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The influence of meteorological parameters on indoor radon in selected traditional Kenyan dwellings

M W Chege[1], I V S Rathore[1], S C Chhabra[2] and A O Mustapha[3]

[1] Department of Physics, Kenyatta University, PO Box 43844, Nairobi, Kenya
[2] Department of Chemistry, Kenyatta University, PO Box 43844, Nairobi, Kenya
[3] Department of Physics, University of Nairobi, PO Box 30197, Nairobi, Kenya

E-mail: amustapha@uonbi.ac.ke

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Abstract

The effects of outdoor temperature, rainfall and wind speed on the indoor radon concentration in four types of traditional hut in Kenya were investigated by performing short-term (about 48 h) measurements with activated charcoal canisters. The concentrations vary widely (30.2–315.4 Bq m^{-3}) during the study period, and the overall mean is 170.3 ± 39.6 Bq m^{-3}. The indoor radon concentration correlates negatively with both the outdoor temperature ($R^2 = 0.06$) and the wind speed ($R^2 = 0.11$) but positively with rainfall ($R^2 = 0.03$). The results showed that changes in meteorological parameters cause more variations in indoor radon concentrations than the differences in the buildings' characteristics (i.e., designs, materials, etc). However, these variations are not significant (at 1% significance level).

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Radon and its decay products are the leading sources of radiation exposure of the general public (UNSCEAR 2000). There is a wealth of information and data on indoor radon, albeit a general lack of representation from many tropical countries, especially on how climatic conditions, construction materials, building patterns, water use, etc, affect the indoor radon in these areas. Preliminary reports of indoor radon measurements in Kenya showed wide variability: 5–1200 Bq m^{-3} according to Mustapha *et al* (2002) and 5–704 Bq m^{-3} according to Maina *et al* (2004). None of the previous studies in Kenya has adequately investigated the effects of building characteristics and/or meteorological parameters on indoor radon.

In the present study we investigated the temporal variation of indoor radon concentration inside traditional huts, which are dwellings for many people in the rural areas of Kenya.

Table 1. Some characteristics of the selected huts. (Note: H = height; D = diameter; L = length; W = width.)

	Building characteristics			
Hut type	Wall dimensions (m)	Roof	Floor	Surface coating
Kikuyu	Cylindrical ($H = 2$; $D = 2$)	Grass	Soil	None
Massai	Rectangular ($H = 2$; $L = 2$; $W = 3$)	Mud	Soil	Cow dung
Luo	Cylindrical ($H = 2$; $D > 2$)	Grass	Soil	None
Luyha	Cylindrical ($H = 2$; $D < 2$)	Mud and grass	Soil	None

The objective is to determine how meteorological parameters and the building characteristics (styles, materials, size, etc) affect the radon concentrations in these dwellings. It is envisaged that the results of this study will be useful in modelling the radon behaviour inside such tropical dwellings.

2. Materials and methods

2.1. Characteristics of the selected dwellings

This study was formulated to take advantage of a model hamlet at the cultural centre of the Kenyatta University in Nairobi, Kenya. The model hamlet was part of the cultural exhibits to showcase the traditional ways of life in the rural Kenya where traditional huts are still common. Four different mud huts were selected for this study; all of them are within 50 m of each other. Their walls were made of mud from the same source, and they share a common underlying soil. The differences are in their sizes, shapes, roofing styles and finishing with respect to surface coatings. The huts are referred to in this report by the names of the ethnic groups (in Kenya) with whom they are most commonly associated, i.e. Kikuyu, Luo, Luyha and Massai huts. They are all single roomed, the walls are made of frames of twigs and wood covered with mud, and every hut has a door and a window that remained open throughout the period of the study. The other major characteristics of the huts are summarised in table 1. Sample photographs of two (Massai and Kikuyu) huts are also provided (figures 1 and 2).

2.2. Measurement of indoor radon concentration

Canisters of activated charcoal, of US Environmental Protection Agency (EPA) type, were used for the measurements. These are metal cans with lids (about 10 cm diameter and 2 cm depth), containing about 70 g of activated charcoal (Gray and Windham 1987). Each canister was weighed before the charcoal was exposed to radon air in the huts by placing them at about 1 m above the ground and far from walls or sources of draughts. The canisters were exposed simultaneously in the four huts for about two days every week. The entire exercise, which also included collection of daily meteorological data from a nearby weather station, lasted for 20 weeks.

After exposure, the metal can was sealed and the canister was reweighed. Following the attainment of secular equilibrium between radon and its short-lived decay products (usually 3 h after the end of exposure), the gamma rays emitted by ^{214}Pb (295 and 352 keV) and ^{214}Bi (609 keV) were counted on a $3'' \times 3''$ NaI(Tl) detector. The spectrometric system also includes a PC installed with an Oxford PCA-P multichannel analyser (MCA) card and its software.

Figure 1. Traditional hut common among the Kikuyu community in Kenya.

Figure 2. Traditional hut common among the Massai community in Kenya.

The activity concentration, C (Bq m^{-3}), of radon in the tested air is given by

$$C = \frac{1000N\,\exp(\lambda t_{\mathrm{d}})}{t_{\mathrm{e}}\varepsilon\mathrm{CF}}, \tag{1}$$

where N is the net counting rate in counts per minute (cpm), ε is the counting efficiency (cpm Bq^{-1}), λ is the decay constant of radon (1.26×10^{-4} min^{-1}), t_{e} is the exposure time in minutes, t_{d} is the decay time, i.e., time in minutes from the middle of exposure to the start of counting, and CF is a calibration factor, i.e., the radon adsorption rate of the charcoal in litres per minute. Details of the evaluation of CF, using the weight gained by the charcoal during exposures in a standard radon chamber, are given by Gray and Windham (1987). The calibration procedure to determine ε has also been described in detail by Mustapha (1999).

Table 2. Temporal variation of indoor ^{222}Rn concentrations and outdoor meteorological parameters.

	^{222}Rn concentration in the huts (Bq m^{-3})					Meteorological parameters		
Study week	Massai	Luo	Kikuyu	Luyha	Weekly mean concentration (Bq m^{-3})	Rainfall (mm)	Mean temp. (°C)	Wind speed (km h^{-1})
1	113.9	236.7	143.6	278.6	193.2 ± 77.3	6.9	24.3	58.5
2	89.1	124.5	119.6	234.0	141.8 ± 63.5	6.7	23.1	64.0
3	80.2	132.9	96.5	89.4	99.7 ± 23.1	0.0	24.0	79.7
4	221.0	161.8	140.0	119.3	160.6 ± 43.9	0.0	24.6	30.4
5	171.9	230.8	151.8	164.6	179.8 ± 35.0	29.3	26.5	64.0
6	151.6	189.2	122.7	113.4	144.2 ± 34.1	8.0	23.2	50.7
7	243.0	277.3	277.3	156.8	238.6 ± 56.8	0.8	23.0	42.9
8	147.8	81.6	58.3	129.5	104.3 ± 41.4	9.4	24.4	56.8
9	251.0	209.0	140.0	179.5	194.9 ± 46.9	0.0	24.2	46.3
10	182.4	137.9	198.4	102.7	155.3 ± 43.4	0.0	24.7	37.8
11	180.5	146.9	131.2	170.6	157.3 ± 22.4	0.0	25.3	23.5
12	155.8	211.1	153.7	260.1	195.2 ± 50.8	18.5	22.0	51.0
13	286.5	203.8	167.5	193.0	212.7 ± 51.5	18.1	22.0	40.8
14	195.0	156.5	161.4	166.9	169.9 ± 17.2	17.4	20.2	39.9
15	83.5	137.6	30.2	292.2	135.9 ± 113.1	0.0	22.5	54.5
16	266.9	204.5	315.4	205.0	247.9 ± 53.7	0.0	21.1	47.4
17	164.2	170.4	143.0	135.2	153.2 ± 16.8	0.0	21.3	35.4
18	99.8	254.6	78.0	180.0	153.1 ± 80.6	0.0	20.4	46.8
19	119.7	235.9	226.7	278.6	215.2 ± 67.6	8.0	20.6	35.9
20	188.9	157.8	148.5	118.6	153.4 ± 29.0	0.0	21.0	36.6
Overall mean	169.6 ± 61.8	183.0 ± 50.2	150.2 ± 67.0	178.4 ± 62.3	170.3 ± 39.6	6.2 ± 8.5	22.9 ± 1.8	47.1 ± 13.3

3. Results and discussion

3.1. Temporal variation of Rn concentrations in the selected dwellings

The values of radon concentrations and meteorological parameters are shown in table 2. The radon concentrations ranged from 30.2 to 315.4 Bq m^{-3} over the measuring period, with an overall average of 170 ± 40 Bq m^{-3}. About 20% of all the measured values reached the ICRP recommended reference levels (200–600 Bq m^{-3}) (ICRP 1993). These values are surprisingly high for such simple structures in a tropical climate. Similarly high concentrations (up to 580 Bq m^{-3}) were reported by Oppon *et al* (1993) in traditional houses constructed from mud bricks in some parts of Ghana. The presence of openings (i.e., doors, windows, cracks, etc) in the walls of these traditional houses does not necessarily result in high rates of ventilation. Gamma-ray spectrometric analyses of samples of soils, from which the walls of the huts were made, showed ^{226}Ra concentrations up to 101 Bq kg^{-1}. This is much higher than the average values reported from elsewhere within Kenya (Mustapha 1999) and beyond (UNSCEAR 2000). These results indicate that radon problems are not confined to temperate climates and masonry dwellings.

There are similarities in the temporal variations of radon in all the four huts (figure 3). The time series data in the four huts show increasing trends of the time-average radon concentrations within the study period. There are also cycles of maxima and minima (of varying amplitudes and periods) superimposed on the background of increasing time-averages.

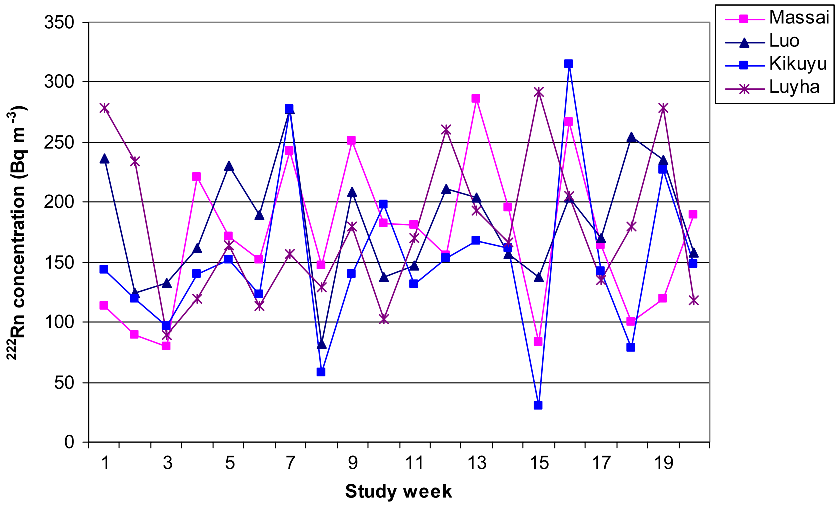

Figure 3. Similar trends and cycles in the temporal variation of radon concentrations in the four huts.

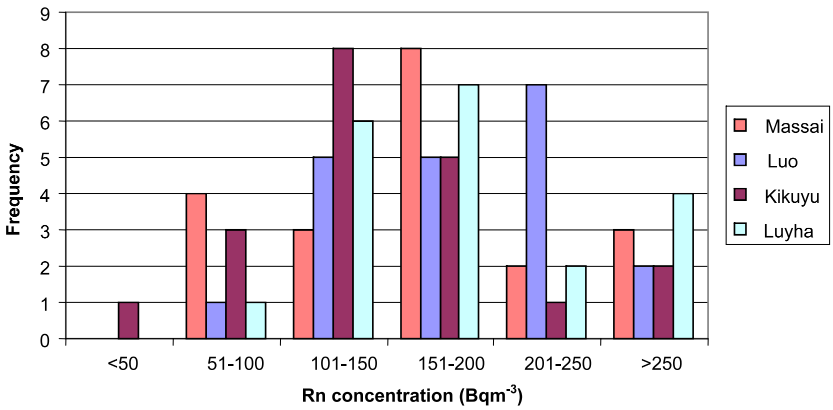

Figure 4. Distribution of ^{222}Rn concentrations in the four huts.

3.2. Comparing the effects of meteorological parameters and building characteristics

Figure 4 shows the distribution of radon concentrations according to hut type. Most of the high radon concentrations were measured in the Luo hut, followed by the Luyha, Massai and Kikuyu huts, in that order. This suggests that a systematic component of the observed variation in the radon concentrations may be due to differences in the characteristics of the huts (see table 1).

A visual inspection of figure 5 shows the existence of correlations between the individual meteorological parameters and indoor radon concentrations. Quantitatively, indoor radon correlates more negatively with wind speed ($R^2 = 0.11$) than with outdoor air temperature ($R^2 = 0.06$), and the correlation is weakest but positive with rainfall ($R^2 = 0.03$) (figures 6–8). An accurate explanation of these observations may require further measurements: for example, of indoor-air and soil-air radon, indoor and outdoor temperature, wind speed, etc. The results, i.e. negative correlations between indoor radon and outdoor wind speed and temperature, agree with what Sesana and Begnini (2004) observed in an uninhabited building at the top of the

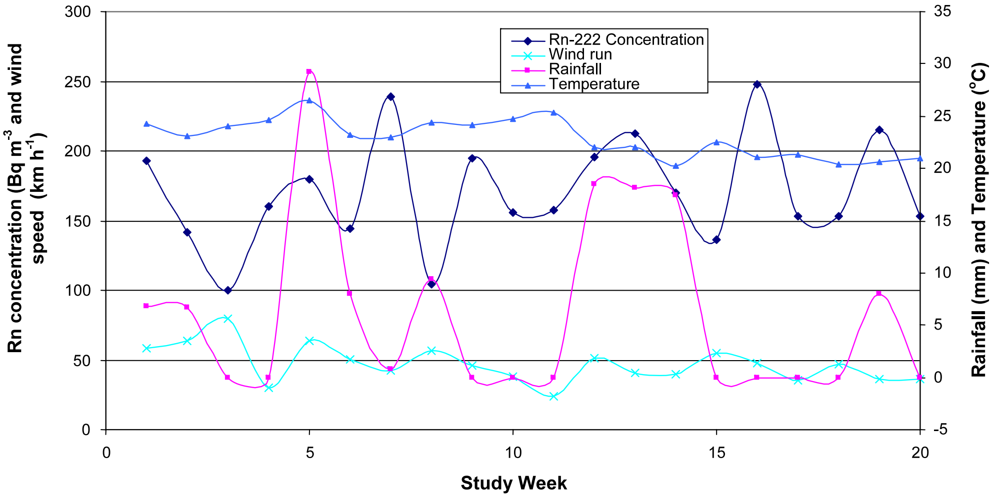

Figure 5. Comparing variation of the weekly average ^{222}Rn concentrations and those of the meteorological parameters.

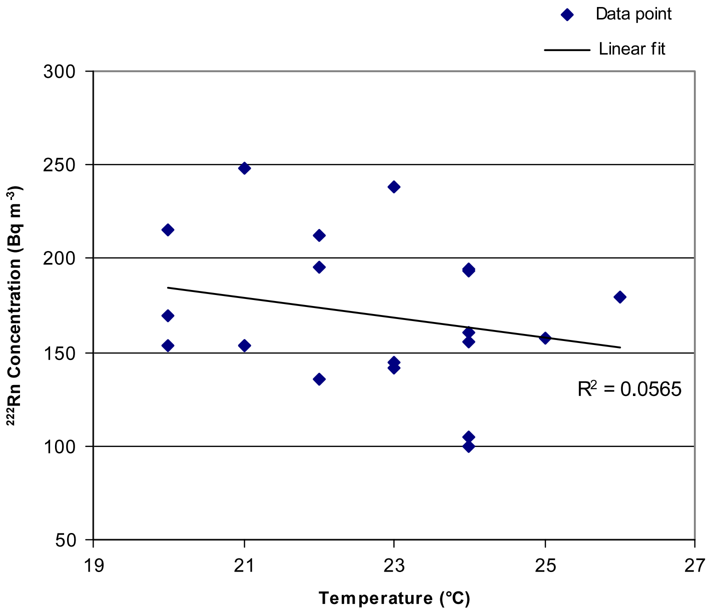

Figure 6. Correlation between variation in ^{222}Rn concentrations and that of outdoor air temperature.

Valassina valley in Italy. But they contrast with the results of Sundal *et al* (2007) who observed positive correlation between outdoor temperature and indoor radon.

The contributions of the two sets of factors (i.e., meteorological parameters on one hand and the building characteristics on the other hand) to the observed variations in the present study were compared quantitatively using the two-way classification F-test. Readers interested in the details of the F-test procedure are referred to the relevant books on the subject, for example Snedecor and Cochran (1994). The results show that meteorological parameters

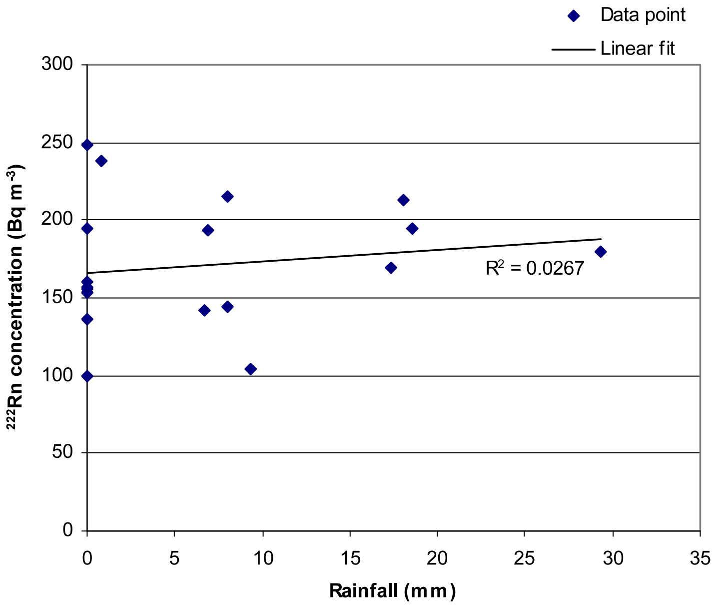

Figure 7. Correlation between variations in ^{222}Rn concentration and those of rainfall.

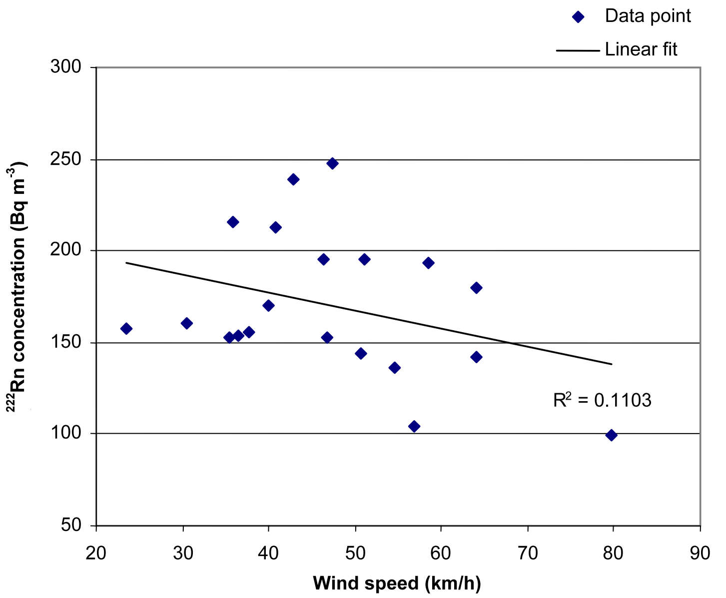

Figure 8. Correlation between variations in ^{222}Rn concentration and those of wind speed.

influence the indoor radon concentrations ($F = 2.3$) more than the building characteristics ($F = 1.3$). Both are less than 3.13, the critical F value at 1% level; therefore, the variations observed, either between one hut and another or within the same hut at different times, are not significant at this significance level. This may be different if there were no such structural similarities among the huts, i.e. if a greater variety of building types were involved. The measurements were largely carried out within one season (raining/cold season). The situation may be different if the survey were to span the extremes of different seasons: for example, if the measurements were to be carried out for a year. Finally, the exact causes of the cyclic components of the variations and their periods were not delineated in this study.

The model huts used in this study were uninhabited, but they are typical dwellings for people in the rural parts of Kenya and many other African countries. Most of these people spend more time outdoors than indoors, except the women and children. Therefore an indoor occupancy factor of 0.6 is more appropriate (Maina *et al* 2004) than the 0.8 used in UNSCEAR reports. Indoor fires are often used for heating or/and cooking in these dwellings, and this may increase the attached fraction of radon decay products. Further studies will be required to determine the realistic values of relevant parameters, for example, the equilibrium factor and dose due to concentrations of radon and its decay products, in such dwellings.

4. Conclusion

Temporal variations of radon concentrations in four model traditional huts have been monitored over a 20-week period. The variations arising from changes in the meteorological conditions are more than those due to the differences in the buildings' characteristics. The radon concentrations in these huts correlate positively with rainfall, but negatively with outdoor air temperature and wind speed. The range (30.2–315.4 Bq m^{-3}) and overall average (170.3 $\pm$ 39.6 Bq m^{-3}) are indications that radon problems may also be encountered in such tropical dwellings. This study should be extended by involving greater number and variety of building types and letting it span over a longer period: for example, one or two years. The frequency of the measurements may also be increased to daily or hourly, and more variables (for example, soil-air radon, outdoor-air radon and indoor temperature) should be included in order to provide more data to help understand the behaviour of indoor radon in tropical dwellings.

Acknowledgments

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