Original Research Article

Seasonal Variation of Indoor Radon (^{222}Ra) and Thoron (^{220}Ra) in the Dwellings of Bathinda District of Punjab, India

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Submission Date: 14-05-2019; Revision Date: 20-07-2019; Accepted Date: 25-08-2019

ABSTRACT

Seasonal concentrations of indoor radon and thoron have been measured in 12 villages (selecting four dwellings in each village) situated in Bathinda district of Punjab, using pin hole based twin cup dosimeters. The radon concentration varied from 20.02±6.08 to 34.97±2.84 Bq m^{-3} in rainy, 33.07±1.21 to 50.14±4.91 Bq m^{-3} in winter, 18.38±6.05 to 54.34±28.84 Bq m^{-3} in spring and 9.02±4.78 to 26.97±20.17 Bq m^{-3} in summer time with an average value of 27.73±6.32, 43.27±5.97, 32.20±14.66 and 18.7±11.97 Bq m^{-3}, respectively. Indoor thoron concentration varied from 11.06±5.39 to 47.39±36.29 Bq m^{-3} in rainy, 7.98±5.90 to 36.76±19.79 Bq m^{-3} in winter, 11.60±5.97 to 76.69±87.28 Bq m^{-3} in spring and 10.59±6.78 to 61.37±45.43 Bq m^{-3} in summer time with an average value of 23.39±15.86, 23.48±10.94, 31.31±22.69 and 28.71±16.36 Bq m^{-3}, respectively. The overall average annual effective radiation dose, to the occupants of the dwellings, corresponding to radon and thoron is 0.88±0.28 mSv y^{-1} and 0.66±0.40 mSv y^{-1}, respectively. An attempt has also been made to find the possible seasonal relationships of indoor radon/thoron concentrations with surface to volume ratio, ventilation conditions and building construction materials of dwellings. Consequently, some contrasting results have been obtained between the behavior of radon and thoron.

Key words: Radon, Thoron, Nuclear track detectors, Annual Effective dose, Seasonal variations.

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INTRODUCTION

The extensive worldwide studies on radon (^{222}Rn) have confirmed that inhalation of radon and its progeny contribute more than half of the natural radiation dose to the general public.[1] Radon causes nearly fourteen percent of lung cancers which is second major cause after smoking.[2] Epidemiological studies have also demonstrated a significant relation between radon levels in homes and leukemia in the inhabitants. Twenty five percent of leukemia in children and adults of all ages may be caused by radon at 50 Bq/m.[3] Another radon isotope (^{220}Rn), commonly called thoron, has also been a traditional object of study in atmospheric science.[4] As far as the radiation dose is concerned, thoron has received relatively less attention than radon. It has been assumed based on a very limited study, that the dose from thoron can be neglected in comparison with that from radon. However, in some parts of the world, thoron can contribute a significant fraction in the total radiation dose.[5] Moreover, some recent case-control studies have shown a linear no-threshold relation between lung cancer risk and radon concentration in dwellings.[6]

Under all these circumstances, dose reduction policies and regulations need to be setup not only for high but also for low levels of radon and thoron. However, the

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DOI : 10.5530/ajbls.2019.8.12

efforts made so far in this direction are satisfactory only in few countries.[2] The task of reducing the health risks from radon and thoron requires their concentration in dwellings to be kept as low as possible. Such measures are effective only if the mechanism of radon and thoron in the dwellings is determined properly. In the present study different types of dwellings constructed in some rural areas of Bathinda district of Punjab, India have been investigated for their indoor radon and thoron levels and the corresponding radiation dose to inhabitants. The area in and around Bathinda district is known for various elevated cancerous and epidemiological fatal diseases due to which it has been under serious debate amongst various scientific communities from the recent past.[7] The major aim of this study is to determine a relation of radon and thoron levels with geological location, season and more importantly with building characteristics such as ventilation, construction material and surface to volume ratio of the dwellings.

Geography of selected area

A total of 48 dwellings in 12 different villages (4 dwellings in each village) of Bathinda were selected for this study. Bathinda is a district of Punjab state which is situated in the northwestern region of India (Figure 1). It is in southern part of Punjab state in the heart of Malwa region. The exact co-ordinates of Bathinda are 30.20°N 74.95°E with an average elevation of 660 ft (201 meters) from the sea level. It is surrounded with other districts, Moga in the North- East, Faridkot and Muktsar in the North-West, Sangrur and Mansa in the East and Sirsa

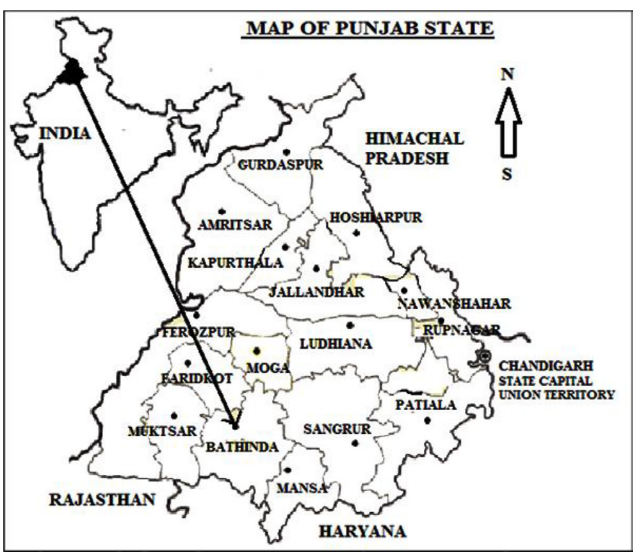

Figure 1: Map of study area (Natt, Burj Sema, Chathewala, Kaureana, Mirjeana, Manuana, Gehlewala, Maur Chart, Burj, Shekhpura, Jogewala and Gatwali) Bathinda district, Punjab, India.

and Fatehabad of Haryana state in the South. Its climate corresponds to high variation between summer and winter temperatures. Average annual rainfall of Bathinda is in the range of 20 mm to 40 mm. The selected villages are spread in around 236 km^2 area and have total population of 26578. Information regarding area was collected from Revenue Department Talwandi Sabo, Bathinda. Population data was obtained from Population Census Department, Bathinda.

Building characteristics

For the measurement of radon and thoron concentrations, one room in each of the 48 dwellings was randomly selected from the type of either living room or bedroom. Most of the dwellings were single-storey and thus roofs were widely exposed to sunlight. The selected rooms had distinguishing characteristics according to construction materials (such as cement, bricks, marble and concrete), ventilation conditions (such as number of rooms and windows) and surface to volume ratio. During summer, ceiling fans were used in most of the rooms and only few used air coolers and air conditioners. All of these characteristics were expected to affect the indoor radon and thoron concentrations.

MATERIALS AND METHODS

Single entry Pin-hole based detectors (Figure 2) were used to measure the concentrations of radon and thoron in the present study. The detector has two identical cylindrical chambers, each having length of 4.1 cm and radius 3.1 cm, which are separated by a pinhole based $^{222}Rn/^{220}Rn$ discriminating plate. Radon and thoron enter the first chamber, called "radon + thoron" chamber, through a filter paper which filters out the decay products of radon and thoron. However, only radon diffuses into the second chamber, called "radon" chamber, through four pin-holes of discriminating plate which cuts off thoron due to its short half-life. Therefore, the LR-115 film kept in the 'radon + thoron' chamber registers the alpha tracks due to radon and

Thoron and their progeny, while the LR-115 film in the 'radon' chamber registers the alpha tracks only due to radon and its progeny. The use of multiple pin-holes of reasonably small radius minimizes the effect of turbulence on $^{222}Rn/^{220}Rn$ transmission factors so that the calibration factor remains independent of indoor turbulence.[9] These detectors, keeping LR-115 Type-II films of size 3×3 cm, were suspended in the selected rooms at a height >200 cm above the ground level (so that the detectors remain undisturbed by the random movement of the residents) and about 50-60 cm below

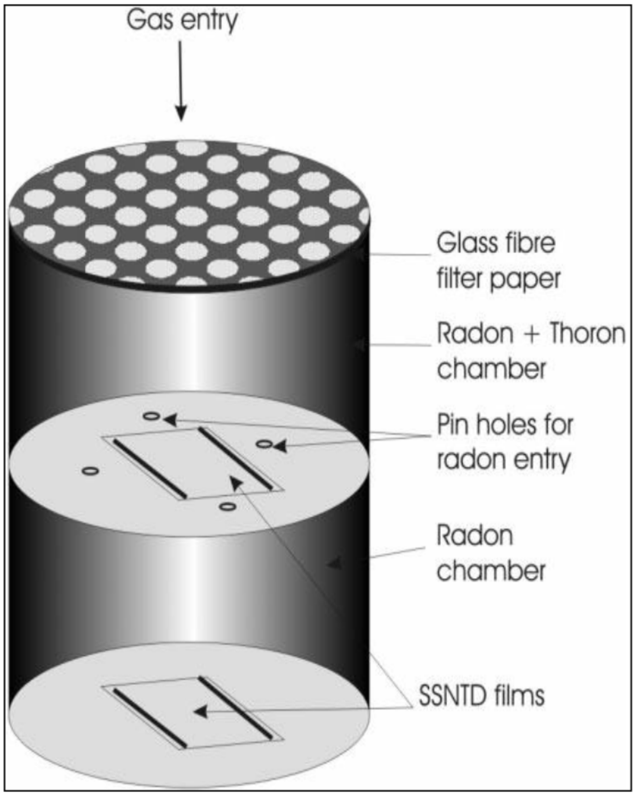

Figure 2: Schematic diagram of Single-entry Pin-hole dosimeter.[8]

the ceiling of the room. The detectors were mounted along the corner of the room about 80 cm away from the two adjacent walls. After the completion of exposure period of 90 days, films were removed from the both chambers and etched using 2.5 N NaOH solution at 60°C for 90 min. After this chemical treatment, the etched films were thoroughly washed and dried. The registered tracks were counted using spark counter. Average concentrations of radon and thoron were calculated by using the following equations:[8]

$$C_R(Bqm^{-3}) = \frac{T_R - B_R}{t \times k_{RR}} \quad (1)$$

$$C_T(Bqm^{-3}) = \frac{[(T_{RT} - B_{RT}) - t \times C_R \times k_{RRT}]}{t \times k_{TRT}} \quad (2)$$

Here k_{RR}, k_{RRT} and k_{TRT} are the calibration factors of radon in 'radon' chamber (0.019±0.003 Tr $cm^{-2}(Bqm^{-3}d)^{-1}$), radon in 'radon+thoron' chamber (0.019±0.003 Tr $cm^{-2}(Bqm^{-3}d)^{-1}$) and thoron in 'radon+thoron' chamber (0.016±0.005 Tr $cm^{-2}(Bqm^{-3}d)^{-1}$), respectively. B_R and B_{RT} are the background counts and T_R and T_{RT} are the tracks obtained after exposure for *t* days in 'Radon' chamber and 'Radon+Thoron' chamber, respectively.

The annual effective dose due to the exposure to radon, thoron and their progeny in the dwellings of study area were calculated using the following relations:[10]

$$\text{Annual effective dose from radon and its progeny} = C_R(Bqm^{-3}) \times 0.46 \times 7000h \times 9\ nSv(Bqhm^{-3})^{-1} \quad (3)$$

$$\text{Annual effective dose from thoron and its progeny} = C_T(Bqm^{-3}) \times 0.09 \times 7000h \times 40\ nSv(Bqhm^{-3})^{-1} \quad (4)$$

RESULTS

Radon/Thoron concentrations

To investigate the seasonal variation in radon and thoron concentrations, the detectors were installed for 90 days in each season (rainy, winter, spring and summer) starting from mid- July 2014 with the rainy season. The seasonal and village to village variations of radon and thoron concentrations are summarized in Table 1a and Table 1b, respectively. The concentration value represented for a village in these tables is the average concentration obtained over the 4 dwellings studied in the same village. Thus, the standard deviation of each average value represents the distribution of concentrations over the 4 dwellings in the village. Table 1a shows that village to village radon concentration varied from 20.02±6.08 to 34.97±2.84 Bq m^{-3} in rainy, 33.07±1.21 to 50.14±4.91 Bq m^{-3} in winter, 18.38±6.05 to 54.34±28.84 Bq m^{-3} in spring and 9.02±4.78 to 26.97±20.17 Bq m^{-3} in summer time. The average values over all the 12 villages (48 dwellings) for the corresponding seasons were found to be 27.73±6.32, 43.27±5.97, 32.20±14.66 and 18.7±11.97 Bq m^{-3} respectively. Table 1b shows that thoron concentration varied from 11.06±5.39 to 47.39±36.29 Bq m^{-3} in rainy, 7.98±5.90 to 36.76±19.79 Bq m^{-3} in winter, 11.60±5.97 to 76.69±87.28 Bq m^{-3} in spring and 10.59±6.78 to 61.37±45.43 Bq m^{-3} in summer time and the average values were found to be 23.39±15.86, 23.48±10.94, 31.31±22.69 and 28.71±16.36 Bq m^{-3}, respectively. Table 2 provides further details of radon and thoron concentrations through frequency distribution for all 48 dwellings. More than 80% of dwellings have radon and thoron concentrations not more than 50 Bq m^{-3} for each season and others have in range 50-150 Bq m^{-3} except one which has thoron concentration unexpectedly high in spring season.

The annual mean concentration of radon over all the seasons and all the 12 villages was obtained as 30 Bq m^{-3}, which is less than the lower limit of the action level

Table 1a: The seasonal variation of average radon concentration with standard deviation (SD) and average annual effective dose in 12 villages of Bathinda District.

Sample location	Average radon concentration, C_R (Bq/m^3)								Average Annual effective Dose (mSv per year)
BATHINDA DIST.	Rainy		Winter		Spring		Summer		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Natt	34.97	02.84	40.05	03.71	18.38	06.05	11.44	06.00	0.75±0.13
Burj Sema	31.39	05.21	41.84	06.20	37.24	21.24	17.94	09.36	0.93±0.30
Chathewala	21.82	01.62	44.88	09.47	38.99	14.00	22.22	32.84	0.92±0.42
Kaureana	22.69	12.32	44.73	06.79	26.90	07.13	21.19	15.43	0.83±0.30
Mirjeana	28.54	08.80	41.00	06.11	29.75	20.54	26.97	20.17	0.91±0.40
Manuana	34.10	03.30	49.85	04.69	20.06	12.50	18.05	09.25	0.88±0.22
Gehlewala	33.33	09.10	43.71	08.25	32.82	16.31	21.27	12.11	0.95±0.33
Maur chart	30.44	07.73	38.52	07.61	36.14	14.92	09.02	04.78	0.82±0.25
Burj	27.55	05.89	41.55	07.33	36.22	10.69	14.69	07.33	0.86±0.23
Shekhpura	25.47	05.91	33.07	01.21	54.34	28.84	17.76	04.77	0.94±0.30
Jogewala	22.55	07.02	50.00	05.42	28.58	16.40	23.79	10.14	0.90±0.28
Gatwali	20.02	06.08	50.14	04.91	27.04	07.34	20.10	11.52	0.84±0.22
Average	27.73	06.32	43.27	05.97	32.20	14.66	18.70	11.97	0.88±0.28

Table 1b: The seasonal variation of average thoron concentration with standard deviation (SD) and average annual effective dose in 12 villages of Bathinda District.

Sample location	Average thoron concentration, C_T (Bq/m^3)								Average Annual effective Dose (mSv per year)
BATHINDA DIST.	Rainy		Winter		Spring		Summer		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Natt	47.39	36.29	33.28	11.61	26.43	18.39	10.59	06.78	0.74±0.46
Burj Sema	34.07	18.50	18.44	09.88	11.60	05.97	21.65	16.50	0.54±0.32
Chathewala	24.52	20.76	15.45	12.39	38.23	17.93	61.37	45.43	0.87±0.61
Kaureana	13.90	10.90	11.28	06.71	20.74	04.32	14.14	06.72	0.37±0.18
Mirjeana	14.32	14.48	13.45	08.55	32.20	27.21	28.81	17.75	0.55±0.43
Manuana	26.60	23.45	20.31	10.46	37.54	45.14	34.82	06.91	0.75±0.54
Gehlewala	27.17	18.66	32.24	14.56	42.18	20.26	24.86	13.74	0.67±0.42
Maur chart	11.06	05.39	20.39	11.63	32.85	06.85	33.72	04.46	0.61±0.18
Burj	27.38	14.87	36.50	19.79	76.69	87.28	31.16	18.66	1.07±0.89
Shekhpura	14.75	07.70	36.76	12.70	16.40	13.34	37.97	33.80	0.67±0.43
Jogewala	19.70	10.59	35.71	07.04	22.35	13.18	22.30	13.15	0.63±0.28
Gatwali	19.83	08.73	07.98	05.90	18.57	12.39	23.17	12.47	0.43±0.11
Average	23.39	15.86	23.48	10.94	31.31	22.69	28.71	16.36	0.66±0.40

(200-300 Bq m^{-3}) recommended by International Commission on Radiological Protection.[11] It is also lower than that of the world average value of 40Bq m^{-3}[1] and the action level (100Bq m^{-3}) recommended by World Health Organization.[12] Table 3 reveals that radon level estimated in present study is much lower than that of some other locations in India studied previously.[13-22] However, most of the previous studies have been carried out using bare mode of detectors, which have not discarded the radon and thoron progeny concentrations in results and hence overestimated the radon and thoron concentrations. Since, the progeny are filtered out by the detectors used in the present study, the present measurements can be treated as more realistic.

DISCUSSION

Annual effective dose

The annual exposure to the inhabitants (annual effective dose) for each of the 12 villages was also calculated. The

Table 2: Frequency distribution of radon and thoron concentrations.

Locations	Season	<50 Bq m^{-3}		50-150 Bq m^{-3}		150-250 Bq m^{-3}	
		Radon	Thoron	Radon	Thoron	Radon	Thoron
48	Winter	41	45	7	3	-	-
48	Rainy	48	43	-	5	-	-
48	Spring	40	42	8	5	-	1
48	Summer	46	46	2	2	-	-

Table 3: Comparison of present study of radon with the study done in other parts of India.

Location	Indoor radon concentration (Bqm^{-3})		
	Range	Average	Reference
Punjab (Bathinda, Faridkot, Tarantaran and Amritsra)	21-119	61	[13]
Punjab (Mohali)	22-45	33	[14]
Punjab and Himachal Pradesh	114-400	194	[15]
Punjab (Amritsar)	60-235	147	[16]
Singhbhum Thrust Belt	25-285	101	[17]
Punjab (Muktsar/Ferozpur)	95-226	110	[18]
Punjab (Bathinda)	95-202	150	[19]
Garhwal Himalayas	12-191	70	[20]
Andhra Pradesh	27-303	75	[21]
Himachal Pradesh	53-297	148	[22]
Present study	18-43	30	-

annual effective dose of radon and thoron received by the residents of the studied area varied from 0.75±0.13 to 0.95±0.33 mSv y^{-1} and 0.37±0.18 to 1.08±0.89 mSv y^{-1} with an average value of 0.88±0.28 and 0.66±0.40 mSv y^{-1} as shown in Table 1a and 1b, respectively. In all the villages, the annual effective dose received by the occupants is less than the lower limit of the recommended action level 3-10 mSv y^{-1}.[23]

Effect of building materials and ventilation conditions

Table 4 shows the type of building construction materials and the ventilation conditions of all the 48 dwellings. There is no significant relation has been between radon and thoron concentrations with the type of building materials. For instance, all of the 4 selected dwellings at village Gatwali and at Shekhpura were only constructed from bricks, however, average radon concentration at Gatwali is maximum (50.14 Bq m^{-3}) and at Shekhpura is minimum (33.07 Bq m^{-3}) in winter. For thoron trend is just opposite at the same villages. These facts suggest that radon and thoron concentrations are independent of the type of the construction materials.

However, ventilation conditions of the dwelling tend to have an apparent effect on the radon concentration. The radon concentrations in well-ventilated dwellings were lower as compared to poorly ventilated dwellings. Here a dwelling with one door and no window is considered as poorly ventilated, with one door and one window is partially ventilated and with more than one door and window as well ventilated. It can be seen from Table 1a that radon concentrations at villages such as Natt, Manuana, Maur chart and Shekhpura, where the selected dwellings were either poorly or partially ventilated (Table 4), are comparatively lower than most of those villages where the dwellings were partially or highly ventilated particularly in summer. It can also be seen that standard deviations (distribution) of radon concentrations around the mean values for each village are higher in summer than in winter. However, in case of thoron no such distinctions are clear. These contrasting behaviours of radon and thoron can be understood from the following relation:[24,25]

$$C = \frac{JS/V + C\lambda_V}{(\lambda + \lambda_V)} \quad (5)$$

where, C is radon/thoron concentration (Bq m^{-3}) in the room, J is the radon/thoron exhalation rate (Bq m^{-2} h^{-1}), S is the exhalation surface area of room (m^2), V is the volume of the room (m^3), C^o is the radon/thoron concentration (Bq m^{-3}) in the outside air, λ_v is the ventilation rate (h^{-1}) of room and λ is the decay constant of radon/thoron. It can be assumed to a good approxi-

Table 4: The Building construction materials, ventilation conditions in 48 dwellings of 12 villages.

Sample location	Dwelling 1		Dwelling 2		Dwelling 3		Dwelling 4	
BATHINDA DIST.	Type	V.C	Type	V.C	Type	V.C	Type	V.C
Natt	H2	II	H2	II	H2	I	H2	II
Burj Sema	H3	II	H4	II	H4	III	H2	II
Chathewala	H2	II	H1	II	H4	III	H2	III
Kaureana	H5	III	H4	II	H2	I	H5	I
Mirjeana	H4	II	H2	I	H2	II	H4	III
Manuana	H4	I	H5	II	H1	II	H1	II
Gehlewala	H1	I	H1	I	H1	I	H1	I
Maur chart	H4	I	H1	II	H1	I	H1	II
Burj	H1	II	H1	III	H1	III	H1	II
Shekhpura	H1	II	H1	I	H1	II	H1	I
Jogewala	H1	II	H1	II	H1	III	H1	II
Gatwali	H1	II	H1	II	H1	II	H1	III

V.C: ventilation condition I: poorly ventilated, II: partially ventilated, III: well ventilated
H1: (Floor: Brick, Roof: Brick) H2: (Floor: concrete, Roof: bricks and white wash) H3: (Floor: concrete, Roof: concrete) H4: (Floor: marble, Roof: Brick and POP) H5:(Floor: Tile, Roof: bricks)

mation that spatial outdoor concentration is constant at least over the area of a given village. Also, the ventilation rate λ_v in winter can be considered negligible for all dwellings, as doors and windows remained closed and electrical appliances such as fans and air coolers are turned off for all the winter time. For the ventilation conditions being almost same for all dwellings in winters, the standard deviation in radon concentration at each village is found to be small. However, in summer doors and windows were always opened and fans and air coolers were frequent in use, which caused ventilation greatly influencing the indoor radon concentration. Since, λ_v may be in the range 1-10 h^{-1} in summer depending upon the number of doors and windows and their size, the rooms with smaller opening areas may have radon concentrations as large as a factor of around 10 than that of rooms with larger opening areas. Thus, it could be one of the possible reasons for high standard deviations in summer. It can also be seen in Table 1a that average radon concentrations over all villages in winter is maximum (43.27 Bq m^{-3}) and in summer is minimum (18.70 Bq m^{-3}), which is again attributed to negligible ventilation in winter and highest in summer. However, the thoron concentration is mainly governed by the decay constant of thoron (λ_{Th}= 45 h^{-1}) because it is much larger than that of radon (λ_{Rn}= 0.007 h^{-1}) and as well as typical ventilation rate in summer (1-10 h^{-1}) so that thoron is removed from all dwellings almost at the same rate i.e. λ_{Th} irrelevant of ventilation rate. Therefore, standard deviation in thoron concentration is not supposed to vary with seasons. However, standard deviations in thoron concentration are comparatively larger than for radon concentration for each season. This could be possible due to the installation position of detectors from the nearest walls. Due to very short half-life of thoron, the diffusion length of thoron in air is very small (about 3 cm) thus its concentration decreases rapidly even within few centimeters of distance from walls.[26] Since, the distance of detector in each room varied by couple of centimeters, it possibly caused a large difference in the measured values of thoron concentration for each room and hence large standard deviations.

Seasonal ratio of radon/thoron concentration

Table 5 shows the seasonal variation of radon and thoron concentrations in terms of winter to summer, winter to spring and winter to rainy ratios. Measured mean values for winter/rainy, winter/spring and winter/summer radon ratios were found as 1.63±0.25, 1.48±0.24 and 2.49±0.28 respectively. Winter to summer ratios for radon were comparatively more than others. This is due to the highest ventilation rate in summer as fans or air coolers were frequently used in addition to opened doors and windows throughout the summer. Whereas, fans and air coolers were not in use late in the rainy and early in the spring season. In case of thoron winter/rainy, winter/spring and winter/summer radon ratios were found as 1.12±0.32, 0.91±0.30 and 1.45±0.32 respectively, which are smaller as compared to that of radon.

Surface to volume ratio

One of the most important parts of this study has been the investigation of the correlation of radon and

Table 5: The winter/summer (W/S); winter/rainy (W/R); winter/spring (W/Sp) ratios of the radon and thoron concentrations.

Sample location	Radon						Thoron					
BATHINDA DIST.	W/R	SD	W/Sp	SD	W/S	SD	W/R	SD	W/Sp	SD	W/S	SD
Natt	1.15	0.23	2.18	0.28	3.50	0.34	0.70	0.23	1.26	0.26	3.14	0.35
Burj Sema	1.33	0.24	1.12	0.23	2.33	0.28	0.54	0.29	1.59	0.37	0.85	0.32
Chathewala	2.06	0.26	1.15	0.22	2.02	0.26	0.63	0.32	0.40	0.30	0.25	0.28
Kaureana	1.97	0.26	1.66	0.24	2.11	0.26	0.81	0.40	0.54	0.37	0.80	0.40
Mirjeana	1.44	0.24	1.38	0.24	1.52	0.25	0.94	0.38	0.42	0.32	0.47	0.33
Manuana	1.46	0.22	2.49	0.26	2.76	0.27	0.76	0.29	0.54	0.28	0.58	0.28
Gehlewala	1.31	0.23	1.33	0.23	2.06	0.26	1.19	0.26	0.76	0.23	6.63	0.49
Maur chart	1.27	0.24	1.07	0.23	4.27	0.37	1.84	0.37	0.62	0.28	0.60	0.28
Burj	1.51	0.25	1.15	0.23	2.83	0.30	1.34	0.25	0.48	0.20	1.18	0.24
Shekhpura	1.30	0.26	0.61	0.22	1.86	0.29	2.47	0.31	2.23	0.30	0.96	0.23
Jogewala	2.22	0.25	1.75	0.23	2.10	0.25	1.81	0.28	1.60	0.27	1.60	0.27
Gatwali	2.50	0.26	1.85	0.24	2.49	0.26	0.40	0.42	0.43	0.42	0.34	0.41
Average	1.63	0.25	1.48	0.24	2.49	0.28	1.12	0.32	0.91	0.3	1.45	0.32

thoron concentrations with surface area to volume ratio, S/V of rooms, which is scarce in literature. According to theoretical relationship (Eqn. 5), radon/thoron concentration is directly related with S/V. To verify this relation, the S/V values were calculated for each room by measuring the dimensions of rooms. Figure 3 and Figure 4 depict the variation of radon and thoron

Concentrations, respectively, with S/V values of 48 rooms. Here, concentrations are the annual average values (averaged over four seasons) for each room. In case of radon, a considerable positive and linear relation (Correlation coefficient R^2=0.35) is found. The direct relation of concentration with surface area is due to the fact that room surface (walls, floor and roof) is the main source of radon. Therefore, more is the surface area higher are the concentrations. However, larger room volume provides more space for radon to disperse around, thus, resulting inverse relation of volume with concentrations. The small value of correlation coefficient is obtained due to the other variables (such as exhalation rate and ventilation rate) also regulating the radon concentration. In case of thoron the correlation coefficient is very small which is due to the fact that a large fraction of thoron decays before it uniformly disperse in the room volume due its very short half-life and hence its concentration becomes irrelevant of room dimensions. This part of study suggests the construction of dwellings with lesser

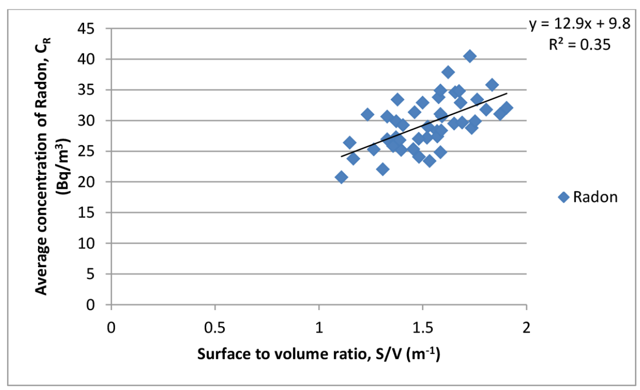

Figure 3: Correlation between concentration of radon and surface to volume ratio of different dwellings.

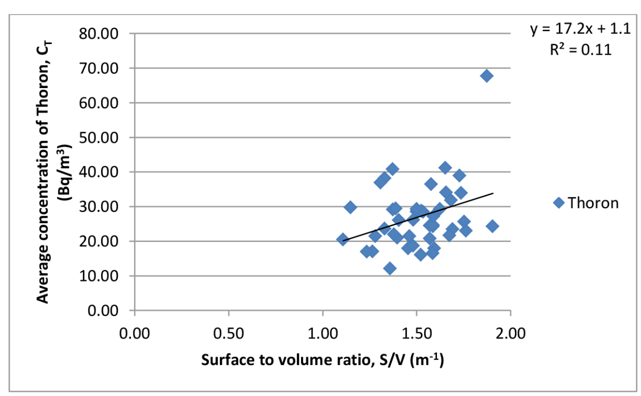

Figure 4: Correlation between concentration of thoron and surface to volume ratio of different dwellings.

surface to volume ratio to reduce adverse effects of radiation exposure resulted from the inhalation of radon.

CONCLUSION

In majority of the dwellings, the annual average radon concentrations are less than the lower limit of the action level (200-300 Bq m^{-3}) recommended by ICRP. In most of the locations, the annual effective doses received by the occupants were much lower than the recommended action level (3-10 mSv y^{-1}). Results show that radon/thoron level varies inversely to ventilation. Hence high levels of indoor radon/thoron were found in poorly ventilated dwellings and vice versa. The positive correlation of radon/thoron concentration with surface to volume ratio signifies the fact that in spacious rooms, concentrations were low. Therefore, this study suggests the construction of dwellings with lesser surface to volume ratio.

ACKNOWLEDGEMENT

The present work is devoted to the Ph.D thesis under Reg. Number: 1111019, Punjab Technical University, Kapurthala. The authors thank the residents living in the selected dwellings who gladly helped during the replacement and collection of the detectors. Authors wish to convey their gratitude to Department of Physics, Dr. BR Ambedkar National Institute of Technology, Jalandhar, India for providing experimental facilities.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Cite this article: Kaur K, Heer MS, Mehra R, Sahota HS. Seasonal Variation of Indoor Radon (^{222}Ra) and Thoron (^{220}Ra) in the Dwellings of Bathinda District of Punjab, India. Asian J Biol Life Sci. 2019;8(2):68-75.