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Radon concentrations in new Danish single family houses

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SUMMARY
In the period from July to September 2007 radon concentrations were measured in 200 occupied single family houses built from 2005 to 2007. The geometrical mean concentration was 35 Bq/m$^3$ and 1 % of the houses had concentrations above 200 Bq/m$^3$. In a subsequent period from December 2007 to March 2008, air change rates were measured and attempts to find the causes of high radon concentrations in the 20 houses with the highest radon concentrations were made. Eighty % of these 20 houses had air change rates below 0.5 h$^{-1}$, but no significant relation between air change rates and radon concentrations were found. In these occupied houses it was not possible to find any direct causes of the high radon concentrations.

KEYWORDS
Radon, single family houses, Air change rate, Cracks

INTRODUCTION
Radon in inhalation air increases the risk of developing lung cancer. According to the World Health Organisation (WHO 2005) radon is the second most important reason for developing lung cancer after active smoking. It has been estimated that radon in dwellings causes around 9 % of all new lung cancer cases in Denmark. This is approximately 300 cases per year. The risk of developing lung cancer because of radon exposure is approximately 25 times higher for smokers than for people who never smoked, but the risk is also substantial for non-smokers.

Radon has been officially acknowledged as a problem in Danish single family houses since 1987 when a government report on high radon levels in dwellings was published (Danish Construction Agency 1987). A decade later, after some comprehensive radon surveys had been performed, a requirement to build airtight to the ground was finally added to the Danish Building Regulations for new single family houses. It is difficult to know if an existing building complies with this requirement and public concern has been raised regarding the effectiveness of the revised Building Regulations to reduce the radon problem in new buildings.

On this background, the present study aims to determine whether a radon problem exists in houses built after the building code was supplemented in 1998 with the requirement to build airtight to the ground.

METHODS
A random sample of 416 houses built in the period from 2005 to 2007 was drawn from the Danish Building Register; and the houses were situated in the municipalities that had the highest average radon concentrations found in a previous investigation (Andersen et al. 2001). The municipalities of Ringe, Svendborg, Egebjerg and Ryslinge in southern Funen, Skovbo,
Ramsø and Vallø in south eastern Zealand, and all municipalities on the island of Bornholm were included. The owners of these houses were invited by letter to participate in the investigation. As many as 305 accepted the invitation and 220 of them received a second letter with two passive radon samplers and instructions on how to use them. The readings were taken during 70 days (Std. dev. 6 days) in the period July to September 2007. Five house owners did not want to participate, one house turned out to be older than expected and 14 sets of samplers were never returned. Two hundred sets of samplers were successfully analysed. Before the measurements all participants had accepted to be informed about the results.

The 20 houses with the highest radon concentrations were selected for further investigation. In these houses a careful inspection and measurements of air change rates, temperature, humidity and CO\textsubscript{2} concentrations of the indoor air were made by the authors of the present paper in the period December 2007 to March 2008. Air change rates were measured by decay of tracer gas centrally in the living room. Gas was dosed in all rooms of the house. All windows were kept closed and all other ventilation related-settings were kept as found. Inner doors were kept open and mixing of air was assured by means of stand fans. Gas concentration, humidity and CO\textsubscript{2} concentrations were measured by INNOVAS gas analyzer type 1312.

**RESULTS**

House concentrations were calculated as geometrical means of the two samplers in each house. Mean standard deviation within the houses was 8 Bq/m\textsuperscript{3} – comparable to the uncertainty of the measurements. In order to compensate for a low radon concentration during the performed summer measurements compared with 12-month averages, a correction factor of 1.5 was applied to the direct measurements before presenting in this paper. This factor was derived from Andersen et al. (2007) as an average value for the period from July to September. Figure 1 shows the fraction of houses in five radon concentration intervals. Most houses had very low concentrations below 50 Bq/m\textsuperscript{3}. At the other end of the scale only 1 %, equal to two houses exceeded the 200 Bq/m\textsuperscript{3} limit.

![Figure 1. Frequency plot for five radon concentration intervals. Measurements from 200 single family houses built in 2005 to 2007. Geometrical mean radon concentration was 37 Bq/m\textsuperscript{3} and geometric standard deviation was 2.](image-url)
The attempts to identify reasons for high radon concentrations were made without destroying existing surface materials and therefore sub-floor structures could not be inspected. It was not possible to identify any major cracks or other possible causes of the elevated concentrations. Figure 2 shows the fraction of houses in five air change rate intervals. These results are from the second part of the study, which included only the 20 houses with the highest radon concentrations. Most houses had lower air change rates than the required design value.

Figure 2. Frequency plot for five air change rate intervals. Measurements from the 20 houses with the highest radon concentrations. Average air change rate was 0.38 h\(^{-1}\).

Figure 3 shows the relation between radon concentrations and air change rates. Statistical analysis shows no significant relation. Earlier studies have shown much greater house to house variation in radon entry rates than in air change rates and apparently this study has too few observations to be able to demonstrate a significant effect of increased air change.

Figure 3. Relation between radon concentration and air change rates.
DISCUSSION
Table 1 shows a significantly lower radon concentration found in the present study in new houses compared with previous measurements in existing houses.

Table 1 Comparison of geometric mean values and fraction of houses exceeding 200 Bq/m$^3$ in the chosen municipalities from a previous investigation by Andersen et al. (2001) and the present investigation.

<table>
<thead>
<tr>
<th></th>
<th>Radon 2001</th>
<th>Radon 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric mean, Bq/m$^3$</td>
<td>106</td>
<td>35</td>
</tr>
<tr>
<td>Fraction &gt;200 Bq/m$^3$, %</td>
<td>14</td>
<td>1</td>
</tr>
</tbody>
</table>

CONCLUSIONS
The geometrical average concentration of radon was 35 Bq/m$^3$ and only 1% of the houses exceeded the official Danish guideline value of 200 Bq/m$^3$. This is a significant improvement when compared with the concentrations in older houses in the same regions. There was no relation found between radon concentrations and measured values for air change rates, moisture, CO$_2$ and temperature. The new houses with the highest radon concentrations had an average air change rate of only 0.38 h$^{-1}$. This value is low compared with the guideline value of 0.5 h$^{-1}$ for Danish dwellings.

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REFERENCES


