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IM REGIERUNGSPRÄSIDIUM STUTT GART



# Newsletter

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## Radon and health

### Editorial

#### Residential indoor radon: where are we now?

Today, radon, a colourless and odourless radioactive gas which seeps into buildings from the ground on which they are built, is recognized as one of several pollutants that pose health risks from indoor air exposure. A clear causal relationship was established in the 1950s between occupational exposure of miners to radon and lung cancer, prompting the classification of radon as carcinogenic to humans by WHO's International Agency for Research on Cancer (IARC) in 1988. Since the 1980s, a large number of studies have examined the relationship between indoor radon and lung cancer in the general population. By pooling these studies, it became clear in 2005 that radon increases the risk of lung cancer in the general population at concentrations found in ordinary homes [1-3].

That same year, WHO established the International Radon Project to support Member States in their activities targeting radon, leading to the landmark publication *WHO Handbook on Indoor Radon - A Public Health Perspective* in 2009 [4]. Since then, the topic of radon has been incorporated in a number of other WHO documents (WHO Guidelines for Indoor Air Quality on *Dampness and Mould* [5] and on *Selected Pollutants* [6]), Guidelines for Drinking-water Quality [7] and an IARC monograph on Radiation [8]).

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Since the evidence is now clear that radon is responsible for a portion of lung cancer cases, the focus over the past few years has shifted to managing the risk from radon. Facing an excellent opportunity for primary prevention, the international radiation protection community has been active on this issue. In particular, international requirements on radon in both dwellings and workplaces have, for the first time, been included in the latest edition of the IAEA General Safety Requirements Part 3 [9] (co-sponsored by eight international organizations, including WHO).

At the European level, the European Union Council Directive 2013/59/Euratom [10], also known as the Basic Safety Standards (BSS) Directive, requires the establishment of a national radon action plan addressing long-term risks from radon in buildings and workplaces for any source of radon. It is expected that

transposition (by 6 February 2018) and implementation of the new BSS Directive, and in particular its requirements on indoor radon, will pose a major challenge for national legislators and regulators in the coming years. For radon in dwellings, the European Directive includes provisions requiring that information is provided about radon at national level, that existing dwellings with radon concentrations above the reference level are identified, and that homeowners are encouraged to introduce mitigation measures. In addition, specific requirements in national building codes have been introduced that are intended to prevent radon ingress in new buildings. Member States of the European Union will need to define national reference levels for indoor radon exposure in both dwellings and in workplaces at or below 300 Bq/m<sup>3</sup>.

Radon, however, is only one of several sources of indoor air pollution, the nature of which varies by geography, climate, lifestyle and housing characteristics. Indoor air pollution of all causes is thought to contribute to 4.3 million deaths per year - the greatest environmental health risk in the world today. In a number of countries, household air pollution caused by the incomplete combustion of fuel in low-efficiency stoves and lamps used for cooking, space heating and lighting represents a sizeable burden of disease, and requires specific interventions as described in the WHO Guidelines for Indoor Air Quality on *Household Fuel Combustion* [11].

The sixty-eighth World Health Assembly, the decision-making body of the WHO, adopted a resolution on Health and the Environment: Addressing the health impact of air pollution in May 2015 [12]. This resolution, endorsed by 194 Member States, stated the need to redouble national efforts to protect populations from the health risks posed by air pollution, urged Member States to raise public and stakeholder awareness of these risks, guide preventive measures and sponsor research on the local causes of air pollution and the epidemiology of its health impact.

In an era when the importance of greenhouse gases and climate change are recognized, it becomes crucial to strike a balance ) between the demands for clean indoor air and energy conservation. In a view to improve energy efficiency in dwellings - with a long-term goal of

meeting targets set in the UN Sustainable Development Goals, and in particular Goal 3 (on health) and Goal 7 (on affordable, reliable, sustainable and modern energy for all) - people are insulating their homes to offset outdoor temperature changes and to help save energy by reducing the need for heating and cooling. These insulation measures can reduce ventilation, trapping harmful pollutants (such as radon) indoors, potentially impacting the health of the occupants. A number of countries, such as the United States Environmental Protection Agency [13], are now recognizing this potential challenge and highlighting solutions.

In this issue of the newsletter, Maria Schnelzer summarizes the health effects of radon in homes, and reviews the epidemiological data that help quantify the risks among people in residential dwellings and miners, and highlights the specific additive risk for lung cancer among smokers. Jonathon Taylor and colleagues discuss the situation in England, where extensive radon mapping has been done, and specific Radon Affected Areas defined. Both monitoring and modelling studies have been performed, providing data and tools that can be used to predict future radon exposures under a range of different mitigation scenarios. Finally, the article by Bernard Collignan discusses the importance of including ventilation planning in any thermal retrofit project intended to conserve energy, and describes the need to perform radon measurements before and after retrofitting, especially in radon prone areas.

*Dr Emilie van Deventer, Team Leader of the Radiation Programme at the World Health Organization, Geneva, Switzerland*  
*E-Mail: [vandeventere@who.int](mailto:vandeventere@who.int)*

## References

- [1] Darby S et al. (2005). Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. *BMJ*, 330(7485):223-227.
- [2] Lubin JH et al. (2005). Adjusting Lung Cancer Risks for Temporal and Spatial Variations in Radon Concentration in Dwellings in Gansu Province, China. *Radiat. Res*, 163:571-579.

- [3] Krewski D et al. (2005). Residential Radon and Risk of Lung Cancer: A Combined Analysis of 7 North American Case-Control Studies. *Epidemiology*, 16:137-145.
- [4] World Health Organization (2009). WHO Handbook on Indoor Radon – A Public Health Perspective, Geneva.
- [5] World Health Organization (2009). WHO guidelines for indoor air quality: Dampness and Mould, Copenhagen.
- [6] World Health Organization (2010). WHO guidelines for indoor air quality: Selected pollutants, Copenhagen.
- [7] World Health Organization (2011). Guidelines for Drinking-water Quality, Geneva.
- [8] International Agency for Research on Cancer (2012). Radiation. (IARC Monographs on the evaluation of carcinogenic risks to humans, Vol. 100D), IARC, Lyon.
- [9] International Atomic Energy Agency (2014). Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, General Safety Requirements, IAEA Safety Standards Series No. GSR Part 3, Vienna.
- [10] European Union (2014). European Council Directive 2013/59/Euratom on basic safety standards for protection against the dangers arising from exposure to ionising radiation and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. OJ of the EU. L13; 57: 1–73.
- [11] World Health Organization (2014). WHO guidelines for indoor air quality: household fuel combustion, Geneva.
- [12] World Health Organization (2015). Health and the Environment: Addressing the health impact of air pollution, Resolution A68/A/CONF./2 Rev.1, Geneva.
- [13] United States Environmental Protection Agency. Energy, Weatherization and Indoor Air Quality, <https://www.epa.gov/indoor-air-quality-iaq/energy-weatherization-and-indoor-air-quality> (accessed 11 December 2017)
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## Health effects of radon in homes

*Dr Maria Schnelzer, Federal Office for Radiation Protection, Department of Radiation Protection and Health, Neuherberg, Germany; E-Mail: [mschnelzer@bfs.de](mailto:mschnelzer@bfs.de)*

Radon gas is the most important natural source of human exposure to ionizing radiation. It is a naturally occurring radioactive gas, which is emitted in varying amounts in rocks and soils all over the world. In the open air it is quickly diluted to low concentrations, but in buildings, mines, or caves it can reach high concentrations. The gas itself is inhaled and mostly exhaled again, but its short-lived decay products ( $^{218}\text{Po}$  and  $^{214}\text{Po}$ ) are deposited in the lung. Thus the lung receives the highest dose when an individual is exposed to radon and its decay products. However, the extrathoracic airways and the skin may also receive appreciable doses (Kendall & Smith 2002).

It is well established that radon can cause lung cancer. Already in 1988 the International Agency for Research on Cancer (IARC) classified radon as a human carcinogen. First evidence for an increased mortality from lung cancer came from epidemiological studies among underground miners. Later studies on the general population have provided convincing evidence that long-term residential radon exposure also increases the risk of lung cancer. Up to now, other health effects of radon have not been consistently demonstrated.

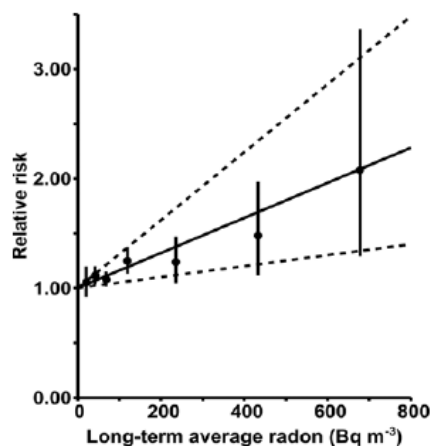
### Lung cancer risk

#### *Residential radon studies*

The association between residential radon and the risk of lung cancer was investigated in a series of case-control studies. In these studies, the exposure to radon and its decay products was assessed retrospectively by measuring radon in the current and previously occupied homes of all study participants (lung cancer cases and controls). Moreover, detailed information on smoking history and other risk factors for lung cancer was gathered. Although the majority of the studies showed a positive association between radon exposure and the risk of lung cancer, the risk coefficients in individual studies often did not reach statistical significance and there was substantial variation

in the estimated radon-induced risks. Therefore, several pooled analyses were performed (Darby et al. 2005, 2006; Krewski et al. 2005, 2006; Lubin et al. 2004).

The largest of these pooled analyses is the European pooling study (Darby et al. 2005, 2006), which includes 7,148 cases and 14,208 controls from 13 European indoor radon case-controls studies on lung cancer. For each study participant individual exposure was calculated as time-weighted average of radon concentrations in all homes occupied over the past 5 - 34 years. Additionally, the random year-to-year variability in measured radon concentration in the homes was taken into account. This analysis showed a statistically significant approximately linear increase in lung cancer risk (excess relative risk, ERR) of 16% per 100 Bq/m<sup>3</sup> (95% CI: 5% - 31%) (see Figure 1). This proportionate increase did not differ significantly by study, age, sex or smoking status. There was no evidence of a threshold below which there was no increase in risk. Even when the analysis was restricted to individuals with radon concentrations below 200 Bq/m<sup>3</sup>, the exposure-response relationship remained statistically significant.



*Figure 1: Relative risk of lung cancer versus long term average residential radon concentration in the European pooling study, based on Darby et al. (2005). Relative risks and 95% confidence intervals are shown for categorical analyses and also best fitting straight line. Risks are relative to that of 0 Bq/m<sup>3</sup>.*

#### *Underground miner studies*

Radon-induced health risks had first been investigated in studies on underground miners. However, extrapolating from studies on miners

to obtain an assessment of the risk of lung cancer from radon in homes is associated with substantial uncertainty. Reasons for this uncertainty are for example: exposures in mines were usually much higher than those in homes, miners were exposed to additional risk factors (e. g. arsenic) and cohorts of underground miners include virtually only adult men. Nevertheless an important advantage of miner studies compared to residential radon studies is the possibility to investigate the factors modifying the exposure-risk relationship, such as age at exposure, time since exposure and attained age. In a joint analysis of eleven underground miner studies conducted by the BEIR VI committee (National Research Council 1999) it was demonstrated that the excess relative risk (ERR) of lung cancer per unit of radon exposure decreases with increasing time since exposure, increasing attained age and increasing exposure rate. This analysis included a total of 60,000 miners in Europe, North America, Asia and Australia, among whom 2,600 deaths from lung cancer had occurred.

This pattern of effect modification was recently confirmed in a large cohort of uranium miners from the former German Democratic Republic (Kreuzer et al. 2017a, Walsh et al. 2015), which was not included in the above mentioned joint analysis. This independent replication of results is particularly interesting as this homogenous cohort, including approximately 59,000 male uranium miners (among them 3,942 deaths from lung cancer), is nearly as large as the eleven cohorts available to the BEIR VI committee combined. Moreover, a statistically significant increased radon-related lung cancer risk was observed in analyses restricted to low levels of radon exposure and low exposure rates in this cohort (Kreuzer et al. 2015, 2017a) and these risk estimates are compatible with those from residential radon studies and other miner studies restricted to low exposures (Rage et al. 2017).

### *Smoking and radon exposure*

Tobacco smoke is the most important risk factor for lung cancer. Therefore it is important to consider how smoking might modify lung cancer risks due to radon. In the pooled residential radon study as well as in the miner studies it was found that radon increases the

lung cancer risk in current smokers, ex-smokers and also in never smokers. The relative increase in lung cancer risk per unit of radon exposure tends to be larger in never smokers compared to current smokers or ex-smokers, but this difference is not statistically significant in any of the studies. As background lung cancer rates are much higher for smokers or ex-smokers than for never smokers, the absolute increase in mortality rate per unit of radon exposure will be much higher for smokers and ex-smokers than for never smokers.

### *Lifetime risk and attributable risk*

From the above mentioned epidemiological studies information on the relative increase in lung cancer risk per unit of radon exposure (ERR) is derived. This information together with some additional information and certain assumptions allows to assess the lifetime risk related to a specific concentration of radon and the fraction of lung cancer deaths attributable to residential radon exposure in a country.

Hunter et al. (2015) calculated lifetime risks of lung cancer mortality up to 75 years of age due to radon exposure for both male and female continuing, ex- and never smokers, based on various risk models and exposure scenarios. Specifically, they calculated the probability that an individual will die from lung cancer as a consequence of a given annual radon exposure received from age 30 years to age 75 years (risk of exposure-induced death, REID). For their calculations they used models from the European pooling study (Darby et al. 2005, 2006), from the BEIR VI joint analysis (National Research Council 1999), from a joint analysis of European miner cohorts (Tirmarche et al. 2009) and from joint analyses of case-control studies nested in these cohort studies (Hunter et al. 2013; Leuraud et al. 2011). Using the European residential radon model they estimated an excess lifetime risk of radon-induced lung cancer death of 8.5% for a male continuing smoker exposed to a radon concentration of 600 Bq/m<sup>3</sup> from age 30 up to age 75 years (see Table 1). That is to say, according to their results it would be expected that among 100 male continuing smokers exposed to a radon concentration of 600 Bq/m<sup>3</sup> from age 30 to age 75 years 8.5 persons would die from lung cancer due to this radon exposure. According to

Hunter and colleagues, reduction of the radon exposure to 100 Bq/m<sup>3</sup> at age 50 years reduces the lifetime risk of this person by 30% to 5.9%. Combining radon mitigation and quitting smoking, both at age 50, would reduce the lifetime risk by 70% to 2.7%.

Lifetime risks calculated by Hunter and colleagues vary between risk models by around a factor of 2, with the BEIR VI model giving the highest risk estimates and the European residential radon model providing the lowest risk estimates. However, the effect of radon mitigation on lifetime risks varies only slightly with the risk model used. Hunter and colleagues found that the lifetime risk of radon-induced lung cancer is substantially higher for continuing smokers and ex-smokers compared to never smokers. Nevertheless the percentage of risk reduction associated with radon mitigation is generally comparable for never smokers, ex-smokers and continuing smokers. Neither lifetime risks nor percentage of risk reduction due to radon mitigation differed greatly between males and females.

In a recent review Ajrouche et al. (2017) identified studies that have assessed the fraction of lung cancer deaths attributable to indoor radon exposure. They included 16 studies from 12 countries in their review. In these countries, the arithmetic mean of the indoor radon concentrations ranged from 21 Bq/m<sup>3</sup> (UK) to 110 Bq/m<sup>3</sup> (Sweden). Ajrouche and colleagues recalculated the attributable fractions in the studies using the joint European residential radon model with a coefficient of 16% per 100 Bq/m<sup>3</sup>. According to their analysis the fraction of lung cancers attributable to

indoor radon exposure ranges from 3% in the United Kingdom to 17% in Romania. Differences in the attributable fractions across countries are mainly due to the different levels of indoor radon concentrations in the different countries. The number of lung cancer deaths attributed to indoor radon exposure per year ranges from 150 in the Netherlands to 21,800 in the USA. In Germany the average indoor radon concentration is approximately 49 Bq/m<sup>3</sup> and the attributable fraction is 5%, resulting in an estimated number of radon-induced lung cancer deaths of 1,900 per year (Menzler et al. 2008).

### Other health effects

Other organs than the lung are also affected by exposure to radon and its short-lived decay products, particularly the extrathoracic airways and the skin (Kendall & Smith 2002). However, to date no strong evidence has been found that residential radon exposure causes other diseases than lung cancer. In several studies associations between indoor radon concentration and risks for different diseases have been observed. However, most of these studies were ecological studies examining the correlation between average radon concentration and average disease rate in different geographical areas. These studies often provide biased and misleading estimates of radon-induced risk, because they cannot control adequately for other potential risk factors. To date none of these associations has been confirmed in a high-quality case-control or cohort study.

The evidence for radon-induced increases in

*Table 1: Estimated excess lifetime risk of radon-induced lung cancer death (REID) in males and females up to age 75 years from age 30 years, based on lifetime exposure constant at various radon concentrations using the European case-control residential model assuming a multiplicative model for radon and smoking (according to Hunter et al. 2015, Table 1).*

| Radon concentration (Bq/m <sup>3</sup> ) | Lifetime risk of lung cancer death from radon exposure in homes (%) |                       |              |                   |                       |              |
|--|---|-----------------------|--------------|-------------------|-----------------------|--------------|
|  | Males   |                       |              | Females           |                       |              |
|  | Continuing smoker   | Ex-smoker from age 50 | Never smoker | Continuing smoker | Ex-smoker from age 50 | Never smoker |
| 50                                       | 0.76  | 0.34                  | 0.06         | 0.59              | 0.29                  | 0.06         |
| 100                                      | 1.51  | 0.69                  | 0.10         | 1.18              | 0.58                  | 0.13         |
| 200                                      | 2.98  | 1.38                  | 0.19         | 2.33              | 1.16                  | 0.25         |
| 400                                      | 5.82  | 2.72                  | 0.39         | 4.59              | 2.30                  | 0.50         |
| 600                                      | 8.53  | 4.05                  | 0.58         | 6.79              | 3.43                  | 0.75         |

the risk of cancers other than lung cancer has also been examined in several underground miner studies. Currently the pattern of results is not consistent, i. e. different associations have been found in different cohorts. In the German cohort there is suggestive evidence for an association between radon exposure and mortality from all cancers other than lung cancer combined, from cancer of the extrathoracic airways (Walsh et al. 2015) and from certain leukemia subtypes (Kreuzer et al. 2017b). However, risks are much smaller than lung cancer risks and the influence of chance and confounding from uncontrolled risk factors, e. g. alcohol, cannot be excluded.

Overall, to date there is no conclusive evidence for radon-induced health effects other than lung cancer. A joint analysis of underground miner cohorts from five countries (Canada, Czech Republic, France, Germany and USA) with nearly 130.000 workers is ongoing. Results from this collaborative project might contribute to a better understanding of radon risks.

## Conclusion

Key messages on the health effects from the WHO Handbook on Radon (WHO 2009) are still valid, particularly:

- Epidemiological studies confirm that radon in homes increases the risk of lung cancer in the general population. Other health effects of radon have not consistently been demonstrated.
- Radon is the second most important cause of lung cancer after smoking in many countries. Radon is much more likely to cause lung cancer in people who smoke, or who have smoked in the past, than in lifelong non-smokers. However, it is the primary cause of lung cancer among people who have never smoked.
- There is no known threshold concentration below which radon exposure presents no risk. Even low concentrations of radon can result in a small increase in the risk of lung cancer.
- The majority of radon-induced lung cancers are caused by low and moderate radon concentrations rather than by high radon concentrations, because in general less

people are exposed to high indoor radon concentrations.

## References

- Ajrrouche R, Ielsch G, Clero E, et al. Quantitative health risk assessment of indoor radon: a systematic review. *Radiat Prot Dosimetry* 2017; 1-9.
- Darby S, Hill D, Auvinen A, et al. Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. *BMJ* 2005; 330(7485): 223-228.
- Darby S, Hill D, Deo H, et al. Residential radon and lung cancer – detailed results of a collaborative analysis of individual data on 7148 persons with lung cancer and 14,208 persons without lung cancer from 13 epidemiologic studies in Europe. *Scand J Work Environ Health* 2006; 32 Suppl 1: 1-83.
- Hunter N, Muirhead CR, Tomasek L, et al. Joint analysis of three European nested case-control studies of lung cancer among radon exposed miners: exposure restricted to below 300 WLM. *Health Phys* 2013; 104(3): 282-292.
- Hunter N, Muirhead CR, F. Bochicchio F, et al. Calculation of lifetime lung cancer risks associated with radon exposure, based on various models and exposure scenarios. *J Radiol Prot* 2015; 35(3): 539-555.
- IARC (1988). Man-made mineral fibres and radon. IARC Monographs on the evaluation of carcinogenic risks to humans. 43. Lyon, International Agency for Research on Cancer.
- Kendall GM, Smith TJ. Doses to organs and tissues from radon and its decay products. *Journal of Radiological Protection* 2002; 22(4): 389-406.
- Kreuzer M, Fenske N, Schnelzer M, et al. Lung cancer risk at low radon exposure rates in German uranium miners. *Br J Cancer* 2015; 113(9): 1367-1369.
- Kreuzer M, Sobotzki C, Schnelzer M, et al. Factors modifying the radon-related lung cancer risk at low exposures and exposure rates among German uranium miners. *Radiat Res.* 2017a, Dec 7. .doi: 10.1667/RR14889.1. [Epub ahead of print].
- Kreuzer M, Sobotzki C, Fenske N et al. Leukaemia mortality and low-dose ionising radiation in the WISMUT uranium miner cohort (1946-2013). *Occup Environ Med* 2017b, 74(4): 252-258.
- Krewski D, Lubin JH, Zielinski JM, et al. Residential radon and risk of lung cancer: a combined analysis of 7 North American case-control studies. *Epidemiology* 2005; 16(2): 137-145.

Krewski D, Lubin JH, Zielinski JM, et al. A combined analysis of North American case-control studies of residential radon and lung cancer. *J Toxicol Environ Health A* 2006; 69(7): 533-597.

Leuraud K, Schnelzer M, Tomasek L, et al. Radon, smoking and lung cancer risk: results of a joint analysis of three European case-control studies among uranium miners. *Radiat Res* 2011; 176(3): 375-387.

Lubin JH, Wang ZY, Boice JD, et al. Risk of lung cancer and residential radon in China: pooled results of two studies. *Int J Cancer* 2004; 109(1): 132-137.

Menzler S, Piller G, Gruson M, et al. Population attributable fraction for lung cancer due to residential radon in Switzerland and Germany. *Health Phys* 2008; 95(2): 179-189.

National Research Council (1999). Committee on health risks of exposures to radon. BEIR VI: Health effects of exposure to radon. National Academy Press, Washington DC.

Rage E, Caer-Lorho S, Laurier D. Low radon exposure and mortality among Jouac uranium miners: an update of the French cohort (1946-2007). *J Radiol Prot.* 2017, Sep 19. doi: 10.1088/1361-6498/aa8d97. [Epub ahead of print]

Tirmarche M, Laurier D, Bochicchio F, et al. (2009). Alpha-risk – quantification of cancer and non-cancer risks associated with multiple chronic radiation exposures: epidemiologic studies, organ dose calculation and risk assessment. Final Scientific Report Project no. 516483. European Commission ([www.doremi-noe.net/pdf/final\\_report/ALPHA-RISK%20Final%20Activity%20Report-Publishable%2021122009\\_V1%202.pdf](http://www.doremi-noe.net/pdf/final_report/ALPHA-RISK%20Final%20Activity%20Report-Publishable%2021122009_V1%202.pdf))

Walsh L, Grosche B, Schnelzer M, et al. A review of the results from the German Wismut uranium miners cohort. *Radiat Prot Dosimetry* 2015; 164(1-2): 147-153.

WHO (2009). WHO Handbook on Indoor Radon 2009, World Health Organization, Geneva.



## Radon and housing research in England and Wales

Jonathon Taylor<sup>1</sup>, Phil Symonds<sup>1</sup>, Clive Shrubsole<sup>1</sup>, James Milner<sup>2</sup>, Ian Hamilton<sup>3</sup>, and Mike Davies<sup>1</sup>

<sup>1</sup>UCL Institute for Environmental Design and Engineering, UCL, London, UK

<sup>2</sup>London School of Hygiene and Tropical Medicine, London, UK

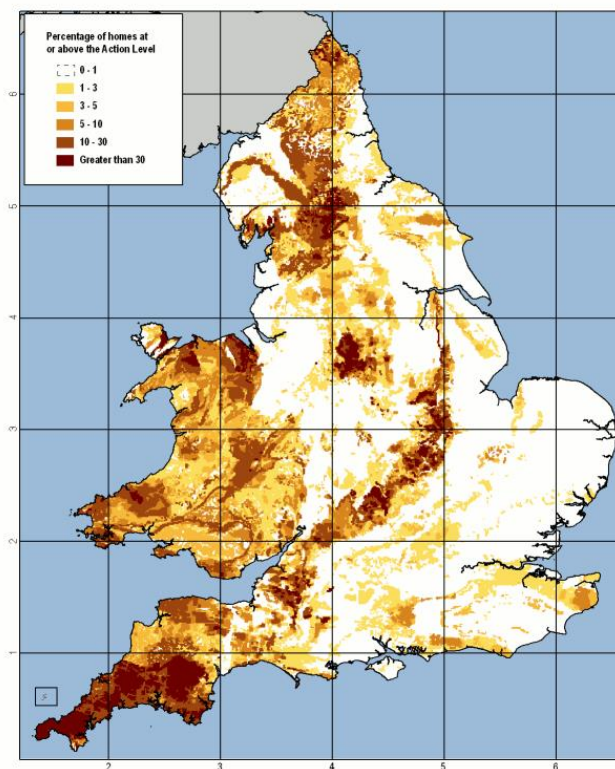
<sup>3</sup>UCL Energy Institute, UCL, London, UK

E-Mail: [j.g.taylor@ucl.ac.uk](mailto:j.g.taylor@ucl.ac.uk)

Radon is a tasteless, odourless and invisible radioactive gas and is the second largest contributor to lung cancer internationally behind smoking. It is carcinogenic, responsible for around 1,100 lung cancer cases annually (PHE, 2009) in the UK. Buildings are an important modifier of radon exposure due to the large proportion of time (~90%) the UK population typically spends indoors. This article reviews existing and ongoing work and explores the association between housing, radon, and health in England, under current and future housing stock scenarios.

The UK has, on average, relatively low levels of radon, with a country-wide average concentration in homes of around 20 Bq/m<sup>3</sup>, in comparison to concentrations of around 50 in Germany, 66 in France, and 108 Bq/m<sup>3</sup> in Sweden (JRC, 2005). Despite the low average concentration, local exposures can be high. Variations in exposure can be attributed to the underlying geology, climate, housing characteristics, and occupant behaviours. The main driver of radon levels is ground type with areas rich in granite rock (such as the South West of England – see Figure 1) often containing higher concentrations of Uranium in the soil. Uranium radioactively decays to radon which can seep in to the home through the floor or cracks in walls (See Figure 2).

Whilst radon rapidly dissipates in the outdoor environment, removal of indoor radon is dependent on building ventilation rates. However, ventilation alone may not decrease radon concentrations as reductions in indoor air pressure caused by ventilation systems or window opening may draw more radon from the underlying soil.



Overall map of radon Affected Areas in England and Wales (axis numbers are the 100-km coordinates of the national grid)  
© Crown copyright. All rights reserved. Health Protection Agency [100018960] [2007]  
Radon potential classification © Health Protection Agency and British Geological Survey copyright (2007)

Figure 1: Percentage of homes above radon action level of 200 Bq/m<sup>3</sup> (source: PHE).

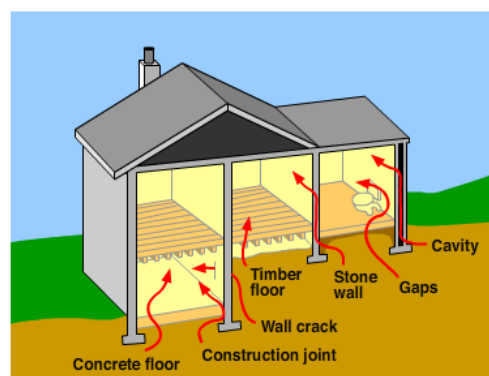


Figure 2: The means in which radon can seep in to the home (source: PHE).

As people typically spend the majority of their time indoors – particularly at home – housing is an important source of exposure. Protective membranes, underfloor or positive ventilation and radon sumps are some of the active measures which can be made in order to reduce exposure. The first requirements for radon protection were introduced in Devon and Cornwall in 1988, which have applied to approximately 39,000 of homes built. In 1999,

radon mitigation guidance was revised to include areas throughout England and Wales, but protection is only mandatory in areas of high risk (where greater than 3% of homes exceed 200 Bq/m<sup>3</sup>). In total, around 89% of the English housing stock was constructed prior to radon guidance in their area (VOA/ONS, 2015).

The English housing stock is amongst the most energy inefficient in Northern Europe (Lowe and Oreszczyn, 2008), and significant improvements in energy efficiency are required to help meet carbon mitigation targets set out in the Paris Climate Change Agreement. With the slow turnover of housing - 70% of the existing buildings are expected to exist in 2080 (Palmer et al., 2011) - it is necessary to focus on retrofitting existing dwellings such as increasing the efficiency of heating systems, increasing fabric insulation levels, and reducing heat losses through fabric airtightening. As housing in England and Wales is typically naturally-ventilated and for the most part constructed without radon preventative measures, retrofits designed to reduce ventilative heat losses may lead to increases in indoor air pollutants such as radon. Consequently, there has been renewed interest in quantifying the changes in radon exposure and subsequent health risks under different energy efficiency adaptation scenarios.

### Monitoring studies

Over the years, the risk of radon in the English and Welsh housing stocks has been investigated by a number of large measurement campaigns in homes across the country. The first large-scale survey (2,093 properties) was performed in the 1980's (Wrixon and Great Britain. National Radiological Protection Board., 1988), where houses were randomly selected in order to form a representative sample of the UK housing stock. The distribution of radon concentrations was found to be skewed (log-normal), with a mean of 20 Bq/m<sup>3</sup> and a median of 10 Bq/m<sup>3</sup>. Following this, a number of national surveys have been undertaken to characterise the distribution of indoor radon concentrations and identify dwellings that exceed the 200 Bq/m<sup>3</sup> action level recommended by Public Health England (PHE).

There are currently radon measurements from over 525,000 homes in England and Wales, obtained between 1980 and 2015 by the National Radiological Protection Board (NRPB), the Health Protection Agency (HPA), and PHE. Basic measurement devices are supplied to occupants to place in their homes. These devices provide an average concentration over a several month measurement period. Indoor measurements of radon can vary significantly over time and season (Miles, 2001), meaning that measurements should be taken over an extended period of time, or across multiple sampling periods.

Based on the aforementioned radon measurement studies, maps (e.g. the one shown in Figure 1) have been produced that show the risks of indoor radon exposure across England and Wales (Miles, 1998). Maps of radon risk are available at 1km (Green et al., 2002; Miles, 1998) resolution, or variable resolution with a typical accuracy of 50m (Miles and Appleton, 2005), as well as maps with corrections for year-to-year variations in concentrations (Miles et al., 2007). Maps are also employed by local authority building control when enforcing the building regulations in order to determine whether radon protective barriers or other mitigation strategies such as pumps and positive pressurisation are required in new developments, major refurbishments or building extensions. Areas where greater than 1% of homes are over the action level of 200 Bq/m<sup>3</sup> are defined as Radon Affected Areas (RAAs). In areas where between 3% and 10% of existing houses are above the action level of 200 Bq/m<sup>3</sup>, regulations require that new homes be built with a protective membrane, while in areas where more than 10% exceed the action level new houses should be built with full radon protection. Where annual average radon concentrations in a home exceed 200 Bq/m<sup>3</sup>, PHE recommends that remediation is carried out in order to achieve a target level of less than 100 Bq/m<sup>3</sup>.

A limitation of the maps is that they do not account for the variation caused by housing. For example, two adjacent houses may have very different indoor radon concentrations due to different housing characteristics such as the air tightness of the dwelling and their situation with the underlying soil characteristics, such as

water movement. It is also possible that, in areas with radon levels below the action level, where mitigation measures are not a statutory requirement, the nature of new construction is such that an increased level of radon exposure may go undetected.

A key method to reducing radon exposure in existing dwellings is remediation, however remediation is voluntary in England and Wales and only a fraction of those who have elevated radon levels choose to take action to reduce levels. For instance, only 40% of households in RRAs have tested radon in their homes, and of these only 15% have taken remediation action (Zhang et al., 2011). In addition, there is no requirement for new buildings to be tested for radon after construction to ensure radon levels are below the target level.

A number of studies have evaluated the health benefits of radon remediation. A tool - the European Community Radon Software (ECRS) (Denman et al., 2005) – has been used to estimate the individual health benefits of radon remediation based on individual circumstances, for a sample of houses in Northamptonshire. Results indicated that the potential health benefits from remediation are significantly less than expected as remediators are typically older, live in smaller households, and tend to smoke less than the population average. Studies have also examined the cost effectiveness of remediation (Coskeran et al., 2009) or installation of protection measures in new housing (Denman et al., 2013) using cost per Quality-Adjusted Life Years (QALY), indicating that interventions are cost-effective provided households with smokers are amongst those taking action.

The effects of housing, and changes in housing technology, on indoor radon concentrations has led to research examining the relative risks of exposure across these housing variants. Hunter et al. (2009) used indoor radon concentrations from around 40,000 dwellings located in six geological units (or the type of underlying rock) to evaluate the impact of dwelling characteristics and age on radon exposure. The study found that geological unit, house type, double glazing, and the date of construction were significantly associated with indoor radon

exposure (see Table 1). In addition, radon concentrations were found to be higher in homes with solid floors, and in homes with partial or complete draught proofing. Regional variations in housing types – for example, the prevalence of flats in urban areas – may lead to spatial variations in exposures (Denman et al., 2013).

*Table 1: Sources of variation in radon exposure using measurements from 39,823 dwellings (Hunter et al., 2009)*

| Source of variation                    | No. of data categories | % of variation explained |
|--|------------------------|--------------------------|
| Geological unit                        | 6                      | 19.7                     |
| House type                             | 6                      | 3.8                      |
| Double-glazing                         | 4                      | 2.3                      |
| Date of building                       | 8                      | 1.1                      |
| Floor level of living area and bedroom | 4                      | 1.0                      |
| Floor type of living area and bedroom  | 4                      | 0.5                      |
| Ownership                              | 5                      | 0.1                      |
| Draught proofing                       | 4                      | 0.1                      |

### Modelling studies

Since the removal of radon from the indoor environment will depend on building characteristics, the potential for increases in radon exposure in England due to energy efficient retrofit of housing has long been evident (Lugg and Probert, 1997). Computer modelling tools – for example multizonal airflow modelling tools such as CONTAM (Dols and Polidoro, 2015) – are useful for modelling ventilation in dwellings, and can model radon ingress into buildings, removal of radon-contaminated air, and variations in radon emission rates due to low air pressure in the building under a variety of scenarios.

A number of modelling studies have examined the role of housing, in particular the energy efficiency modification of housing, on radon exposure in the indoor environment. Airflow models are often coupled to health calculations in order to provide an estimate of the variations in risk across the stock, and following a range

of different retrofit adaptations. These models can be linked to building stock models – representing the range of housing variants across the stock – in order to estimate radon exposure at the population level. The impacts of indoor radon exposure on mortality may then be calculated using life table methods, which calculate gains of losses in life expectancy given changes in radon exposure.

Milner et al. (2014) used CONTAM to model the indoor concentrations of radon in houses under a range of different home energy efficiency interventions, using a building stock model based on the statistically representative English Housing Survey (EHS) database. Results indicated that simply increasing the air tightness of dwelling without additional purpose-provided ventilation (PPV) such as extract fans and trickle vents would increase radon concentrations by 56.6% (21.2 Bq/m<sup>3</sup> to 33.2 Bq/m<sup>3</sup>), leading to an additional annual burden of 4,700 life years lost and a peak of 278 deaths in England. Models where additional PPV (such as trickle vents or an extract fans) along with the energy efficiency measures, resulted in around 100 additional death and 1,700 life years lost per year. The reason for this relatively small reduction is that the mechanical ventilation modelled - in this case extract fans - only operate intermittently, whilst radon is a continuous source, with levels building up before the use of the extract fan. Additionally, trickles vents had marginal impact, as their function is primarily dependant on external metrological conditions and pressure differences between the indoor and outdoor environment. A third scenario – with Mechanical Ventilation with Heat Recovery (MVHR) systems – were found to reduce indoor radon levels and consequent health risks, but only under the condition that they are properly installed and functioning correctly.

Hamilton et al. (2015) used a similar approach based on CONTAM models and the EHS to assess the health impacts of energy efficiency changes to the English housing stock. The models output radon exposure alongside other indoor air pollutants (including second-hand tobacco smoke, PM<sub>2.5</sub> from indoor and outdoor sources, and mould) and indoor winter temperatures in order to consider optimal retrofit solutions. This study forms the basis for

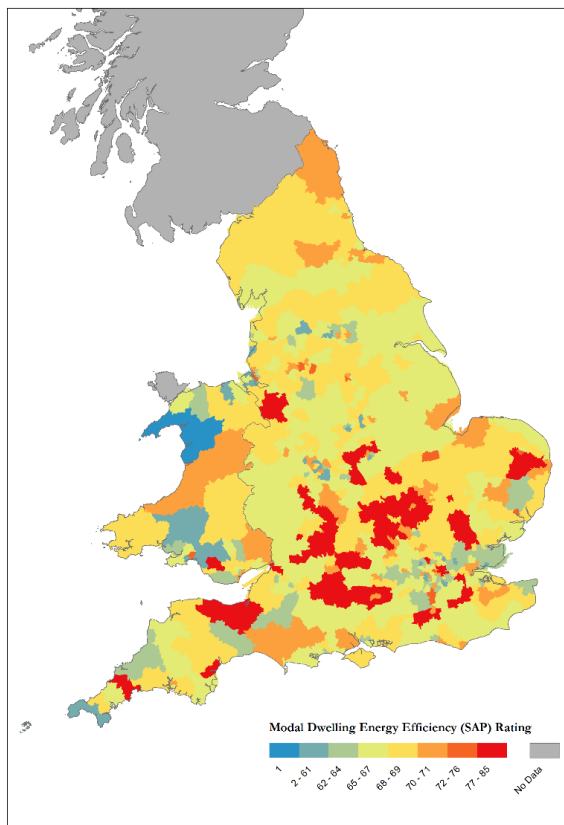
the Health Impact of Domestic Energy Efficiency Model (HIDEEM) which has been incorporated in the National Household Model used by the UK Department for Business, Energy and Industrial Strategy (BEIS). Results from the model were used to estimate changes in quality adjusted life years (QALYs) over 50 years from cardiorespiratory diseases, lung cancer, asthma, and common mental disorders. This study estimated between 75 and 97 QALYs would be lost per 10,000 population over a 50 year period due to lung cancer from radon exposure, if supplemental ventilation is not provided during retrofit.

### Ongoing studies

Current work at UCL is investigating the relationship between housing and radon exposure by combining housing data with measured levels of indoor radon to create the largest known sample of dwellings investigated to date. In addition to the EHS, England and the UK have a collection of databases with housing characteristics, including a number with address-level information including the following:

- Homes Energy Efficiency Database (HEED); contains records on housing energy efficiency installations
- National Energy Efficiency Data-Framework (NEED) database; fills in missing data by estimating housing characteristics based on a combination of housing databases
- Energy Performance Certificate (EPC) database; recently been made available, using housing EPCs, taken prior to a dwellings sale or rental.

The databases contain information on housing characteristics, such as dwelling type, construction age and materials, number of rooms, and estimates of the building energy efficiencies. Such databases enable the spatial distribution of housing parameters to be matched against measured indoor radon data using address matching, or based on spatial location. Figure 3 shows an example of the spatial variation in housing energy efficiency, based on the energy performance rating of surveyed dwellings in the EPC dataset.



*Figure 3. The modal energy efficiency rating in each constituency in England and Wales (determined using the UK Governments Standard Assessment Procedure for Energy Rating in Dwellings, SAP) according to the EPC database.*

The availability of large sets of housing data allows for the matching of housing data to measured indoor radon levels. Currently, analysis is investigating correlations between housing characteristics from the HEED database and PHE's radon datasets. The HEED database is valuable in that it contains temporal data showing the date when energy efficiency retrofits have been installed. Dwellings in both datasets have been matched by postcode, resulting in a sample of 474,464 dwellings with paired radon and housing data. Analysis is examining radon concentrations by housing characteristics such as dwelling type, region, and wall type to determine if radon concentration is associated with any such characteristics. Additional analysis will be performed, looking at radon concentrations in a subsample of 73,959 dwellings where there are radon concentrations following an energy efficiency intervention in the dwellings, such as cavity wall insulation, installation of a new boiler, or airtightening. This will help to

determine what effect energy efficiency interventions have on indoor radon concentrations.

### Future Research Directions

The evidence base from empirical measurements and the impact of energy efficiency retrofits on radon exposure will help make it possible to develop advanced simulation tools to be used by researchers, government and industry. It will also help provide more targeted information to households to enable them to understand the risk and effectiveness of mitigation; and, raise awareness of radon exposure and its mitigation among households and retrofit installers.

### Conclusions

While the average levels of radon exposure in England and Wales are relatively low compared to some other countries, the necessary changes to the housing stock to increase energy efficiency may lead to a significant change in population radon exposure and associated health problems. Building physics tools and combined housing and measured radon data can provide valuable insight in understanding the relationship between housing characteristics and indoor radon exposures, and can be used to predict future exposures under a range of different policy scenarios. Recommendations on future policy need to be made using a holistic approach where multiple criteria (including radon) are taken into consideration.

### References

- Coskeran, T., Denman, A., Phillips, P., et al. (2009). A critical evaluation of the cost-effectiveness of radon protection methods in new homes in a radon Affected Area of England. *Environment International* 35, 943–951.
- Denman, A.R., Philips, P.S., Tornberg, R., et al. (2005). Analysis of the individual health benefits accruing from a domestic radon remediation programme. *Journal of Environmental Radioactivity* 79, 7–23.
- Denman, A.R., Sinclair, J., Phillips, P.S., et al. (2013). The cost effectiveness of radon reduction programmes in domestic housing in England and Wales: The impact of improved radon mapping and housing trends. *Environment International* 59, 73–85.

- Dols, W.S., Polidoro, B.J. (2015) CONTAM 3.2 User Guide and Program Documentation. NIST, Gaithersburg, MD, USA.
- Green, B.M.R., Miles, J.C.H., Bradley, E.J., et al. (2002). Radon Atlas of England and Wales. NRPB, Didcot.
- Hamilton, I., Milner, J., Chalabi, Z., et al. (2015) Health effects of home energy efficiency interventions in England: a modelling study. *BMJ open* 5, e007298.
- Hunter, N., Muirhead, C. R., Miles, J. C., & Appleton, J. D. (2009). Uncertainties in radon related to house-specific factors and proximity to geological boundaries in England. *Radiation protection dosimetry*, 136(1), 17-22.
- JRC. (2005) An overview of radon surveys in Europe. Brussels, Belgium.
- Lowe, R., Oreszczyn, T. (2008) Regulatory standards and barriers to improved performance for housing. *Energy Policy* 36, 4475–4481.
- Lugg, A., Probert, D. (1997) Indoor radon gas: A potential health hazard resulting from implementing energy-efficiency measures. *Applied Energy* 56, 93–196.
- Miles, J. (2001) Temporal Variation of Radon Levels in Houses and Implications for Radon Measurement Strategies. *Radiation Protection Dosimetry* 93, 369–375.
- Miles, J. (1998) Development of maps of radon-prone areas using radon measurements in houses. *Journal of Hazardous Materials* 61, 53–58.
- Miles, J.C.H., Appleton, J.D. (2005) Mapping variation in radon potential both between and within geological units. *Journal of Radiological Protection* 25, 257–276.
- Miles, J.C.H., Appleton, J.D., Rees, D.M., et al. (2007) Indicative Atlas of Radon in England and Wales. Health Protection Agency, London, UK.
- Milner, J., Shrubsole, C., Das, P., et al. (2014) Home energy efficiency and radon related risk of lung cancer: modelling study. *BMJ* 348, f7493–f7493.
- Palmer, J., Cooper, I., Cheng, V. (2011) Great Britain's housing energy fact file 2011. DECC, London, UK.
- PHE. (2009) Radon and Public Health. Report of an independent Advisory Group on Ionising Radiation. Chilton, UK.
- VOA/ONS (2015) Dwelling Age Group Counts (LSOA). Valuation Office Authority. Office for National Statistics, London.
- Wrixon, A.D. and NRPB. (1988) Natural radiation exposure in UK dwellings. NRPB, Didcot, UK.
- Zhang, W., Chow, J., Meara, J., et al. (2011) Evaluation and equity audit of the domestic radon programme in England. *Health Policy* 102, 81–88

## Radon and energy conservation in existing buildings

*Bernard Collignan. Senior Scientist. Health and Comfort Department. Centre Scientifique et Technique du Bâtiment (CSTB). France; E-Mail: [bernard.collignan@cstb.fr](mailto:bernard.collignan@cstb.fr)*

### Context

Outdoor radon levels are generally low, and the health risks associated with radon exposure primarily occur in indoor environments. The radon concentration observed indoors depends on many parameters. The soil below the building is the primary contributor to the presence of radon indoors. The intensity of this source depends on the nature of the ground (granite, till, clay, etc.). Soil permeability to air and presence of cracks or major faults in the ground facilitate the radon transfer to buildings. The effect of soil moisture on the seasonal variations of the indoor radon concentration has also been observed. Moreover, the environmental setting (i.e., rural or urban) of the building can affect the radon transfer indoors. In addition to the influence of soil parameters, building characteristics, such as the type of foundation, type of ventilation system and the air exchange rate, also affect the indoor radon concentration. The combination of specific building characteristics with high ground radon potential can result in the accumulation of high levels of radon indoors.

For energy saving and to reduce the emission of greenhouse gases, policies in many countries have been implemented to reduce energy consumption in all economic sectors, particularly in the building sector, which is an important contributor. In this context, thermal retrofitting (renovation of existing buildings to conserve energy) is a key target in the housing sector. However, it may enhance the airtightness of the building envelope, thus potentially reducing the air exchange rate. If the ventilation is not correctly managed, indoor radon accumulation can result.

The airtightness of the building envelope primarily refers to the part of the dwelling shell that is above the floor. The floor in contact with the ground is generally not included. As a result, pressure differentials between indoors and outdoors could be accentuated and the radon fluxes entering the dwelling through the

floor could be enhanced. Considering this phenomenon, along with a possible reduction of the air exchange rate, higher indoor radon concentrations can be expected in thermally retrofitted dwellings. Several studies have already demonstrated that thermal retrofitting a building can lead to increases in the indoor radon concentration, primarily because of decreased ventilation rate. The potential for associated health risks, such as an increased incidence of lung cancer, is significant.

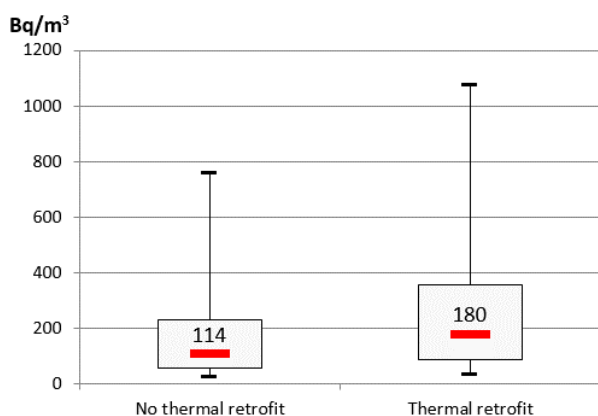
Two studies summarized below highlight this issue.

### 1. Statistical analysis on the relationships between indoor radon concentrations, thermal retrofit and dwelling characteristics

The objective of this study was to evaluate the influence of thermal retrofitting and other building characteristics on the indoor radon concentration based on measurements performed in a set of houses (Collignan et al., 2016). A monitoring campaign was conducted on a sample of more than 3,400 dwellings in Brittany, France from 2011-2014. Radon measurements were collected using one passive dosimeter per dwelling over two months during the heating season. Building characteristics such as the period of construction, construction material, type of foundation, type of heating system, type of ventilation system, and thermal retrofit were determined using a self-administered questionnaire. Statistical analysis was used to explore the relationship between the indoor radon concentrations and building characteristics. A dwelling was considered to have undergone a thermal retrofit if one or more of the following three modifications were reported by the occupants: replacement of windows, addition of thermal insulation, or acting on the ventilation of the building.

The results show the strong interrelationships of the building characteristics. However, the statistical model showed that thermal retrofitting alone has a significant effect on the indoor radon concentration, independently from all the other variables. On this sample, and based on the definition of thermal retrofit we formulated above, 56% of the houses had undergone thermal retrofit and 44% had not.

It appeared that the thermally retrofitted houses have higher radon concentrations than the houses that were not retrofitted. More precisely, the indoor radon concentrations increase by 21% on average in houses that have undergone a thermal retrofit compared to those that had never been retrofitted (figure1).



*Figure 1: Comparison of indoor radon concentration, P<sup>5</sup>, P<sup>25</sup>, P<sup>50</sup> (median), P<sup>75</sup> and P<sup>95</sup> for houses having undergone a thermal retrofit and houses that had not.*

These results, which confirm the findings of previous studies, could be explained by an increase of airtightness of the building envelope following rehabilitation works, such as changing windows or adding thermal insulation that rarely include proper management of the ventilation. Moreover, the probable induced modification of indoor pressure fields promotes radon entry into the dwelling. Thus, the use of statistical analysis of a large sample of houses, comparing indoor radon measurement of houses having thermal retrofit with ones which have not, yielded results that confirm the findings of previous studies that either illustrated the effect of thermal retrofitting through radon measurements performed before and after retrofit works in houses.

## 2. Impact of ventilation systems and air permeability of a building on the mechanisms governing the indoor radon activity concentration

For a given ground radon potential and a given building, the main factors influencing the

presence of indoor radon are indoor depressurization and the air exchange rate of the building. Indoor depressurization (generated by the stack effect and by the running of ventilation and heating systems) increases radon entry into the building from the ground. This parameter depends mainly on the building characteristics, such as its height, the airtightness of its envelope, or the nature and performance of the ventilation system. In addition, the dilution of indoor radon concentration will depend on the air renewal of the building.

The previous results from bibliography appear to show that indoor radon concentration can be significantly affected by variations in the air permeability of a given building and its ventilation system. To better understand the indoor environmental conditions affecting the indoor radon concentration, a sensitivity analysis was conducted using a numerical model of ventilation (Collignan & Powaga 2017). This model has been adapted to take into account the effect of variations in the indoor environmental conditions (depressurization and air exchange rate) on the radon entry rate and on the indoor radon concentration.

The sensitivity analysis used four classical ventilation types associated with different levels of air permeability as briefly described below.

- No ventilation system: Air renewal of the dwelling is only generated through air leakages of the building envelope.
- Natural ventilation system (NVS): this type of ventilation system induces natural air inlets and outlets in low and high positions of the façade for humid rooms.
- Mechanical exhaust ventilation system (MEVS): air enters naturally into occupied rooms (bedrooms and living rooms) through natural air inlets and is extracted mechanically from humid rooms (kitchen, bathroom and toilets).
- Mechanical balanced ventilation system (MBVS): air is forced mechanically into occupied rooms (bedrooms and living rooms) and extracted mechanically from humid rooms (kitchen, bathroom and toilets).

Four levels of the air permeability, quantified in the model with the index ( $I_a$ ) representing the air flow rate per square meter of envelope, under a depressurization level of 4 Pa, could represent

<sup>1</sup> P=Percentile. The XX<sup>th</sup> percentile is the value below which XX% of the observations may be found.



the initial state of the dwelling and the impact of three types of thermal retrofit works as presented in table 1. These are not measured values, but were selected input values that represent a trend. For example, in this model, the outside thermal insulation is considered to have a greater effect on the building airtightness than the inside thermal insulation.

*Table 1: Input values for air permeability of the envelope of the building ( $I_4$ ) used in ventilation model*

| $I_4$ ( $\text{m}^3 \cdot \text{h}^{-1} \cdot \text{m}^{-2}$ ) | Type of works                                   |
|--|---|
| 1.6  | Reference case                                  |
| 1.2  | Changing windows                                |
| 1.0  | Changing windows and inside thermal insulation  |
| 0.8  | Changing windows and outside thermal insulation |

Table 2 shows the annual averaged radon concentration calculated for the different cases relative to the reference case, which is chosen as the dwelling with NVS and  $I_4$  equal to  $1.6 \text{ m}^3 \cdot \text{h}^{-1} \cdot \text{m}^{-2}$ . A reference case has been chosen to highlight the impact of different configurations and to avoid showing absolute radon level.

The beneficial impact of ventilation on radon concentrations is illustrated in the table and holds true regardless of the air permeability of the building. MEVS was found to be more efficient than NVS because the constant exhaust air flow imposed induces a better air exchange rate over the year. Moreover, the MBVS is more efficient than the MEVS for an equivalent air renewal. This difference is due to the lower indoor depressurization using the MBVS, which does not increase the radon entry rate compared to the MEVS.

For all types of ventilation, when the dwelling becomes more airtight, the indoor radon

concentration increases. This is due to a decrease of air permeability which has an initial impact on a decrease of air exchange rate of the dwelling. This is particularly visible for the cases with “no ventilation system” and for the NVS. However, when the ventilation system is efficient (MEVS or MBVS), the increase of the annual averaged indoor radon concentration with the decrease in air permeability is relatively low because of the efficient dilution generated by the air exchange rate. It can be concluded that when thermal retrofitting is undertaken in a dwelling, it is important to include in the work the installation of an efficient ventilation system to avoid a significant increase in radon exposure for the occupants.

Another trend illustrated in table 2 is the importance of ventilation in especially airtight houses (e.g.  $I_4 = 0.8$ ). In such an airtight dwelling, the failure of the ventilation system, for whatever reason, could result in significant increase of the indoor radon concentration. In comparison, for a more leaky dwelling (e.g.  $I_4 = 1.6$ ), the impact of ventilation failure on the indoor radon concentration is less important. This last point highlights the need to install and to maintain an efficient ventilation system in new and renovated airtight buildings.

Note that these calculations are only illustrative and mainly qualitative. For example, they do not take into account occupant behavior, which could impact the air renewal via management of the opening of windows or acting on ventilation system components. However, these results show that installation of an efficient ventilation system could mitigate the impact of a thermal retrofit process on indoor radon concentrations and also improve the initial situation. A thermal retrofit that does not consider ventilation could result in a significant increase of indoor radon concentrations.

*Table 2: Annual averaged indoor radon concentration relative to the reference case (in gray box)*

| Air permeability of dwelling $I_4$ ( $\text{m}^3 \cdot \text{h}^{-1} \cdot \text{m}^{-2}$ ) | $I_4 = 1.6$ | $I_4 = 1.2$ | $I_4 = 1.0$ | $I_4 = 0.8$ |
|---|-------------|-------------|-------------|-------------|
| <b>No ventilation system</b>  | 1.78        | 2.38        | 2.86        | 3.57        |
| <b>Natural ventilation system (NVS)</b>   | 1           | 1.25        | 1.44        | 1.71        |
| <b>Mechanical exhaust ventilation system (MEVS)</b>   | 0.87        | 0.96        | 1.01        | 1.09        |
| <b>Mechanical balanced ventilation system (MBVS)</b>  | 0.56        | 0.63        | 0.66        | 0.72        |

## Conclusion

In the efforts to improve energy efficiency of houses and other buildings, it is important to carefully consider ventilation in any thermal retrofitting plan. While ventilation is a general consideration for indoor air quality, it is especially true in radon prone areas. Measuring radon concentrations prior to initiating a thermal retrofit project could help inform the planning, and the need for specific types of protective measures, particularly, in radon prone areas.

Overall, these results highlight the need to consider the indoor environment quality when addressing energy savings to avoid deteriorating the indoor air quality, consequently affecting the occupants' health. This consideration is even more crucial in a context where energy saving will remain the driving force in the building sector in the coming years.

## References of studies summarized in this article:

Collignan B., Le Ponner E., Mandin C. Relationships between indoor radon concentrations, thermal retrofit and dwelling characteristics. *Journal of Environmental Radioactivity* 165 (2016) 124e130. doi.org/10.1016/j.jenvrad.2016.09.013

Collignan B, Powaga E. Impact of ventilation systems and energy savings in a building on the mechanisms governing the indoor radon activity concentration. *Journal of Environmental Radioactivity* (nov. 2017). <https://doi.org/10.1016/j.jenvrad.2017.11.023>

## Other references:

Arvela, H., Holmgren, O., Reisbacka, H., Vinha, J., 2014. Review of low-energy construction, air tightness, ventilation strategies and indoor radon: results from Finnish houses and apartments. *Radiat. Protect. Dosim.* 162, 351–363. doi:10.1093/rpd/nct278.

Arvela, H., Holmgren, O., Hänninen, P., 2016. Effect of soil moisture on seasonal variation in indoor radon concentration: modelling and measurements in 326 Finnish houses. *Radiat. Protect. Dosim.* 168, 277–290. doi:10.1093/rpd/ncv182.

Bochicchio, F., Žunić, Z.S., Carpentieri, C., Antignani, S., Venoso, G., Carelli, V., Cordedda, C., Veselinović, N., Tollefsen, T., Bossew, P., 2014. Radon in indoor air of primary schools: a systematic survey to evaluate factors affecting radon concentration levels and their variability. *Indoor Air* 24, 315–326.

Borgoni, R., De Francesco, D., De Bartolo, D., Tzavidis, N., 2014. Hierarchical modeling of indoor radon concentration: how much do geology and building factors matter? *J Environ Radioact.* 138, 227-237.

Demoury, C., Ielsch, G., Hemon, D., Laurent, O., Laurier, D., Clavel, J., Guillevic, J., 2013. A statistical evaluation of the influence of housing characteristics and geogenic radon potential on indoor radon concentrations in France. *J. Environ. Radioact.* 126, 216-225.

Fojtíková, I., Navrátilová Rovenská, K., 2014. Influence of energy-saving measures on the radon concentration in some kindergartens in the Czech Republic. *Radiat. Prot. Dosim.* 160, 149–153. doi:10.1093/rpd/ncu073.

Fojtíková, I., Navrátilová Rovenská, K., 2015. Methodology for measurement in schools and kindergartens: experiences. *Radiat. Prot. Dosim.* 164, 612–617. doi:10.1093/rpd/ncv340.

Jiránek, M., Kačmaříková, V., 2014. Dealing with the increased radon concentration in thermally retrofitted buildings. *J. Radiat. Protect. Dosim.* 160, 43–47. doi:10.1093/rpd/ncu104.

Milner, J., Shrubsole, C., Das, P., Jones, B., Ridley, I., Chalabi, Z., Hamilton, I., Armstrong, B., Davies, M., Wilkinson, P., 2014. Home energy efficiency and radon related risk of lung cancer: modelling study. *BMJ* 348, 7493 doi:10.1136/bmj.f7493.

Pampuri, L., Goyette Pernot, J., 2014. Indoor air quality in new or renovated energy-efficient buildings, preliminary results of radon measurement campaigns in French and Italian parts of Switzerland, ROOMS 2014 Conference, . 6-7 October 2014, Bad Ischl, Austria.

Pressyanov, D., Dimitrov, D., Dimitrova, I., 2015. Energy-efficient reconstructions and indoor radon: the impact assessed by CDs/DVDs. *J. Environ. Radioact.* 143, 76-79.

Ringer, W., 2014. Monitoring trends in civil engineering and their effect on indoor radon. *J. Radiat. Prot. Dosim.* 160, 38–42. doi:10.1093/rpd/ncu107.

## Publications and Resources on Radon

In this chapter, we have compiled literature (without any claim of completeness) that gives you a good overview of radon. So you will find handbooks, guidelines and other publications regarding environmental conditions (air/indoor air and water), home and buildings and health. Furthermore, we refer to projects and interactive radon maps. Recent literature about radon and housing and health you will find in the next chapter [Literature](#).

### Environment (e.g.: air/indoor air, water)

[WHO handbook on indoor radon: a public health perspective](#)

WHO, 2009 (languages: English, Spanish, Japanese, Portuguese)

[WHO guidelines for indoor air quality: selected pollutants](#)

WHO, 2010 (see chapter 7 about radon)

[Air quality guidelines for Europe](#)

WHO, 2000 (see chapter 8.3 about radon)

[Guidelines for drinking-water quality: Fourth edition incorporating the first addendum](#)

WHO, 2017 (see chapter 9.7 about Radon)

[Radiation protection and safety of radiation sources: International basic safety standards](#)

WHO, 2014 (languages: English, Arabic, Chinese, French, Russian, Spanish)

### Home and Buildings

[EPA assessment of risks from radon in homes](#)

EPA, 2003

[Natürliche Radioaktivität in Baumaterialien und die daraus resultierende Strahlenexposition](#)

BfS, 2012 

[ICRP Publication 126: Radiological protection against radon exposure](#)

Ann. ICRP 43(3), 2014

[Umweltradioaktivität und Strahlenbelastung: Jahresbericht 2015](#)

BfS, 2016 

[Radon - ein kaum wahrgenommenes Risiko](#)

BfS, 2016 

[National and regional surveys of radon concentration in dwellings](#)

IAEA (Analytical Quality in Nuclear Applications), 2013

### Directives and Laws

[Directive 2013/59/EURATOM: basic safety standards for protection against the dangers arising from exposure to ionising radiation](#)

Official Journal of the European Union, 2014

[Richtlinie 2013/59/EURATOM zur Festlegung grundlegender Sicherheitsnormen für den Schutz vor den Gefahren einer Exposition gegenüber ionisierender Strahlung](#)

Amtsblatt der Europäischen Union, 2014 

[Gesetz zum Schutz vor der schädlichen Wirkung ionisierender Strahlung \(Strahlenschutzgesetz - StrlSchG\) \(2017\)](#) 

## Health

[ICRP publication 115: Lung cancer risk from radon and progeny and statement on radon](#)

ICRP 40(1), 2010

[IARC monograph on radiation: Volume 100 D – A review of human carcinogens](#)

IARC, 2012

[IARC monographs on the evaluation of carcinogenic risks to humans: Man-made mineral fibres and radon](#) (volume 43)

IARC, 1988

[IARC monographs on the evaluation of carcinogenic risks to humans: Tobacco smoke and involuntary smoking](#) (volume 83 – see chapter 2.3. Synergistic carcinogenic effects of tobacco smoke and other carcinogens)

IARC, 2004

## Projects and associations

### International Radon Project (IRP)

[WHO | Radon](#);

[Survey on radon guidelines, programmes and activities](#) (final report, 2007)

### European Radon Association (ERA)

[Radon regulations in Europe](#) (Abstract: II ERA workshop, Prague 2014)

## Interactive Radon Maps (few examples)

EU: [Radiological maps - European Commission](#)

Finland: [Radon maps of Finland - STUK](#)


Germany: [BfS - Geoportal des BfS](#)

Ireland: [Radon map: Environmental Protection Agency, Ireland](#)

United Kingdom: [UKradon - UK maps of radon](#)

United States: [EPA Map of Radon Zones | Radon | US EPA](#)

## Literature

In this section we will provide a collection of recent housing and health publications from a variety of backgrounds. Literature published in German is indicated with the German flag .

### Table of Topics

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### Allergies and Respiratory Diseases / Smoking

#### [Radon as a risk factor of lung cancer](#)

Gawełek E, Drozdowska B, Fuchs A  
Przegl Epidemiol. 2017; 71:90-98 (*free full text*)

#### [Residential radon: The neglected risk factor in lung cancer risk scores](#)

Torres-Duran M, Fernandez-Villar A, Barros-Dios JM, Ruano-Ravina A  
J Thorac Oncol. 2016; 11:1384-1386 (*free full text*)

#### [Indoor air contaminants and their impact on respiratory pathologies](#)

Carazo Fernández L, Fernández Alvarez R, González-Barcala FJ, Rodríguez Portal JA  
Arch Bronconeumol. 2013; 49:22-27 (*free full text*)

#### [Geographical correlations between indoor radon concentration and risks of lung cancer, non-hodgkin's lymphoma, and leukemia during 1999-2008 in Korea](#)

Ha M, Hwang SS, Kang S, Park NW, Chang BU, Kim Y  
Int J Environ Res Public Health. 2017; 14(4). pii: E344 (*free full text*)

#### [Residential radon and lung cancer: a cohort study in Galicia, Spain](#)

Barbosa-Lorenzo R, Ruano-Ravina A, Cerdeira-Caramés S, Raíces-Aldrey M, Barros-Dios JM  
Cad Saude Publica. 2017; 33(6):e00189415 (*free full text*)

#### [Residential radon and COPD. An ecological study in Galicia, Spain](#)

Barbosa-Lorenzo R, Ruano-Ravina A, Ramis R, Aragonés N, Kelsey KT, Carballeira-Roca C, Fernández-Villar A, López-Abente G, Barros-Dios JM  
Int J Radiat Biol. 2017; 93:222-230

[Residential radon and cancer mortality in Galicia, Spain](#)

López-Abente G, Núñez O, Fernández-Navarro P, Barros-Dios JM, Martín-Méndez I, Bel-Lan A, Locutura J, Quindós L, Sainz C, Ruano-Ravina A  
Sci Total Environ. 2018; 610-611:1125-1132 (*free full text*)

[Measurement of radon concentration in dwellings in the region of highest lung cancer incidence in India](#)

Zoliana B, Rohmingliana PC, Sahoo BK, Mishra R, Mayya YS  
Radiat Prot Dosimetry. 2016; 171:192-195

[Evaluation of different radon guideline values based on characterization of ecological risk and visualization of lung cancer mortality trends in British Columbia, Canada](#)

Branion-Calles MC, Nelson TA, Henderson SB  
BMC Public Health. 2015; 15:1144 (*free full text*)

[Lung cancer risk at low radon exposure rates in German uranium miners](#)

Kreuzer M, Fenske N, Schnelzer M, Walsh L  
Br J Cancer. 2015; 113:1367-1369 (*free full text*)

**Indoor Air**[<sup>222</sup>Rn, <sup>220</sup>Rn and their progenies measured in the air of different dwellings and workplaces and resulting alpha radiation doses to the eyes of individuals](#)

Misdaq MA, Elouardi B, Ouguidi J  
Health Phys. 2017 Nov; 113:363-374

[A pilot study to examine exposure to residential radon in under-sampled census tracts of DeKalb County, Georgia, in 2015](#)

Stauber CE, Dai D, Chan SR, Diem JE, Weaver SR, Rothenberg R  
Int J Environ Res Public Health. 2017; 14(3). pii: E332 (*free full text*)

[Assessment of airborne exposures and health in flooded homes undergoing renovation](#)

Hoppe KA, Metwali N, Perry SS, Hart T, Kostle PA, Thorne PS  
Indoor Air. 2012; 22:446-456 (*free full text*)

[Indoor radon in micro-geological setting of an indigenous community in Canada: A pilot study for hazard identification](#)

Sarkar A, Wilton DH, Fitzgerald E  
Int J Occup Environ Med. 2017; 8:69-79 (*free full text*)

[Update of Ireland's national average indoor radon concentration - Application of a new survey protocol](#)

Dowdall A, Murphy P, Pollard D, Fenton D  
J Environ Radioact. 2017; 169-170:1-8

[Critical aspects of radon remediation in karst limestone areas: some experiences in schools of South Italy](#)

Tunno T, Caricato AP, Fernandez M, Leonardi F, Tonnarini S, Veschetti M, Zannoni G, Trevisi R  
J Radiol Prot. 2017; 37:160-175

[Distribution of radon concentrations in child-care facilities in South Korea](#)

Lee CM, Kwon MH, Kang DR, Park TH, Park SH, Kwak JE  
J Environ Radioact. 2017; 167:80-85

[Radiation dose due to radon and thoron progeny inhalation in high-level natural radiation areas of Kerala, India](#)

Omori Y, Tokonami S, Sahoo SK, Ishikawa T, Sorimachi A, Hosoda M, Kudo H, Pornnumpa C, Nair RR, Jayalekshmi PA, Sebastian P, Akiba S  
J Radiol Prot. 2017; 37:111-126

[Radon and thoron in-air occupational exposure study within selected wine cellars of the Western Cape \(South Africa\) and associated annual effective doses](#)

Botha R, Newman RT, Lindsay R, Maleka PP  
Health Phys. 2017 Jan;112(1):98-107

[First step towards the geographical distribution of indoor radon in dwellings in Albania](#)

Tushe KB, Bylyku E, Xhixha G, Dhoqina P, Daci B, Cfarku F, Xhixha MK, Strati V  
Radiat Prot Dosimetry. 2016; 172:488-495

[Utility of short-term basement screening radon measurements to predict year-long residential radon concentrations on upper floors](#)

Barros N, Steck DJ, William Field R  
Radiat Prot Dosimetry. 2016; 171:405-413

[Indoor radon survey in Visegrad countries](#)

Müllerová M, Kozak K, Kovács T, Smetanová I, Csordás A, Grzadziel D, Holý K, Mazur J, Moravcsík A, Neznal M, Neznal M  
Appl Radiat Isot. 2016; 110:124-128

[Radon in indoor air of primary schools: determinant factors, their variability and effective dose](#)

Madureira J, Paciência I, Rufo J, Moreira A, de Oliveira Fernandes E, Pereira A  
Environ Geochem Health. 2016; 38:523-33

[Effect of soil moisture on seasonal variation in indoor radon concentration: modelling and measurements in 326 Finnish houses](#)

Arvela H, Holmgren O, Hänninen P  
Radiat Prot Dosimetry. 2016; 168:277-290 (*free full text*)

[Quantitative health risk assessment of indoor radon: A systematic review](#)

Ajrrouche R, Ielsch G, Cléro E, Roudier C, Gay D, Guillevic J, Laurier D, Le Tertre A  
Radiat Prot Dosimetry. 2017; 19:1-9

## **Mould and Dampness**

[Exposure and health effects of fungi on humans](#)

Baxi SN, Portnoy JM, Larenas-Linnemann D, Phipatanakul W; Environmental Allergens Workgroup  
J Allergy Clin Immunol Pract. 2016; 4:396-404 (*free full text*)

[Impact of climate change on the domestic indoor environment and associated health risks in the UK](#)

Vardoulakis S, Dimitroulopoulou C, Thornes J, Lai KM, Taylor J, Myers I, Heaviside C, Mavrogianni A, Shrubsole C, Chalabi Z, Davies M, Wilkinson P  
Environ Int. 2015; 85:299-313 (*free full text*)

[The effect on the radon diffusion coefficient of long-term exposure of waterproof membranes to various degradation agents](#)

Navrátilová Rovenská K  
Radiat Prot Dosimetry. 2014; 160:92-95

## Light and Radiation

### [Effects of radon and UV exposure on skin Cancer mortality in Switzerland](#)

Vienneau D, de Hoogh K, Hauri D, Vicedo-Cabrera AM, Schindler C, Huss A, Rössli M; SNC Study Group  
Environ Health Perspect. 2017; 125(6):067009 (*free full text*)

### [Inhalation dose and source term studies in a tribal area of Wayanad, Kerala, India](#)

Bhaskaran R, Damodaran RC, Kumar VA, Panakal John J, Bangaru D, Natarajan C, Sathiamurthy BS, Mundiyanikal Thomas J, Mishra R  
J Environ Public Health. 2017; 2017:1930787 (*free full text*)

### [Adaptation of the human population to the environment: Current knowledge, clues from Czech cytogenetic and "omics" biomonitoring studies and possible mechanisms](#)

Rossnerova A, Pokorna M, Svecova V, Sram RJ, Topinka J, Zölzer F, Rossner P Jr  
Mutat Res. 2017; 773:188-203 (*free full text*)

### [DNA excision repair and double-strand break repair gene polymorphisms and the level of chromosome aberration in children with long-term exposure to radon](#)

Larionov AV, Sinitsky MY, Druzhinin VG, Volobaev VP, Minina VI, Asanov MA, Meyer AV, Tolochko TA, Kalyuzhnaya EE  
Int J Radiat Biol. 2016; 92:466-474

## Housing Conditions

### [Comprehensive survey of household radon gas levels and risk factors in southern Alberta](#)

Stanley FK, Zarezadeh S, Dumais CD, Dumais K, MacQueen R, Clement F, Goodarzi AA  
CMAJ Open. 2017; 5:E255-E264 (*free full text*)

### [The relation between radon in schools and in dwellings: A case study in a rural region of Southern Serbia](#)


Žunić ZS, Bossew P, Bochicchio F, Veselinovic N, Carpentieri C, Venoso G, Antignani S, Simovic R, Čurguz Z, Udovicic V, Stojanovska Z, Tollefsen T  
J Environ Radioact. 2017; 167:188-200

### [Lung and stomach cancer associations with groundwater radon in North Carolina, USA](#)

Messier KP, Serre ML  
Int J Epidemiol. 2017; 46:676-685 (*free full text*)

## Thermal Comfort / Energy

### [Heizen, Raumtemperatur](#)

Umweltbundesamt, 2017  (*free full text*)

### [Buildings with environmental quality management, part 2: Integration of hydronic heating/cooling with thermal mass](#)

Romanska-Zapala A, Bomberg M, Fedorczyk-Cisak M, Furtak M, Yarbrough D, M Dechnik M  
Journal of Building Physics 2017; <https://doi.org/10.1177/1744259117735465>

### [Health effects of home energy efficiency interventions in England: a modelling study](#)

Hamilton I, Milner J, Chalabi Z, Das P, Jones B, Shrubsole C, Davies M, Wilkinson P  
BMJ Open. 2015; 5(4):e007298



## Urban Planning / Built Environment

### [Public open spaces and leisure-time walking in Brazilian adults](#)

Florindo AA, Barrozo LV, Cabral-Miranda W, Rodrigues EQ, Turrell G, Goldbaum M, Cesar CLG, Giles-Corti B

Int J Environ Res Public Health. 2017 ;14(6). pii: E553 (*free full text*)

### [Increasing the use of urban greenways in developing countries: A case study on Wutong Greenway in Shenzhen, China](#)

Chen Y, Gu W, Liu T, Yuan L, Zeng M

Int J Environ Res Public Health. 2017 ; 14(6). pii: E554 (*free full text*)

### [Acute effects of visits to urban green environments on cardiovascular physiology in women: A field experiment](#)

Lanki T, Siponen T, Ojala A, Korpela K, Pennanen A, Tiittanen P, Tsunetsugu Y, Kagawa T, Tyrväinen L


Environ Res. 2017; 159:176-185 (*free full text*)

## Urban Health

Schlicht, W

Springer Spektrum, Wiesbaden, 2017 (book) 

### [HafenCity Universität Hamburg \(HCU\): Klimafolgenanpassung innerstädtischer hochverdichteter Quartiere in Hamburg \(KiQ\)](#)

Behörde für Umwelt und Energie Hamburg, 2017 

## Social Inequality

### [Variation with socioeconomic status of indoor radon levels in Great Britain: The less affluent have less radon](#)

Kendall GM, Miles JC, Rees D, Wakeford R, Bunch KJ, Vincent TJ, Little MP

J Environ Radioact. 2016; 164:84-90

## Noise

### [Road traffic noise and children's inattention](#)

Weyde KV, Krog NH, Oftedal B, Magnus P, Øverland S, Stansfeld S, Nieuwenhuijsen MJ, Vrijheid M, de Castro Pascual M, Aasvang GM

Environ Health. 2017; 16(1):127 (*free full text*)

### [Residential road traffic noise and general mental health in youth: The role of noise annoyance, neighborhood restorative quality, physical activity, and social cohesion as potential mediators](#)

Dzhambov A, Tilov B, Markevych I, Dimitrova D

Environ Int. 2017; 109:1-9

### [Classroom acoustics as a consideration for inclusive education in South Africa](#)

Van Reenen C, Karusseit C

S Afr J Commun Disord. 2017; 64(1):e1-e10

### [Classroom listening conditions in Indian primary schools: A survey of four schools](#)

Sundaravadhanan G, Selvarajan HG, McPherson B

Noise Health. 2017; 19:31-40 (*free full text*)

[Short-term annoyance from nocturnal aircraft noise exposure: results of the NORAH and STRAIN sleep studies](#)

Quehl J, Müller U, Mendolia F  
Int Arch Occup Environ Health. 2017; 90:765-778

[Exposure to road, railway, and aircraft noise and arterial stiffness in the SAPALDIA Study: Annual average noise levels and temporal noise characteristics](#)

Foraster M, Eze IC, Schaffner E, Vienneau D, Héritier H, Endes S, Rudzik F, Thiesse L, Pieren R, Schindler C, Schmidt-Trucksäss A, Brink M, Cajochen C, Marc Wunderli J, Rösli M, Probst-Hensch N  
Environ Health Perspect. 2017; 125(9):097004 (*free full text*)

[Long-term exposure to transportation noise and air pollution in relation to incident diabetes in the SAPALDIA study](#)

Eze IC, Foraster M, Schaffner E, Vienneau D, Héritier H, Rudzik F, Thiesse L, Pieren R, Imboden M, von Eckardstein A, Schindler C, Brink M, Cajochen C, Wunderli JM, Rösli M, Probst-Hensch N  
Int J Epidemiol. 2017; 46:1115-1125 (*free full text*)

[Transportation noise exposure and cardiovascular mortality: a nationwide cohort study from Switzerland](#)

Héritier H, Vienneau D, Foraster M, Eze IC, Schaffner E, Thiesse L, Rudzik F, Habermacher M, Köpfli M, Pieren R, Brink M, Cajochen C, Wunderli JM, Probst-Hensch N, Rösli M; SNC study group  
Eur J Epidemiol. 2017; 32:307-315

[WHO environmental noise guidelines for the European region: A systematic review on environmental noise and adverse birth outcomes](#)

Nieuwenhuijsen MJ, Ristovska G, Dadvand P  
Int J Environ Res Public Health. 2017; 14(10). pii: E1252 (*free full text*)

[Breast cancer and exposure to aircraft, road, and railway-noise: a case-control study based on health insurance records](#)

Hegewald J, Schubert M, Wagner M, Dröge P, Prote U, Swart E, Möhler U, Zeeb H, Seidler A  
Scand J Work Environ Health. 2017; 43:509-518

[Community noise exposure and its effect on blood pressure and renal function in patients with hypertension and cardiovascular disease](#)

Dzhambov AM, Tokmakova MP, Gatseva PD, Zdravkov NG, Gencheva DG, Ivanova NG, Karastanev KI, Vladeva SV, Donchev AT, Dermendzhiev SM  
Folia Med (Plovdiv). 2017; 59:344-356

## Miscellaneous

[Risk of cancer associated with residential exposure to asbestos insulation: a whole-population cohort study](#)

Korda RJ, Clements MS, Armstrong BK, Law HD, Guiver T, Anderson PR, Trevenar SM, Kirk MD  
Lancet Public Health 2017; 2: e522-528

[Hazards of residential exposure to household asbestos](#)

de Klerk N, Reid A  
Lancet Public Health 2017; 2: e490-491

[A European-wide <sup>222</sup>Rn and <sup>222</sup>Rn progeny comparison study](#)

Schmithüsen D, Chambers S, Fischer B, Gilge S, Hatakka J, Kazan V, Neubert R, Paatero J, Ramonet M, Schlosser C, Schmid S, Vermeulen A, Levin I  
Atmos. Meas. Tech. 2017, 10, 1299-1312

[Mutagenic potential assessment associated with human exposure to natural radioactivity](#)

Marcon AE, Navoni JA, de Oliveira Galvão MF, Garcia ACFS, do Amaral VS, Petta RA, Campos TFDC, Panosso R, Quinelato AL, de Medeiros SRB  
Chemosphere. 2017; 167:36-43

## Event Announcements

### 2018

#### **HiAP 2018 - A Strategy for Improving Population Health**

6th of February 2018

London, United Kingdom

Further information: [HiAP 2018 - Health in All Policies](#)

#### **Competition/ Wettbewerb "Blauer Kompass" 2018**

Deadline for applications: 11th of March 2018

Umweltbundesamt, Berlin

Further information: [Wettbewerb Blauer Kompass | Umweltbundesamt](#)

#### **Resilient Cities 2018: 9th Global Forum on Urban Resilience and Adaptation**

26th - 28th of April 2018

Bonn, Germany

Further information: [Resilient Cities 2018](#)

#### **ÖGD-Fortbildung: Klimawandel und Gesundheit**

16th of May 2018

Stuttgart, Germany

Further information: [snezana.jovanovic@rps.bwl.de](mailto:snezana.jovanovic@rps.bwl.de) 

#### **Green cities for a greener future**

21st - 25th of May 2018

Brussels, Belgium

Further information: [EU Green Week 2018](#)

#### **Grüne Dächer und vertikales Grün - Potenziale, Strategien, Instrumente**

18th & 19th of June 2018

Berlin, Germany

Further information: [Grüne Dächer und vertikales Grün, DIFU](#) 

#### **First WHO Global Conference on Air Quality and Health**

30th of October - 1st of November 2018

Geneva, Switzerland

For more information, please contact: [ambientair@who.int](mailto:ambientair@who.int)

## Message Board

In this section we will inform you about activities and projects related to housing and health that are being carried out by WHO or the WHO CC. This may relate to ongoing activities and projects, as well as invitations to participate in data collections or case study projects.

### WHO work on indoor, built and urban environments

#### WHO work on urban green spaces

Over the last years, the WHO European Centre for Environment and Health has carried out intense work on the health relevance of urban green spaces, and how they can help to make cities more healthy and equitable. The project resulted in two main reports on the health impacts of urban green spaces, and the effectiveness of urban green space interventions.

To support practitioners and decision-makers at the local level involved with the design, planning, development and maintenance of urban green spaces, the main conclusion of the green space work have been summarized in an action brief which has been launched in June 2017. This action brief has raised considerable interest in many countries, and various national actors have committed to translating the brief into their national languages. Next to the original action briefs provided by WHO in English and Russian, a French version is already available (produced by the French Healthy Cities Network) and there are forthcoming versions in Dutch, Finnish, German, Italian and Portuguese.

The WHO reports can be accessed [here](#) and the action brief in Russian and English can be accessed [here](#).

The French version can be accessed on the website of the [French Healthy City network](#).

#### Planning cities to boost physical activity

A new publication from WHO/Europe is offering guiding principles for the WHO European Region to move towards increased physical activity in urban settings by transforming public spaces in ways that promote physically active lifestyles.

With more than 80% of the European population expected to live in urban areas by 2030, cities have a pivotal role to play in promoting and protecting health and well-being. Governments across the Region have recognized the need to prioritize physical activity, in particular in the context of cities. Answering the call of this strong political mandate, the new report explores options and strategies to boost physical activity in cities and advocates urban planning as a means to prevent physical inactivity.

The report can be accessed [here](#).

#### UN Climate Change Conference (COP 23) in Bonn, Germany: Health actions for the implementation of the Paris Agreement

On Sunday 12 November 2017, the Prime Minister of the Republic of Fiji, in cooperation with the World Health Organization, convened a high-level event on health actions for the implementation of the Paris Agreement.

The event convened a high-level discussion with esteemed panelists, to showcase the ongoing initiatives of national governments, and the wider health community, in implementing the health commitments of the Paris agreement, and the health and climate agenda. It also assessed the current state of progress, and identify the ongoing barriers to stronger action to protect and promote health while addressing climate change.

Watch the video of the event [here](#).

At COP23, WHO and the UNFCCC signed a new Memorandum of Understanding (MoU) to renew the two institutions' joint commitment to tackle public health challenges emerging from rising temperatures and to help countries boost the efficiency of their response to climate change

Find more information on the collaboration [here](#).

### **Health economic assessment tool (HEAT) for walking and for cycling. Methods and user guide on physical activity, air pollution, injuries and carbon impact assessments.**

The promotion of cycling and walking for everyday physical activity not only promotes health but can also have positive effects on the environment.

A recent WHO publication summarizes the tools and guidance developed to facilitate this shift: the methodology for the economic assessment of transport infrastructure and policies in relation to the health effects of walking and cycling; systematic reviews of the economic and health literature; and guidance on applying the health economic assessment tools and the principles underlying it.

It has been updated to consider the health effects of road crashes and air pollution and the effects on carbon emissions. The tool can be used for several types of assessment, for example:

- assessing current (or past) levels of cycling or walking, such as showing the value of cycling or walking in a city or country;
- assessing changes over time, such as comparing before-and-after situations or scenario A versus scenario B (such as with or without measures taken); and
- evaluating new or existing projects, including calculating benefit–cost ratios. HEAT can be used as a stand-alone tool or to provide input into more comprehensive economic appraisal exercises or prospective health impact assessment.

The tool can be accessed [here](#).

#### **Imprint**

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Landesgesundheitsamt Baden-Württemberg  
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Baden-Württemberg State Health Office

phone +49 (0)711• 904 35000

fax +49 (0)711• 904 35105

WHO Collaborating Centre for Housing and Health

Head: Dr. Karlin Stark

Nordbahnhofstrasse 135

70191 Stuttgart

[who.cc@rps.bwl.de](mailto:who.cc@rps.bwl.de)

[www.whocc-housing-and-health.de](http://www.whocc-housing-and-health.de)

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##### **Editors:**

Dr. Snezana Jovanovic, Dr. Katharina Gabriela Cibis

Dr. Guido Fischer, Stefan Kluge