An Energy Efficient Approach for Radon Management
Part I: Radon Assessment

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ABSTRACT

This paper involves assessing radon concentrations at the heating, ventilating and air-conditioning (HVAC) environment of Hong Kong University of Science of Technology (HKUST). Ninety rooms with various configurations were selected at random and evaluated in detail. A time-integrated active sampling instrument as well as a passive activated charcoal canister radon detection system were used for the study. With the central HVAC system in the normal operating mode, data on location characteristics, as well as average and peak radon concentrations were collected and analysed.

The results indicated that radon concentrations increased linearly as a function of the length of the HVAC shut off period. On the other hand, after the HVAC system was resumed, radon concentrations dropped exponentially. While the average radon level (106.78 Bq/m^3) for all samples was approximately 50% of the World Health Organisation's (WHO) recommended level (200 Bq/m3), about 10% of the actual readings in excess of this WHO limit. 46% of the these rooms also showed peak average radon concentration (264.39 Bq/m3) exceeded this WHO limit. Factors which influence the result were identified and evaluated.

INTRODUCTION

The local granitic rocks in Hong Kong contain a relatively high uranium background. As these rocks are crushed and mixed with cement to form concrete for building construction, radon is released into the indoor environment, posing an increased risk of lung cancer for building occupants. This is of particular concern for occupants of "tight" buildings, such as those air-conditioned offices, classrooms and laboratories on the 60-hectare campus of HKUST with majority of the indoor air in recirculation.

The project commenced during the second half of 1996 with a major objective of identifying an energy efficient approach to manage the radon issue of concern. This was to include employing active control methods of reducing radon levels after its entry into the building. We focused on optimising the operational schedules of HVAC system to achieve an energy efficient measures of keeping the indoor radon at an acceptable level. In addition, we also evaluated some of the passive control methods to prevent radon from entering the room environment by assessing the effectiveness of various internal surface covering materials.

Radon is a naturally occurring, colourless, odourless, almost chemically inert and radioactive gas is formed during the radioactive decay of uranium. The main isotope of radon is ^{222}Rn, which is a direct decay product of radium (^{226}Ra). ^{226}Ra is naturally and continuously released into the environment as the earth crust contains ^{238}U. Radon itself decays to radioactive daughters in form of short-lived radioactive particles which remain suspended in the air. When these are inhaled, they irradiate the human lungs and increase the risk of developing lung cancer. This risk increases as the level of radon and the duration of exposure increases[1].

According to the 1982 report of the United Nation Scientific Committee on the Effects of the Atomic Radiation (UNSCEAR), radon and its daughters contribute about 50% to the effective dose equivalent from all natural radiation sources to the public[2]. Statistically, the lifetime risk of death to a non-smoker at the WHO Radon Action Level of 200 Bq/m^3 is about 10 per 1000 of the population; for a smoker etc., is about 10 times higher. Comparatively, the lifetime risk of death from fire and flames is about 1 per 1000 of the population. Road traffic accidents carry a lifetime risk of death of about 10 per 1000[3]. It is essential that the health of HKUST occupants, particularly that of the hardworking students who devote most of their time studying in air-conditioned indoor environment, such as classrooms and libraries etc., should be properly evaluated. The purpose of this study was to thoroughly investigate and accurately define the actual indoor radon risk concerned.

MATERIALS AND METHODS

Investigated Items and Indicators

1. Daily average concentration of indoor radon (Bq/m^3).
2. Daily peak concentration of indoor radon (Bq/m^3).
3. Room location or construction characteristics:
   a. Is the room in contact with ground soil?
   b. Does the room have a fume cupboard?
   c. How many hours per day does the HVAC system operate?
   d. When does the HVAC cease to operate at night? (Clock)

Selection of the Rooms for Sampling Study

90 rooms were selected randomly for investigation. They included:

Offices:	30 nos.(With FC supply in average size of 210 m^3)
Classrooms:	16 nos.(With AHU/FC supply in average size of 147 m^3)
Laboratories:	15 nos.(With AHU/FC supply in average size of 160 m^3)
Workshops and stores:	13 nos.(With AHU/FC supply in average size of 317 m^3)
Corridors and lobbies:	6 nos. (With AHU/FC supply or natural ventilation)
Others:	10 nos.(With AHU/FC supply or natural ventilation), where,

FC/AHU stands for Fan Coil/Air Handling Unit in HVAC system (replenished with fresh air).

Instrumentation for Radon Measurements

1. *The measuring instruments*

a. A time-integrated active continuous monitoring sampler known as "RAD7 Professional Continuous Radon Gas Monitor (RAD7)" made by U.S. Niton Corporation was used. In this instrument, air is continuously pumped through a set of filter elements and a detection unit which measure radiation from airborne radon and its daughters etc.

b. A passive sampling system known as "Radon-II Counting System for Activated Charcoal Canister (Charcoal Canister)" made by Nucleus Inc. was also used. They consisted of tightly sealed packages of activated charcoal that allowed air to diffuse through them when the caps were removed. After exposed for a few days, the charcoal adsorbed radon and its daughters start to accumulate due to radioactive decay. They were sealed and analysed.

2 *Preparation of the instruments*

a. The RAD7 was calibrated approximately 6 months before this sampling study;

b. The Charcoal Canister was calibrated using the RAD7 as a secondary standard.

3 *Locations of the samplers*

The samplers were set up in rooms at around one meter above ground and at locations one meter away from all walls, HVAC inlets and exhausts.

4 *Measurement intervals*

a. Charcoal Canisters: 24 to 48 hours continuously;

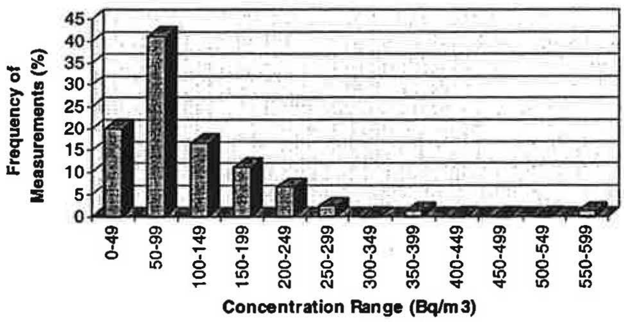
b. RAD7: 24 or 48 hours with samples taken at 30 or 60 minutes intervals.

RESULTS

Characteristics of Radon Concentrations in terms of Distribution Patterns

Figure 1 shows the frequency distribution pattern of radon measurements for the HVAC environment of HKUST. The pattern is similar to the results cited in other literature[4]-[7]. Comparing the results as reported by the Environmental Protection Department of Hong Kong[8] (EPDHK), the frequency distribution in each concentration range was almost identical.

Figure 1. Frequency Distribution of Indoor Radon Measurements at HKUST



Characteristics of Radon Concentrations in terms of Daily Variation Patterns

Figure 2 and 3 present the daily variation pattern of radon in HKUST rooms with the HVAC system in operation and those patterns in rooms with natural ventilation overnight. Overall 95% of rooms surveyed in the main campus building fit the pattern of Figure 2. The lowest radon level in Figure 2 was measured at the time immediately prior to the switching off of the central HVAC system and the highest level occurred at the time immediately before it resumed operation the next morning. The radon concentration was observed to increase linearly during the HVAC OFF period but decreased exponentially after the HVAC was ON.

Defining the Average & Peak Radon Levels at HKUST

In this sampling study, handy charcoal canisters were used as the main samplers for data collection. The RAD7 was used as a comparative standard device to establish the regression relationship between the average and peak radon levels. Using this relationship, a mathematical model was developed to predict the daily peak radon concentrations in the HVAC environment of HKUST by correlating the data obtained.

1. *Regression between Charcoal canister and RAD7 Sampling Methods*

The regression between the daily average concentrations obtained from charcoal canisters and RAD7 was established. The mathematical relationship was modelled as:

$C_{Rad7} = 11.24 + 1.25\ C_{canister}$ ...(1)

($r = 0.97$, $r^2 = 0.94$, $p<0.01$)

2 *Assessment of Radon Concentrations of concern at HKUST*

From the results of our sampling study, we observed:

a. The daily average radon concentrations of rooms sampled at HKUST was 106.79 Bq/m^3 which is significantly lower than the WHO Radon Action Level[5] of 200 Bq/m^3 ($t=10.53$, p<0.01). This 200 Bq/m^3 standard was also adopted by EPDHK[7]. 10.11% of these rooms showed radon concentrations in excess of the WHO Radon Action Level.

b. The peak average radon concentrations of rooms sampled was 264.39 Bq/m^3 which is significantly higher than the WHO Radon Action Level ($t=3.12$, $p<0.01$). 46.08% of the rooms evaluated shows radon concentrations in excess of the WHO Radon Action Level.

Figure 2. Daily Variation Pattern of Indoor Radon Concentrations in Rooms of HKUST with HVAC system

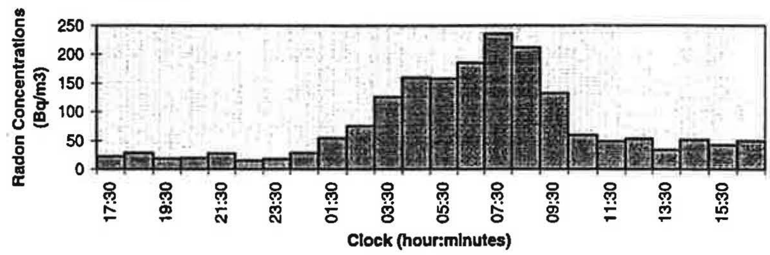
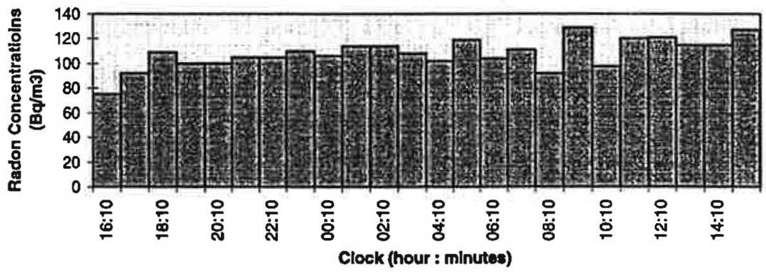


Figure 3. Daily Variation Pattern of Indoor Radon Concentrations in Rooms of HKUST with Natural Ventilation



3. *Regression between Average and Peak Radon Concentrations*

The regression between the daily average and daily peak concentrations obtained by RAD7 was established as shown in Figure 4. The mathematical relationship was modelled as:

$C_{peak} = 17.22 + 2.31\ C_{daily}$ ...(2)

($r = 0.96$, $r^2 = 0.91$, $p<0.01$)

4. *Factors Influencing the radon concentrations*

Figure 5 shows the major factors influencing the radon levels of the HVAC environment of HKUST during the study.

DISCUSSION

Comparison of HKUST Results with those of EPDHK

Table 1 summarises the results of the sampling study reported by EPDHK in 1994[9]. The average concentrations for all premises in Hong Kong was reported at 98 Bq/m^3 and, that observed at HKUST was 106.79 Bq/m^3. Statistical analysis ($t=0.9928$, $p>0.05$) confirms there is no significant different between these two sets of data.

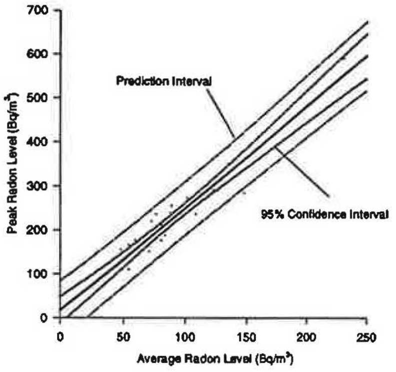


Figure 4. Regression between Average & Peak Radon Levels

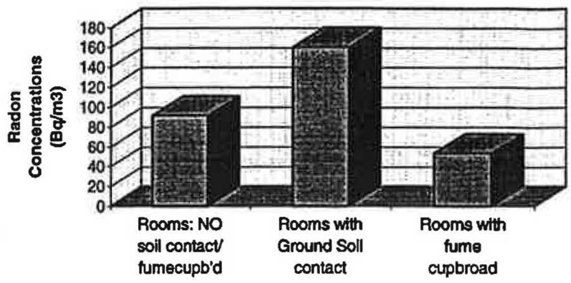


Figure 5. Factors Affecting the Radon Levels

Table 1. Average Radon Levels in Hong Kong*

Classification of areas	Radon Concentration
Residential	86 Bq/m^3
School	83 Bq/m^3
Office	140 Bq/m^3
Factory	115 Bq/m^3
Public Place	106 Bq/m^3
Hospital	42 Bq/m^3
All Premises	**98 Bq/m^3**

* Investigated by EPD of Hong Kong, September 1994[9].

Table 2. Reference & Action Levels in 14 Countrie

Country	Existing Dwellings[a]	Future Dwelling
Australia	200 Bq/m^3	200 Bq/m^3
Austria	400 Bq/m^3	400 Bq/m^3
Belgium	400 Bq/m^3	400 Bq/m^3
Canada	800 Bq/m^3	800 Bq/m^3
Finland	400 Bq/m^3	200 Bq/m^3
Germany	250 Bq/m^3	250 Bq/m^3
Ireland	200 Bq/m^3	200 Bq/m^3
Luxembourg	150 Bq/m^3	150 Bq/m^3
Netherlands	20 Bq/m^3	20 Bq/m^3
Norway	800 Bq/m^3 [b]	200 Bq/m^3
Sweden	400[c] /200[d] Bq/m^3	200 Bq/m^3 [c]
Switzerland	1000[c] /400[d] Bq/m^3	400 Bq/m^3 [c]
United Kingdom	200 Bq/m^3	200 Bq/m^3
United States	150 Bq/m^3	Same as outdoor

[a]Reference levels for dwellings with the except of those marked with [c and d]; [b]Remediation in range 200-800 Bq/m^3 should cost less than US $400; [c]Regulatory Limit; and [d]Recommended upper limit for remediation

Comparing Radon Reference and Action Levels with 14 different countries

Table 2 presents the Radon Reference and Action Levels in 14 different countries[10]. Except Netherlands, the lowest reference Level amongst these countries is 150 Bq/m^3[10] (Luxembourg & USA) which are higher than the HKUST daily average level of 106.79 Bq/m^3.

Factors influencing Indoor Radon Concentrations

In general, there are several situations in which indoor radon concentrations are affected. These include source strength of radon bearing materials (soil, water, building materials & natural gas etc.), structural characteristics of the building environment which affect radon entry and removal, and meteorological conditions. In this study, We focused specifically on the followings:

1. *Fume cupboard* (structural characteristics)

Figure 5 presents the impact fume cupboards in the sampled rooms. The radon level in the rooms equipped with one or more fume cupboards was significantly lower than those without cupboards ($t=4.08$, $p<0.01$). This can be attributed to the increase of exhaust ventilation through these units resulting in the reduction of indoor radon concentrations.

2. *Soil Contact* (Source strength)

Figure 5 summarises the effect of contact with ground soil. Radon levels in rooms in contact with ground soil were significantly higher than in rooms above ground level ($t=2.68$, $p<0.01$). This increase could be attributed to the radon released from ground soil which then seeped into the indoor environment in addition to those released from the concrete walls etc..

3. *HVAC ON/OFF hours* (Structural characteristics)

By excluding the factors of ground contact and fume cupboards, a trend was observed: the longer the HVAC OFF period, the higher the indoor radon concentrations. Statistical analysis confirms a significant correlation between the length of the HVAC OFF hours and indoor radon concentrations ($Y = 37.68 + 5.26 X$, $r = 0.2729$, $p<0.05$).

CONCLUSION

The following conclusions can be drawn from this set of sampling studies:

1. There is good correlation between the real-time, active radon sampling results and passive sampling results. This confirms the value of an inexpensive charcoal canister system for radon monitoring;
2. Using the model derived from this set of sampling studies, one can accurately predict peak radon concentrations from average radon levels in the HVAC areas. Both of these data are useful for engineering control purposes as well as for health risk assessment considerations;
3. The distribution of radon concentrations observed at HKUST matches well with the community data reported by the Environmental Protection Department of Hong Kong;
4. While the vast majority of the measured average radon concentrations were within the WHO Action Level, 10% of the data indicated average concentrations in excess of this action level and 46 % of the measured peak concentration readings were above the Limit;
5. After the HVAC system of the rooms has been OFF, the radon levels increased linearly, however, they decreased exponentially upon the resumption of the HVAC services.

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