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EXPERIMENTAL STUDIES ON THE INDOOR RADON AND RADON DAUGHTER CONCENTRATIONS BUILD-UP IN JAPANESE HOUSES

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Abstract

Measurements of radon and radon daughter concentrations along with other factors, such as, ventilation rates, wind velocity, radon generation rates from building materials, amount of radium contained and indoor and outdoor temperatures and humidities, were conducted in a simple block-shaped experimental house in order to study concentration build-up mechanism of the radon released from building materials and soil underneath the house. Results showed that the most important factor for radon build-up was ventilation rate of the room. The data was compared to the results of seven actual houses and a model house of prefabricated house manufacturer and was found to be considerably high. Theoretical analysis was also made to testify the mass balance of radon in the room.

Introduction

With the increasing demand for improvements in the air-tightness of building envelopes as an energy conservation measure, considerable attention has been focused on the exposure to radon and its daughters in residential environments. In contrast with research situation in Japan (we have just begun nation-wide survey on the indoor radon levels in dwellings), comprehensive surveys (1) and many researches (2) are made in European and North American Countries; even the environmental standards are already established in Sweden (3). But we have still many subjects to be studied to clarify the radon build-up mechanisms and to establish the effective counter measures.

Measurements of radon and radon daughter concentrations along with other factors, such as, ventilation rates, wind velocity, radon generation rates from building materials, amount of radium contained, and indoor and outdoor temperatures and humidities, were conducted in a simple block-shaped experimental house in order to study concentration build-up mechanisms of the radon released from building materials and soil under the house.

Outlines of the Measurements

Measurements were conducted for two experimental houses and seven actual

Table 1 Outlines of the Houses Measured.

House	Type	Structure	Year after const-ruction	Room measured	Description of each house neighboring environments
Masonry	Experimental house	Heavy concrete blocks	1	Test room for thermal envi-ronment ($A=28\ m^2$, $V=99m^3$)	A house originally built for building thermal performance experiments. Built in an open rural area.
PSH	As Masonry	Prefabricated timber-flame	2	Bed room ($A=10m^2$)	Same as "Masonry", but more practical type. Same type building is commercially available.
A	2-storied de-tached house	Prefabricated steal-flame	5-10	Living room ($A=36m^2$)	Densely populated residential area without any high-rise building.
I	2-storied de-tached house	Conventional timber-flame	5-10	Living room ($A=16m^2$)	Well-planed new residential area having unsold site.
N	5-storied apartment house (4F)	Conventional reinforces concrete	1	Living room ($A=12m^2$)	Apartment blocks for govern-ment workers. The blocks are consisted of 5 buildings and one unconstructed site.
O	7-storied apartment house (7F)	Conventional steal-flamed reinforced	3	Living room ($A=18m^2$)	South side of the building is facing to a small hill, and north side is a densely populated residential area.
S	2-storied de-tached house	Prefabricated steal-flame	5-10	Living room ($A=16m^2$)	Newly developed residential area having a stadium in the neighborhood.
T	1-storied de-tached house	Prefabricated timber-flame	5-10	Living room ($A=16m^2$)	Newly developed residential area having dense population.
Y	2-storied de-tached house	Conventional timber-flame	5	Living room ($A=16m^2$)	The house is built in a rural area.

houses with occupants (in Table 1). These seven houses were considered to be the representative house in Japan. The measuring period for "Masonry" was May 12, - June 5, and July 16, - August 7, 1986, the period for "PSH" was June 13, - July 7, 1985, and the term for seven houses with occupants was autumn of 1985 - winter of 1986. During the measurement, all openings of the room measured were usually closed. But in the case of the measurement conducted for Masonry July 29, - August 6, all openings were opened during daytime (7 am to 7 pm). Ventilation rates of the rooms were measured for each opening condition. The concentrations of radon and radon daughters were measured with continuous monitor (Model RGA-400, EDA Ltd. Canada). Radium content of building material and soil was determined by germanium detector. Radon flux from building material was determined by scintillation counter putting sample of the material in a small cell. Ventilation rates of each house were measured using a CO_2 tracer gas decay method.

Results of the Measurements

Experimental house Masonry

Fig. 1 and 2 show the examples of hourly fluctuation patterns of concentrations of radon and its daughters. Two day and half after shutdown of all the openings of room, where ventilation of the room was about 0.07 ACH, indoor levels reached to the steady state value of 300 Bq/m^3 for radon and 150 Bq/m^3 for radon daughters. These are almost same levels as Swedish Measurements (4). And the ventilation rate of 0.07 ACH is much lower than the NRC's results, 0.39 ACH on the average (5). It is considered that major reason of the high concentrations are the low ventilation rate.

On the other hand we can see no steady value in the curves of radon and its daughters obtained only half day after shutdown. Peaks of these curves were about 100 Bq/m^3 for radon and about 50 Bq/m^3 for daughters, and were very lower than the previous maximum values. These levels decreased to almost zero within a couple of hours after opening of doors and windows, when ventilation rates were 3 to 8 ACH for wind speed of 0.4 to 1.6 m/s (Fig. 3). This tendency clearly shows that indoor radon levels were strongly affected by the ventilation rate. There is, however, no specific relation between indoor radon levels and the factors other than ventilation rate.

Experimental House PSH (Passive Solar House)

Fig. 4 shows the example of indoor radon and its daughter concentration fluctuation patterns at PSH. Indoor levels of PSH were 50 Bq/m^3 and 20 Bq/m^3 at their maximum, and were much lower that of the Masonry. The values of PSH were almost same level as American data (4). Ventilation rate of the house was 0.42 ACH, which is very similar to NRC's data (5).

Seven Houses with Occupants

Table 2 shows results of the measurements at 7 houses with occupants. The indoor radon gas levels in these houses were almost 0 to 5.6 Bq/m^3 and were very much lower than those in the Masonry, and radon daughters were not detected in any house. The reason of this low level is, also, considered to be the high ventilation rate as shown in table 2.

Table 2 Measurement Results of Indoor Radon Levels and Ventilation Rates

House	Radon Gas Bq/m^3	Radon Daughters Bq/m^3	Ventilation Rate ACH
Masonry	Fig. 1 & 2		0.07(all closed) Fig. 3(door open)
PSH	Fig. 4		0.42(all closed)
A	0	0	1.7 (all closed) 1.9 (all closed)
I	0	0	3.8 (all closed)* 0.91(all closed)
N	5.6	0	1.0 (all closed)
O	5.6	0	0.55(all closed) 0.56(all closed)
S	0	0	1.1 (all closed) 1.5 (all closed)
T	0	0	1.9(window open) 0.62(all closed)
Y	0	0	0.46(all closed) 0.45(all closed)

* Wind direction changed.

Mass Balance of Radon Gas in the Masonry

If radon gas emitted into the room is distributed uniformly and instantaneously, indoor radon concentration Ca would be expressed as;

$$Ca = q / (Q + V \times D_f)$$

where Q: ventilation rate (m^3/h)
q: generation rate of radon gas (pCi/h)
D_f: Decay factor of radon gas (1/h)

In this equation, since Q is expressed as N x V and N = 0.07 ACH, the Q is 0.07 x 99 = 6.93 m^3/h. Then, as D_f is ln 2 / $T_{1/2}$, where $T_{1/2}$ is half life of radon, D_f x V becomes (0.693 / 3.8 x 24) x 99 = 0.75 m^3/h. Finally, as q is considered sum of flux from building materials Fw and from soil Fs, we must estimate both separately. We have obtained the data from the measurement that the Fw was 2.98 mBq/m^2s, and total surface area of the room was about 118 m^3, so total emission rate from the surrounding materials was 2.98 x 118 = 350 mBq/s. Although we could not measure the Fs, we try to estimate it referring the Nazaroff's data, 11 Bq/m^2s (6). Since the house Masonry has no crawl space, it can be assumed that all the radon gas generated from the soil underneath this house comes into the room through the floor. If it is true, total flux from soil would be estimated as 11 x 28 = 308 Bq/s because floor area of the room was 28 m^2. Therefore the estimated concentration of the room would be

$$Ca = (350 + 308) \times (1/1000) \times 3600 / (6.93 + 0.75) = 308 \ Bq/m^3$$

As the estimated value is fairly similar to the measured value, 300 Bq/m^3, obtained as steady state data two and half days after the shutdown of the room door, it might be considered that our assumptions for the mass balance analysis are not unsuitable.

Conclusions

1. Indoor radon levels of simple-shaped experimental house were fluctuated clearly reflecting ventilation rate, and were agreed with estimated value calculated from bass balance model.

2. Indoor radon levels of the houses with occupants were very much lower than the experimental house. The reason of this low level was high ventilation rate of these houses.

Acknowledgment

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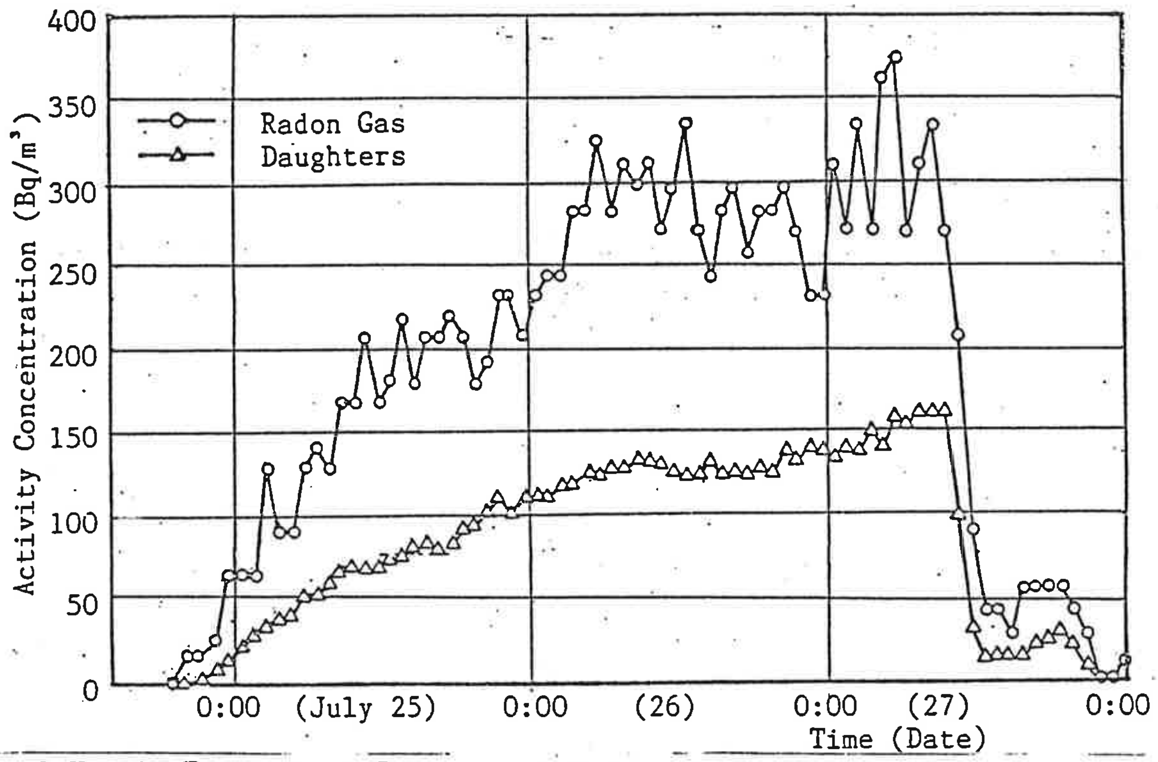

Fig. 1 Hourly Fluctuation Patterns of Indoor Concentrations of Radon and its Daughters Measured in the House "Masonry"; all openings closed.

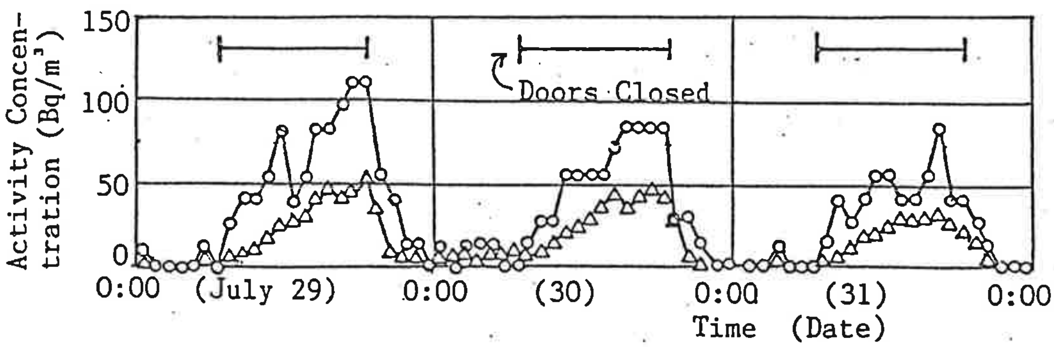

Fig. 2 Same to Fig. 1; openigs closed only during daytime (7 am - 7 pm)

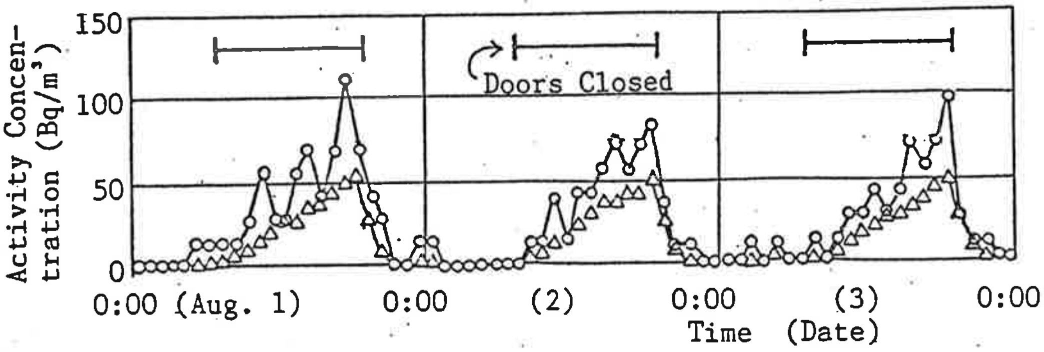

Fig. 2 Same to Fig. 1; openigs closed only during daytime (7 am - 7 pm) (continued)

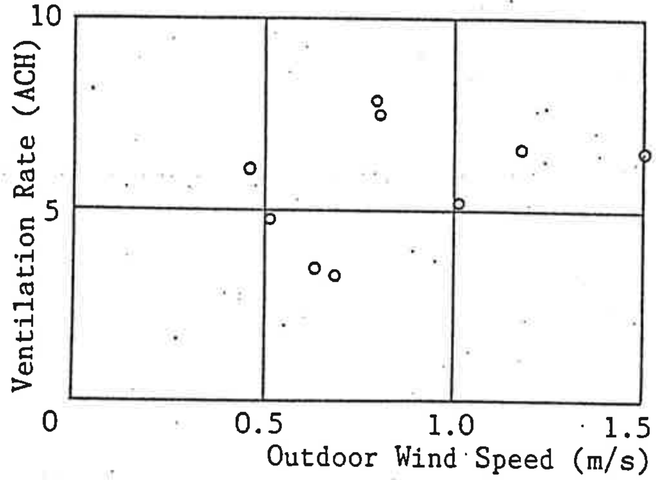

Fig. 3 Relationship between Ventilation Rates and Outdoor Wind Speeds Obtained at the Masonry.

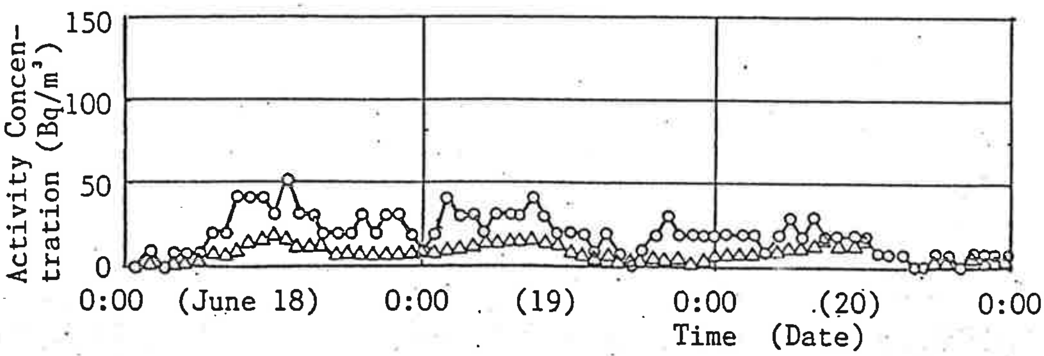

Fig. 4 Hourly Fluctuation Patterns of Indoor Concentrations of Radon and its Daughters Measured in the House "PSH"; all openings closed.