Methodology for the characterization of the envelope airtightness of the existing housing stock in Spain

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ABSTRACT

It has already been proved that air leakage causes a great impact in the energy performance of buildings in cold climates. In recent years, many studies have been carried out in northern Europe, US and Canada. Regulations in these countries establish maximum air leakage rates for the construction of new dwellings and the refurbishment of the existing ones. However, there is a lack of knowledge relating to the housing stock in Spain.

In temperate climate countries, air leakage has traditionally been part of natural ventilation. On the one hand, current Spanish building regulations (CTE) establish controlled ventilation in dwellings to ensure indoor air quality (IAQ). On the other hand, air leakage is only considered concerning windows characteristics. Ventilation rates are calculated based on ideal airtight envelopes. Therefore, problems of over-ventilation, uncontrolled air flows, poor indoor air quality and energy consumption are caused.

A national research is being accomplished within INFILES project (2016-2018), where nine Universities on different locations are participating with coordinated field measurement campaigns.

The dwellings to be tested were chosen by establishing a nonprobability statistical sampling method. With the aim of representing the major characteristics of the Spanish housing stock in the most reliable way, a proportional quota sampling scheme was designed: as a consequence, 411 tests are being carried out in order to characterize the airtightness of the construction system of the envelope and to determine typical air leakage paths in dwellings. Stratification was performed with real data by taking into account different variables which have been proved to be relevant concerning airtightness: climate zone, year of construction and typology (single-family houses or multi-family buildings).

The air leakage rate is being determined using a standardized building pressurization technique, in accordance with UNE-EN 13829 and ISO 9972:2006 regulations. Typical air leakage paths are determined using infrared image technique. A specific software has been developed to retain dwellings characterization data: location, year of construction, typology, size, height, construction technology, property developer, retrofitting state, window area, energy systems, and others, up to a total of 140 parameters.

The aim of the project is to develop a wide database with representative samples of residential buildings in Spain. In this way, it will be possible to relate the main factors that have an

impact on airtightness. The main objective is to know ventilation rates due to air leakage and its energy impact in order to design guidelines with real data, which is obtained from the tests. A subsequent control regulation proposal for the envelope airtightness will be developed. Consequently, Spanish regulations will be consistent with European directives.

KEYWORDS

Air leakage; residential buildings; fan pressurization test; Blower Door

1 INTRODUCTION

In recent years, the interest on airtightness in buildings has significantly grown. European Directives [1] set the need to enhance the energy performance of buildings, which is affected by uncontrolled air leakage through the building envelope. The lack of airtightness can also cause problems of over-ventilation, thermal comfort, noise, uncontrolled air flows, poor indoor air quality (IAQ) and affect the health of its occupants.

Most European countries have already adapted their regulations [2], establishing maximum values of air leakage rates. However, there has not been a development of regulations in southern Europe. Still, some studies on airtightness have been carried out in recent years in Italy [3], Greece [4], Portugal [5],[6] and Spain [7],[8], [9] .

D'Ambrosio Alfano et al. [3] conducted an experimental study on 20 residential buildings in southern Italy focusing on metrological aspects, energy consumption and indoor comfort. Sfakianaki et al. [4] also performed 20 tests in dwellings in Greece, which were classified according to their airtightness level. They also performed a statistical test between regression coefficients of the measurements.

In Portugal, Ramos et al. [5] studied 49 apartments from two social housing neighbourhoods to investigate the impact of user behaviour on airtightness levels. Pinto et al. [6] carried out airtightness tests on 5 flats in Portugal with identical construction characteristics in the same building, with the aim of characterizing the air permeability of building and components.

In Spain, Tiberio and Branchi [7] tested more than 120 apartments of 25 recent buildings in northern Spain to determine the most important reasons for the increase of air leakage rates. Fernández-Agüera et al. [8] conducted Blower Door tests in 45 units in seven early twenty-first-century buildings in southern Spain. Results were reported and compared to the data of other buildings in southern Europe and a statistical analysis was performed.

Meiss and Feijó-Muñoz [9] established an evaluation procedure for the energetic effects of air leakage through an experimental study carried out in 13 dwellings in residential blocks, located in the north and central part of Spain. It has been estimated that air leakage in Spain represents between 10.5 and 25.4% of winter energy demand in buildings built under the current Spanish Technical Building Code (CTE) [10], between 21.9 and 27% in buildings subject to CT-79 Regulations [11] and between 11.3 and 13.0% in old buildings without energy regulation (but retrofitted by their owners) [9].

In order to provide a response to the lack of knowledge in this field in Spain, a national research is being accomplished within *INFILES* project BIA2015-64321-R (2016-2018): *Energy impact of airtightness level in residential buildings in Spain: analysis and characterization of the air leakage*.

A wide database with representative samples of residential buildings in Spain is being developed. The aim of the research project is to understand the airtightness behaviour of the architectural envelope in the Spanish residential building stock by means of an experimental and numerical study, which is being carried out throughout the Spanish geography. Air leakage rates of typical construction system solutions are being characterized and quantified. Guidelines for Spanish regulations, which currently do not consider airtightness, will be proposed in order to be consistent with European directives.

2 REGULATIONS IN SPAIN

In Spain and Mediterranean countries, ventilation has traditionally been done in a natural way. Thus, air leakage supplied the lack of mandatory ventilation systems [8]. Regulations have tended to an increasing thermal insulation of that envelope, which led to a better energy performance of buildings. However, it also affected IAQ as a consequence of the lack of ventilation. To solve this, in 2006, Spanish regulations [12] implemented specific ventilation systems to assure an adequate IAQ. Nevertheless, ventilation rates are calculated based on ideal airtight envelopes and air leakage is not considered, resulting in oversized ventilation systems.

Currently, air leakage is only taken into account concerning windows characteristics (Table 1), as part of the *DB-HE "Limitation of the energy demand"* [13].

Table 1: Maximum airtightness values for the elements of the envelope concerning climate zones in winter[$m^3/h{\cdot}m^2$] at a pressure difference of 100Pa

Parameter	Zone α	Zone A	Zone B	Zone C	Zone D	Zone E
Windows airtightness	≤50	≤50	≤50	≤27	≤27	≤27

Zone α refers the Canary Islands climate, zones A and B mild-climate areas and zones C, D and E to cold climates.

3 METHODOLOGY

3.1 Sampling

A sampling has been carried out with the aim of reproducing the Spanish building stock to extrapolate the results to other cases in similar conditions defined by its parameters.

As Price et al. [14] mentions, the best way to estimate the relevant statistical distribution of leakage parameters would be to perform measurements in a simple random sample of dwellings. However, such a sampling strategy would be impractical, since it would require significant resources. Taking into account the objectives and characteristics of the present research, a quota sampling scheme has been considered, even though uncertainty is always larger with a non-probability sampling than with a simple random sample. The Spanish housing-stock is partitioned into non-overlapping groups called strata.

A proportional allocation is established. That is, the number of samples per stratum is determined proportional to its size (Equation 1):

$$\mathrm{N_i} = \mathrm{n} \cdot \frac{N_\mathrm{i}}{\mathrm{N}} \qquad (1)$$

where:
N_i = sample size of stratum i.
n = sample size.
N_i = population size of stratum i.
N = population size.

3.1.1 Parameters considered

Previous studies, which have established predictive models in residential buildings based on factors directly related to airtightness, have been assessed (Table 2).

Table 2: Parameters considered in previous characterization studies.

Parameter	Sfakianaki et al. (2008)	Price et al. (2006)	Orme et al. (1994)	McWilliams et al. (2006)	Sherman (2006)	Chan et al. (2012)	Erinjeri et al. (2009)	Zou (2010)	Montoya et al. (2010)	Pan (2010)	Krstic et al. (2015)
Age of the building	x		x	x	x	x	x	x	x		x
Type of construction/ construction building system	x	x	x					x	x	x	x
Floor area		x		x	x	x	x		x	x	
Climate zone	x			x	x	x	x			x	
Height/number of storeys		x			x	x		x	x		
Type of foundation/floor structure			x	x		x		x			
Energy-Efficiency Programs				x	x	x		x			
Significant penetrations										x	
Economic status				x	x	x					
Surface area								x		x	x
Ducted air system through unconditioned space			x			x					
Ventilation type/presence of ducts				x				x			
Joinery/sealing			x								x
Retrofitting work/renovation						x		x			
Insulation position/thickness									x		x
Window frame length	x							x			
Complex floor plan			x		x						
Air barrier			x							x	
Design target										x	
Management context										x	
% transparent part of the envelope											x
Windows/glazing											x
Installation layer								x			
Heating system									x		

The majority of the studies agree that the most relevant parameters are the age of the building, type of construction/materials, floor area and climate zone. It is assumed that if the sample reproduces the building stock with respect to important characteristics, it will reproduce it in the same way with respect to minor characteristics.

The age of the building has an impact on airtightness in several ways. Firstly, materials and their joints become deteriorated overtime [15]. An increase of 10-15% on air leakage every 10 years has been estimated [16], [17]. Secondly, construction systems are developed and improved. However, in milder-climate countries, where there is no airtightness standard for new buildings, recent dwellings are not necessarily more airtight than older ones [18]. Thirdly, the age of the building is associated with regulations, which establish requirements and conditions the building construction systems.

It has been considered advisable to eliminate floor area as a parameter. The representativeness of the sample would be ensured, since a parallelism between the year of construction and the floor area has been found. Greater surfaces are registered in houses before 1900, 1980s and

1990s, whereas in the 1950s and 1960's the houses were designed with markedly inferior floor areas [19].

Construction building system is not initially used as a sampling parameter because statistical sources do not contemplate its actual distribution in the housing stock in Spain. Regarding type of construction, most studies focus on the characterization of single-family housing. However, in Spain multi-family buildings represent more than 70% of real estate [20], so the study must inexorably reflect both typologies, with particular focus on multi-family dwellings.

Climate zone has also an important influence on airtightness of dwellings. Buildings in cold climates tend to be tighter due to comfort and energy behaviour, whereas in milder climates dwellings are leakier [16]. Climate zones not only determine weather conditions, but also building systems and regulations [21].

All things considered, the sampling method takes into account objective parameters whose distribution is known. Age of the building involves 10 periods of time, according to data sources [19]; typology is considered within two categories (single-family and multi-family buildings) [19]; a wide variety of climate zones is covered, divided into 4 areas: Oceanic, Continental (cold climates), Mediterranean (mild climate) and Hot desert area (Canary Islands) (Figure 1).

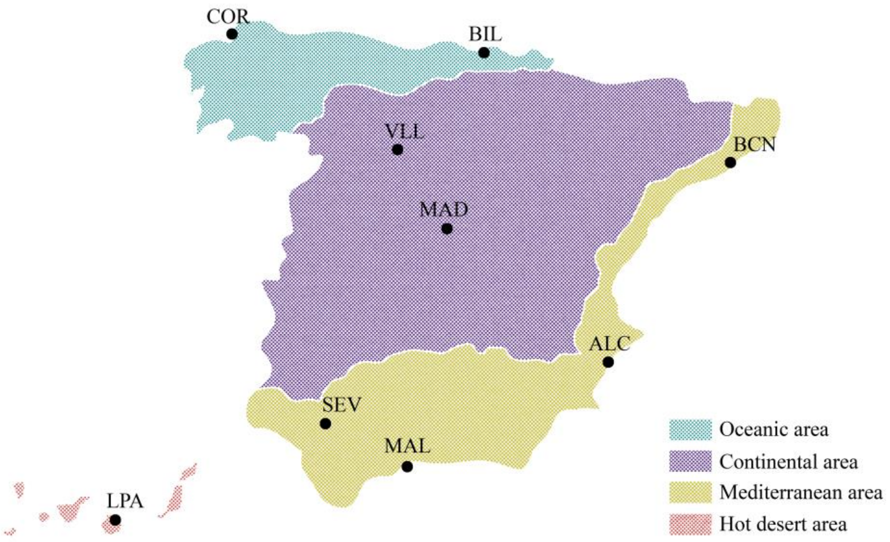


Figure 1: Location of the participant universities and climate zones in Spain.

where:
COR: La Coruña. Universidad de la Coruña
BIL: Bilbao. Universidad del País Vasco
VLL: Valladolid. Universidad de Valladolid
MAD: Madrid. Universidad San Pablo CEU
BCN: Barcelona. Universidad Politécnica de Cataluña
ALC Alicante. Universidad de Alicante
MAL: Málaga. Universidad de Málaga
SEV: Sevilla. Universidad de Sevilla
LPA: Las Palmas. Universidad de las Palmas de Gran Canaria

3.1.2 Size and distribution of the sample

The number of tests is conditioned by the purpose of the study, the accepted accuracy, the availability of the resources and the duration of the research project. Since the kind of sampling used has a probabilistic structure, the formulation used to obtain the sample size in random processes for large populations is used (Equation 2).

$$n = \frac{Z^2 \sigma^2}{E^2} \qquad (2)$$

where:
Z is the critical value, depending on the confidence level.
σ is the population standard deviation (unknown value in Spain)
E is the margin of error
n is the sample size

σ value has been calculated from an experimental study carried out in Italy [3], due to the similarity of both contexts and related climate conditions. Considering Z = 1.96 for a confidence level of 95%, σ = 17.584 and E = ±0.4, a sample size of 423 tests is obtained. Due to the numerical rounding made in the stratification, the total sum of tests is slightly reduced (411). The specific sample distribution is detailed in Table 3.

Table 3: Sample distribution

		Oceanic		**Continental**		**Mediterranean**				**Hot desert**
Age of the building	**Type**	**COR**	**BIL**	**VLL**	**MAD**	**BCN**	**ALC**	**MAL**	**SEV**	**LPA**
<1900	S	1	-	-	-	1	1	-	-	-
	M	-	1	-	2	3	-	-	-	-
1900-1920	S	1	-	-	-	1	-	-	-	-
	M	-	1	-	2	3	-	-	-	-
1921-1940	S	1	-	-	-	1	-	-	-	-
	M	-	1	-	3	4	-	-	-	-
1941-1950	S	1	-	-	-	1	1	-	1	-
	M	-	1	-	3	3	1	-	1	-
1951-1960	S	1	-	-	1	1	1	1	1	-
	M	1	3	-	8	7	1	1	1	1
1961-1970	S	1	-	-	1	2	1	1	2	1
	M	3	7	2	19	19	5	3	4	2
1971-1980	S	1	-	-	3	3	2	2	2	1
	M	5	5	2	23	22	8	6	5	2
1981-1990	S	1	-	-	3	3	3	2	2	1
	M	2	1	1	9	6	5	5	2	2
1991-2001	S	1	-	1	4	3	2	2	3	1
	M	3	2	1	13	10	3	4	3	2
2002-2011	S	2	-	1	3	2	3	1	3	1
	M	6	3	1	13	9	12	6	3	2
	TOTAL	31	25	9	110	104	49	34	33	16

where:
S: single-family houses
M: multi-family dwellings

3.2 Testing method.

Measuring campaigns are organized between late 2016 and 2017, taking into account the number of tests to be carried out on each location and the typical climatic conditions, since regulations [22] restrict wind velocity during the test.

All the tests are being performed following a determined common protocol which includes the preparation of the dwellings and the cases classification proceeding.

Tests are conducted according to EN-13829 [22] and ISO 9972:2015 [23] with a Fan pressurization method, commonly called Blower Door Test using an automated performance test. Depressurization and pressurization tests are carried out within the deliberately conditioned space. During the test, all openings of the envelope are closed or sealed [22]. Measurements of air flow rate and indoor-outdoor pressure difference are taken over a range of applied pressure differences in increments of 6 Pa. The minimum pressure difference is 11 Pa and the highest-pressure difference is 65 Pa.

The building leakage curve is calculated as:

$$q = C \cdot \Delta p^n \qquad (3)$$

where:
q is the air flow rate through the building envelope [m^3/h]
C is the air leakage coefficient [$m^3/(h \cdot Pa^n)$]
Δp is the induced pressure difference [Pa]
n is the air flow exponent (0.5-1 for fully developed turbulent and laminar flow respectively).

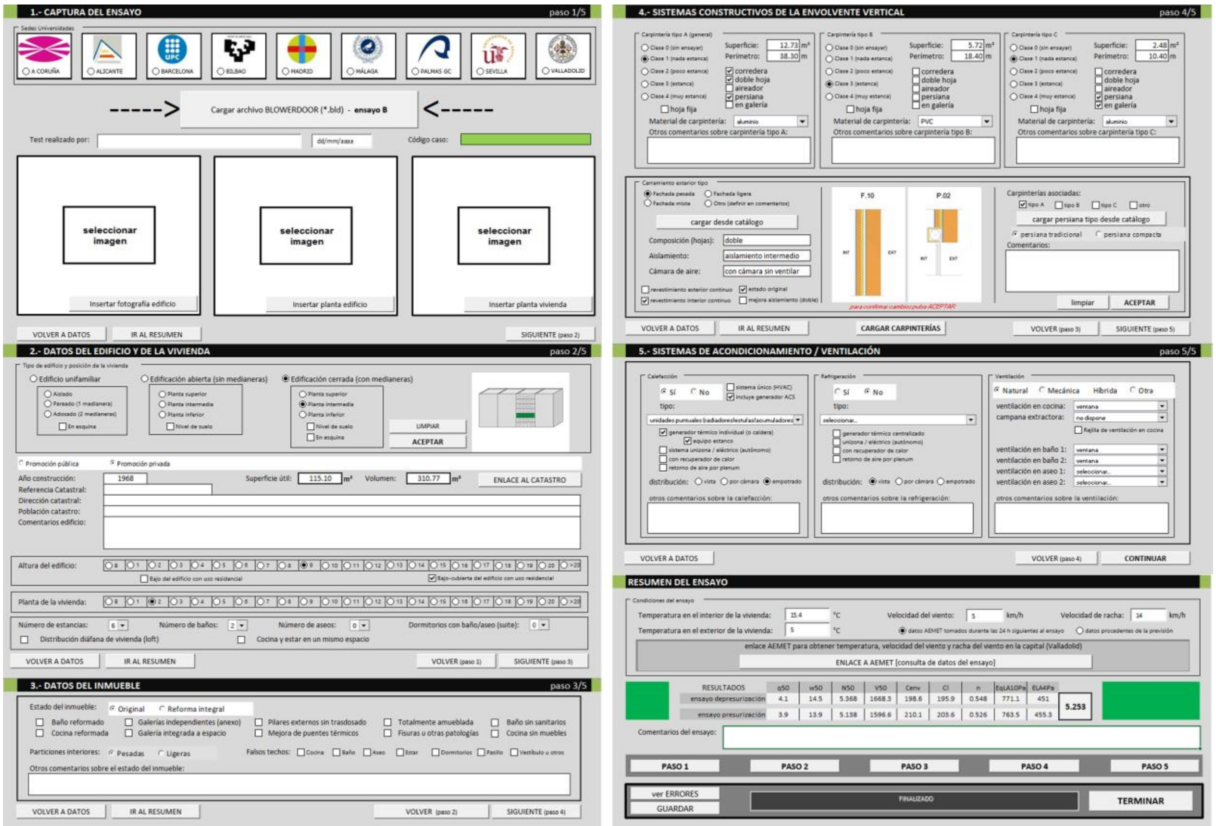
Methods A (test of the building in use) and B (test of the building envelope) are performed as describe in EN-13829 [22]. The fan is mounted on the main door. During the depressurization stage, leakage paths are identified using infrared image technique with a thermographic camera.

3.3 Parameters under study

A specific tool, *infil-APP* (Figure 2), has been developed to retain dwellings characterization data in a dataset format. The objective is the fulfilment of a wide database for a subsequent analysis of the parameters that have a major influence on airtightness.

The tool has been conceived for easy, fast and intuitive use. It retains: graphic information, test results, climatic conditions during the test and a wide characterization of parameters; and stores them tabulately. Year of construction, location, detailed dimensions (net floor areas, envelope surface areas and internal volumes), heat loss form factor, typology of the building and its position with respect to adjacent houses or apartments, property developer, height, number of rooms, retrofitting state, furnishing, presence of false ceilings, construction technology, area and perimeter of window frames and blinds, energy and ventilation systems, among others, are also saved. Once each case study is completed, a full report and a data sheet are obtained.

Figure 2: *Screenshots of infil-APP*.



Airtightness values of the buildings will be compared taking into account 50 Pa as a reference pressure. Air change rate (n_{50} value) and air permeability (q_{50} value) is analysed, considering the inner volume of the measured building and the envelope area respectively.

4 CONCLUSIONS

A rigorous and simple methodology has been established in order to carry out coordinated field measurement campaigns. The aim of INFILES project (ref. BIA2015-64321-R) is to know the behaviour of the envelope of the housing stock in Spain regarding airtightness. A quota sampling scheme has been designed to create a wide database, taking into account different parameters related to air leakage: climate zone, year of construction and typology (single-family houses or multi-family buildings).

With *infil-APP*, characterization data and results are being retained in a homogeneous dataset. In this sense, a subsequent analysis of the results can be performed, guaranteeing the same proceedings and criteria.

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