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An assessment of the effectiveness of UK building regulations for new homes in Radon Affected Areas

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ABSTRACT

Radon, a naturally occurring radioactive gas generated underground by radioactive decay of nuclides contained in certain types of rocks, can concentrate inside buildings, where it poses the second-largest risk factor for lung cancer, after smoking. The highest concentrations of domestic radon in the UK occur in the south-western counties of Devon and Cornwall, but certain areas in Northamptonshire and surrounding counties in the English Midlands also have high levels. It has been shown that it is possible both to reduce the radon concentrations in existing houses and to build new homes with appropriate protection. Since 1999, the UK's Building Regulations have specified that all new homes should be built with a combined radon-proof/damp-proof membrane plus, in Radon Affected Areas, a sump under the building. However, the building regulations do not require that the radon level is measured once the house is built and so there is little information on the effectiveness of these measures. Builders generally do not mention radon, and when asked, just confirm that their houses are built to current standards.

To better understand the efficacy or otherwise of the currently mandated radon-protection measures, a cross-sectional investigation was carried out in 26 new housing developments in high-radon areas in Northamptonshire. In a targeted mail-shot, 1056 householders were invited to apply for a free radon test; 124 replied (11.7%). In total, 94 pairs of detectors were returned (70.1% of responders), of which two were spoiled, giving a total of 92 results.

Following processing and seasonal correction, the arithmetic mean radon concentration in the target houses was 45% of the arithmetic mean radon concentration in existing houses in the postcode sectors where the houses were built and were approximately log-normally distributed. No results exceeded the UK Action Level of 200 Bq. m^{-3} but three were above the Target Level of 100 Bq. m^{-3}.

The results suggest that the radon-proof membranes in general ensure that radon concentrations in new homes constructed in accordance with the Building Regulations in Radon Affected Areas (RAAs) are satisfactorily low. However, there is a very small statistical probability that levels in a small number of homes will be close to or above the Action Level, particularly in areas of high radon potential. As a result, the Public Health England (PHE) recommendation for testing in the first year of occupation should be adopted as a legal requirement.

1. Introduction

Radon gas is the second most significant risk factor for lung cancer after tobacco smoking. Radon is a naturally occurring radioactive gas and has a variable distribution throughout the world, depending primarily on underlying geology. Significant concentrations exist in the built environment in some regions and case-control studies have demonstrated an increase in lung cancer in people with raised radon levels in their homes (AGIR, 2009). The risks from radon and tobacco smoking are considered to be multiplicative (Gray et al., 2009). As a result, an Action Level of 200 Bq. m^{-3} was established in the UK, above which house-holders are encouraged to take remedial action to reduce radon levels.

To provide protection for newly-built homes, standards have been introduced into the UK Building Regulations to ensure that new houses in Radon Affected Areas (RAAs) had precautions included at the time of construction. Interim guidance was first implemented in 1988 and, following field trials in Devon and Cornwall, protection against radon

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was added to the Building Regulations in 1992, and established in their current form in 2000. Current regulations require a suitable radon-proof membrane, of 1200 Gauge (300 μm thickness) polythene or equivalent, to be used as combined radon-protection and damp-course in new-build houses in RAAs. In addition, in areas of higher radon potential, where over 10% of existing houses have been found with raised radon levels, a sump is required to enable future implementation of pumped extraction of gas from below the ground floor if subsequently indicated by post-construction testing of indoor radon levels. However, routine post-construction testing of radon levels has not been specified in the UK. It should be noted that post-construction testing should be carried out when the building is occupied and heated. There has been no evaluation of these precautions in routine use since the initial field trials in the 1980s, apart from a modest case study by Groves-Kirkby et al. (2006) on a single housing estate in Northamptonshire in 1992.

The Radon Atlas of England and Wales (Miles et al., 2007; Rees et al., 2010) presents radon concentration data for RAAs for geographical and administrative areas ranging in size from county to postcode sector and estimates the percentage of homes exceeding the 200 Bq. m^{-3} Action Level (Radon Potential). Postcode sectors (ie NN12 3) are areas with mean populations of around 7,500, but with a significant variation. Rural postcode sectors cover a much larger area than urban postcode sectors. Fig. 1(a) indicates the location of Northamptonshire in Central England, while Fig. 1(b), plotted at postcode sector resolution, confirms that the County has a number of areas of high radon potential. Northamptonshire is situated largely on Jurassic bedrock (around 200 million years old) (Hains and Horton, 1969). The regions of highest radon production are associated with the Northamptonshire Sand Ironstone, which contains significant amounts of phosphorus and associated uranium underlain with phosphorus-rich pebbles, the Upper Lincolnshire Limestone, and their associated glacial sands and gravels (Sutherland and Sharman, 1996). In addition, Northamptonshire soils are relatively permeable, permitting significant soil-gas movement. On average, 7.1% of existing houses in Northamptonshire have radon levels over the Action Level, with some postcode sectors (NN8 1, NN6 8, NN14 1) exceeding 20%. In the last decade there has been significant building of new homes across the county.

2. Methods

To better understand the efficacy or otherwise of the currently mandated radon protection measures, a limited cross-sectional investigation was carried out. Using the Radon Atlas (Miles et al., 2007; Rees et al., 2010), housing estates built after 2005, and preferably after 2012 (i.e. in the last five years), in areas of high radon potential in Northamptonshire, were sought. In total, 26 estates built by a number of different contractors were identified. Overall, 84% of houses in the final dataset were built between 2014 and 2017. For each estate, specific addresses were identified using the UK Postcode Directory (Royal Mail Postcode and Address Finder). A total of 1056 householders were invited to apply for a free radon test. Invitations to individual householders to participate in the study were made by letter issued by the University of Northampton, addressed by house-number and postcode. Householders wishing to participate were invited to email a Northamptonshire radon measurement company[a] to request a free radon test and to provide information regarding the date the house was built. Householders identified themselves to the radon measurement company in accordance with their standard terms and conditions, and the radon measurement company provided their standard service free of charge. Householders' identities were not revealed to the University, which received only postcode and radon test information from the radon measurement company.

The standard UK methodology using 3-month exposures of etched track detectors – one in the living room and one in the bedroom – was used. The result was calculated by taking a weighted-average of the two readings, and seasonally corrected, as enumerated in Howarth and Miles (2008), to give an estimate of the mean annual radon concentration level in each house.

3. Results

The 1056 invitation letters were sent out in five mailshots (the first two being followed-up with reminders), resulting in a total of 124 responses, a response rate of 11.7%. This is summarised in Table 1.

From those 124 responses, 94 participants returned radon detectors (75.8% of responders; 8.9% of total), although, for two houses, only one of the two detectors yielded a measurement.

The coverage by postcode sector is shown in Table 2.

Radon measurements were carried out with start dates from October 2016 until April 2017. The weighted average data, without seasonal correction, ranged from 11 to 161 Bq. m^{-3}, with seven results exceeding the UK Target Level of 100 Bq. m^{-3}, while the seasonally corrected radon concentrations ranged from 8 to 129 Bq. m^{-3}. The results for all participants were below the UK Action Level of 200 Bq. m^{-3}. Only three seasonally corrected results exceeded the UK Target Level, being just inside the lower limit of the equivocal range around the Action Level, as shown in Fig. 2. There were no outliers. The results were approximately log-normally distributed, with arithmetic and geometric means of 40 Bq. m^{-3} and 34 Bq. m^{-3} respectively.

4. Discussion

As noted, none of the measured radon concentrations exceeded the UK Action Level of 200 Bq. m^{-3}, with just three, in the range 120–130 Bq. m^{-3}, exceeding the 100 Bq. m^{-3} UK Target Level. This provides strong evidence that the application of the current Building Regulations relating to radon protection has resulted in new houses in Northamptonshire generally having radon levels below the Action Level. The sample size is too small to conduct analysis by postcode, estate or year of build.

The results have an arithmetic mean that is 45% of the arithmetic mean of the radon levels in existing houses in the postcode sector areas where the houses were built. The lack of outliers in this dataset provides convincing evidence that no membrane failure or damage has occurred in any of the houses tested. It should be noted that it is not known whether any of the houses involved in this study have had any building works carried out which might affect the integrity of the radon-proof membrane.

The upstairs:downstairs ratios for this dataset, shown in Fig. 3, are similar to those previously found by Denman et al. (2007) in un-remediated existing houses in Northamptonshire, suggesting that any radon entering the houses is not generated by building materials. This is consistent with Gunby et al. (1993) who suggested that these sources are negligible in the UK, although these cannot be definitively discounted. The membrane specification has a very low, but finite, radon permeability which is consistent with the modest radon levels in some results and the three results over the Target Level.

Denman et al. (2016) noted that, when interpreting short-term radon measurements in homes with annual average radon levels above the Action Level, short-term radon variability, due to weather, occupancy and other factors, could potentially result in values close to, but below, the Action Level, and suggested a protocol for re-testing when these values were within a statistically-derived equivocal range bracketing the Action Level. According to the statistical analysis, for the radon potential of this dataset, 0.86% of results (approximately 1 in 120) would fall within the equivocal range around the Action Level. A retest is the only reliable way of resolving an equivocal result and,

[a] Radon Centres Ltd, Unit 10 Grove Farm, Grove Farm Lane, Moulton, Northampton NN3 7TG, UK.

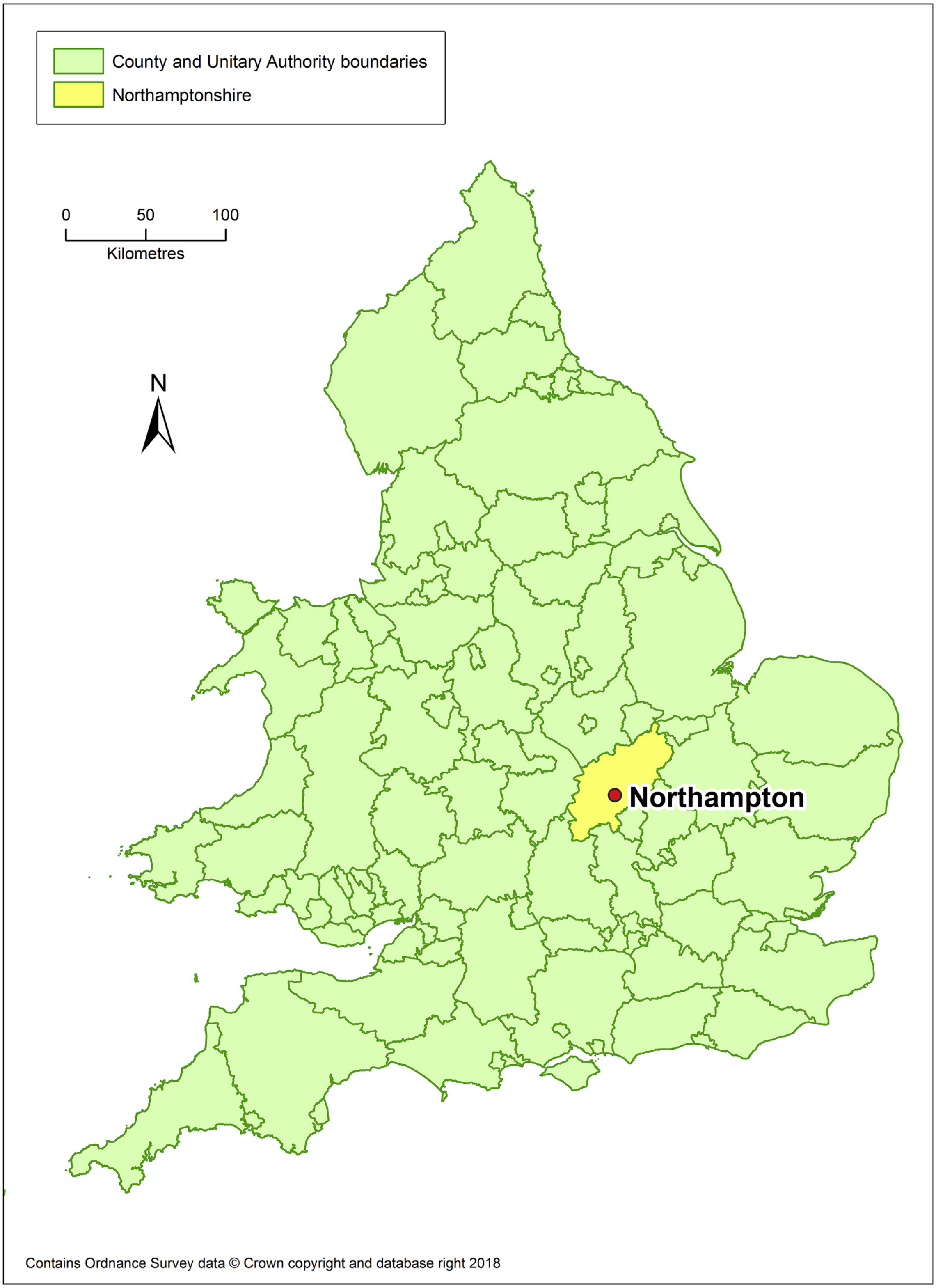

Fig. 1. Study Area. (a) Location of the county of Northamptonshire in Central England. (b) Study area, mapped at postcode-sector resolution, showing variation in radon potential (*Source;* Miles et al., 2007).

assuming that the first-test/retest combination accounts for the equivocal range, the retest result would then stand and, in approximate terms, half the retest results (approximately 1 in 240) would be expected to fall above the absolute Action Level.

The proportion of existing houses over the Action Level in postcode sectors where the new houses in this study were built ranged from 2.6% (NN11 8) to 22.5% (NN14 2) the maximum value for the county, with an average of around 12%. However, there are areas of the country with greater radon potential (e.g. North-East Oxfordshire, postcode sector OX15 6, where this proportion exceeds 40%, and Devon and Cornwall, where the proportion can reach 60%). In such areas of very high radon potential, there would be a significant probability that the

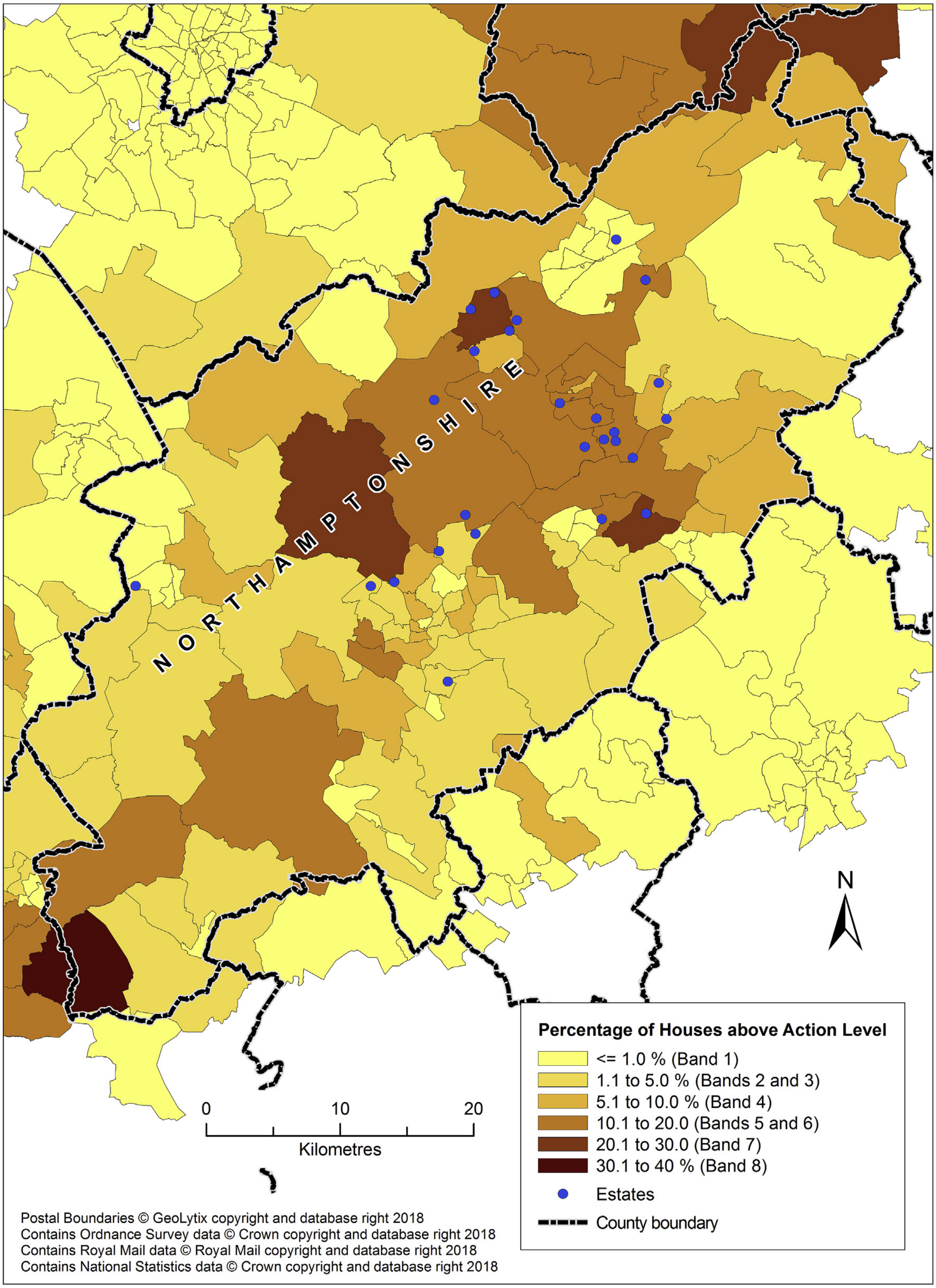

Fig. 1. (*continued*)

radon-proof membrane would not reduce the radon level sufficiently, and that a fan would need to be fitted to the sump to achieve sufficient protection. This, of course, would only be discovered if the householder were to test radon levels after occupying the house.

The results of this study are consistent with the earlier case study in the NN6 9 postcode sector in Northamptonshire, reported by Groves-Kirkby et al. (2006), where average radon levels in a set of homes constructed with radon-proof membranes were estimated to have been 64% of those of pre-existing houses of indeterminate construction in the same postcode sector, and are similar to studies in other countries. In Norway, average radon levels in newly-built detached houses were 53% of those in existing houses (Finne et al., 2018), while in Finland, Arvela et al. (2012) showed that average radon levels for houses built from 2006 to 2008 were 67% of the levels in those built from 2000 to 2005,

Table 1
Mailshot response.

Mailshot	MS1	MS2	MS3	MS4	MS5	Total
First	158	264	110	435	89	1056
Reminder	133	173	–	–	–	
Response 1	18	28	16	44	6	112
Response 2	6	6	–	–	–	12
Total Response	24	34	16	44	6	124
Response Rate	15.2%	12.9%	14.5%	10.1%	6.7%	11.7%

Table 2
Breakdown of mailshot coverage by postcode.

Postcode Sector	Sent	Returned	Percentage of Existing Houses Above Action Level 4
NN11 8	2	2	2.6%
NN14 1	99	1	16.4%
NN14 2	161	16	22.5%
NN14 4	24	5	9.6%
NN14 6	50	5	7.3%
NN15 5	150	18	14.3%
NN15 6	29	1	10.9%
NN15 7	35	4	15.0%
NN17 5	18	3	4.0%
NN2 8	68	5	7.3%
NN3 7	59	4	2.8%
NN4 6	32	4	4.5%
NN5 6	166	17	2.7%
NN6 9	118	16	16.9%
NN8 1	20	2	22.2%
NN8 4	25	1	16.3%
Total	**1056**	**124**	

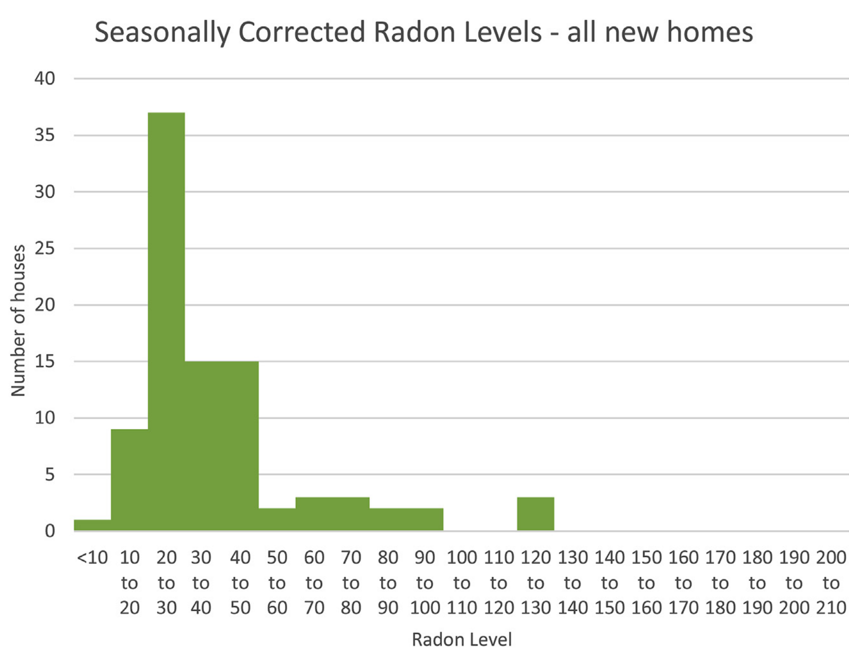

Fig. 2. Distribution of Seasonally-Corrected Radon Levels in the study sample.

prior to building regulations for radon reduction being introduced. In Ireland, where the Building Regulations are identical to those in the UK, Long and Fenton (2012) noted an average reduction of 50% in local authority houses with radon-proof membranes, but noted that a "number of houses exceeding the reference level shows the importance of a radon measurement once a new house is occupied."

The low response rate by householders to this project, which is disappointing but not unexpected based on reported evidence from comparable surveys such as the Radon Equity Audit of Zhang et al. (2011) suggests that assessing radon risk is not a high priority for new householders, who are perhaps reassured by the inclusion by the builders of membrane (and sump) to the required standard.

5. Conclusions

Current UK Building Regulations relating to the provision of radon protection ensure that radon levels in new houses in the RAAs assessed in Northamptonshire are below the UK Action Level, are lower than those in houses built without radon protection measures, and the reduction is similar to those found in other countries.

However, the study shows a low but definable risk that a small proportion of new houses in areas of high radon potential would be expected to exceed the current Action Level. With the large number of houses being built, a formal programme of radon testing would have a clear environmental health value in areas of high radon potential, for postcode sectors with greater than 20% of existing houses over the Action Level.

Recently, PHE have recommended that radon levels in new houses in RAAs should be tested in the first year of occupation. The present study shows a low, but quantifiable, risk that radon levels will exceed the Action Level in any RAA, and therefore supports this recommendation.

This study also suggests that there is little knowledge or enthusiasm amongst householders about the risks of radon, or that new homeowners have other priorities. Raising public awareness of the risks of radon remains a challenge in the UK.

Funding

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.

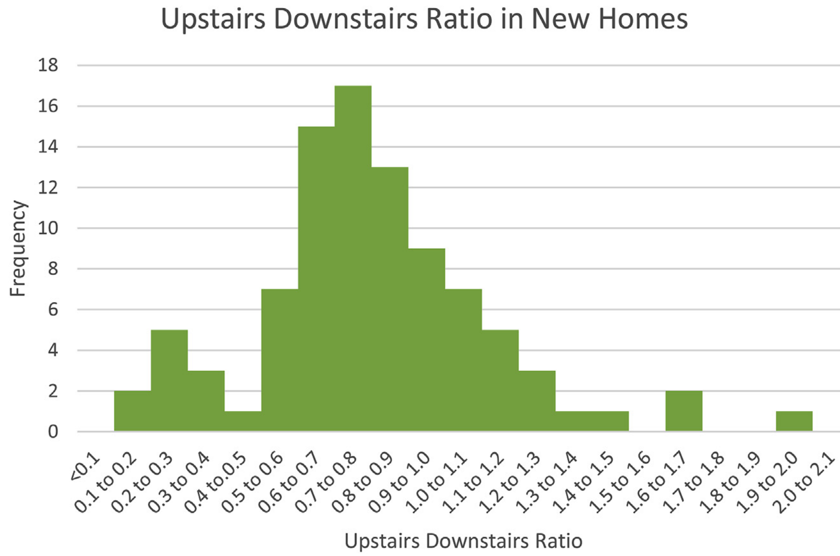

Fig. 3. Distribution of upstairs:downstairs ratio of detector results.

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