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CONTRIBUTION TO THE ASSESSMENT OF SHELTER-IN-PLACE EFFECTIVENESS AS A COMMUNITY PROTECTION MEASURE IN THE EVENT OF A TOXIC GAS RELEASE

María Isabel Montoya Rodríguez

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Dra. Eulàlia Planas Cuchi

CERTEC – Centre d’Estudis del Risc Tecnològic
Departament d’Enginyeria Química
Escola Tècnica Superior d’Enginyers Industrials de Barcelona
Universitat Politècnica de Catalunya

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Chapter 4. Characteristics of Catalan single-family dwellings stock

“For everything there is a season, and a time for every matter under heaven”
Ecclesiastes 3:1

As there is no empirical data available concerning Catalan single-family dwellings airtightness or ACH, we decided to apply the LBNL airtightness model to Catalan dwellings in order to have an approach of the airtightness distribution. For the application of the LBNL airtightness model to Catalunya, census tracts were chosen as the calculation units because they are the smallest geographically referenced population elements from which dwelling characteristics such as floor area, number of stories, and year of construction can be obtained. Therefore, the first section of this chapter, deals with the distribution of current single-family dwellings characteristics available at the census information. The second part analyzes the distribution of average and extreme meteorological conditions across Catalunya, and classifies census tracts according to climatic zones used by the LBNL airtightness model. Finally, we used a stochastic simulation to mimic single-family dwellings characteristics distribution by census tract, in order to apply the LBNL airtightness model to Catalan dwellings and have an approximate airtightness distribution.
4.1 Characteristics of Catalan single-family dwellings

The latest housing census in Spain dates from 2001 in which variables studied regarding dwellings comprise: type, useful area in square meters, number of rooms, number of floors, number of dwellings, type of owner, status and period of construction of the building, among others (INEbase, 2001). According to the results of this census reported by the Statistical Institute of Catalunya (IDESCAT, 2001), Catalunya accounts for 773627 single-family dwellings, from which 65% (504022) are classified as primary residences. Primary residences refer to those dwellings used as permanent or habitual residences throughout the year or most part of the year. Distribution of these residences by provinces across Catalunya shows that 57% are located at Barcelona, 16.6% at Girona, 10.7% at Lleida and 15.7% at Tarragona (IDESCAT, 2001). For the following analysis we only considered primary residences, since only these data was provided by the IDESCAT.

Characteristics analyzed comprised those that influence the airtightness like the number of stories, the floor area and the period of construction, which are also needed to apply the LBNL airtightness model. Figure 4.1 presents the distribution of these characteristics for single-family dwellings in Catalunya. Regarding the number of stories (Figure 4.1.a), most of the dwellings have two or three stories and only 0.4% have more than 3 stories. Concerning the floor area, census criteria defined it as the area enclosed within the exterior walls, regardless uninhabitable basements and attics, but 100% of the terrace area if it is closed and 50% if it is only covered. Distribution of the floor area shows that approximately 95% of the dwellings have areas between 40 and 209 m², being the range 90-99 m² the most representative (Figure 4.1.b). For the year of construction (Figure 4.1.c) there is a significant increment in the number of dwellings built by year after 1950; almost 55% of the existing dwellings in 2001 were built or reformed after 1970. The year of construction as defined by the census is the approximate year of construction or last substantial reform. A substantial reform is considered when the changes are such, that almost a new building was made.

Above information gives a global perception of the distribution of these features concerning the whole Catalunya; however, these distributions may vary from site to site. Therefore, with the aim of making a more detailed analysis and to obtain geo-referenced distributions of these characteristics, we decided to use census tracts as they are the smallest territorial divisions for which this information is available.
Figure 4.1 Frequencies and cumulative frequencies distributions of single-family dwellings in Catalunya. a) Number of stories, b) Floor area, c) Year of construction. (IDESCAT, 2001)
Distribution by census tracts

Census tracts are territorial units that consist of a defined and delimited area specially used for government elections and statistical studies. The criterion used to establish these units in Spain is based on the number of people within the area, which should be between 500 and 2000 (Ley Orgánica 5/1985). Currently, Catalunya accounts for 5223 census tracts of which 8.6% lack of single-family residences, and 0.2% are not available in the geographical information system (GIS) format of Catalunya census tracts, obtained from the IDESCAT (Figure 4.1). Most of the census tracts are located in the province of Barcelona (73.3%), followed by Tarragona (9.7%), Girona (9.5%) and Lleida (7.5%).

![Figure 4.2 Distribution of census tracts in Catalunya by provinces](image)

The distribution of the number of single-family dwellings by census tract is shown in Figure 4.3, where it can be seen that 55% of the census tracts have less than 50 dwellings. The discrete distribution of floor area, number of stories and year of construction by census tract was gathered from the buildings census data of 2001, an example of how is the data organized is shown in Annex A. The geometric mean (GM) for each one of these variables by census tract was calculated and assigned to the respective census tract. In order to make a geographical representation of the characteristics distribution across Catalunya, we used the range where the GM lies. Figure 4.4, Figure 4.5 and Figure 4.6 show the distribution of the floor area, the
number of stories and the year of construction in Catalunya, respectively. Concerning the year of construction it can be seen that newer dwellings are mainly located at the south along coastline. With regards to the floor area, bigger dwellings appear in the north-east while smaller are located to the west.

![Figure 4.3 Distribution of the number of single-family dwellings in Catalunya by census tract](image)

![Figure 4.4 Single-family dwellings' floor area distribution by census tract in Catalunya](image)
Figure 4.5 Single-family dwellings’ number of stories distribution by census tract in Catalunya

Figure 4.6 Single-family dwellings’ year of construction distribution by census tract in Catalunya
**Construction typology**

Catalan single-family residences structure type is closely related to the constructions techniques prevailing during the construction period. At Catalunya, Chavez et al. (1999) reported three constructions periods: before 1950, between 1950 and 1970, and after 1970. The buildings constructed up to 1950 are mainly of mud and brick walls; predominating those with braces walls. Between 1950 and 1970 the buildings were mostly in brick walls; of these at least 50% lack of effective reinforced concrete straps and 50% had no bracing by the lack of cross walls to load bearing walls. Finally, buildings built after 1970 followed the same type of construction than in the previous period but in this case the buildings were standardized through building regulations (Real decret 1324/1972 MV-201, 1972) and since 1973, constructions had to fulfill the conditions of this norm. This period also introduced the type of construction of reinforced concrete, which is considered to cover about 25% of residential buildings built in this period.

As described above, there is a prevalence of the usage of heavy materials in the construction of single-family dwellings in Catalunya. This tendency might be also the result of the prevalence of these materials in the zone over light materials like wood (wood frame) or steel. Today, this trend continues and the distribution of residential construction licenses reported by Arroyo and Pérez (2008) for 2007, shows that only 6% of the constructions involved light structures (Table 4.1).

<table>
<thead>
<tr>
<th></th>
<th>Reinforced concrete</th>
<th>Metal frame</th>
<th>Load bearing walls</th>
<th>Mixed and others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Barcelona</strong></td>
<td>6823</td>
<td>987</td>
<td>2761</td>
<td>561</td>
<td>11132</td>
</tr>
<tr>
<td><strong>Girona</strong></td>
<td>2441</td>
<td>208</td>
<td>931</td>
<td>130</td>
<td>3710</td>
</tr>
<tr>
<td><strong>Lleida</strong></td>
<td>1855</td>
<td>81</td>
<td>582</td>
<td>110</td>
<td>2628</td>
</tr>
<tr>
<td><strong>Tarragona</strong></td>
<td>3258</td>
<td>174</td>
<td>1321</td>
<td>221</td>
<td>4974</td>
</tr>
<tr>
<td><strong>Catalunya</strong></td>
<td>14377</td>
<td>1450</td>
<td>5595</td>
<td>1022</td>
<td>22444</td>
</tr>
</tbody>
</table>
4.2 Meteorological conditions in Catalunya

We have compiled average temperatures and wind speeds across Catalunya by season and census tract. Average temperatures were taken from the Climatic Atlas of Catalunya (1997), which contains a map for every month with the distribution of average temperatures across Catalunya. Using the GIS Miramon, average temperatures were transferred to the census tract layer by month in a geo-referenced way; later, averages by seasons were computed (winter: December, January and February; spring: March, April and May; summer: June, July, August; autumn: September, October and November). Distributions obtained are shown in Figure 4.7, where a wide range of temperatures can be observed.

Wind speed data was not available in a GIS format. Therefore, the information was taken from the monthly average records of the 150 meteorological stations across Catalunya reported at the Anuari de dades meteorològiques (2003). Since there is not a meteorological station by census tract, average wind speed was estimated by comarca, the political subdivision of Spain’s provinces. As meteorological stations are located at different altitudes, all records were corrected to 3 m using the correction method of Eq. 2.53, and a terrain description of rural areas with low buildings. Distributions obtained are shown in Figure 4.8, where wind speeds are generally small ranging from 0.5 to 2.5 m/s.

In addition to average conditions, extreme conditions were also assessed. For temperatures, averages minimums or averages maximums were taken by season depending on which ones lead to a higher indoor-outdoor temperature difference, assuming an indoor temperature of 18 °C. Therefore, averages minimums were chosen for winter, spring and autumn while averages maximums for summer. Data was taken from the Digital Climatic Atlas of Catalunya (2001), and was transferred to the census tracts in a geo-referenced way using Miramon. Results obtained are shown in Figure 4.9. Concerning the wind speed, the averages of the daily maximums wind speeds by moth were taken from the Anuari de dades meteorològiques (2003) for each meteorological station. The data was also corrected to 3 m, as in the case of average wind speeds. Average maximums wind speeds by comarcas are presented in Figure 4.10.
Figure 4.7 Distributions of average temperatures (°C) in Catalunya by season
Figure 4.8 Distributions of average wind speed (m·s⁻¹) in Catalunya by season
Figure 4.9 Distributions of average extreme temperatures (°C) in Catalunya by season
Figure 4.10 Distributions of average maximums wind speeds (m·s⁻¹) in Catalunya by season

4.2.1 Climatic zones

In order to apply the LBNL airtightness model to Catalunya, we identified climatic zones present in Catalunya according to the criteria followed by the LBNL described in Table 2.9. In Catalunya, even the coldest zones, like Vall D’Aran or Pallars Sobirà, do not present more than 5050 HDD. Therefore, the classification was made based on annual precipitation and only humid and dry climates were considered, since they comprise the zones with less than 5400 HDD. Average outdoor temperature and precipitation by month were taken from the annuals
meteorological data report by month (Anuari de dades meteorològiques, 2003). The distribution of climatic zones by census tract obtained for Catalunya, are shown in Figure 4.11 where it can be seen that most of the territory present a humid climate and dry zones are located to the west.

![Figure 4.11 Distribution of climatic zones in Catalunya according to the LBNL airtightness model classification](image)

4.3 Estimation of the ACH distribution across Catalunya using the LBNL airtightness model

To compute the airtightness distribution of Catalan dwellings using the LBNL airtightness model (Eq. 2.45), we test two different approaches: one using the geometric means of dwellings characteristics by census tracts, and other using a stochastic simulation in order to represent each dwelling. In both situations, the possibility of floor leakage was not considered \( P_{\text{floor}} = 0 \) since crawl spaces in the construction type of Catalan dwellings, are very well insulated and therefore the possibility of airflow through the floor is considered negligible. Also, the possibility of participation in an energy-efficiency program and the possibility of classification as a low-income house were excluded \( P_{\text{eff}} = P_{L} = 0 \), since our aim was to assess the airtightness of standard houses.