Building characteristics and determinants of the radon concentrations in dwellings

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Eline LE PONNER
INTRODUCTION

TWO DATABASES

> Concarneau Cornouailles Agglomération (CCA), France
> Limousin, France

OBJECTIVE OF THE STATISTICAL ANALYSIS

- To assess the impact of building characteristics on the radon concentration in dwellings
### PRESENTATION OF THE DATA

<table>
<thead>
<tr>
<th></th>
<th>CCA</th>
<th>LIMOUSIN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location</strong></td>
<td>9 municipalities</td>
<td>3 departments</td>
</tr>
<tr>
<td></td>
<td>50 600 inhabitants</td>
<td>738 633 inhabitants</td>
</tr>
<tr>
<td><strong>Date of the study</strong></td>
<td>Autumn 2011 – Spring 2014</td>
<td>December 2014 – May 2015</td>
</tr>
<tr>
<td><strong>Sampling</strong></td>
<td>Volunteer → 4 479 <strong>measurement sets</strong> distributed</td>
<td>Volunteer → 1 500 <strong>measurement sets</strong> distributed</td>
</tr>
<tr>
<td><strong>Number of observations</strong></td>
<td>- 3 233 single houses</td>
<td>- 1 069 single houses</td>
</tr>
<tr>
<td></td>
<td>- Complete set: 2045 observations</td>
<td>- Complete set: 423 observations</td>
</tr>
<tr>
<td><strong>Radon potential of soil</strong></td>
<td>High and relatively homogeneous on the territory</td>
<td>High but not homogeneous on the territory:</td>
</tr>
<tr>
<td>Reference: IRSN (Institut de Radioprotection et de Sûreté Nucléaire)</td>
<td></td>
<td>- 135 municipalities with high or medium potential</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 9 municipalities with low potential</td>
</tr>
</tbody>
</table>

**One measure:** 1 dosimeter per dwelling
Self-administered questionnaire to obtain the dwelling characteristics

Questions regarding:
- Housing type
- Owner
- Number of occupied levels
- Lowest level occupied at least one hour per day
- Construction period
- Type of foundation
- Buried or semi-buried walls
- Construction material (main for CCA data and recoded for Limousin data)
- Thermal retrofit
- Ventilation system
- Type of windows

Limousin questionnaire: identification of the location of the dosimeter

→ 9% of people do not put the dosimeter at the lowest occupied level at least one hour per day
Distribution of indoor radon concentrations in CCA:
- P5 : 32 Bq.m⁻³
- P95 : 928 Bq.m⁻³
- Mean : 296 Bq.m⁻³
- Median : 147 Bq.m⁻³

Distribution of indoor radon concentrations in Limousin:
- P5 : 47 Bq.m⁻³
- P95 : 1751 Bq.m⁻³
- Mean : 499 Bq.m⁻³
- Median : 221 Bq.m⁻³

Action thresholds:

<table>
<thead>
<tr>
<th>Concentrations of radon (in Bq.m⁻³)</th>
<th>% individual houses in CCA</th>
<th>% individual houses in Limousin</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 300</td>
<td>75%</td>
<td>62%</td>
</tr>
<tr>
<td>&lt; 400</td>
<td>82%</td>
<td>71%</td>
</tr>
<tr>
<td>[300 ; 1000 ]</td>
<td>21%</td>
<td>28%</td>
</tr>
<tr>
<td>[400 ; 1000 ]</td>
<td>13%</td>
<td>19%</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td>4%</td>
<td>10%</td>
</tr>
</tbody>
</table>
> **Common characteristics between the two databases:**

- More than 90% are owners in CCA and Limousin
- More than 80% have the lowest occupied level at least one hour per day on the ground floor
- More than 60% have 2 levels inhabited

> **Different characteristics between the two databases:**

- 23% of buried or semi-buried walls in CCA against 56% in Limousin
- Construction material: 59% in hollow concrete block or hollow brick and 18% in granite in CCA
  
  22% in concrete/full brick, hollow concrete block or hollow brick
  
  and 46% in granite in Limousin
- Type of foundation: 45% slab-on-grade and 2% basement without slab in CCA
  
  18% slab-on-grade and 16% basement without slab in Limousin
- The dwellings are older in Limousin than CCA
A dwelling was considered to have undergone a thermal retrofit if there has been thermal insulation and/or ventilation and/or a window replacement.

> **In Limousin:**

![Pie chart showing thermal renovation and no thermal renovation in Limousin]

- Thermal renovation: 33%
- No thermal renovation: 67%

> **In CCA:**

![Pie chart showing thermal renovation and no thermal renovation in CCA]

- Thermal renovation: 44%
- No thermal renovation: 56%
CHARACTERISTICS OF SINGLE HOUSES
Principal Component Analysis – Relationships between variables in CCA

- Built after 1982
- No thermal retrofit
- Hollow brick or hollow concrete block

- Built before 1948
- Granite

- Built between 1949 and 1958
- Thermal retrofit
- Simple glazing
- Simple and double glazing

- Built between 1975 and 1982
- Basement with slab

- Built before 1948
- Granite
CHARACTERISTICS OF SINGLE HOUSES
Principal Component Analysis – Relationships between variables in Limousin

- Built before 1948
  - Granite
  - Thermal retrofit

- Recent houses (after 1975)
  - 1 occupied level
  - No thermal retrofit

- Some variables:
  - Living area in contact with the ground
  - 2 occupants and more
  - No buried walls
  - Stack space
  - Granite
  - Creuse
  - Ventilation: no system
  - 2 inhabited levels
  - Slab-on-grade
  - Simple glazing
  - Mixed (with granite)
DETERMINANTS OF INDOOR RADON CONCENTRATIONS

Results of generalized linear regression for CCA

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$ (SE)</th>
<th>Impact</th>
<th>$\beta$ standardized</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>4.81 (0.09)</td>
<td>-</td>
<td>0</td>
<td>$&lt;$0.0001***</td>
</tr>
<tr>
<td>Type of foundation: (ref.: crawl space)</td>
<td></td>
<td></td>
<td></td>
<td>$&lt;$0.0001***</td>
</tr>
<tr>
<td>Slab-on-grade</td>
<td>0.43 (0.05)</td>
<td>0.54</td>
<td>0.21</td>
<td>$&lt;$0.0001***</td>
</tr>
<tr>
<td>Combined foundation</td>
<td>0.21 (0.07)</td>
<td>0.23</td>
<td>0.07</td>
<td>0.0021***</td>
</tr>
<tr>
<td>Basement with slab</td>
<td>0.21 (0.06)</td>
<td>0.23</td>
<td>0.07</td>
<td>0.0011***</td>
</tr>
<tr>
<td>Basement without slab</td>
<td>0.23 (0.14)</td>
<td>0.26</td>
<td>0.03</td>
<td>0.1021</td>
</tr>
<tr>
<td>Main construction material: (ref.: concrete of full brick)</td>
<td></td>
<td></td>
<td></td>
<td>$&lt;$0.0001***</td>
</tr>
<tr>
<td>Other (wood, etc.)</td>
<td>0.04 (0.14)</td>
<td>0.04</td>
<td>0.01</td>
<td>0.7901</td>
</tr>
<tr>
<td>Granite</td>
<td>0.51 (0.09)</td>
<td>0.67</td>
<td>0.22</td>
<td>$&lt;$0.0001***</td>
</tr>
<tr>
<td>Hollow concrete block or hollow brick</td>
<td>-0.01 (0.07)</td>
<td>-0.01</td>
<td>-0.01</td>
<td>0.8466</td>
</tr>
<tr>
<td>Other stone</td>
<td>0.69 (0.09)</td>
<td>0.99</td>
<td>0.19</td>
<td>$&lt;$0.0001***</td>
</tr>
<tr>
<td>Ventilation system: (ref.: no system)</td>
<td></td>
<td></td>
<td></td>
<td>0.0263*</td>
</tr>
<tr>
<td>Mechanical ventilation system</td>
<td>-0.10 (0.05)</td>
<td>-0.10</td>
<td>-0.05</td>
<td>0.0595*</td>
</tr>
<tr>
<td>Natural ventilation system</td>
<td>-0.15 (0.06)</td>
<td>-0.14</td>
<td>-0.06</td>
<td>0.0173**</td>
</tr>
<tr>
<td>Thermal retrofit (ref.: no)</td>
<td>0.19 (0.04)</td>
<td>0.21</td>
<td>0.09</td>
<td>$&lt;$0.0001***</td>
</tr>
</tbody>
</table>

**POSITIVE impact:**
- Slab-on-grade: $\uparrow$ 54%
- Combined foundation: $\uparrow$ 23%
- Basement with slab: $\uparrow$ 23%

**NEGATIVE impact:**
- Natural ventilation system: $\downarrow$ 15%

**POSITIVE impact:**
- Granite: $\uparrow$ 67%
- Other stone: $\uparrow$ 99%

Slab-on-grade and granite: 2 characteristics that most influence

> Adjusted-$R^2$: 0.22 $\Rightarrow$ 22% of variations of radon concentrations are explained
## DETERMINANTS OF INDOOR RADON CONCENTRATIONS

Results of generalized linear regression for Limousin

<table>
<thead>
<tr>
<th>Variable</th>
<th>β (SE)</th>
<th>Impact</th>
<th>β*</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>4.83 (0.35)</td>
<td>0</td>
<td>0</td>
<td>&lt;0.0001***</td>
</tr>
<tr>
<td>Radon potential of soil (ref.: low)</td>
<td>0.48 (0.22)</td>
<td>0.62</td>
<td>0.09</td>
<td>0.0314*</td>
</tr>
<tr>
<td>Lowest level had at least an hour a day</td>
<td></td>
<td></td>
<td></td>
<td>0.0169*</td>
</tr>
<tr>
<td>(ref.: basement/garden level)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>downstairs</td>
<td>-0.16 (0.25)</td>
<td>-0.15</td>
<td>-0.05</td>
<td>0.5350</td>
</tr>
<tr>
<td>1st floor and more</td>
<td>-0.54 (0.28)</td>
<td>-0.42</td>
<td>-0.16</td>
<td>0.0555</td>
</tr>
<tr>
<td>Ventilation system (ref.: no system)</td>
<td></td>
<td></td>
<td></td>
<td>0.3368</td>
</tr>
<tr>
<td>Natural ventilation system</td>
<td>0.04 (0.09)</td>
<td>0.04</td>
<td>0.02</td>
<td>0.6746</td>
</tr>
<tr>
<td>Mechanical ventilation system</td>
<td>-0.10 (0.10)</td>
<td>-0.10</td>
<td>-0.05</td>
<td>0.3158</td>
</tr>
<tr>
<td>Construction material</td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.0001***</td>
</tr>
<tr>
<td>(ref.: concrete of full brick, hollow concrete block or hollow brick)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (wood, etc.)</td>
<td>-0.07 (0.27)</td>
<td>-0.07</td>
<td>-0.01</td>
<td>0.8013</td>
</tr>
<tr>
<td>Other stone</td>
<td>0.20 (0.19)</td>
<td>0.22</td>
<td>0.05</td>
<td>0.2912</td>
</tr>
<tr>
<td>Granite</td>
<td>0.64 (0.12)</td>
<td>0.90</td>
<td>0.35</td>
<td>&lt;0.0001***</td>
</tr>
<tr>
<td>Mixed (with granite)</td>
<td>0.36 (0.12)</td>
<td>0.43</td>
<td>0.17</td>
<td>0.0040**</td>
</tr>
<tr>
<td>Thermal retrofit (ref.: no)</td>
<td>0.24 (0.09)</td>
<td>0.27</td>
<td>0.12</td>
<td>0.0083**</td>
</tr>
</tbody>
</table>

- **POSITIVE impact:**
  - High potential: ↑62%
  - Granite: ↑90%
  - Mixed (with granite): ↑43%
  - Thermal retrofit: ↑27%
  - Granite and mixed (with granite): 2 characteristics that most influence

> Adjusted-$R^2$ : 0.16 ⇒ 16% of variations of radon concentrations are explained
SUMMARY OF THE RESULTS:

> Building characteristics are very much related

> **Major determinants of radon sources:**  
  - Construction material → **Granite**  
  - Type of foundation → **Slab-on-grade**  
  - Radon potential of soil  
  - Thermal retrofit

> Low variance of the concentrations is explained:  
  - Random phenomena not measurable  
  - Some characteristics not available in the questionnaire
CONCLUSION

LIMITATIONS:

> Self-response: the quality and relevance of responses

PERSPECTIVES:

> To compare this data with other database (e.g., Finistère)

> To predict radon concentrations from dwelling characteristics and potential of the soil

ASSOCIATED PUBLICATION:

Thank you for your attention