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INDOOR RADON CONCENTRATION LEVELS IN SOME SELECTED OFFICES AT IBRAHIM BADAMASI BABANGIDA UNIVERSITY, LAPAI, NIGERIA AND ITS ATTENDANT ANNUAL EFFECTIVE DOSE

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ABSTRACT
Although radon concentrations in outdoor environments are generally low, the indoor concentrations can become appreciably high thereby affecting the indoor air quality and causing some severe health challenges. Thirty (30) offices from the ground floor and first floor of some buildings within Ibrahim Badamasi Babangida (IBB) University campus, Lapai Nigeria, were randomly selected for indoor radon concentration (C_{Rn}) measurement using RAD7 continuous radon monitor. Annual effective dose was also computed to determine the level of public exposure. The results showed that radon concentration values for all the offices on the ground floor ranged between 9.6±2.7 Bqm^{-3} and 90.7±8.1 Bqm^{-3}, with mean value of 28.5±4.8 Bqm^{-3} while the range of radon concentration at first floor was 2.5±1.4 Bqm^{-3} - 80.4±7.5 Bqm^{-3}. All the measured indoor radon concentration levels were less than the 100 Bqm^{-3} action level proposed by World Health Organization (WHO). Average annual absorbed dose for both ground and first floors were 0.36±0.06 mSvy^{-1} and 0.24±0.05 mSvy^{-1} respectively, with corresponding mean annual effective dose of 0.86±0.15 mSvy^{-1} and 0.58±0.11 mSvy^{-1} in sequence. These values were below the 1.0 mSvy^{-1} safety limit set for public. Although the results did not suggest any immediate exposure threat to the public, it is important that the University staffs are adequately informed of indoor radon levels and its attendant health hazards. Improved and adequate ventilation of all the office buildings is highly encouraged in order to keep the radon levels as low as reasonably achievable (ALARA).

Keywords: Indoor radon concentration, IBB University, RAD7 monitor, annual absorbed dose, annual effective dose, Nigeria.

INTRODUCTION
The exposure of human being to ionising radiation from natural sources is a continuous inescapable feature of life on Earth. Radon (^{222}Rn) is an invisible and odourless gas which is a member of the ^{238}U series. It decays with a half-life of 3.82 days and when it is inhaled it penetrates into the lungs. Its most dangerous daughters are ^{218}Po and ^{214}Po which emits α-particles with high energy of 6.0 MeV and 7.7 MeV, respectively. The interaction of such high energy particles with the lung and continuous deposition leads to its damage and the incidence of lung cancer (UNSCEAR, 2000; Yehuwdah, 2006). Radon, its isotopes and their progeny contribute fifty two percent (52 %) of the total annual effective dose to the general public from natural radiation sources (UNSCEAR, 2008). Measurement of indoor and outdoor radon has been carried out in many countries of the world during the last few decades. Results of such investigations have shown that continuous exposure to radon gas and its daughters (polonium, bismuth and lead) causes lung cancer and other radiation induced sicknesses such as Alzheimer and Parkinson disease (UNSCEAR, 2000; Yehuwdah, 2006, Canada, 2014; Ajrouche *et al*., 2018; Gaskin *et al*., 2018). Radon causes the majority of deaths resulting from lung cancer; lung cancer death from radon annually is 16 %, 10 %, 7.0 %, 6.2 %, 6.1 % and 5.9 % in Canada, France, Poland, Hungary, Armenia and Turkey, respectively(Canada, 2014; Ajrouche *et al*., 2018; Gaskin *et al*., 2018). Study shows that humans living in temperate climate spend 80 % and 20 % of their time indoor (schools, offices, homes or other buildings) and outdoor, respectively (ICRP, 1991). Radon concentrations are higher indoors and in areas with minimal ventilation (WHO, 2009). For most people, the greatest exposure to radon occurs in the home where people spend much of their time, though indoor workplaces may also be a source of exposure (WHO, 2009). The increased health risk from radon has lead several countries to include radon control in their buildings.

Few literatures on radon levels in buildings are available in developing countries. However, in Nigeria only radon concentration levels in buildings from south-western part of the country were reported (Oni *et al.,* 2012; Okeji *et al.,* 2013; Ademola *et al.,* 2015; Afolabi *et al.,* 2015; Asere and Ajayi 2017; Obed *et al.,* 2018; Sokari, 2018; Usikalu *et al.,* 2018; Akabuogu *et al.,* 2019; Chenko *et al.,* 2019; Avwiri *et al.,* 2020; Oladapo *et al.,* 2020; Olaoye *et al.,* 2020; Ndubisi *et al.,* 2021; Asere *et al.,* 2022; Olowookere *et al.,* 2022). Hence, this work investigates the radon concentration levels in IBB University buildings and its effect on the occupants. Investigating radon concentration levels will provide information on levels of radon indoors and the associated health risks as well as implementing a national radon programme aimed at reducing both the overall population risk and the individual risk for people living with high radon concentrations.

MATERIALS AND METHODS
Study site
Ibrahim Badamasi Babangida University (IBBU) is one of the higher institutions founded and managed by the Niger State Government since 2005. It is located in Lapai town, Lapai local government are of Niger state (Fig. 1). The institution which has about seven faculties, with students and staff population of about 15000 and 1500 respectively, play host to students and visitors from all over the world.

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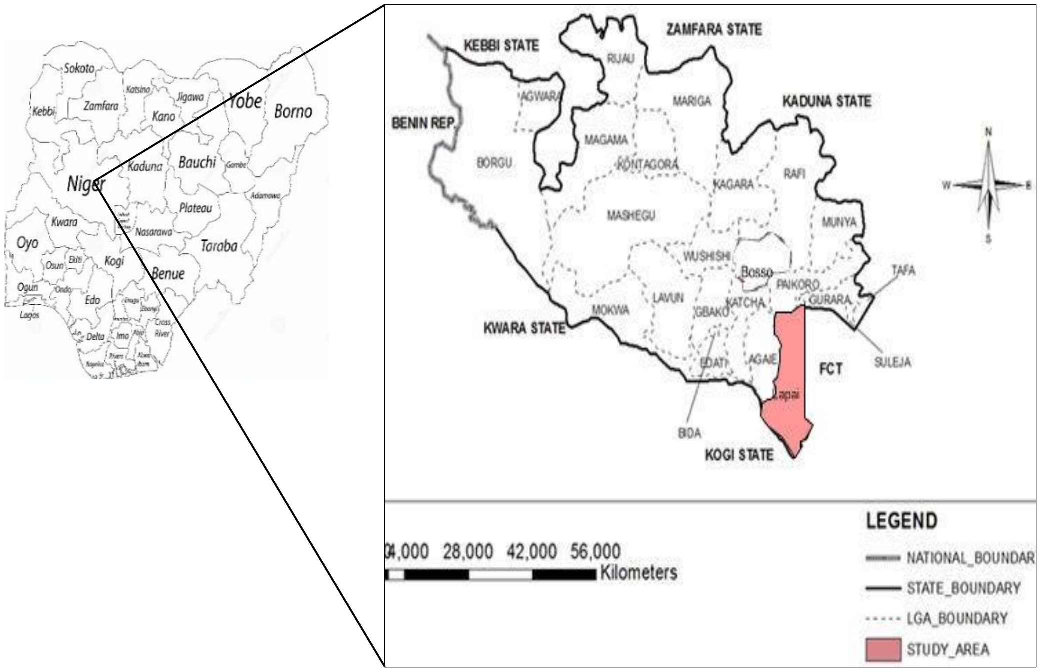

Figure 1: Map of Nigeria showing the study site, Niger State

Measurement

Thirty (30) offices, including fifteen (15) (GF1 - GF15) from the ground floor and fifteen (FF1 - FF15) from first floor of some buildings within Ibrahim Badamasi Babangida (IBB) University campus were randomly chosen for indoor radon and other parameter measurements. The nature and ventilation style of the measured offices are given in Table 1, with the flowchart of step-by-step methodological approach shown in Fig. 2. Rad7 electronic radon monitor (Fig. 3) from DURRIDGE Company, USA was used for measurement. It is a Passivated Ion-implanted Planar Silicon (solid-state) detector whose principle of operation is the electrostatic collection of alpha emitters with spectral analysis. RAD7 was setup in sniff mode which allows air containing only radon gas to be drawn automatically from the environment into RAD7 chamber through the inlet filter. The radon monitor was taken to each measuring location and placed away from the wall, at about 1 m above the ground. Before each measurement, the monitor was purged outdoor for about 10 minutes to clear the sample chamber of radon gas and daughters. Each location was measured for 24 hours with results saved hourly. The results were viewed afterwards, analyzed and mean radon concentration within the period of measurement of office was computed using CAPTURE software.

Table 1: Description and characteristics of offices in IBB University buildings randomly selected for indoor radon and other parameters measurements.

LOCATION	CODE	FLOOR	TYPE OF ROOM	VENTILATION
Administrative building	GF1	Ground floor	Office	Normal
	GF2	Ground floor	Office	Normal
	GF3	Ground floor	Office	Normal
	GF4	Ground floor	Office	Normal
	GF5	Ground floor	Office	Normal
	GF6	Ground floor	Office	Normal
FNS building	GF7	Ground floor	Laboratory	Normal
R & D building	GF8	Ground floor	Office	Normal
NIMASA building	GF9	Ground floor	Office	None
	GF10	Ground floor	Office	Normal
FAST building	GF11	Ground floor	Office	Normal
SA building	GF12	Ground floor	Office	Normal
	GF13	Ground floor	Office	Normal
ICT building	GF14	Ground floor	Office	Normal
	GF15	Ground floor	Office	Normal

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FNS building	FF1	First floor	Office	Normal
	FF2	First floor	Office	Normal
	FF3	First floor	Office	Normal
	FF4	First floor	Office	Normal
	FF5	First floor	Office	Normal
R & D building	FF6	First floor	Office	None
FAST building	FF7	First floor	Office	Normal
FA building	FF8	First floor	Office	None
	FF9	First floor	Office	Normal
FMSS building	FF10	First floor	Office	Normal
	FF11	First floor	Office	Normal
	FF12	First floor	Office	Normal
	FF13	First floor	Office	Normal
FEA building	FF14	First floor	Office	Normal
	FF15	First floor	Office	Normal

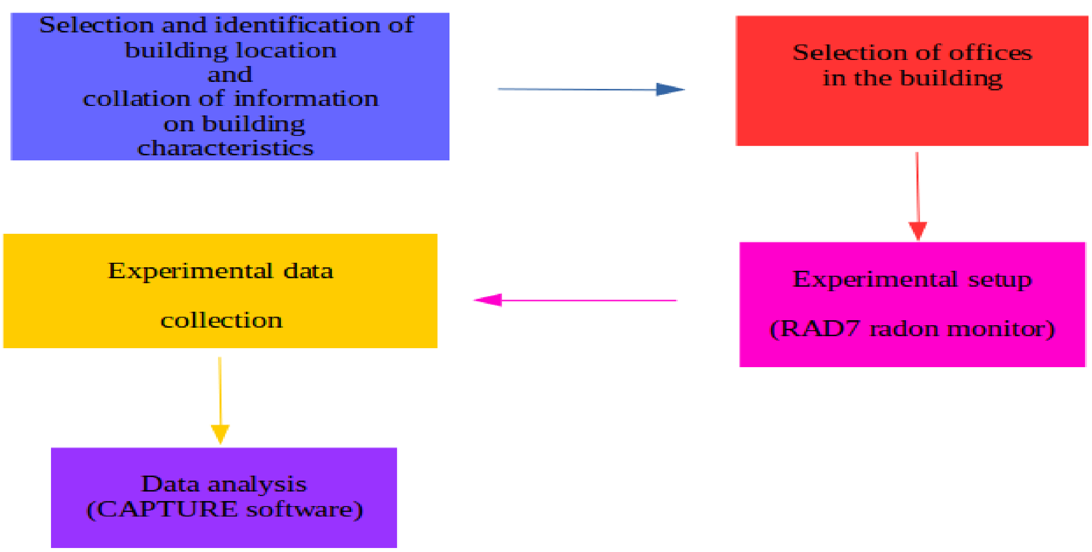

Figure 2: Flowchart of the step-by-step methodological approach

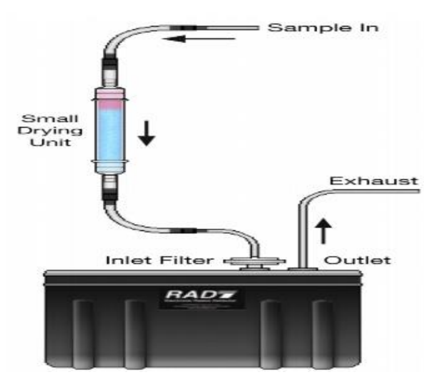

Figure 3: RAD7 radon monitor setup

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Dose estimation

The indoor radon concentrations measured in each location of the study were used to estimate the annual absorbed doses and annual effective doses. The annual absorbed dose (AAD) was calculated using equation (Usikalu *et al.,* 2017) :

$$AAD\ (mSvy^{-1}) = C_{Rn} \times D_c \times F \times H \times T \quad (1)$$

where AAD is the annual absorbed dose ($mSvy^{-1}$), C_{Rn} is the indoor radon concentration (Bqm^{-3}), D_c is the dose conversion factor (9×10^{-6} mSv h^{-1} per Bqm^{-3}), F is the equilibrium factor for radon (0.4), T is hours in a year (8760) and H is the occupancy factor (0.4) (ICRP, 1990).

Similarly, the annual effective dose (AED) was calculated by using equation 2.

$$AED\ (mSvy^{-1}) = AAD \times W_R \times W_T \quad (2)$$

where AED is the annual effective dose, AAD is the annual absorbed dose ($mSvy^{-1}$) computed from equation 1, W_R is the weighting factor for alpha particles (20) and W_T is the tissue weighting factor for the lung (0.12)(Bodansky *et al.,* 1987).

RESULTS AND DISCUSSION

Indoor radon and physical parameters

The indoor radon concentration values can vary depending on soil types, temperature, humidity, change in pressure, radon source strength underneath the bedrock, time of season, level of ventilation and occupancy (WHO, 2009; Ptiček et al., 2020). Figs. 4 and 5 illustrate the correlations between indoor radon concentrations and physical parameters of the offices in both ground and first floors respectively. As seen in Fig. 4, the measured temperatures across all the offices on the ground floor are averagely the same (≈ 29^{0}C), with mean relative humidity of 69%. The same trend is seen to occur on the first floor (Fig. 5) with temperatures averaging around 29^{0}C with average relative humidity of 71%. Variations in radon concentration levels across all the offices, despite the near uniform temperatures shows that temperature and relative humidity have rather insignificant influence on indoor radon concentration

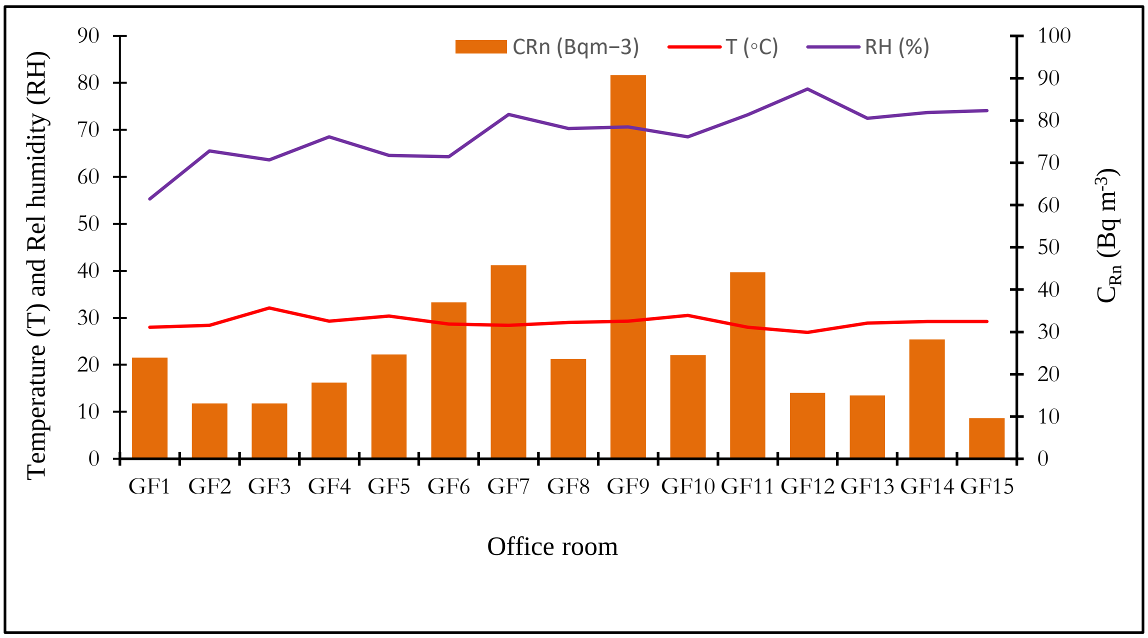

Figure 4: Radon Concentrations versus the temperature and relative humidity of offices on ground floor

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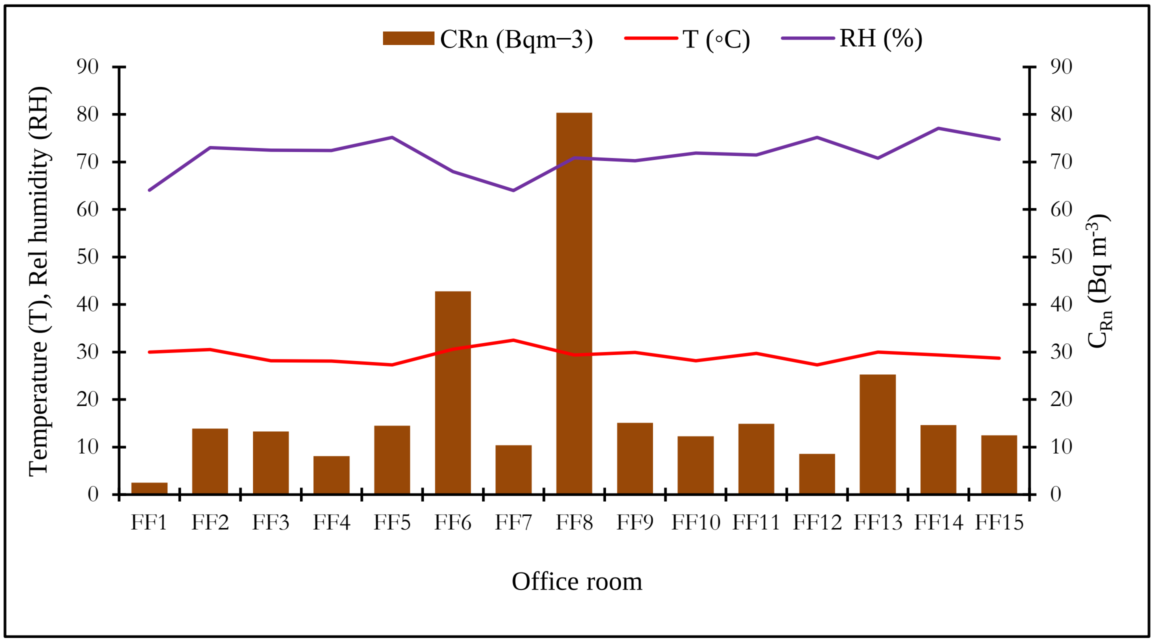

Figure 5: Radon Concentrations versus the temperature and relative humidity of offices on first floor.

Radon concentration

The measured radon concentration together with the temperature and relative humidity of all the offices measured are presented in Table 2. Radon concentration values for all the offices on the ground floor varied from 9.6±2.7 Bqm^{-3} to 90.7±8.1 Bqm^{-3}, with ground floor average radon concentration value of 28.5±4.8 Bqm^{-3}. Concentration values for first floor ranged between 2.5±1.4 Bqm^{-3} and 80.4±7.5 Bqm^{-3}, with mean value of 19.3±3.7 Bqm^{-3}. Rooms GF9 on the ground floor and FF8 on the first floor recorded highest radon concentration values of 90.7±8.1 Bqm^{-3} and 80.4±7.5 Bqm^{-3} respectively. This can be attributed to lack of cross ventilation in the two offices due to continuous closure of all windows at all times, hence radon gas got trapped and accumulated over long period. Mean radon concentration generally at the ground floor (28.5±4.8 Bqm^{-3}) was seen to be higher than the overall mean value (19.3±3.7 Bqm^{-3}) of the first floor. This slight variation may be due to the closeness of the radon source strength underneath the bedrock, more-so that the elevation of buildings above ground can result in decrease of radon concentration level. The observed trend of decreasing radon concentration with height agree with the submission of Vulkan (1997) that the higher the elevation in a building, the lower the radon level. Despite the high concentration values recorded in some offices however, all the measured indoor radon levels were less than 100 Bqm^{-3} action level proposed by the World Health Organization (WHO, 2009). Similarly, the average concentration values at both the ground floor and the first floor were found to be below the world average of 40 Bqm^{-3} (UNSCEAR, 2000). Although results of this study indicates an inconsequential level of radon exposure hazards, attention must be given to the fact that every radon exposure level however small according to US EPA, carries with it a measure of radiation risk.

Results of this study are seen to be lower than those of similar investigations reported by Obed *et al.* (2010) in a university community in Ibadan, Oyo state, Nigeria and Afolabi *et al.* (2015) in Obafemi Awolowo University, Ile-Ife, Nigeria.

Table 2: Indoor radon concentration (C_{Rn}), temperature (T), and relative humidity (RH) in the offices of selected buildings in IBB University**.**

LOCATION	CODE	FLOOR	T (◦C)	RH (%)	C_{Rn} (Bqm^{-3})
Administrative building	GF1	Ground floor	28.0	55.3	23.9±3.9
	GF2	Ground floor	28.4	65.5	13.1±3.1
	GF3	Ground floor	32.1	63.6	13.1±3.4
	GF4	Ground floor	29.3	68.5	18.0±3.6
	GF5	Ground floor	30.4	64.6	24.7±4.1
	GF6	Ground floor	28.7	64.3	37.0±5.2
FNS building	GF7	Ground floor	28.4	73.3	45.8±6.0
R & D building	GF8	Ground floor	29.0	70.3	23.6±6.6
NIMASA building	GF9	Ground floor	29.3	70.6	90.7±8.1

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	GF10	Ground floor	30.5	68.5	24.5±5.4
FAST building	GF11	Ground floor	28.0	73.2	44.1±5.6
SA building	GF12	Ground floor	26.9	78.7	15.6±3.5
	GF13	Ground floor	28.9	72.5	15.0±6.0
ICT building	GF14	Ground floor	29.2	73.7	28.2±5.0
	GF15	Ground floor	29.2	74.1	9.6±2.7
		Min.			**9.6±2.7**
		Max.			**90.7±8.1**
		Mean	**29.1**	**69.1**	**28.5±4.8**
FNS building	FF1	First floor	30.0	64.1	2.5±1.4
	FF2	First floor	30.5	73.0	13.9±3.1
	FF3	First floor	28.2	72.5	13.3±3.1
	FF4	First floor	28.1	72.4	8.1±2.5
	FF5	First floor	27.3	75.2	14.5±3.2
R & D building	FF6	First floor	30.6	68.0	42.8±5.5
FAST building	FF7	First floor	32.5	64.0	10.4±2.8
FA building	FF8	First floor	29.4	70.9	80.4±7.5
	FF9	First floor	29.9	70.3	15.1±3.1
FMSS building	FF10	First floor	28.2	71.9	12.3±3.0
	FF11	First floor	29.7	71.5	14.9±4.7
	FF12	First floor	27.3	75.2	8.6±3.6
	FF13	First floor	30.0	70.8	25.3±5.6
FEA building	FF14	First floor	29.4	77.1	14.6±3.3
	FF15	First floor	28.7	74.8	12.5±3.0
		Min.			**2.5±1.4**
		Max.			**80.4±7.5**
		Mean	**29.4**	**71.3**	**19.3±3.7**

Annual absorbed dose and annual effective dose

Annual absorbed dose (AAD) and annual effective dose (AED) to the public from exposure to radon gas in all the offices investigated are presented in Table 3. Computed annual absorbed dose (AAD) for the offices at the ground floor varied between 0.12±0.03 and 1.14±0.10 mSvy^{-1} with an average value of 0.36±0.06 mSvy^{-1}. The corresponding annual effective dose (AED) at the ground floor ranged from 0.29±0.08 to 2.75±0.25 mSvy^{-1}, with a mean value of 0.86±0.15 mSvy^{-1}. Similarly, average AAD for all the offices at the first floor was found to be 0.24±0.05 mSvy^{-1}, with a corresponding mean AED of 0.58±0.11 mSvy^{-1}. Highest AED of 2.75±0.25 mSvy^{-1} was recorded in office room GF9 on the ground floor, while office room FF8 on the first floor recorded a corresponding high AED of 2.43 ±0.23 mSvy^{-1}. These high values are not unconnected with the enhanced level of radon concentrations in the two offices. Although about 20% of offices on the ground floor and about 20% of offices on the first floor recorded AED values slightly above 1.0 ±0.23 mSvy^{-1}, average AED values for both the ground and the first floors were lower than the precautionary limit of 1.0 mSvy^{-1} set for the public (ICRP, 1991).

Table 3 Annual absorbed dose (AAD) and annual effective dose (AED) in the offices of selected buildings in IBB University**.**

LOCATION	**CODE**	**FLOOR**	**C_{Rn} (Bqm^{-3})**	**AAD (mSvy^{-1})**	**AED (mSvy^{-1})**
Administrative building	GF1	Ground floor	23.9±3.9	0.30±0.05	0.72±0.12
	GF2	Ground floor	13.1±3.1	0.17±0.04	0.40±0.09
	GF3	Ground floor	13.1±3.4	0.17±0.04	0.40±0.10
	GF4	Ground floor	18.0±3.6	0.23±0.05	0.54±0.11
	GF5	Ground floor	24.7±4.1	0.31±0.05	0.75±0.12
	GF6	Ground floor	37.0±5.2	0.47±0.07	1.12±0.16
FNS building	GF7	Ground floor	45.8±6.0	0.58±0.08	0.71±0.20
R & D building	GF8	Ground floor	23.6±6.6	0.30±0.07	1.12±0.16
NIMASA building	GF9	Ground floor	90.7±8.1	1.14±0.10	2.75±0.25
	GF10	Ground floor	24.5±5.4	0.31±0.07	0.74±0.16
FAST building	GF11	Ground floor	44.1±5.6	0.56±0.07	1.34±0.17
SA building	GF12	Ground floor	15.6±3.5	0.20±0.04	0.47±0.11
	GF13	Ground floor	15.0±6.0	0.19±0.08	0.45±0.18
ICT building	GF14	Ground floor	28.2±5.0	0.36±0.06	0.85±0.15
	GF15	Ground floor	9.6±2.7	0.12±0.03	0.29±0.08

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		Min.	**9.6±2.7**	**0.12±0.03**	**0.29±0.08**
		Max.	**90.7±8.1**	**1.14±0.10**	**2.75±0.25**
		Mean	**28.5±4.8**	**0.36±0.06**	**0.86±0.15**

FNS building	FF1	First floor	2.5±1.4	0.03±0.02	0.08±0.04
	FF2	First floor	13.9±3.1	0.18±0.04	0.42±0.09
	FF3	First floor	13.3±3.1	0.17±0.04	0.40±0.09
	FF4	First floor	8.1±2.5	0.10±0.03	0.25±0.08
	FF5	First floor	14.5±3.2	0.18±0.04	0.44±0.10
R & D building	FF6	First floor	42.8±5.5	0.54±0.07	1.30±0.17
FAST building	FF7	First floor	10.4±2.8	0.13±0.04	0.31±0.08
FA building	FF8	First floor	80.4±7.5	1.01±0.09	2.43±0.23
	FF9	First floor	15.1±3.1	0.19±0.04	0.46±0.10
FMSS building	FF10	First floor	12.3±3.0	0.16±0.04	0.37±0.09
	FF11	First floor	14.9±4.7	0.19±0.06	0.45±0.14
	FF12	First floor	8.6±3.6	0.11±0.05	0.26±0.11
	FF13	First floor	25.3±5.6	0.32±0.07	0.77±0.17
FEA building	FF14	First floor	14.6±3.3	0.18±0.04	0.44±0.10
	FF15	First floor	12.5±3.0	0.16±0.04	0.38±0.09
		Min.	**2.5±1.4**	**0.03±0.02**	**0.08±0.04**
		Max.	**80.4±7.5**	**1.01±0.09**	**2.43±0.23**
		Mean	**19.3±3.7**	**0.24±0.05**	**0.58±0.11**

CONCLUSION

Fifteen (15) offices each randomly selected from the ground floor and the first floor of selected buildings in Ibrahim Badamasi Babangida University (IBBU), Lapai, Niger state were investigated for indoor radon concentration levels using RAD7 radon monitor. The temperature and relative humidity were found to be uniform in virtually all the offices except for some well ventilated ones that witnessed slight variations due to constant airflow. Although slightly enhanced radon levels were recorded for some offices on the two floors possibly due to poor ventilation, measured indoor radon levels in all the investigated offices were less than 100 Bqm^{-3} action level proposed by the World Health Organization (WHO). Mean radon concentration levels for the offices on the ground floor and first floor were 28.5±4.8 Bqm^{-3} and 19.3±3.7 Bqm^{-3} respectively, which were below the world average of 40 Bqm^{-3} recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Estimated average annual absorbed dose for both ground and first floors were 0.36±0.06 $mSvy^{-1}$ and 0.24±0.05 $mSvy^{-1}$ respectively, with corresponding mean annual effective dose of 0.86±0.15 $mSvy^{-1}$ and 0.58±0.11 $mSvy^{-1}$ in sequence. These values are lower than the recommended safety threshold of 1.0 $mSvy^{-1}$. Although the results of this investigation did not suggest any radiation incidence that may require immediate intervention, cross ventilation across all offices is recommended and encouraged so as to prevent accumulation of radon gas after long period that may lead to unnecessary human exposure. Results of this study could serve as preliminary baseline data for future studies within and outside the IBBU campus.

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