Measurement of the Radon Exhalation rate and Characteristic Parameters of Aerated Concrete Blocks

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Content

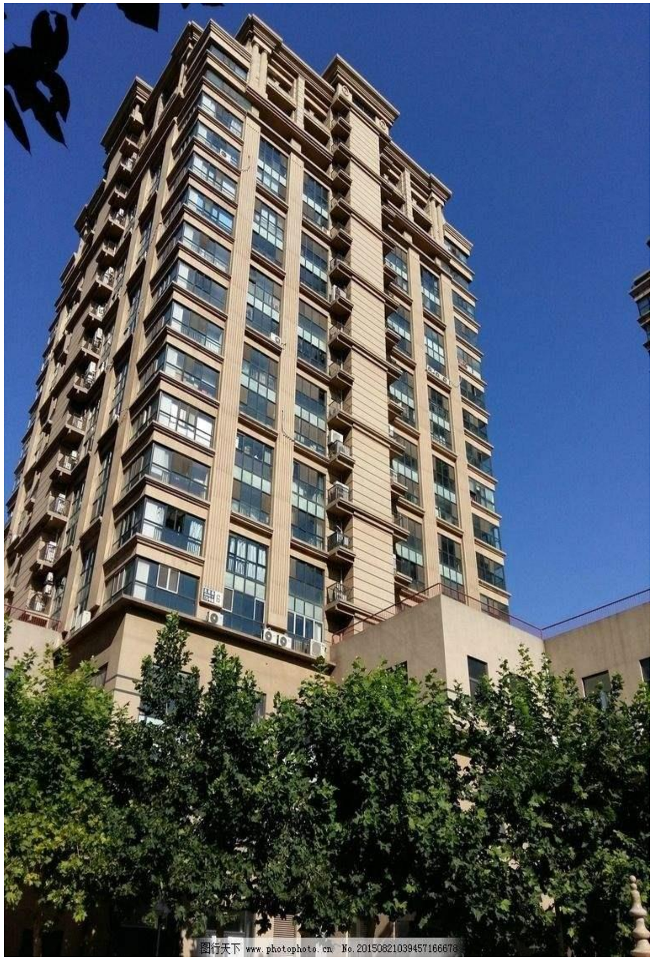
1 Introduction
2 Materials and methods
3 Results and discussion
4 Conclusions

Introduction

- Since 1990s, modern buildings characteristic of multi-storey construction are prevailing in cities, china.

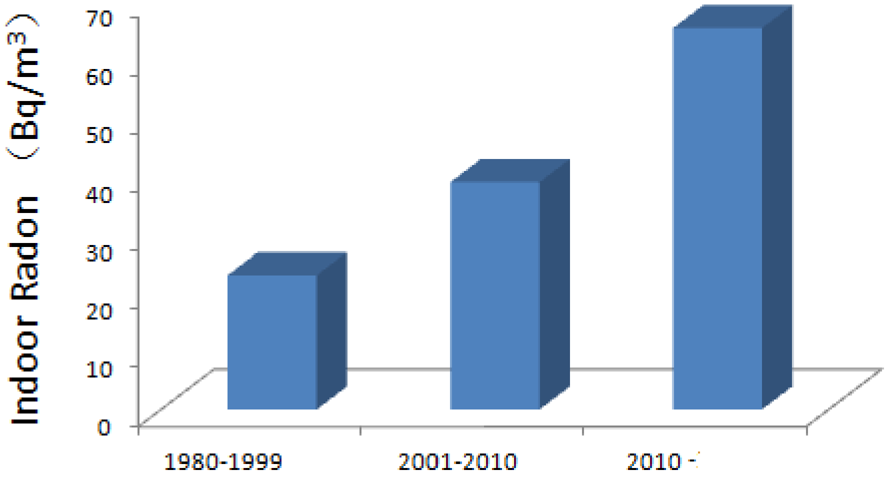
- Surveys reveals that there is a significant increase in the concentration of radon in residential dwellings, china.

- Based on the obtained results, it was found that the indoor radon concentration in the buildings increasing with its construction years .



Typical residential building in China

➢It showed an continuous increase trend with the age for indoor radon concentration in china.



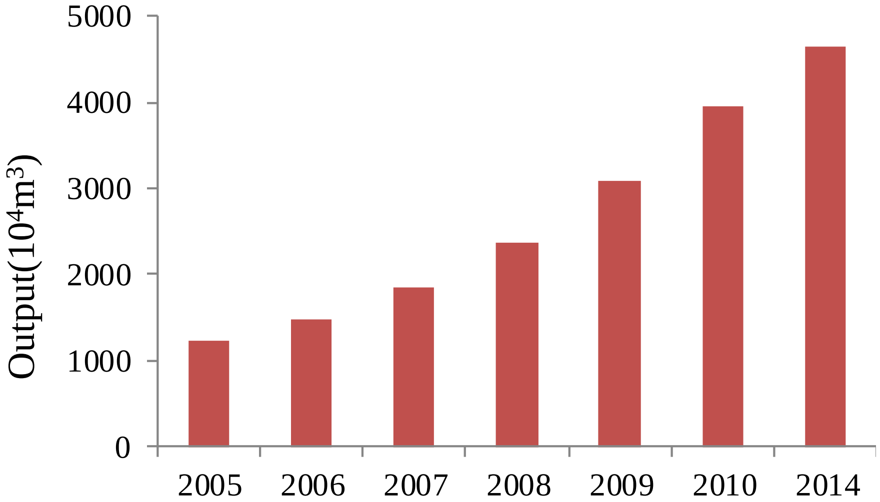
The increase trend with the age for indoor radon concentration in china.

➢ A survey of new residential buildings in Guangzhou in 2015-2016 showed that the average indoor radon concentration was 84.2 Bq/m^3 (n=1796), and more than 24% houses exceeding 100 Bq/m^3, and the houses exceeding 200 Bq/m^3 accounted for 3%.

- A kind of new building material called aerated concrete is widely used in modern multi-storey construction buildings, due to its advantages such as light weight, good insulation properties, strong seismic capacity, and easy construction.

- The government encourage to use this new building materials due to its energy efficiency, and its output is increasing with the year.

- Light weight and porous are the important characteristics of aerated concrete, and its porosity is generally divided into closed porosity and open porosity, and open porosity which connected with the outside may be have a direct impact on the radon exhalation rate.



Annual production of aerated concrete in China

- **It is necessary to understand the radon exhalation rate and characteristic parameters of aerated concrete blocks.**

- **In order to provide useful information on indoor radon control from its source.**

- **It is also a first study to carry out the systematic research on aerated concrete blocks and radon in china.**

Materials and methods

- A total of 39 samples of aerated concrete block from national inspected samples in 2014 and 2015 were selected.
- Involving 14 provinces and 3 municipalities

Production places of aerated concrete block samples

- The dry density

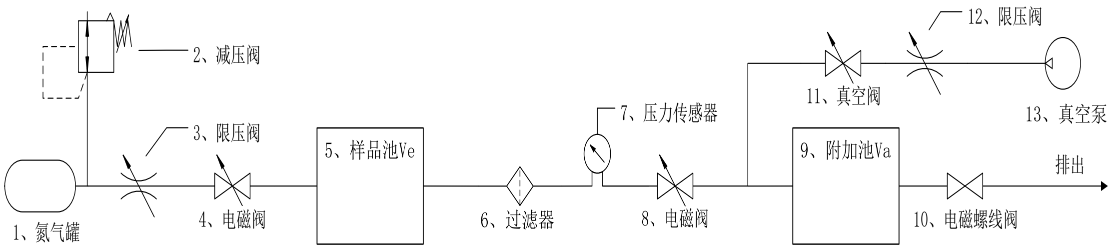
The sample was cut into the size of 60mm×30mm×30mm with volume of V, then placed in a dry oven at 65 °C until constant weight m, the dry density D_{dry} is calculated：

$$D_{dry} = m/V (g/cm^3)$$

➢The open porosity

Volume expansion method was used to measure the open porosity of the samples. UltraPYC 1200e Density Analyzer is used to measure the open porosity of the samples.

The experimental procedure is as follows: Nitrogen gas is introduced into the sample cell Ve through the solenoid valve 4, at which time the system pressure value is P. The pressure is then regulated to P_2, and the solenoid valve 8 is opened to allow the additional cell volume Va to communicate with the sample cell and the pressure drops to P_3.



Ultrapyc 1200e device schematic diagram

The impermeable volume of the sample is

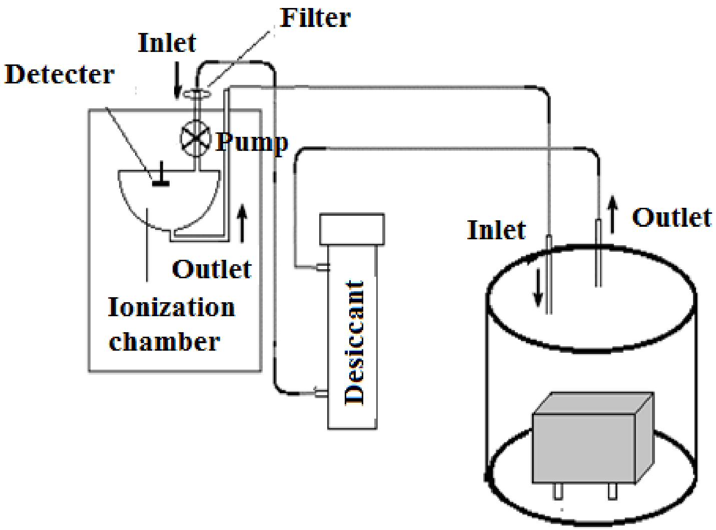
$$V_p = V_e + \frac{V_a}{1 - \frac{P_2}{P_3}}$$

Where P_2 is the pressure value set by the instrument, kPa; P_3 is the pressure value after the connection between the additional pool and the sample cell, kPa.

From the ratio of Vp to the apparent volume V_G of the sample, the open porosity of the sample is

$$\varepsilon = \frac{V_G - V_p}{V_G} \times 100\%$$

➢The radon exhalation rate was measured by the closed box method with a continuous radon monitor.



The radon exhalation rate measurement device

➢The cylindrical enclosed box is made of plexiglass, with the inner diameter 28.1 cm, the height 25cm, the volume 0.0155m^3,and leak rate is 0.0011 h^{-1}.

➢Radon concentrations in the container were determined by RAD7（DURRIDGE Co. Inc., USA）, operated in the AUTO mode at a 60 min counting cycle for 24 hours.

- The increase of radon activity concentration can be fitted with an exponential function:

$$C(t) = \frac{\phi . S}{V \cdot \lambda} \cdot (1 - e^{-\lambda t})$$

Where C is activity concentration in the accumulation container at time t (Bq/m^3), S is effective surface (m^2), V is effective volume(m^3),λis the sum of radon decay constant and time constant of back diffusion and time constant of leakage,ϕ is surface exhalation rate（$Bqm^{-2}h^{-1}$）.

- At the beginning of the accumulation process, the initial slope of the curve is independent of back diffusion, assuming that radon loss by leakage is negligible, the accumulation phase can be approximated by a linear increase of radon activity concentration in the accumulation container as described by

$$C(t) = \frac{\phi . S}{V} \cdot t$$

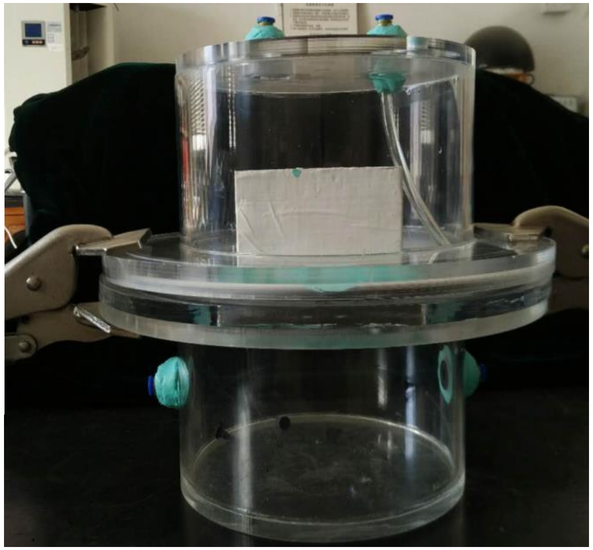
- The radon exhalation rate was determined by the slope of the initial growth curve , as formula:

$$\varphi = CCF \times V/S$$

where *CCF* is the e slope of the initial growth curve in Bqm^{3} h^{-1}.

- The diffusion length measurement is based on observing the radon flow from a chamber with high radon concentration through the medium to a second chamber with a much lower radon concentration.
- The diffusive flow of radon through porous media is described by the Fick's law.

$$\frac{\partial C(x,t)}{\partial t} = D\frac{\partial^2 C(x,t)}{\partial x^2} - \lambda C(x,t)$$



The setup of radon diffusion length measurement

- The relationship between the growth slope of radon concentration in measuring chamber and the diffusion length of radon can be expressed as

$$L = \sqrt{\frac{b_{fitted}\, d\, V}{C_1\, S\, \lambda}}$$

where L is the diffusion length of radon(m), b_{fitted} is growth slope of radon concentration in measuring chamber, d is the thichness of the sample (m), V is the rest volume of the measuring chamber (m^3) ， C_1 is radon concentration in reservoir chamber (Bq/m^3)， S is the area of observed radon flux (m^2) ， λ is decay constant of radon (s^{-1}).

The diffusion coefficient is

$$D = L^2 \times \lambda$$

- The Radium content is determined by gamma spectrometry using HPGe detectors (GEM-30185-Plus, Ortec), with a energy resolution of 1.85 keV for the 1332 keV ^{60}Co peak, with relative efficiency of 30%.

- The samples were dried in a dry oven at 100 ° C until constant weight, sieved through a 60 mesh sieve and then placed in a measuring cup and sealed for 21 days. The activity of ^{226}Ra was calculated by the gamma ray energy of 609 keV emitted by ^{214}Bi .

Results and discussion

Table 1 The dry density, the porosity, radium content and radon exhalation rate measurement result

Level	n	D_{dry} (kg/m^3)	ρ (%)	C_{Ra} (Bq/kg)	J （$Bqm^{-2}h^{-1}$）
B04	2	480±22.6 464~496	78.8±1.0 78.1~79.1	41.4±41.2 12.3~70.5	3.7±1.0 3.0~4.5
B05	8	582±9.7 570~596	76.6±3.3 70.1~81.1	50.7±30.9 20.2~99.0	7.1±7.1 0.6~22.8
B06	20	647±27.5 601~697	74.9±2.0 72.0~78.8	68.8±31.4 22.7~136	7.6±5.2 0.6~18.0
B07	6	742±23.6 705~778	71.2±1.4 68.4~72.4	68.0±25.9 28.9~96.2	9.5±5.3 2.6~14.6
B08	3	828±21.4 803~840	69.3±3.4 67.1~73.2	61.8±29.2 29.8~86.9	4.1±2.4 2.6~6.9
Total	39	654±82.5 464~840	74.4±3.3 67.1~81.1	63.0±30.4 12.3~136	7.3±5.4 0.6~22.8

Table 2 The radon diffusion length and diffusion coefficient of aerated concrete block

level	n	L（m）		D_f（$10s^{-1}$）	
		X±S	Range	X±S	Range
B04	2	0.66±0.11	0.58~0.74	0.94±0.32	0.71~1.16
B05	5	0.70±0.20	0.49~1.01	1.10±0.65	0.51~2.13
B06	8	0.65±0.10	0.51~0.75	0.91±0.25	0.54~1.17
B07	3	0.84±0.10	0.74~0.93	1.50±0.33	1.15~1.81
Average	18	0.70±0.15	0.49~1.01	1.06±0.45	0.51~2.13

Table3 Comparison of Aerated Concrete and traditional building materials

Building materials	D (kg/m^3)	C_{Ra} (Bq/kg)	ρ (%)	D_f ($10s^{-1}$)	L (cm)	Jp ($Bqm^{-2}h^{-1}$)
Aerated Concrete	654 464~840	63 12~136	74 67~81	0.86 0.4~1.6	70 50~100	7.3 1~33
Clay Brick	2300	50	20-40	0.35	16~40	0.2
Ordinary Concrete	2000~2600	50	13-40	0.007	6~21	1.1 2.2~3.6

The radon exhalation rate and radon diffusion length of aerated concrete are much higher than that of traditional building materials.

So the aerated concrete may contribute to the high indoor radon concentration in modern buildings in china.

- There are two samples with radium content exceeding 100Bq/kg, accounting for 5.1%, and no samples exceeding the national standard 200 Bq/kg.
- However, there are quite a few residential buildings with indoor radon concentration exceeding the national control level in china recently.
- So China's current building material standard is only applicable to traditional building materials, and the standard is needed for new building materials, such as aerated concrete.

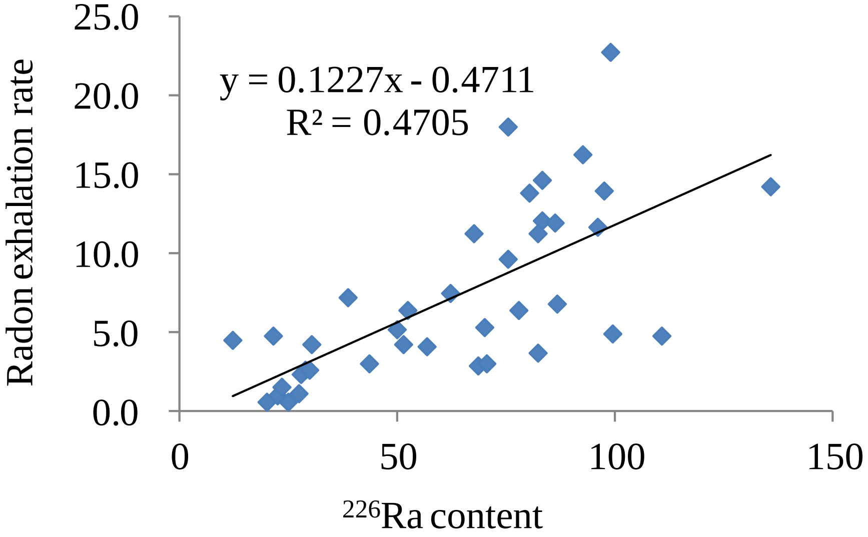


Figure 5 Correlation of radon exhalation rate and radium content

There is a positive correlation between the radon exhalation rate of the aerated concrete and the ^{226}Ra content, and the correlation coefficient $R^2 = 0.4705$.

➢The correlation of the radon exhalation rate and the open porosity of the samples showed that there is a weak relationship , and the correlation coefficient $R^2 < 0.1$.

➢So porosity is may not the key factor that influence the radon exhalation rate of the aerated concrete.

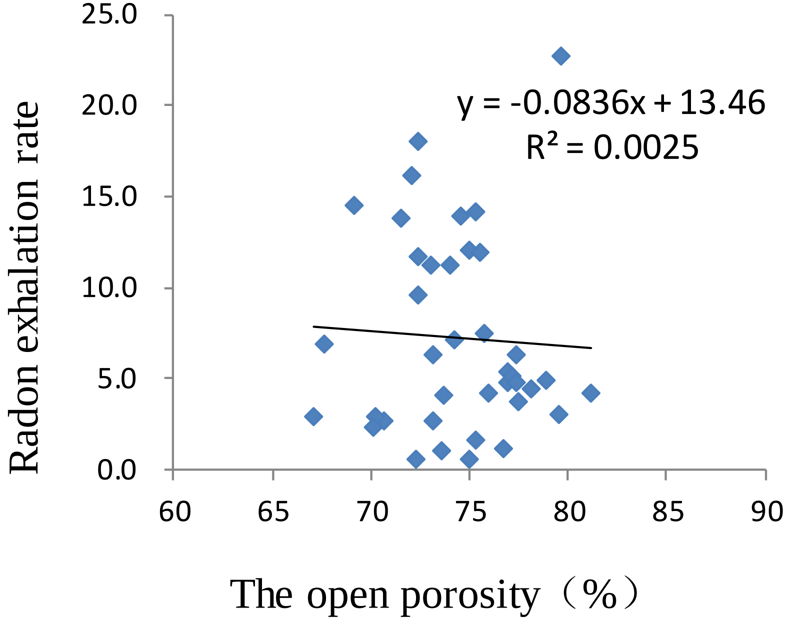


Figure 7 Correlation of the radon exhalation rate and the open porosity

➢The radon exhalation rate may be related to the particle size of the raw material, the process parameters, the distribution of radium and its microstructure of aerated concrete . A more comprehensive analysis is required.

Conclusions

- **The aerated concrete may contribute to the high indoor radon concentration in modern buildings in china.**
- **The standard is needed for new building materials, such as aerated concrete.**
- **The work could provide the scientific basis for radon control from source of building materials.**

Thank you for attention