids were removed.

The air sampling rate was about 10 l min^{-1} and the sampling lasted for 30 min. The measurements started 3 h after sampling and lasted for 120 min. The detection system was the EG & G ORTEC γ-spectrometry system consisting of a 4″ cylindrical HPGe detector with a relative efficiency of 90% housed in a lead shield. The minimum detection limits were 2.0 Bq m^{-3} for both gases. The calibration of the whole system was based on that for passive sampling (USEPA, 1986) and was outlined by Yu et al. (1998a,1999).

The surveys were made during a hot and humid season (July–December), which was similar to the season when the measurements were taken for the study by Yu et al. (1998b). The time of each measurement was confined to 9 a.m.–5 p.m. during the daytime to ensure more uniform experimental conditions. To make the surveys more complete, the PAEC of ^{222}Rn and ^{220}Rn progeny (in WL) were also measured simultaneously using the five-count filter method (Thomas, 1972; Fu-Chia & Chia-Yong, 1978; Zhang & Luo, 1983; Yu et al., 1999).

Due to the short half-life of ^{220}Rn, its concentration decreases rapidly with the distance from the wall (Katase, Matsumoto, Sakae & Ishibashi, 1988). Therefore, sampling was fixed at a position of 30 cm from the wall and 1 m from the floor. The air sampling sites were chosen to be as stagnant as possible, i.e., they were away from windows and doors, since the concentrations of ^{222}Rn, ^{220}Rn and their progeny will be influenced by the air flow.

3. Results and discussion

Fig. 1 shows the relationship between ^{222}Rn and ^{220}Rn concentrations, which is approximately linear with a correlation coefficient of 0.86. Fig. 2 shows the relationship between the PAEC and ^{222}Rn concentration, while Fig. 3 shows the corresponding relationship for ^{220}Rn. Both show positive correlations as expected.

The mean values of gas concentration, PAEC and equilibrium factor F for ^{222}Rn were 48 ± 32 Bq m^{-3}, 5.2 ± 5.1 mWL and 0.38 ± 0.13, respectively, and the corresponding values for ^{220}Rn were 14 ± 7 Bq m^{-3}, 2.7 ± 2.1 mWL and 0.050 ± 0.016, respectively. The corresponding values for residential sites (Yu et al., 1999) were 27 ± 8 Bq m^{-3}, 1.8 ± 1.4 mWL and 0.24 ± 0.13, respectively, for ^{222}Rn, and 11 ± 4 Bq m^{-3}, 1.2 ± 0.9 mWL and 0.029 ± 0.015, respectively, for ^{220}Rn. All these results and those from a previous investigation of Rn properties in offices (Yu et al., 1998b) are summarized in Table 1 for comparison. It can be seen that the results for RC and PAEC(Rn) in the present work agree well with those of Yu et al. (1998b), which is expected because of the similar experimental conditions. The concentrations of gas and progeny for both ^{222}Rn and ^{220}Rn were, in general, higher in offices than in dwellings probably due to the poorer air exchange in offices.

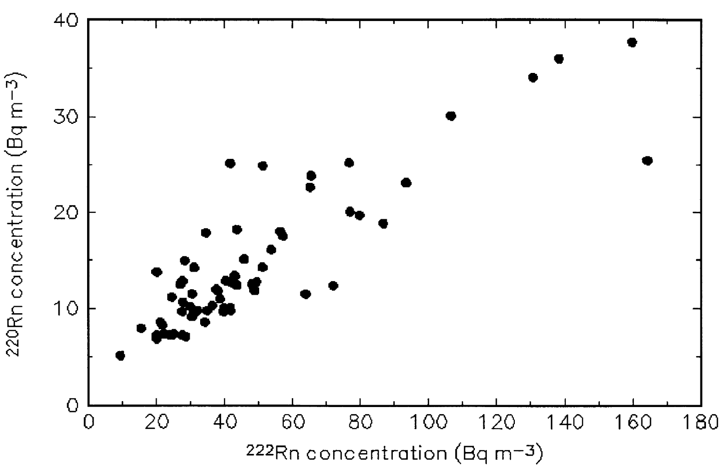

Fig. 1. Relationship between ^{222}Rn and ^{220}Rn concentrations.

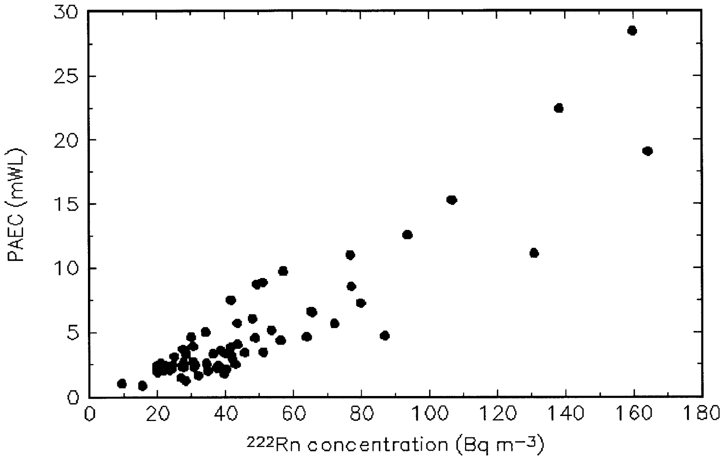

Fig. 2. Relationship between PAEC and gas concentration for ^{222}Rn.

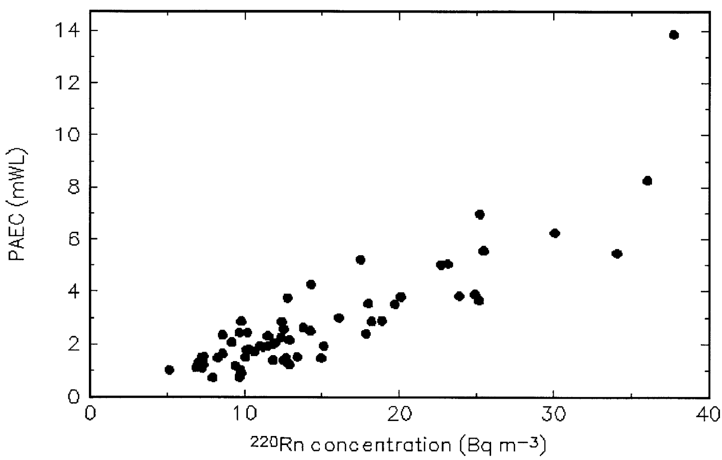

Fig. 3. Relationship between PAEC and gas concentration for ^{220}Rn.

The factors affecting the indoor concentrations of ^{222}Rn, ^{220}Rn and progeny were also investigated. The *t*-test method is applied to identify the factors which significantly affect the ^{222}Rn, ^{220}Rn and ^{220}Rn progeny concentrations.

3.1. Building characteristics

The effects of the type of air conditioners used are shown in Table 2. Almost all the offices surveyed (59 out of 65) were air conditioned. The data are divided into categories for split-type air conditioned, central air conditioned and window-type air

Table 1
The average concentrations of ^{222}Rn (RC) and ^{220}Rn (TC) (both in Bq m^{-3}), and the average PAEC values for ^{222}Rn [PAEC(Rn)] and ^{222}Rn [PAEC(Tn)] (both in mWL) in offices. Results from previous investigations are also shown for comparison

	Mean	Reference
RC	48 ± 32	Present work
RC	51 ± 32	Yu et al. (1998b)
RC (Dwellings)	27 ± 8	Yu et al. (1999)
TC	14 ± 7	Present work
TC(Dwellings)	11 ± 4	Yu et al. (1999)
PAEC(Rn)	5.2 ± 5.1	Present work
PAEC(Rn)	5.7 ± 6.3	Yu et al. (1998b)
PAEC(Rn) (Dwellings)	1.8 ± 1.4	Yu et al. (1999)
PAEC(Tn)	2.7 ± 2.1	Present work
PAEC(Tn) (Dwellings)	1.2 ± 0.9	Yu et al. (1999)

conditioned. The type of air conditioners significantly affected the properties of both ^{222}Rn and ^{220}Rn. The gas concentration, PAEC and F values were highest for split-type air conditioners and lowest for window-type air conditioners. It is also worth noting that the results for window-type air conditioners were very similar to those for air-conditioned residential sites (Yu et al., 1999), all of which used window-type conditioners.

The effects of building age on ^{222}Rn and ^{220}Rn properties are shown in Table 3. To obtain even sample sizes, the data are divided into two sets with building ages $\leqslant 10$ years and > 10 years. It appeared that the building age did not have significant effects on the gas concentrations and PAEC values. This was in contrast to the situation of residential sites, in which the values of both ^{222}Rn and ^{220}Rn gas concentrations and PAEC decreased as building age increased (Yu et al. 1999). The difference was surprising since ^{222}Rn exhalation rates from internal building surfaces were found to decrease with the building ages in general (Yu, Chan & Young, 1995; Yu, Young, Stokes, Kwan & Balendran, 1997b). The variation of ^{222}Rn and ^{220}Rn gas concentrations with the building age is shown in Figs. 4 and 5 for different types of air conditioners used. It can be seen that the gas concentration tends to decrease with the building age for window-type air conditioners and natural ventilation in the case of ^{222}Rn. On the other hand, the gas concentration tends to increase with the building age for central air conditioning. When all the data are combined, no particular time trends are readily observable.

3.2. Meteorological parameters

The effects of rainfall are shown in Table 4. The data are divided into two categories for no rainfall and rainfall (> 0 mm) per day. It can be seen that the PAEC and

Table 2
Effects of type of air conditioners used on ^{222}Rn and ^{220}Rn concentrations in offices
(a) For ^{222}Rn

Air-conditioner	Number	RC (Bq m^{-3})	PAEC (Rn) (mWL)	*F*
Split	10	63 ± 55	9.7 ± 9.8	0.51 ± 0.14
Central	26	47 ± 23	5.5 ± 3.2	0.42 ± 0.12
Window	23	37 ± 19	3.4 ± 2.4	0.33 ± 0.08
Dwellings (AC)	20	32 ± 7	2.8 ± 1.6	0.32 ± 0.15

Comparison between	Confidence level (%)		
	RC	PAEC(Rn)	*F*
Split / Central	78	95	94
Split / Window	95	99	100
Central / Window	90	99	100

(b) For ^{220}Rn

Air conditioner	Number	TC (Bq m^{-3})	PAEC (Tn) (mWL)	*F*
Split	10	18 ± 11	4.5 ± 4.0	0.064 ± 0.016
Central	26	15 ± 6	3.0 ± 1.5	0.055 ± 0.015
Window	23	12 ± 6	2.0 ± 1.1	0.044 ± 0.009
Dwellings (AC)	20	13 ± 3	1.9 ± 1.1	0.039 ± 0.018

Comparison between	Confidence level (%)		
	TC	PAEC(Tn)	*F*
Split / Central	70	90	88
Split / Window	95	99	100
Central / Window	91	99	100

F values drop when there is rainfall. The phenomenon is consistent with that observed for dwellings (Yu et al., 1999). With rainfall, the aerosol content in the atmosphere should be smaller so the amount of unattached ^{222}Rn progeny should be greater and the PAEC and *F* values decreases.

The effects of relative humidity are shown in Table 5. The data are divided into two categories for relative humidity $\leqslant 54\%$ and $> 54\%$. It can be seen that the PAEC and *F* values decrease as the relative humidity increases. When relative humidity is high, the higher water content in air will enhance the deposition of aerosols thus decreasing the aerosol content in the air, so the PAEC and *F* values decrease as Yu et al. (1999) reported for dwellings.

Table 3
Effects of building age on ^{222}Rn and ^{220}Rn in offices
(a) For ^{222}Rn

Building age (yr)	Number	RC (Bq m^{-3})	PAEC (Rn) (mWL)	*F*
⩽ 10	31	49 ± 30	5.8 ± 5.9	0.41 ± 0.15
> 10	34	44 ± 32	4.6 ± 4.2	0.36 ± 0.10
Comparison between	Confidence level (%)			
	RC	PAEC(Rn)	*F*	
⩽ 10 / > 10	51	67	87	

(b) For ^{220}Rn

Building age (yr)	Number	TC (Bq m^{-3})	PAEC (Tn) (mWL)	*F*
⩽ 10	31	15 ± 9	3.1 ± 2.6	0.052 ± 0.018
> 10	34	14 ± 6	2.5 ± 1.5	0.048 ± 0.013
Comparison between	Confidence level (%)			
	TC	PAEC(Tn)	*F*	
⩽ 10 / > 10	64	75	83	

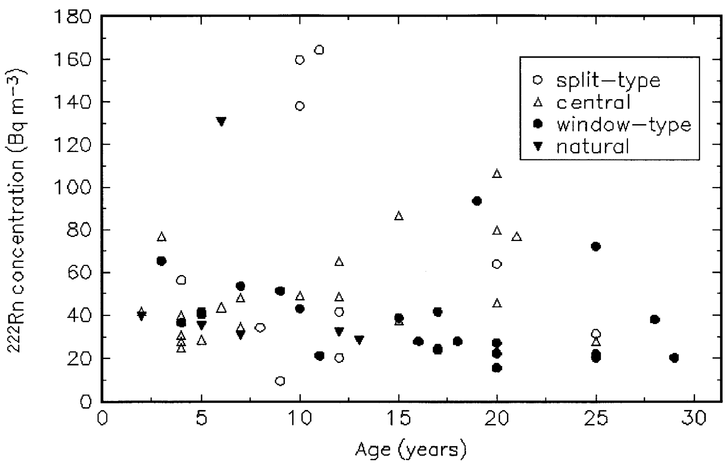

Fig. 4. Variation of ^{222}Rn gas concentration with the building age for different types of air conditioners used and for natural ventilation.

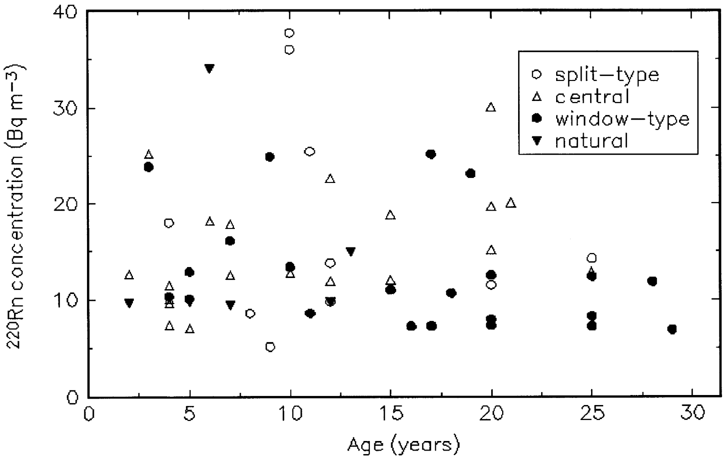

Fig. 5. Variation of ^{220}Rn gas concentration with the building age for different types of air conditioners used and for natural ventilation.

Table 4
Effects of rainfall on ^{222}Rn and ^{220}Rn in offices
(a) For ^{222}Rn

Rainfall (mm)	Number	RC (Bq m^{-3})	PAEC (Rn) (mWL)	*F*
= 0	30	51 ± 32	6.3 ± 5.6	0.43 ± 0.15
> 0	35	42 ± 30	4.2 ± 4.4	0.34 ± 0.10

Comparison between	Confidence level (%)		
	RC	PAEC(Rn)	*F*
= 0 / > 0	75	90	99

(b) For ^{220}Rn

Rainfall (mm)	Number	TC (Bq m^{-3})	PAEC (Tn) (mWL)	*F*
= 0	30	15 ± 8	3.2 ± 2.6	0.056 ± 0.019
> 0	35	14 ± 7	2.3 ± 1.5	0.045 ± 0.011

Comparison between	Confidence level (%)		
	TC	PAEC(Tn)	*F*
= 0 / > 0	54	90	99

Table 5
Effects of indoor relative humidity on ^{222}Rn and ^{220}Rn in offices
(a) For ^{222}Rn

Relative humidity (%)	Number	RC (Bq m^{-3})	PAEC (Rn) (mWL)	*F*
$\leqslant 54$	32	46 ± 33	6.1 ± 5.9	0.45 ± 0.13
> 54	33	46 ± 29	4.3 ± 4.0	0.32 ± 0.10

Comparison between	Confidence level (%)		
	RC	PAEC(Rn)	*F*
$\leqslant 54$ / > 54	17	86	100

(b) For ^{220}Rn

Relative humidity (%)	Number	TC (Bq m^{-3})	PAEC (Tn) (mWL)	*F*
$\leqslant 54$	32	14 ± 9	3.1 ± 2.6	0.058 ± 0.015
> 54	33	15 ± 6	2.4 ± 1.5	0.043 ± 0.013

Comparison between	Confidence level (%)		
	TC	PAEC(Tn)	*F*
$\leqslant 54$ / > 54	12	84	100

The effects of indoor and outdoor temperature difference are shown in Table 6. The data are divided into two categories for temperature difference $\leqslant 3.4$°C and > 3.4°C. It can be seen that the values for gas concentrations and PAEC decrease while *F* remains unchanged when the temperature difference increases, which was also observed by Yu et al. (1999) for dwellings. These results were expected because a larger temperature difference will enhance air exchange which lowers the gas concentration and PAEC values.

4. Conclusions

1. ^{222}Rn and ^{220}Rn concentrations in 65 offices in Hong Kong were surveyed using the system reported by Yu et al. (1998a). The mean values of gas concentration, PAEC and equilibrium factor for ^{222}Rn were 48 ± 32 Bq m^{-3}, 5.2 ± 5.1 mWL and 0.38 ± 0.13, respectively, and the corresponding values for ^{220}Rn were 14 ± 7 Bq m^{-3}, 2.7 ± 2.1 mWL and 0.050 ± 0.016, respectively.

Table 6
Effects of indoor and outdoor temperature difference on ^{222}Rn and ^{220}Rn in offices
(a) For ^{222}Rn

Temperature difference (°C)	Number	RC (Bq m^{-3})	PAEC (Rn) (mWL)	*F*
$\leqslant 3.4$	35	51 ± 38	6.1 ± 6.4	0.40 ± 0.15
> 3.4	30	40 ± 18	4.1 ± 2.4	0.37 ± 0.11

Comparison between	Confidence level (%)		
	RC	PAEC(Rn)	*F*
$\leqslant 3.4$ / > 3.4	85	91	58

(b) For ^{220}Rn

Temperature difference (°C)	Number	TC (Bq m^{-3})	PAEC (Tn) (mWL)	*F*
$\leqslant 3.4$	35	16 ± 9	3.2 ± 2.7	0.051 ± 0.015
> 3.4	30	13 ± 4	2.2 ± 0.9	0.049 ± 0.013

Comparison between	Confidence level (%)		
	TC	PAEC(Tn)	*F*
$\leqslant 3.4$ / > 3.4	95	96	58

2. The concentrations of gas and progeny for both ^{222}Rn and ^{220}Rn in offices were in general higher than those in dwellings, which might be due to the poorer air exchange in offices.
3. The type of air conditioners used and the indoor and outdoor temperature difference show some effects on ^{222}Rn, ^{220}Rn and progeny concentrations, while rainfall and relative humidity affect only the progeny concentrations.
4. The ^{222}Rn and ^{220}Rn gas concentrations tend to decrease with the building age for window-type air conditioners and natural ventilation, while these tend to increase for central air conditioning. When all the data are combined, no particular time trends are readily observable.

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