7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient Buildings and Urban Environments

ibpc2018.org | #ibpc2018

Radon levels in rented accommodation

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ABSTRACT
Indoor radon levels were measured in 221 homes located in 53 buildings, including 28 multi-occupant houses and 25 single-family terraced houses. The homes consisted of rented accommodation located in buildings recorded as being constructed before 2010 and after the year 1850. In addition, the radon level was measured in the basement in 9 of the buildings.
The mean year value of the indoor radon level was 30.7 (1–250) Bq/m^3. The indoor radon level exceeded 100 Bq/m^3 in 5.9% of the homes, all located in single-family terraced houses. The variable single-family terraced houses explained 5.9% of the variation in indoor radon levels, and although associations were positive, none of these, besides homes in single-family terraced houses, were statistically significant. Approx. 75% of homes exceeding 100 Bq/m^3 indoor radon level had levels between 100 and 200 Bq/m^3 and 25% had indoor radon levels exceeding 200 Bq/m^3. Significant differences in indoor radon levels were found in homes located in multi-occupant houses. Additionally, the risk of indoor radon levels exceeding 100 Bq/m^3 in homes in multi-occupant houses was found to be very low, but the risk was highest on the ground floor in a building constructed with slab on ground.

KEYWORDS
Radon, measurements, homes, rented accommodation, mean year value.

INTRODUCTION

Radon-222 develops from the radioactive decay of radium-226 and has a half-life of 3.8 days. This noble gas seeps through soil into buildings, and if it is not evacuated, there can be much higher exposure levels indoors than outdoors (Nazaroff, 1992), which is where human exposure occurs (Brunekreef and Holgate, 2002). In this way, radon affects occupants through the indoor climate.

The World Health Organization recommends states to introduce requirements for the maximum concentration of radiation from natural sources in the indoor air. These recommendations are the result of the World Health Organization's evaluation of radon as being responsible for 3-14% of lung cancer incidents, depending on the average radon exposure in different countries (Zeeb and Shannoun, 2009). Results show radon to be the second-largest cause of lung cancer (tobacco smoking is still the primary cause). Radon exposure must be taken seriously in the struggle against radon-induced lung cancer due to the large number of people who are exposed daily in buildings and especially in residential buildings (Zeeb and Shannoun, 2009). If people spend their whole life in a house with an average radon concentration in the indoor air that exceeds 200 Bq/m^3, their risk of getting lung cancer is higher than 1%. This is far too high and higher than what in other contexts is acceptable for a single-factor risk (Andersen et al., 1997). Therefore, it is crucial to ensure a low radon level in the indoor air and to prevent radon from infiltrating into buildings.

Since 2010, Danish buildings must be constructed so as to ensure indoor radon levels below 100 Bq/m^3 as the mean year value (Danish Enterprise and Construction Authority, 2010). For all other buildings including homes it is recommended that the mean year value for the indoor radon levels should be below 100 Bq/m^3.

In this study, radon levels in rented accommodation were measured in the winter of 2013/14 and again in the winter of 2014/15. The paper shows how well 221 homes for rented accommodation perform, with respect to the Danish Building Regulations for homes constructed after 2010 and with respect to the recommendations for older homes, with regard to radon and to identifying the association between indoor radon in these homes and floor level, multi-occupant houses, single-family terraced houses, and basements. The number of homes with radon levels exceeding 100 and 200 Bq/m^3 was determined.

MEASUREMENTS

Measurements were carried out in 221 homes for rented accommodation and in 9 basements. Families and building owners were invited to participate in a radon monitoring programme. The programme took place in the heating periods of 2013/2014 and 2014/2015 between November and May. 196 homes were located in 28 multi-occupant houses and 25 homes were located in single-family terraced houses. Homes were selected from regions where other studies have shown a 1-30% chance of finding detached single-family houses with radon levels exceeding 200 Bq/m^3, (Andersen et al., 2001a). Three detectors were distributed to each participant by mail in sealed aluminum-coated envelopes and returned after the integration period in a pre-stamped envelope. Each participant was asked to fill in a questionnaire regarding the date when exposure started and ended, as well as type of room in which the detector was placed. Participants were instructed regarding placement of the detectors (>25 cm from a wall and away from strong draughts and heat) and also instructed to clean and ventilate their homes as they usually would, so that representative levels were obtained. Information regarding year of construction, basement, crawl space, and building and roof materials was gathered from the Danish Building and Housing Register (Christensen, 2011). Information gathered from the Danish Building and Housing Register was used to make sure that homes represented typical rented accommodation in Denmark. In accordance with Danish recommendations for radon measurements in private homes, the simplest assessment of radon concentrations is based on direct integrated measurements (Rasmussen and Wraber, 2011a, Wraber and Rasmussen, 2011b), thus no indirect measurements (geological samples, soil gas measurements, external gamma radiation, etc.) were performed in this study.

DWELLINGS

Homes were either rented accommodation located in buildings privately owned by landlords or social housing owned by the Danish association of non-profit rented accommodation. Buildings were multi-occupant houses and single-family terraced houses. The buildings represented the building technique and commonly used building materials used in Denmark from 1850 until today. Buildings from this period can be grouped into three types:

- Multi-occupant house built between 1850 and 1920. The buildings were constructed with a solid brick wall founded on masonry foundations. Sometimes single natural stones might be included in the foundations and outer walls. Suspended floors were timber floor constructions. Suspended floors were horizontal partitions and included timber beams. They were traditionally constructed from the top with floor boards, clay infill, wooden boards, empty space, wooden boards and a layer of plaster on straw. The timber beams were usually of good quality with the dimensions approximately

200 mm by 200 mm, see Figure 1. Solid floor against the ground were made of concrete, asphalt or soil.

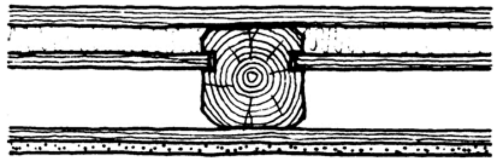

Figure 1. Suspended floors include from top floor boards, clay infill, wooden boards, empty space, wooden boards and a layer of plaster on straw.

- Multi-occupant house built between 1920 and 1960. The buildings were constructed with solid brick walls or cavity walls founded on cast-on-site concrete foundations. Suspended floors were timber floor constructions, see Figure 1 or reinforced concrete suspended floors cast on site. Solid floors against the ground were made of concrete.

- Multi-occupant house or single-family terraced house built in the period from 1960. The buildings were constructed with load-bearing concrete constructions as prefabricated elements above the ground. Foundations and load-bearing basement walls were made of concrete cast on site. Suspended floors were made of reinforced concrete usually as prefabricated concrete elements. Solid floors against the ground were of concrete cast on site.

EQUIPMENT

The detectors used were closed passive etched track detectors, made from CR39 plastic film placed inside an antistatic holder. Analysis were carried out by an ISO 17025 and ISO 14001 certified as well as EMAS (European Eco-Management and Audit Scheme) registered laboratory. Measurement methods are accredited according to standards of SWEDAC (Swedish board of Accreditation and Conformity Assessment) and accepted in 18 European countries by the European Cooperation for Accreditation of Laboratories (EAL).

RESULTS

Radon was measured for a median duration of 90 days (min–max: 60 – 194 days). A single representative indoor radon concentration for each home was calculated as the arithmetic average of the three measurements and used in all statistical analyses.

Table 1 shows the distribution of the determined mean year values of the radon concentration grouped according to floor level in intervals of 50 Bq/m^3. The minimum value was 1 Bq/m^3, the maximum value was 250 Bq/m^3. The standard variation was 38.3 Bq/m^3, the median value was 18 Bq/m^3 and the mean value was 30.7 Bq/m^3. The ratio of homes with a mean year value of the radon concentration ranging between 100 Bq/m^3 and 200 Bq/m^3 was 4.5%. The ratio of homes with a mean year value of the radon concentration exceeding 200 Bq/m^3 was 1.4%. The ratio of homes with a mean year value of the radon concentration exceeding 100 Bq/m^3 was 5.9%.

Table 2 shows the distribution of the determined mean year value of the radon concentration in homes, with a basement or a crawlspace as the lowest level facing the ground, grouped by floor level and in intervals of 50 Bq/m^3. The minimum value was 1 Bq/m^3, the maximum value was 206 Bq/m^3, the standard variation was 32.3 Bq/m^3, the median value was 17 Bq/m^3 and the mean value was 26.2 Bq/m^3.

Table 1. The number of homes grouped according to the determined mean year values of the radon concentration is shown by their location, as the floor number, and in intervals of 50 Bq/m^3.

	0-50	51-100	101-150	151-200	>200	Number of homes
Ground floor	58	18	7	3	3	88
1st Floor	50	0	0	0	0	51
2nd Floor	38	0	0	0	0	38
3rd Floor	30	0	0	0	0	30
4th Floor	6	0	0	0	0	6
5th Floor	8	0	0	0	0	8
Number of homes	190	18	7	3	3	221
Ratio in %	86.0	8.1	3.1	1.4	1.4	100

Table 2. The number of homes, grouped by the determined mean year value of the radon concentration shown by their location and in intervals of 50 Bq/m^3, in a building with a basement or a crawlspace at the lowest level facing the ground.

Location (floor number)	0-50	51-100	101-150	151-200	>200	Number of homes
Ground floor	42	9	6	2	1	60
1st Floor	43	0	0	0	0	43
2nd Floor	34	0	0	0	0	34
3rd Floor	28	0	0	0	0	28
4th Floor	5	0	0	0	0	5
5th Floor	6	0	0	0	0	6
Number of homes	158	9	6	2	1	176
Ratio in %	89.8	5.1	3.4	1.1	0.6	100

For homes in a building with a slab on ground in the accommodation on the lowest level facing the ground, the minimum value was 10 Bq/m^3, the maximum value was 250 Bq/m^3, the standard variation was 53 Bq/m^3, the median value was 33 Bq/m^3 and the mean value was 50 Bq/m^3.

Table 3 shows the distribution of the determined mean year value of the radon concentration in homes grouped in intervals of 50 Bq/m^3 for homes located on the ground floor in multi-occupant houses.

Table 3. The number of homes grouped by the determined mean year value of the radon concentration in intervals of 50 Bq/m3. Homes were located on the ground floor in multi-occupant houses.

	0-50	51-100	101-150	151-200	>200	Number of homes
Home over basement/crawlspace	42	5	0	0	0	47
Ratio i %	89.4	10.6	0	0	0	100
Home with floor on ground	9	7	0	0	0	16
Ratio in %	56.3	43.7	0	0	0	100

Figure 2 shows the mean year value of the radon concentration in homes measured in the winter of 2013/2014 and in the winter of 2014/2015. Results are shown for homes where the first measurements showed results exceeding the recommended radon level for homes. Homes were located in single-family terraced houses. The mean year value of the radon concentration was determined with an accuracy of 20 Bq/m³ to 40 Bq/m³.

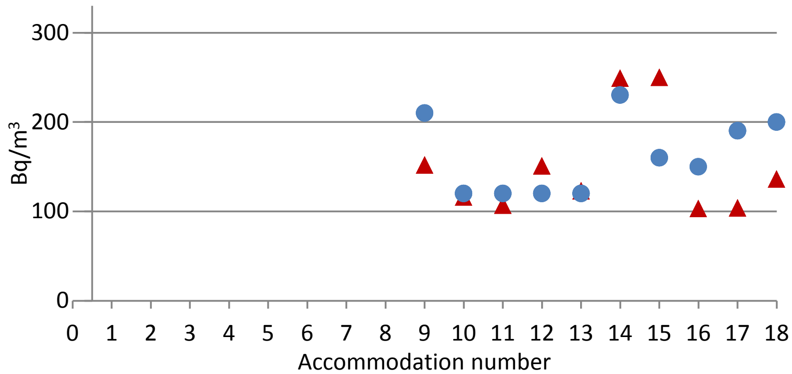

Figure 2. Mean year value of the radon concentration i homes measured in the winter of 2013/2014 (**Read ∆**) and again in the winter of 2014/2015 (**Blue o**). Each accommodation is given a number.

DISCUSSION

This study found a mean year value of the indoor radon level of 30.7 Bq/m³ ranging between 1 and 250 Bq/m³. In total, 5.9% (13 of the 221) homes had indoor radon levels exceeding 100 Bq/m³, all located in single-family terraced houses. The variable single-family terraced houses were statistically significant and explained 5.9% of the variation in indoor radon levels.

The mean year value of the radon level of 30.7 Bq/m³ is somewhat lower than the population-weighted average annual radon concentration of 59 Bq/m³ for all Danish homes (Andersen et al., 2001a, b). The population-weighted average annual radon concentration of 59 Bq/m³ was based on 1-year measurements in 3012 single-family homes and 101 multifamily (apartment buildings) in Denmark.

The present study found the indoor radon level exceeded 100 and 200 Bq/m³ in 10 (4.5%) and 3 (1.4%) homes, respectively. Approx. 75% of homes with indoor radon levels exceeding 100 Bq/m³ had levels between 100 and 200 Bq/m³ and 25% had indoor radon levels exceeding 200 Bq/m³. Significant differences in indoor radon levels were found in homes located in multi-occupant houses. The risk of indoor radon levels exceeding 100 Bq/m³ in homes in multi-occupant houses is very low, but if there is a risk, it is most likely to be found in the lowest accommodation in a building with a slab on ground. A risk of indoor radon levels exceeding 100 Bq/m³ was found in homes in single-family terraced houses.

The municipalities selected in the present study were previously characterised as having the highest levels of residential radon concentration indoors in Denmark (1–30% of homes with levels over 200 Bq/m³) (Andersen et al., 2001a). Measurements showed that the soil type was the main determinant of indoor radon levels (Andersen et al., 2001a, b). The present study did not include measuring radon levels in soil. The homes in this study were located on clayey/sandy to clayey soil, with 2–18% sand and gravel content (Andersen et al., 2001b; Greve and Breuning-Madsen, 1999), and although radon variation in these soils can be expected, this is not described at each specific home location.

The mean year value of the radon concentration in homes was measured in the winter of 2013/2014 and again in the winter of 2014/2015. Measurements were carried out twice in homes where the first measurements showed results exceeding the advised radon level for buildings of 100 Bq/m^3. These homes were all located in single-family terraced houses. Results from the first measuring period correspond with the results from the second measuring period. However, results show that the radon concentration indoors is affected by seasonal variations and the use of the home.

CONCLUSION

This study found a mean year value of the indoor radon level of 30.7 Bq/m^3 ranging between 1 and 250 Bq/m^3 in homes in rented accommodation. In total, 5.9% (13 of the 221) homes had indoor radon levels exceeding 100 Bq/m^3, all located in single-family terraced houses. Approx. 75% of homes exceeding 100 Bq/m^3 indoor radon level had levels between 100 and 200 Bq/m^3 and 25% had indoor radon levels exceeding 200 Bq/m^3. Significant differences in indoor radon levels were found in homes located in multi-occupant houses. The risk of indoor radon levels exceeding 100 Bq/m^3 in homes in multi-occupant houses is very low, but if there is a risk, it is most likely to be found in the lowest accommodation in a building with a slab on ground. A risk of indoor radon levels exceeding 100 Bq/m^3 was found in homes in single-family terraced houses.

ACKNOWLEDGEMENT

This study was supported by the Danish association of private landlords of multi-occupant houses and the Danish association of non-profit rented accommodation.

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