

An Energy Efficient Approach for Radon Management

Part III: Radon Management

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ABSTRACT

This paper describes the management of radon concentrations at the Hong Kong University of Science and Technology (HKUST). Applying our derived specific modification factor in the radon concentration predictive mathematical models, we were able to accurately estimate radon concentrations under different conditions of Heating, Ventilating and Air-conditioning (HVAC) operations. Various combinations of HVAC operating schemes were tested mathematically. Many possible combinations demonstrate optimal effects.

Examples include maintaining a minimal air exchange rate without operating the full HVAC systems to address the other comfort factors during the off work hours, the early actuation of the HVAC system at the beginning of the work day together with the early shut down of the system towards the end of the regular work day, etc. In addition to this, small climate chamber studies were conducted to evaluate the radon emission reduction effect of using p-u based paint covering on various building materials used at HKUST. The results confirmed the Polyurethane-based paint is a good wall treatment material, which can effectively reduce radon emission from the room walls by approximately 50%. This mitigation approach of treatment can also minimize the daily HVAC operational hours while achieving low radon levels at minimal energy consumption.

INTRODUCTION

This paper focuses on a scheme of energy-efficient approaches for controlling indoor radon concentration. Without addressing the radon issue, HKUST already spends hundreds of thousands of US dollars each month on energy. Not including the thousands number of window and split type air-conditioners, there are over 200 air handling units (AHU) and thousands of fan coil units supported by a 7,000 TR HVAC plant on campus. A thorough energy audit has been conducted and the hourly cost per unit air-conditioned space has been defined. The challenges are: 1) To design an optimal HVAC operational schedule, and 2) To apply polyurethane-based (p-u) paints as internal surface covering which will enable the management of indoor radon concentrations at the highest energy efficiency. Using the findings of Part I & II, this paper explores the radon management techniques involving the development of various energy-efficient approaches for radon control. The goals are to evaluate:

a. The effect of a modified HVAC operational schedule as a means of radon mitigation (An "active control method" to reduce radon levels after its entry into the building);

b. The effect of polyurethane-based (p-u) internal room surface coverings as a radon prevention measure (A "passive control method" to prevent radon from entering the building).

MATERIALS AND METHODS

Small Climate Chamber Studies

1. *Small climate chamber*

A small PVC climate chamber was made by Indoor Air Quality Laboratory of the Hong Kong Polytechnic University for radon study. It is 32cm x 21cm x 20cm in volume (13.44 cm³) with a small electrical fan to provide forced air circulation (DC 12 V).

2. *Different building materials tested*

The building materials tested include: (1) a nude brick (22cm x 9.5cm x 7cm), (2) a gypsum board (20cm x 9.5cm x 5cm), (3) a cement brick (14.5cm x 15cm x 10cm) and (4) a background air control (without any material in the small climate chamber).

3. Different surface treatments applied

The radon emission treatments for the nude brick included: Step 1: nude brick without covering, Step 2: the same brick covered with water-based limestone paints, and Step 3: the same brick, covered with a second layer of polyurethane-based paints.

4. Investigated Items and Indicators

- $C(t)$: Radon concentration in chamber during experiment (Bq/m^3);
- t : Elapsed time during experiments (hr);
- T : Air temperature in chamber ($^{\circ}C$); and
- H : Air humidity in chamber (%).

Room Chamber Studies

1. Experimental room chamber

Same experimental room chamber and set up as described in Part I and II.

2. Investigated items and indicators

Parameter	Description of items & Indicators	Units
C	Indoor radon concentration taken during experiment	Bq/m^3
t	Elapsed time (variable) during experiment	hrs
S	Surface area of room chamber selected for experiment	m^2
V	Volume of room chamber	m^3
L	Loading factor of room chamber, $L = S/V$	$m^2/m^3, /m$
R	Radon emission rate from room chamber surfaces	$Bq/m^2/hr$
U	Flow velocity of HVAC inlet	m/sec
F	Cross-sectional area of HVAC inlet air ducting	m^2
A	Fresh air volume per hour, $A = 3600 U \cdot F$	m^3/hr
N	Fresh air exchange rate, $N = A/V$	ACH, /hr
k	Source decay rate	/hr, per hr
T	Air temperature in room chamber	$^{\circ}C$
H	Humidity in room chamber	%
P	Air pressure	mm Hg.

3. Source reduction with different treatments

- With water-based limestone applied on internal surfaces of room chamber, the source treatment for radon emission was undertaken following the order of the previous experiments at in paper, Part II. The original room condition of the building (with water-based limestone paints) was compared with the later one after applying p-u paints. N was set at 0.25, 0.5, 1.0, 2.0 or 4.0 ACH for comparison.
- One or two layers of polyurethane-based paints applied on the internal surfaces
- Previous findings in small climate chamber studies indicated applying p-u paint was a means to reduce radon emission from source. To confirm, effects in a real room environment was investigated with surface treatments in one layer as the second treatment, and in two layers as the third treatment. N was set at 0.5 and 1.0.

Measurements for Radon Concentrations

Same measuring instrument, the RAD7 and set up were used as per Part I & II papers.

Measurements for the Other Indicators

Same auxiliary measuring instruments were used as per Part I & II papers.

RESULTS OF THE CHAMBER STUDIES

Small Climate Chamber Studies

1. Radon emissions after applying different coverings on building material surfaces

In Figure 1, the radon concentrations (Bq/m^3) from the different coverings are shown. In summary, the radon levels in decreasing order are listed as: Nude Brick > Water-based Limestone Painting > Polyurethane-based paints > Air Control. ($p < 0.01$). To conclude, the climate chamber study indicates the possibility of p-u paint in reducing the radon emission up to a significant level of 50%.

2. Radon emissions with different HKUST building materials

Figure 2 presents the results of the radon emission from different building materials taken from the HKUST site. The radon emitted from different materials placed into the chamber were observed with the following decreasing order: Nude Brick > Cement Brick > Gypsum Board > Air Control ($p < 0.01$). In conclusion, the nude bricks are confirmed to be the main sources of radon emission in the main building of HKUST.

Room Chamber Studies

Figure 3 presents the effect of wall coverings (p-u paints) on room chamber surfaces. These include room conditions with and without p-u based paints. The radon concentrations after the room chamber was coated with two layers of p-u based paints was observed to be the lowest with air exchange rates set at 0.5 and 1.0 ACH.

Figure 1. Small Climate Chamber Study for Surface Coverings

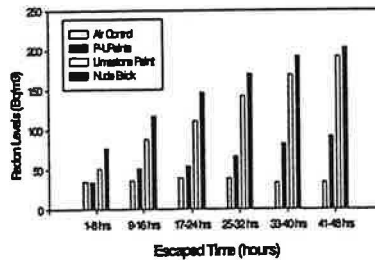


Figure 2. Small Climate Chamber Study for Building Materials

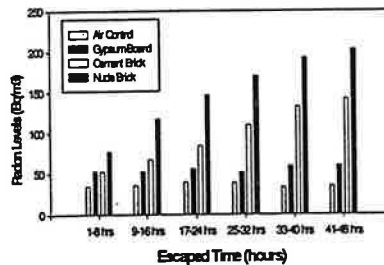
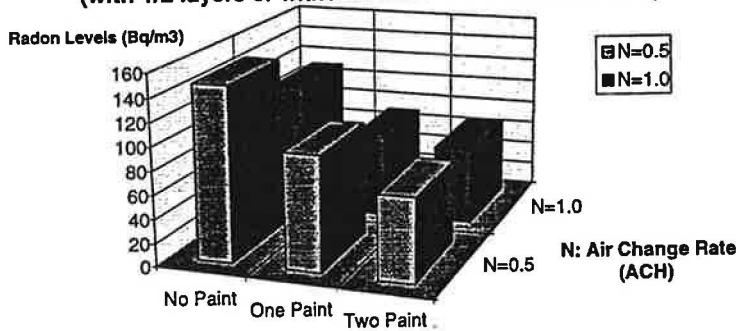


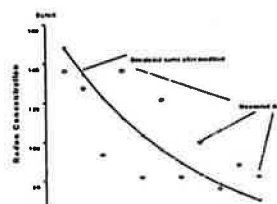
Figure 3. Daily Average Radon Levels in Room Chamber (with 1/2 layers or without Paints on all Walls & Floor)



Wall & Floor Treatment with 1/2 layers or Without Paint

Figure 4 presents the result for vent-on-hs, using the model with same modification factors. The only different parameter was the R value changed from 8.6 to 4.84 $Bq/m^2/hr$.

SIMULATED RESULTS OF HVAC OPERATIONS



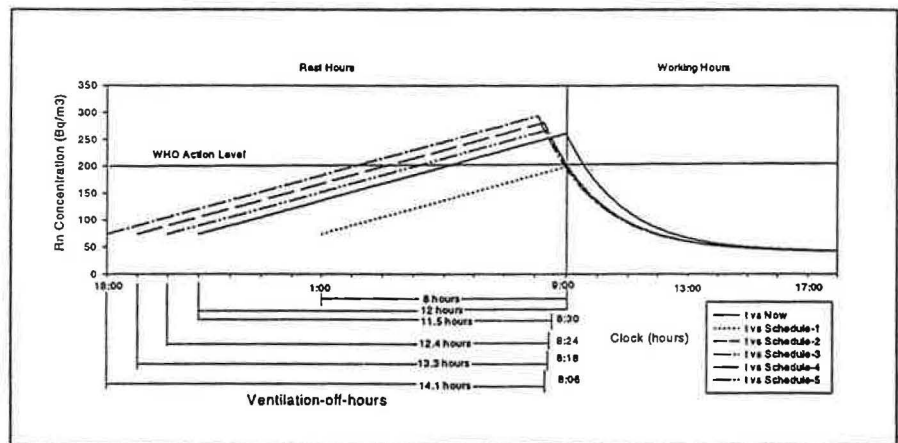
Operating Conditions at HKUST

Using the past energy records for two years at HKUST, the following data were derived for simulating AHU consumption: a. 12 hr/AHU/day, b. 40 HK\$/hr/AHU and c. N is about 1.0 ACH (to comply with normal HVAC practice).

Table 1. Simulated schedules to manage radon levels with energy efficiency consideration

Operation Schedules	V-off-time	V-on-time	V-off-hrs	$C_{(v-off)}$	hours-before-9:00	$C_{(9:00)}$	V-on-hrs	Daily operational cost for one typical AHU (HK\$)
Now	21:00	9:00	12	260.6	0	60.6	12	480
1	1:00	9:00	8	198.3	0	198.3	16	640
2	21:00	8:30	11.5	252.8	0.5	202.4	12.5	500
3	20:00	8:24	12.4	266.8	0.6	203.9	11.6	464
4	19:00	8:18	13.3	280.8	0.7	204.9	10.7	428
5	18:00	8:06	14.1	293.3	0.9	195.6	9.9	396

Figure 5. Simulated schedules to manage radon levels with energy efficiency consideration



Operation Schedules Adjusted

1. Application of equations (1) and (2)^{[1][2][3]}

$$C_{(t)} = C_o + RLt \quad \dots(1)$$

$$C_{(t)} = \frac{RL}{MN - k} [\exp(-kt) - \exp(-MNT)] + (C_o - C_{in})\exp(-MNT) + C_{in} \quad \dots(2)$$

From previous findings in Part I & II with results $L=1.81$, $R= 8.6$, $C_o=31.22$, $k=0.01$ ^[4], N/M is $1.0/0.55$, $C_o=260$ (264.39 & 260.61 from Part I & II resp. for indoor concentration estimated just before the HVAC system was turned on, or peak concentration)

2. Simulation of HVAC operation schedules

Table 1 and Figure 5 are the result of radon concentration simulation:

3. AHU consumption when the internal surfaces/walls are coated with p-u paints

When the walls are coated with p-u based paints:

R is $4.8 \text{ Bq/m}^2/\text{hr}$ (radon emission rate from the room surface),

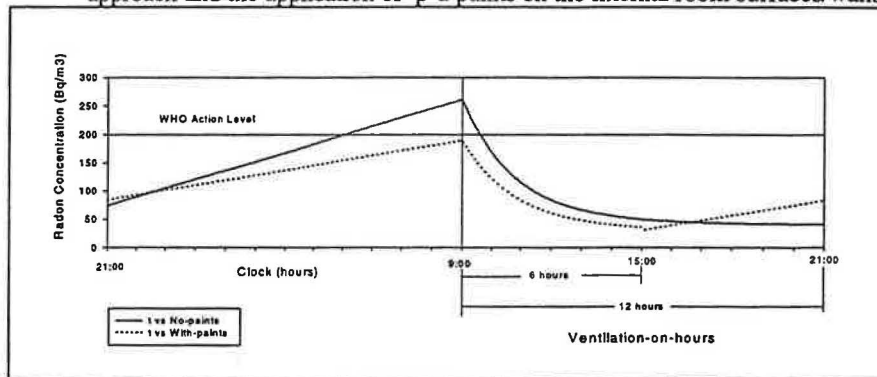
C_o is 31.22 Bq/m^3 (concentration just before the HVAC system was turned off), and the rest of the variables are the same.

Table 2 and Figure 6 provides the required simulation results.

Table 2. Simulated energy efficiency schedules to manage radon levels after applying p-u paints on the internal room surfaces/walls.

Schedules	V-off-time	V-on-time	V-off-hours	C(9:00)	V-on-hours	Daily operation cost for one typical AHU
Without Paint	21:00	09:00	12	260.6	12	480 HK\$
With one layer of p-u Paint	15:00	09:00	18	189.1	6	240 HK\$

Figure 6. Simulated schedules for managing radon level with energy efficient management approach and the application of p-u paints on the internal room surfaces/walls.



DISCUSSION

Requirement for Radon Control

According to our previous study on defining radon levels, the daily average radon level of 106.79 Bq/m^3 is found to meet the requirement of WHO Action Level of 200 Bq/m^3 . However, the application of the As Low As Reasonably Achievable (ALARA) principle is also another important factor to look at when considering human exposure to natural radiation especially for those intermittent high level exposures as found in HKUST environment. A balance of risks and benefits is always an essential part of the environmental health.

The Energy-efficient Requirement

IAQ and energy consumption are always two conflicting issues when managing modern building environments with a central HVAC system. The result of this study can provide building operators with an energy-efficient approach to operate the HVAC system and, at the same time, to manage the indoor radon issue simultaneously. Considering an university complex like HKUST, equipped with more than numerous AHU, the potential savings can be easily up to thousands of U.S. dollars a year. However, if a higher radon mitigation effect is required as shown in this paper, via p-u paint coating combined with HVAC scheduling etc., considerable investment is expected in terms of renovation. This is also a matter of risk and benefit balance.

Radon Reduction Methods

There are a lot of studies carried out on the measures of indoor radon control^{[6][7]}, the reduction factors of different types of surface coverings have been properly evaluated. Many results recommended polyurethane coatings are superior to other surface covering materials in terms of radon emission reduction. Our experimental results also confirm their findings. However, the developed active radon control method of optimising HVAC operational schedules is regarded to be more favourable than the passive method of applying surface coverings because of the intensive cost involvement of the latter.

Validation and Limitation of Model developed

1. Preliminary validation of the ventilation-on-hours model developed

The model was regarded to have successfully validated in a preliminary way during the processing of experiment with N parameters in variation, the results were observed to be smooth matching one and other. The previous study can confirm the statement. The model was further validated by the variation of the R parameters, from 8.60 to 4.85 Bq/m³, as presented in our room chamber study. This involves the evaluation of different Polyurethane-based surface covering effects on preventing radon emission from walls. Figure 7 summarises the results which confirms the modified radon predictive model with same modification factors is capable of matching the data well.

2. Limitation of the modified radon predictive models

More studies might be required to validate the models in a more thorough sense especially the model modification part due to different environment configurations may yield different modification factors. This study contributes the method in arriving the essential parameters whereas future researchers can apply into their own situation whenever required.

Economic Assessment

From the engineering viewpoint, energy conservation is a global concern especially when it links up with the environmental health issue of radon. To make a proper decision with respect to benefit and risk, a thorough economic assessment is required. However, when talking about thousands of offices, classrooms and laboratories etc. of the whole university, the figures can be extremely high. An intensive financial assessment is required to arrive a good balance of the benefit and risk for the university itself and the individual occupants. Work is on-going to determine the optimum control strategy involving both passive and active methods.

CONCLUSION

The results of this study yield the following conclusions:

1. By exercising the radon level predictive mathematical model, one can determine the optimal HVAC operational schedules to achieve an acceptable radon concentration at the best energy efficiency;
2. The application of Polyurethane-based wall covering materials has a significant effect on reducing indoor radon emission;
3. The combined use of Polyurethane-based wall covering materials together with an optimal operational schedule for the HVAC systems can effectively reduce the indoor radon concentrations; and,
4. This model is useful for other HVAC facilities. It can be used to determine the best energy efficient approach for controlling indoor radon concentrations.

REFERENCES

- 1 Roache, N.F.; Guo, Z.; Fortmann, R. & Tichenor, B.A. 1996. "Comparing the Field and Laboratory Emission Cell (ELEC) with Traditional Emission Testing Chambers", *Characterising Sources of Indoor Air Pollution and Related Sink Effects*, Edited by Bruce A. Tichenor, STP 1287, ASTM PCN: 04-012870-17, pp. 98-111.
- 2 Guo, Z., Tichenor, B.A.; Krebs K.A. and Roache, N.F 1996. "Considerations on Revisions of Emissions Testing Protocols", *Characterising Sources of Indoor Air Pollution and Related Sink Effects*, Edited by Bruce A. Tichenor, STP 1287, ASTM PCN: 04-012870-17, pp. 225-235.
- 3 Lawless, P.A.; Smith, D.D.; Ensor D.S.; and Sparks L.T. 1996. "A Large Dynamic Chamber for Characterising Particulate and VOC Emissions", *Characterising Sources of Indoor Air Pollution and Related Sink Effects*, Edited by Bruce A. Tichenor, STP 1287, ASTM PCN: 04-012870-17, pp. 34-43,
- 4 Nerc, A.1989. "Earth, Air Radon and Home", *Physics Today*, pp. 32-39. (April 1989)
- 5 Jandel Scientific Software, 1995. *SigmaPlot User's Manual*.
- 6 Jong P.D.; Dijk V.W.,1994. "Reduction of the Radon Entry Rate from Building Materials by Industrial Surface Coatings", *Radiat. Protect. Dos.*, Vol. 56, Nos 1-4, pp. 178-183.
- 7 Leovic D.W.; Roth R., 1993. "Radon Control Strategies", *Manual on Radon*.