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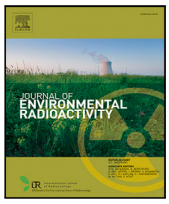

Spatial distribution of radon in an experimental room ☆

Raphael Grapentin *, Antoine Geiser, Roger Blaser Zürcher

School of Architecture, Construction and Geomatics, University of Applied Sciences and Arts Northwestern Switzerland, Hofackerstrasse 30, Muttenz 4132, Switzerland

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ABSTRACT

The spatial distribution of radon and the relevance of the placement of radon detectors relative to the entry path of radon-containing air in an experimental room was investigated. A radon emanation source was used from which the air was transported with a constant air flow into the room. The radon contaminated air was released under a floor element used for electrical wiring which has multiple holes connecting to the inner volume of the room. At 36 equally spaced lattice points in the room the radon activity concentration was measured with two different solid-state nuclear track detectors of type Radonova Radtrak and Radonova Rapidos. The radon exposure on the detectors was accumulated over 72 days. Additionally, an electronic measurement device of type Saphymo AlphaGUARD was used as reference. It indicated a radon exposition of 475(1) kBq h/m^3. The detectors of type Radtrak had a mean exposition of 564(36) kBq h/m^3 and the ones of type Rapidos 496(15) kBq h/m^3. Except for one outlier both types of detector showed a homogeneous distribution of radon in the room. Therefore, we have shown that under these experimental conditions the placement of the radon detector does not significantly influence the measurement result.

1. Introduction

Radon is a naturally occurring radioactive noble gas. It originates in the uranium-radium decay series (Kozempel, 2017). Therefore it is present everywhere on earth mainly in areas with increased uranium concentrations in the soil, subsoil and bedrock. From there the radon is transported through diffusion or advective gas flows (Bruno, 1983). It may also penetrate building envelopes which can lead to increased radon concentrations in buildings. Especially long term exposure to radon can pose a significant risk for developing lung cancer (WHO, 2009). That is why measuring the radon concentration in rooms with high occupancy is necessary to prevent such health hazards. One method to measure radon concentration in air is with solid-state nuclear track detectors (Durrani and Ilic, 1997).

When conducting a radon measurement the examiner must decide where to place the measurement device. In Swiss regulations concerning domestic and occupational radon exposure, a guidance is given to place the measurement devices on the height of the head with at least one metre distance to windows and doors (Anon, 2023a). Furthermore, this guidance recommends to keep radon detectors away from any heat sources. Also, more recommendations on the placement of radon detectors in a room are made by Anon (2019). There it is said to place the measurement devices between one and two metres above ground and to keep the detectors away from any heat, fat or water sources. Moreover, the detectors shall be placed 20 cm away from walls with a high content of thorium in order to avoid the influence of ^{220}Rn, without specifying a value for high content of thorium.

Additionally, it is in the interest of the examiner to not lose any measurement devices during the exposure period of multiple months. Throughout this time the object to be measured, i.e. home or workplace, is occupied which poses the risk of removal of the detectors. Also, the inhabitants or workers should not be influenced by the presence of radon detectors. All these factors make the placement of radon measurement devices a challenging task.

Previously, simulations of spatial radon distributions where radon emanation from the building material was the only radon entry into the room were presented (Chauhan et al., 2014). Also, influences of ventilation were simulated (Rabi and Oufni, 2018), furthermore, the radon and thoron distribution was studied (Urosevic et al., 2008). These reports only take into account the radon emanation from building materials which is typically not the reason for an increased radon concentration in indoor air, the dominant path of radon entry are advective gas flows (Renken and Rosenberg, 1995; Nazaroff, 1992). The spatial distribution of radon in a room with advective radon entry from the ground was never reported before.

In this experiment, a typical situation where the main radon entry occurs due to advective radon intrusion from the ground and whether

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* Corresponding author.
E-mail address: raphael.grapentin@fhnw.ch (R. Grapentin).

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the placement of radon detectors plays a significant role in the outcome of a measurement was investigated.

2. Materials and methods

2.1. Experimental room

In order to avoid exposure of persons to increased radon concentrations a container previously used as laboratory for building technologies was used. This container is made of a wooden structure with insulation and consisted of only one room. The length of the room was 4.5 m with a width and height of both 3.2 m, resulting in a total air volume of 46 m^3. The room had an access door on one side and windows on the opposite side. Additionally the container was built on a rotatable structure giving a crawl space between the ground and the container of 0.5 m height. The experiment was conducted in Muttenz, Switzerland, and the container was oriented north during the experiment such that no direct sunlight may shine through the windows. The air tightness of the room was previously measured. For a depression of −50 Pa between the inside versus outside, the air permeability of the building envelope was $q_{a50} = 1.58\,m^3/hm^2$. This value gives the air flow in cubic metres per hour per surface area of the building envelope for the given pressure difference. The Swiss standard for indoor air quality defines a maximal acceptable value of 2.4 m^3/hm^2 with recommended value of 0.6 m^3/hm^2 for new buildings (SIA, 2014).

2.2. Radon source

In this experiment we only focused on the most abundant radon isotope ^{222}Rn which is the decay product of ^{226}Ra (Sicius, 2015). A radon flow source was used, made with a historical watch painted with radioactive luminescent paint. Previous measurement determined the activity of ^{226}Ra to be 179(9) kBq. All uncertainties given are $\pm 1\sigma$. This watch was placed in a stainless steel container with an air inlet and outlet. The radon emanation source and its emanation power were previously characterised, the results of this characterisation are as follows. Using outside air with an air flow rate of 5.00(5) L/min and a relative humidity of 39.7(5) % through the emanation source, a radon activity concentration of 1235(148) Bq/m^3 was measured in the outlet air. This results in an emanation power of $\chi = 0.27(0.04)$. For the experiment, the same air flow rate with outside air was used, which means that the relative humidity and therefore the emanation power and radon activity concentration, were not constant over the measurement duration.

2.3. Air flow

An air pump was used in combination with a throttle valve to generate an air flow of 5 L/min. The pump captured air from the outside, from where the air flow is conducted into the radon flow source accumulating a significant amount of radon in the source container. From the air outlet of the source container, the air was guided to the bottom of the room and released into a channel used for electric wiring. The channel was covered by a loose wooden panel with holes. The setup is shown in Fig. 1. This setup is close to a typical situation in a building, where radon intrusion occurs on the lowest floor via a disturbance in the floor or poorly sealed conduit bushing. To conduct the air flow we used tubes made from polyamide.

2.4. Radon measurement devices

In this experiment we used two types of solid-state nuclear track detectors and one electronic measurement device as a reference. The solid-state nuclear track detectors were of type Radonova Radtrak and Radonova Rapidos. The specifications of the detectors are given in Table 1.

The difference between these detectors is the inner volume of the chamber. The detector of type Rapidos has a larger inner volume which leads to a higher sensitivity compared to those of type Radtrak. After exposure to radon the detectors were sent back to the manufacturer for evaluation. Since the aim of this experiment was not to characterise or calibrate the radon detectors, we chose a commercially available solution. The manufacturer of these radon detectors participated in comparison measurements with the detectors of type Radtrak, which are also authorised radon detectors in Switzerland (Anon, 2023b). Therefore, they fulfil the requirements by Swiss law, especially the standard deviation for repeated measurements is lower than 15 % (The Federal Council, 2012). The detectors of type Rapidos are not authorised radon detectors in Switzerland.

The electronic measurement device used was of type Saphymo AlphaGUARD DF2000. This device uses a ionisation chamber to measure the radon concentration time resolved. The measurement chamber can be used in a diffusion mode or air can be actively exchanged with an internal pump. For this experiment the device was used in diffusion mode with an integration time of one hour. This device has a measurement range of 2 Bq/m^3 to 2 MBq/m^3, the linearity error and the calibration error given by the manufacturer are <3 % and ±3 % respectively.

2.5. Experimental procedure

First, the door to the room was opened to reduce the radon concentration to that of the outside air. The radon source and the air flow was setup as described in Sections 2.2 and 2.3 respectively and as shown in Fig. 1 but with the pump still deactivated and the valves of the radon emanation source closed.

Next, a square lattice inside the room was setup with package cord. This lattice consisted of three horizontal layers with each three by four lattice points, resulting in a total of 36 lattice points in the room. The lowest layer was directly on the floor, the second layer at 1.5 m and the third layer at 2.7 m above the floor. The horizontal distance between each lattice point was 1 m. At every lattice point one solid-state nuclear track detector of each type was installed. Also, one detector of each type was place directly at the air outlet in the channel under the floor. Additionally, we installed temperature trackers at every lattice point in the room.

In the following we will refer to each lattice point in (x,y,z) notation, where x and y correspond to the position on layer z, corresponding to the axes labels in Fig. 2. The air outlet was located under lattice point (1,1,0). On the lowest layer, the electronic measurement device was placed in one corner at location (0,0,0). An installation at another layer would have required a substantial structure in the room, potentially influencing the air movement and therefore the radon distribution in the room. The specific corner was chosen, because there was neither the door nor the window on one of the adjacent walls. Therefore, leakages of outside air into the room were assumed to be low at this position.

Third, the electronic measurement device was started, the pump activated and the door and windows were closed. Removing the radon detectors from the packaging whilst installing them, already started the measurement. The experiment was then running for 72 days.

After this duration the experiment was stopped by deactivating the air pump, stopping the electronic measurement device and removing the radon detectors from the lattice points. These detectors were then sent back to the manufacturer, where we added two new detectors of each type to the shipment as recommended by Butterweck et al. (2016). This was done to evaluate potential radon exposition during transport. Also, the temperature trackers were stopped and evaluated.

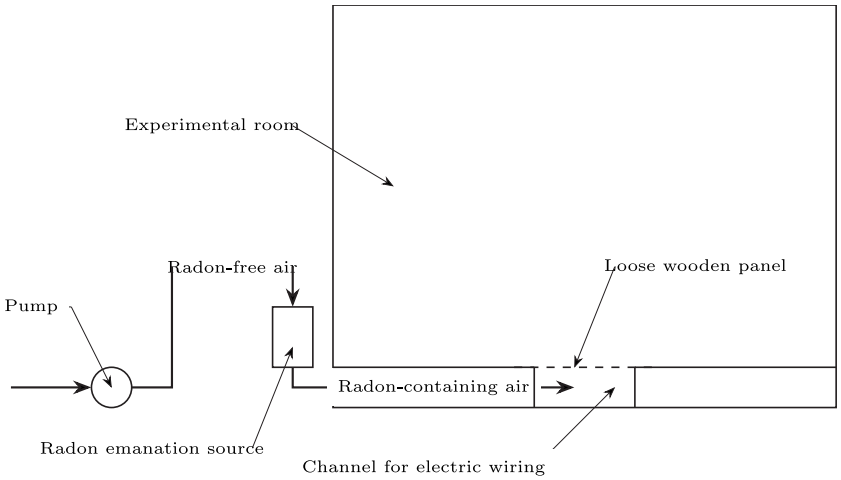

Fig. 1. Side view of experimental setup with the air flow indicated by the bold arrows.

Table 1
Technical specifications of the two types of radon detectors used in the experiment given by the manufacturer. The typical background is the radon exposition expected to be reported by the manufacturer when the detector was not exposed by the customer.

Specifications	Radonova Radtrak	Radonova Rapidos
Exposition range [kBq h/m^3]	30 - 50000	10 - 25000
Uncertainty	6% at 400kBq h/m^3	10% at 50kBq h/m^3
Detector sensitivity [(Tracks/cm^2)/(kBq h/m^3)]	2.1	4.6
Typical Background [kBq h/m^3]	15	4

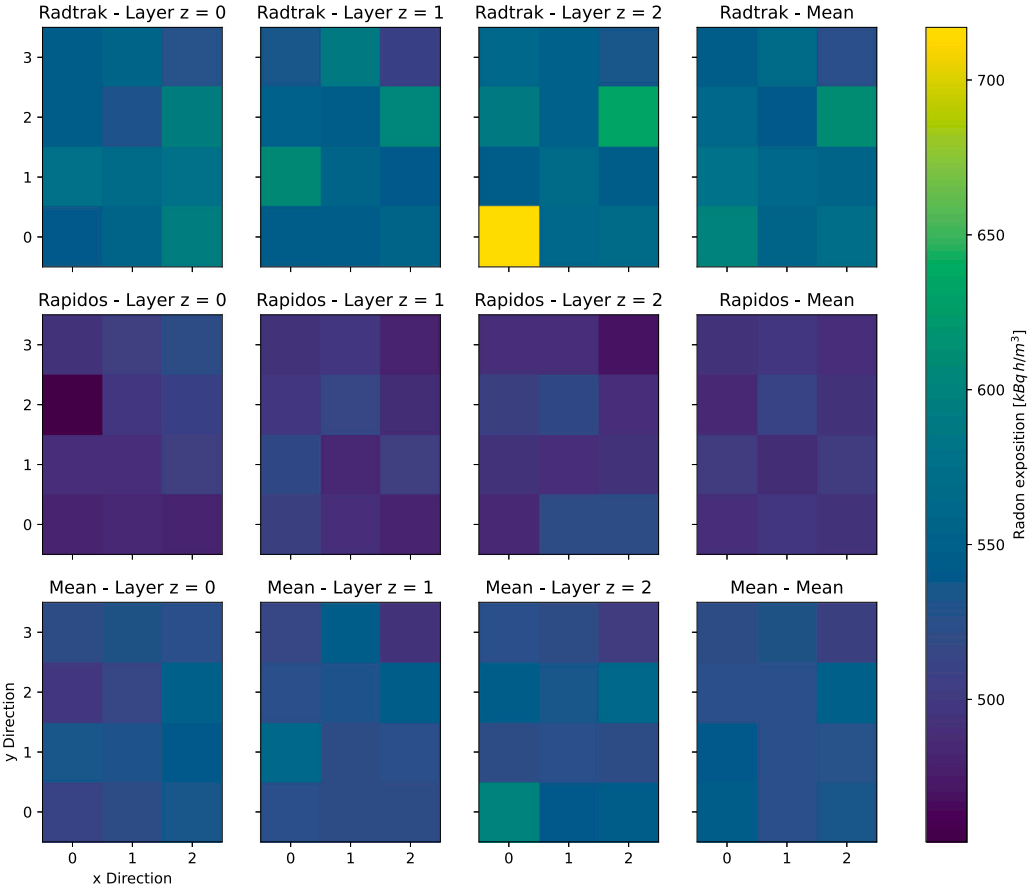

Fig. 2. Visualisation of all measured values and each measurement point. In the upper row the results of the detectors of type Radtrak and below those of type Radpidos are shown for all three layers. The colorbar indicates the radon exposition of each detector. Additionally the mean values for each layer and each type of detector are shown in the bottom row and the right column respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

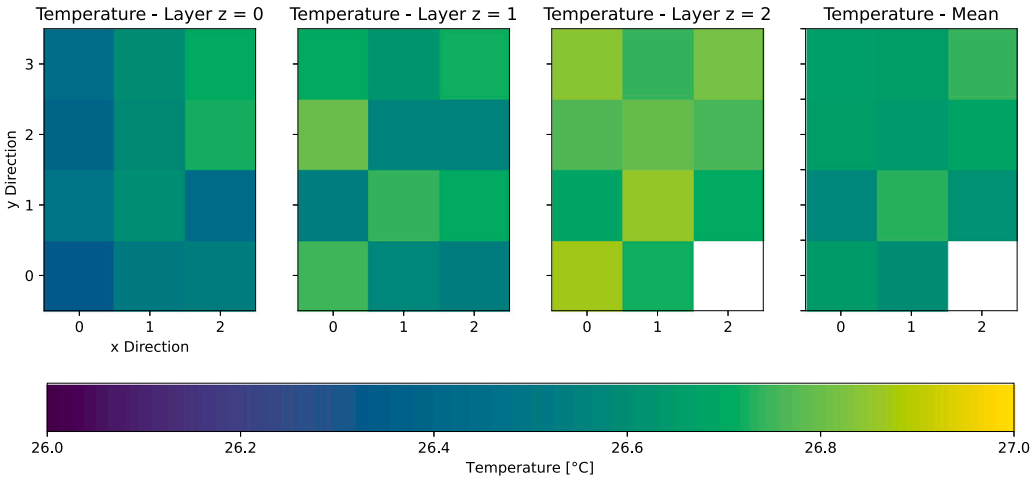

Fig. 3. Results of the temperature measurement. For each lattice point the mean temperature over the measurement period is shown. Additionally the mean over all layers is shown in the right grid. The data from the temperature measurement at (2,0,2) was lost due to an error while handling the device, due to that error the mean value at (2,0) is omitted.

3. Results

The measured radon exposition of all radon detectors are graphically shown in Fig. 2 in units of radon exposition in $\mathrm{kBq\,h/m^3}$. The radon exposition is the time integration of the radon activity concentration and therefore any time variations, due to changes in air humidity and therefore radon emanation power of the source, are already taken into account. In Fig. 4 a histogram for both types of detectors is shown. In both charts a Gaussian fit is shown and the value of the reference device is indicated.

The electronic reference measurement device measured time resolved radon activity concentrations which were integrated to a total radon exposition of $475(1)\,\mathrm{kBq\,h/m^3}$. The reference device was placed at measurement point (0,0,0). The measured exposition corresponds to an average radon activity concentration of $275(1)\,\mathrm{Bq/m^3}$.

For the radon detectors at the lattice points the highest radon exposition was $717(50)\,\mathrm{kBq\,h/m^3}$ and measured by detector of type Radtrak at measurement point (0,0,2). The lowest value was measured at point (0,2,0) with detector of type Rapidos and was $454(34)\,\mathrm{kBq\,h/m^3}$. The mean exposition of all detectors of type Radtrak was $564(36)\,\mathrm{kBq\,h/m^3}$ and $496(15)\,\mathrm{kBq\,h/m^3}$ for the detectors of type Rapidos. These values give an average radon activity concentration of $326(21)\,\mathrm{Bq/m^3}$ and $287(9)\,\mathrm{Bq/m^3}$ for the detectors of type Radtrak and Rapidos respectively. The blank detectors added to the shipment showed low radon exposition compared to the exposed detectors of the experiment. The values were $28(8)\,\mathrm{kBq\,h/m^3}$, $9(8)\,\mathrm{kBq\,h/m^3}$ and $4(3)\,\mathrm{kBq\,h/m^3}$, $6(3)\,\mathrm{kBq\,h/m^3}$ for the two detectors of type Radtrak and the two of type Rapidos respectively. The two detectors at the air outlet in the channel for electric wiring under the loose wooden panel showed $813(55)\,\mathrm{kBq\,h/m^3}$ for type Radtrak and $739(55)\,\mathrm{kBq\,h/m^3}$ for type Rapidos. These values give an average radon activity concentration of $470(32)\,\mathrm{Bq/m^3}$ and $428(32)\,\mathrm{Bq/m^3}$ respectively. For the passive radon detectors, the uncertainties are reported by the manufacturer after evaluation of each detector. The electronic measurement devices gives an error for each measured radon activity concentration at each hour.

The mean temperatures over the measurement duration are shown in Fig. 3. The values were between 26 °C and 27 °C. The data from the detector at position (2,0,2) was lost due to an operational error while handling the device.

4. Discussion

4.1. Comparison of radon detectors

The detectors of type Radtrak consistently measured higher values than the ones of type Rapidos. The values of the latter were found to be closer to the reference value given by the electronic measurement device but still above. The mean value of the detectors of type Rapidos was $496(15)\,\mathrm{kBq\,h/m^3}$ which is 4 % larger than the reference and a standard deviation of 3 %. The standard deviation found in this experiment is smaller than the value given in the technical specifications of the manufacturer but at another exposition. For the other type of detectors the mean value was $564(36)\,\mathrm{kBq\,h/m^3}$ which is 16 % above the reference and a standard deviation of 6 %. This value is in accordance with the uncertainty given by the technical specifications of the manufacturer at a comparable exposition. Also this standard deviation is in accordance with the comparison measurement conducted by Swiss federal institute for metrology, where a standard deviation of 7 % was found for the detectors of type Radtrak (Maret and Peier, 2022). The detectors of type Rapidos were not included in this study.

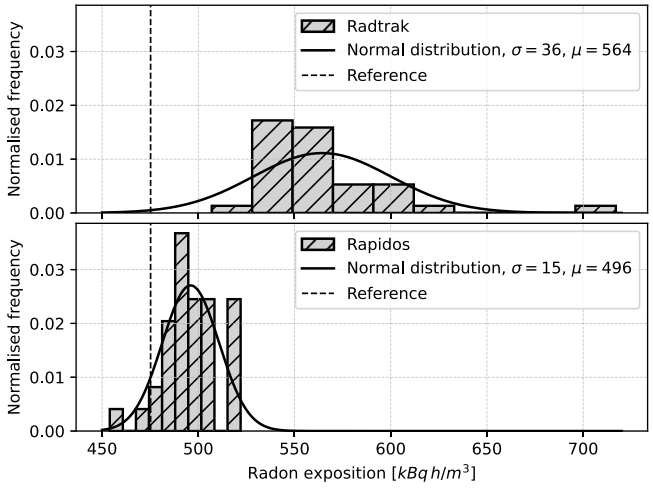

Fig. 4. Histograms of all measurements differentiated by type of detector. Additionally, a Gaussian fit is calculated for each data set. The dashed line indicates the exposition of the electronic reference radon measurement device. Both charts are displayed in normalised frequency.

The difference in measured radon exposition of the two types of detectors is explained by the difference in sensitivity. For the detector of type Rapidos the manufacturer reports a sensitivity more than twice the sensitivity of the other type of detector. Since the relative error of the detector scales with the square root of the number of tracks divided by the number of tracks, the detector with higher sensitivity will have a larger number of tracks and is therefore expected to lie closer to the

Table 2
P-values of the t-test for the hypothesis that the radon exposition was different on each layer. Values above 0.05 mean that the difference between the mean values for the given combination of layers is random and not significant. Comparing a layer to itself and conducting the t-test was omitted.

Radtrak	Layer 0	Layer 1	Layer 2
Layer 0		0.81	0.32
Layer 1	0.81		0.27
Layer 2	0.32	0.27	
Rapidos	**Layer 0**	**Layer 1**	**Layer 2**
Layer 0		0.51	0.48
Layer 1	0.51		0.90
Layer 2	0.48	0.90	

true value and closer to the electronic reference device, as long as no saturation of the detectors occur. Furthermore the standard deviation of all detectors of that type is smaller than the one of the other type of detector.

Moreover the expositions of all detectors are around 1 % to 4 % of the maximal exposition range, shown in Table 1. At higher expositions the difference between both types of detectors is expected to be smaller than reported here. This is due to increased number of tracks on the detector leading to increased accuracy.

4.2. Radon activity concentration

Furthermore it was shown that the average radon activity concentration in the room was significantly lower than the radon activity concentration in the air flow after the radon emanation source.

Assuming an air-tight steady state where the air flow containing radon is the only input of air into the room and excess air leaves the room to maintain a steady pressure, a radon activity concentration of 1051 Bq/m^3 is expected. Originating from the ^{226}Ra activity of the source of 179 kBq and an emanation power of 0.27 resulting in 48 kBq of ^{222}Rn equally distributed over46 m^3.

The measured values of 326(21) Bq/m^3 and 287(9) Bq/m^3 for the two types of detectors show, that also outside air enters the room, therefore confirming the low air-tightness measured before the experiment.

The pressure difference between the inside of the container and the outside was not measured during the experiment, but the results show that dilution with outside air must have taken place in the room.

4.3. Outliers

Regarding all detectors of type Radtrak, two outliers were found and are shown in Fig. 5 in dataset “Radtrak - All”. First, the detector of type Radtrak at measurement point (0,0,2) which returned the highest value of 717(50) $kBq\,h/m^3$ is considered to be an outlier. The other detector of type Rapidos at the same location showed a value of 486(36) $kBq\,h/m^3$ which is within the 95 % confidence interval of all detectors of type Rapidos. Also the other detectors at the neighbouring positions measured values within the 95 % confidence interval of each type of detectors.

Second, the detector of type Radtrak at position (2,2,2) is considered an outlier and reported 631(45) $kBq\,h/m^3$. The detector of type Rapidos at this location return a value of 491(36) $kBq\,h/m^3$ and shows therefore no significantly increased value compared to the mean value of 496(15) $kBq\,h/m^3$ for all detectors of type Rapidos.

For all detectors of type Rapidos, one outlier was found at position (0,2,0), as shown in Fig. 5 in dataset “Rapidos - All”. This detector reported a value of 454(34) $kBq\,h/m^3$. The detector of type Radtrak at the same position reported a value of 547(39) $kBq\,h/m^3$, which is close to the mean value of all detectors of that type and well within the 95 % confidence interval.

Furthermore the blank detectors added to the shipment showed values below 30 $kBq\,h/m^3$. Therefore the high values on the outliers of type Radtrak could not have accumulated during shipping. Since all detectors were shrink-wrapped in air tight radon-proof packaging before start of the experiment an accumulation or exposition to radon prior the measurement can be excluded. For all three outliers, an external manipulation during the measurement can be precluded, since the experimental room was empty, locked and not used, during that time. Finally, there might have been an error in the manufacturer’s production or evaluation.

4.4. Spatial distribution

4.4.1. Vertical distribution

In Fig. 5 for each layer and type of detector a boxplot is shown. Again it is clear that, not only over all layers but also for each single layer, the detectors of type Radtrak measured higher values than those of type Rapidos. To evaluate the difference in radon exposition on the different layers we performed t-tests with the hypothesis that there is a significant difference in radon activity concentration between the layers (Fischer et al., 2020). For that we compared the 12 values of each layer with those of any other layer. This test was done separately for each type of detector. The p-values are shown in Table 2. For each combination of layers and for both types of detectors the p-values are considerably larger than 0.01 or even 0.05. This means that the difference between the mean values for each layer and each type of detector is expected to be random and not due to a significant inhomogeneity in radon activity concentration.

4.4.2. Horizontal distribution

In Fig. 5, the mean values between both types of detector for each position on one layer are shown. In the dataset “Mean - Layer z = 0”, there are no outliers and therefore, the fluctuations are assumed to be random. Other so in the mean values of layer z = 1, “Mean - Layer z = 1”. This dataset shows two outliers, found at position (0,1,1) and (2,3,1). The mean value at position (0,1,1) was 563(41) $kBq\,h/m^3$. For the detector of type Radtrak at that position, the measured radon exposition was 608(43) $kBq\,h/m^3$ which is 8 % above the mean value of all detectors of that type. In Table 1, it is shown that the manufacturer gives an uncertainty of 6 % at an exposition of 400 $kBq\,h/m^3$. Therefore, the difference of 8 % to the mean value is within the 2σ range, i.e. the 95 % confidence interval, and not considered significant. The detector of type Rapidos at that position showed a value of 518(39) $kBq\,h/m^3$, which is 4 % above the mean value of all detectors of that type of 496(15) $kBq\,h/m^3$. The given uncertainty is 10 % at 50 $kBq\,h/m^3$. Assuming a constant uncertainty of 10 % over the whole measurement range, the found difference of 4 % is not significant.

The second outlier in the mean values of layer z = 1 is located at position (2,3,1). There, the detector of type Radtrak showed a value of 507(36) $kBq\,h/m^3$ which is 10 % below the mean value of all detectors of that type. This is also within the 2σ range, i.e. the 95 % confidence interval, and not considered significant. For the detector of type Rapidos at that position, the measured value was 480(35) $kBq\,h/m^3$. This is 3 % below the mean of all detectors of that type and also within the 2σ range.

Therefore, each of the detectors in layer z = 1 leading to the two outliers in the mean values, are within the 95 % confidence interval given by the uncertainty of the measurement devices.

In the mean values of layer z = 2, there is one outlier at position (0,0,2). This is due to the detector of type Radtrak at that position, as previously discussed in 4.3. Therefore, the mean value at this position is neglected.

Moreover, it is especially interesting to notice that the detectors directly placed at the air outlet in the channel for electric wiring under the loose wooden panel showed expositions of 813(55) $kBq\,h/m^3$ for type Radtrak and 739(55) $kBq\,h/m^3$ for type Rapidos. These values are 44 % and 49 % above the mean values for each type of detector respectively, and therefore significantly higher than the measured values

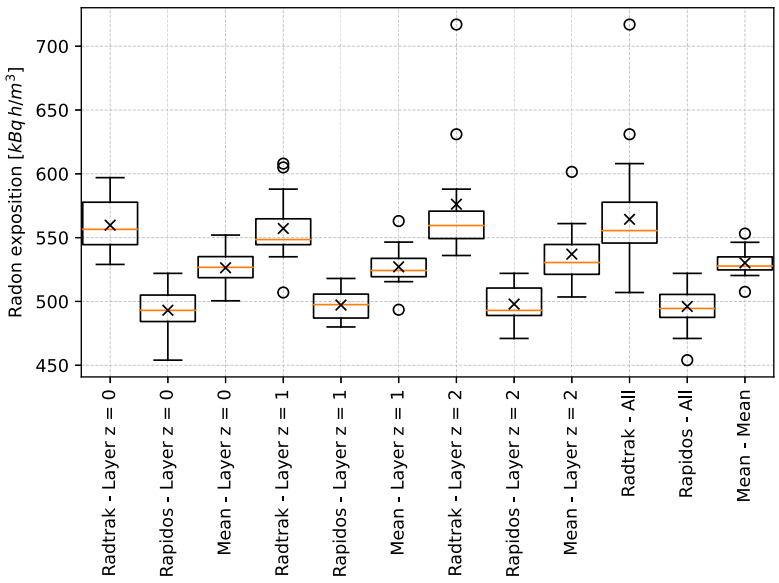

Fig. 5. Comparison of the results differentiated by type of detector and measured layer. First, the measurement data from detectors of type Radtrak on layer z = 0 and second, from the detectors of type Rapidos on layer z = 0 is shown. Third, for each position on layer z = 0 the mean between the two detectors is calculated resulting in 12 data points shown in "Mean - Layer z = 0". This is repeated for layers z = 1 and z = 2. "Radtrak - All" and "Rapidos - All" shows the data of all detectors of type Radtrak and Rapidos respectively. "Mean - Mean" consists of 12 data points shown in the bottom right of Fig. 2 also denoted as "Mean - Mean". In this graphic, the median and mean for each data set are represented by the line and cross respectively, the box shows quartile one to three, the whiskers show the furthest data point within 1.5 times the inter-quartile range.

at the lattice points in the room. Whereas the detectors at position (1,1,0) directly above that channel showed no significant increase. Also the overall air-tightness of the container must have influenced this difference between the radon activity concentration in the room and the channel for wiring. This means that the dilution and distribution of radon in the room is faster than the input of radon from the channel under the loose wooden panel into the room.

Finally, it was shown that the radon exposition of the detectors and therefore the radon activity concentration was homogeneous in each layer.

4.5. Temperature

The results of the temperature measurement are shown in Fig. 3, also the mean values over all layers are shown.

First, the data from one temperature measurement device was lost due to an operational error during the setup of the experiment. Therefore the mean value at position (2,0) in the rightmost plot is omitted.

Second, the mean temperatures over the measurement duration are within one degree Celsius. But the mean temperatures at layer z = 0 were generally lower than those at layer z = 2. Also on layer z = 0 the temperature was lower on the left side than on the right side. This might have been due to an inhomogeneity in solar irradiation possibly affecting the right side of the container. The weather effects outside the container were not taken into account in this experiment.

In Fig. 6 the maximum temperature difference between any lattice point is evaluated for each hour and shown as histogram. This shows that the maximum temperature difference in the room was at or below 1 °C for around 60 out of 72 days during the measurements.

Thanks to the measurement of the temperature during the experiment, it was shown that the advective air flow in the room was not strong enough to create a homogeneous temperature distribution. Therefore the advective air movement in the room must not have been the primary mechanism distributing the radon homogeneously in the room. Consequential, the diffusive movement must have been the predominant mechanism distributing the radon.

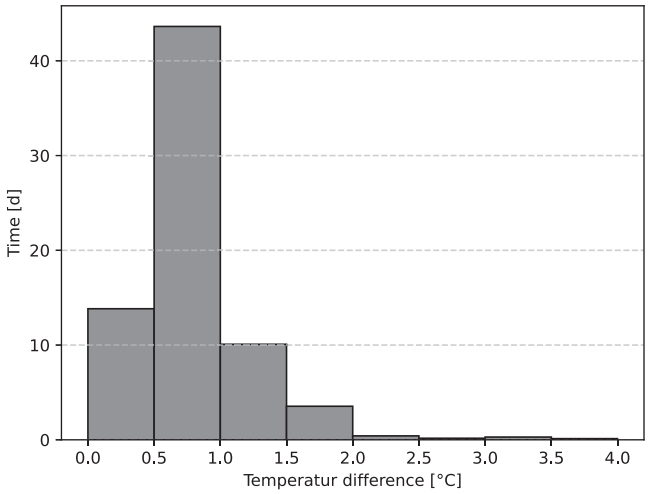

Fig. 6. Occurrences of temperature difference between the lowest and highest temperature of all lattice points evaluated each hour and shown in units of days. The highest temperature difference was 3.5 °C.

5. Conclusion

In this experiment the spatial distribution of radon in an experimental room was investigated. A radon emanation source was used to generate air containing radon. The air was conducted through an air outlet placed in a channel for electric wiring under a floor element such that the air could pass through gaps in the floor which resembles an advective intrusion of radon into a building. At 36 lattice points defined in the room the radon exposition was measured over 72 days with two different types of passive radon detectors. Additionally an electronic measurement device was used as reference at one lattice point.

The mean radon exposition of the passive radon detectors at the lattice points was 564(36) kBq h/m^3 and 496(15) kBq h/m^3 for detectors of type Radonova Radtrak and Radonova Rapidos respectively. This corresponds to a standard deviation of 6 % for type Radtrak and 3 % for type Rapidos. The electronic measurement device showed an exposition of 475(1) kBq h/m^3. The differences in measured radon expositions between all lattice points was shown to be random. Therefore, the radon activity concentration was homogeneous in the experimental room.

Furthermore, it was also shown, that the detectors inside the radon entry point, i.e. the channel for electric wiring, reported elevated radon

expositions of $813(55)\,kBq\,h/m^3$ for type Radtrak and $739(55)\,kBq\,h/m^3$ for type Rapidos. The detectors at the lattice points in the room in the vicinity to the radon entry point showed no elevated radon exposition. Therefore, if an examiner unknowingly places a single radon detector in a room, close to the radon entry point, the detector still returns the average radon concentration in the room and not an elevated value due to the small distance to the radon entry point.

Finally, it was shown that the placement of the radon detectors does not play a significant role when conducting a radon measurement. And it is proposed that the recommendations for the placement of radon detectors in Switzerland are revised.

Further experiments may investigate different sizes of rooms. Finding a boundary in area or volume at which the radon concentration is no longer homogeneous. Also, the results found in this report may be confirmed in a room with naturally elevated radon concentrations.

CRediT authorship contribution statement

Raphael Grapentin: Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **Antoine Geiser:** Validation, Methodology, Conceptualization. **Roger Blaser Zürcher:** Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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