Airtightness and energy impact of air infiltration in residential buildings in Spain

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ABSTRACT

Addressing the airtightness of the building envelope is key to achieve thermal comfort, good performance of ventilation systems and to avoid excessive energy consumption. Previous studies have estimated an energy impact on infiltration on the heating demand between 2 and 20 kWh/(m^2·y) in regions with temperate climates. In Spain, this issue has not yet been addressed in depth. This study aims to assess the energy impact of uncontrolled air flows through the building envelope in residential buildings in Spain. For this purpose, airtightness results of more than 400 blower door tests have been analyzed. Multi-family and single-family dwellings built in several periods and located in 9 regions with different climate characteristics have been studied. Infiltration was found to have an energy impact in the range 2.43 – 19.07 kWh/(m^2·y) for the heating demand, whereas it is not so significant regarding the cooling demand. The obtained results show great potential for energy saving in the country.

KEYWORDS

Air leakage; Blower Door, energy impact; residential buildings; fan pressurization test

1 INTRODUCTION

The European Union is committed to reducing greenhouse gas emissions, establishing a sustainable, competitive and decarbonised energy system by 2050. It is estimated that buildings are responsible for approximately 36% of all CO_2 emissions and that almost 50% of the final energy consumption of the Union is used for heating and cooling. 80% of it is consumed in buildings (European Parliament 2018). Therefore, it seems essential to establish strategies that support the renovation of national buildings stocks, facilitating their transformation into nearly zero energy buildings (nZEB).

In this context, one of the factors that have a great impact is the presence of air infiltration. The constant improvement and EPB-requirements in the transmittance of the construction elements has led to the grown relevance or the entrance of outdoor air in the total energy consumed by the residential sector.

In Mediterranean countries, however, airtightness has still not been broadly addressed. The fact that ventilation is not controlled and normally done by manually opening the windows, means that air infiltration is the only continuous air inlet. It has already been estimated that the energy impact of air infiltration on the heating demand can account for around 10 kWh/(m^2·y) in regions with a moderately cold climate (2500 degrees-day) (Carrié and Wouters 2013), or an increase on the heating demand from 5 to 20 kWh/(m^2·y) in countries with temperate climates (Spiekman 2010). In Spain, it has been estimated that air infiltration can be responsible for up to 27.4% of the energy demand (Meiss and Feijó-Muñoz 2014).

National building regulations in Spain are gathered in the National Building Code (CTE), which was first released in 2006 and updated several times so far (Ministerio de Fomento del Gobierno de España 2017). Requirements regarding the limitation of energy demand are gathered in DB HE. Concerning airtightness, there is only a limitation on the permeability of windows depending on the climate zone. That means that global airtightness is not taken into account in spite of the increasing weight of the energy impact of air leakage on the overall energy performance of buildings. A new update of CTE is expected to be released in 2019. Although measures are taken to implement nZEB following European Directive 2018/844 (European Parliament 2018) on the energy performance of buildings and energy efficiency, no update regarding airtightness is expected.

However, even though regulations in Spain do not include airtightness requirements of the whole building envelope, the official tools for the EPB-requirements verification consider air infiltration as a parameter. Global permeability is calculated considering permeability of doors and windows, air leakage of the opaque part of the envelope and air inlets. Since tests performance is not mandatory, default values are almost always used: 0.63 h^{-1} for residential buildings and 0.80 h^{-1} for tertiary.

Given the relevance of airtightness from an energy point of view, the purpose of this paper is to analyze the energy impact of air infiltration in Spain from real airtightness measurements in order to evaluate its importance in the total energy consumption in dwellings.

2 METHODOLOGY

2.1 Sample

Since airtightness is not mandatory in Spain, there is a lack of data on air infiltration in buildings. Tests are only performed to comply with specific energy programmes (Passivhaus, BREEAM, LEED, etc.), by constructors who wish to ensure the quality of construction or as a diagnostic tool in case of poor energy performance of the building or before retrofitting actions. In any case, this data is scarce, not publicly available and belong to a very specific type of buildings, which are not representative of the housing stock of the country. Some studies on airtightness in Spain have already been carried out so far focused on the specific type of dwellings (Meiss and Feijó-Muñoz 2014; Jiménez Tiberio and Branchi 2013; Fernández-Agüera et al. 2016). Recently, another study established a database with more than 400 representative cases (Feijó-Muñoz et al. 2018), which will constitute the sample for this study.

The considered database includes cases in different climate zones, built in different periods of time and gathers both single and multi-family dwellings. The dwellings tested were chosen based on a representative sample of the existing housing stock in Spain by means of a non-probabilistic quota sampling scheme.

The most represented climate areas were Mediterranean (209 cases located in Barcelona (BCN), Alicante (ALC), Málaga (MAL) and Sevilla (SEV)) and Continental (129 cases located in Madrid (MAD) and Valladolid (VLL)), but also Oceanic (47 cases located in Bilbao (BIL) and La Coruña (COR)) and the Canary Islands (16 cases located in Las Palmas de Gran Canaria (LPA)) were included in the sample. The age of the cases tested was proportional to the existing building stock, being the periods 1960-1979 (37%) and 1980-2006 (39.5) the most represented ones. Concerning typology, 325 cases were apartments (81%) and 76 cases were single-family houses (19%).

2.2 Testing method

The assessment of the building airtightness was approached by means of the fan pressurization method, according to ISO 9972 (International Organization for Standardization 2015). Regarding building preparation, any intentional opening in the building envelope was closed or sealed (Method B). The correct calibration of the equipment was ensured to maintain accuracy specifications of 1% of reading, or 0.15 Pa. On the other hand, according to ISO 9972, the overall uncertainty is highly dependent upon the environment during the test, being lower than 10% in most cases in calm conditions.

The infiltration curve is calculated as follows (Equation 1):

$$V_{env} = C_{env}(\Delta p^n) \quad (1)$$

where:

V_{env}: air flow rate through the envelope of the dwelling [m^3/h]

C_{env}: air flow coefficient [$m^3/ (h \cdot Pa^n)$]

Δp: induced pressure difference [Pa]

n: pressure exponent [-]

In order to compare air leakage rates, the air flow rate values were normalized by the building thermal envelope area, A_E [m^2] and internal volume V [m^3], and reported at 50 Pa, q_{50} [$m^3/(h \cdot m^2)$] and n_{50} [h^{-1}] respectively, interpolated from measurements. However, operational pressure differences are typically an order of magnitude lower than 50 Pa at around 4 Pa (Jones et al. 2015). There have been many studies in this regard so far. The first studies that first assessed the relationship between n_{50} and n_{nat} (air change rate in natural conditions) where carried out in the 70' and 80' (Kronvall 1978), (Persily and Linteris 1983). Subsequently, Sherman (Sherman 1987) reported a linear relationship (Equation 2), which is often refered as the *Sherman's ratio*:

$$n_{nat} = \frac{n_{50}}{20} \quad (2)$$

Sherman developed this model, maintaining the assumption of a linear relationship between the air change rate at a pressure difference of 50 Pa and under natural conditions but considering an empirical correction factor N scaling it according to local climate, air leakage path size, dwelling height and shielding (Equation 3).

$$n_{nat} = \frac{n_{50}}{N} \quad (3)$$

This model has been broadly applied in national building codes and standards, although it must be emphasized that the use of a scaling factor is a simplified treatment of a complex reality (Chan et al. 2005). Furthermore, it is worth mentioning that it does not allow to distinguish the origin of air infiltration in the case of apartments in buildings. In this case, given that the study is a first approximation to the energy impact of air infiltration in Spain, a simplified model has been addressed and the most unfavourable situation was approached, considering that the whole air infiltration is produced in the surface in contact with the outdoor environment.

2.3 Energy impact assessment

Infiltration can contribute a significant amount to the overall heating or cooling load of a building (Buchanan and Sherman 1998). Several models have been developed so far but there is no common criterion about the appropriate model to evaluate the energy impact of infiltrations. The energy load was obtained by means of a simplified model using the classical infiltration calculation (Equation 4).

It is obtained as a product of the air infiltration flow, the specific air capacity and the temperature difference between the inside and the outside of the dwelling. The concept of degree-day was applied, relating the average temperature outside the tested dwelling and the comfort indoor temperature (21°C for heating and 25°C for cooling). It is important to note that this estimation is theoretical and real energy consumption depends on the particular temperature conditions of the dwellings (Feijó-Muñoz et al. 2019). Some authors have emphasized that this method might be well acceptable when calculating the load due to concentrated leakage (through large openings, short paths), but it could entail a considerable overestimation of the energy impact in the case of diffuse leakage (small cracks, where heat exchange between the infiltrating air and the wall may occur) (Younes, Shdid, and Bitsuamlak 2012).

$$Q_{inf} = C_p \cdot G_t \cdot V_{inf} \quad (4)$$

where:

Q_{inf} is the annual energy loss [kWh/y] due to air infiltration for heating Q_{inf-H} and cooling Q_{inf-C}. Annual energy losses are expressed per unit area

C_p is the specific heat capacity of the air, which is 0.34 Wh/(m^3·K)

G_t are the annual degree days [kKh/y], both for heating (G_{t-C}) with a base comfort temperature of 21 °C, and for cooling (G_{t-R}) with a base comfort temperature of 25 °C

V_{inf} is the air leakage rate [m^3/h]

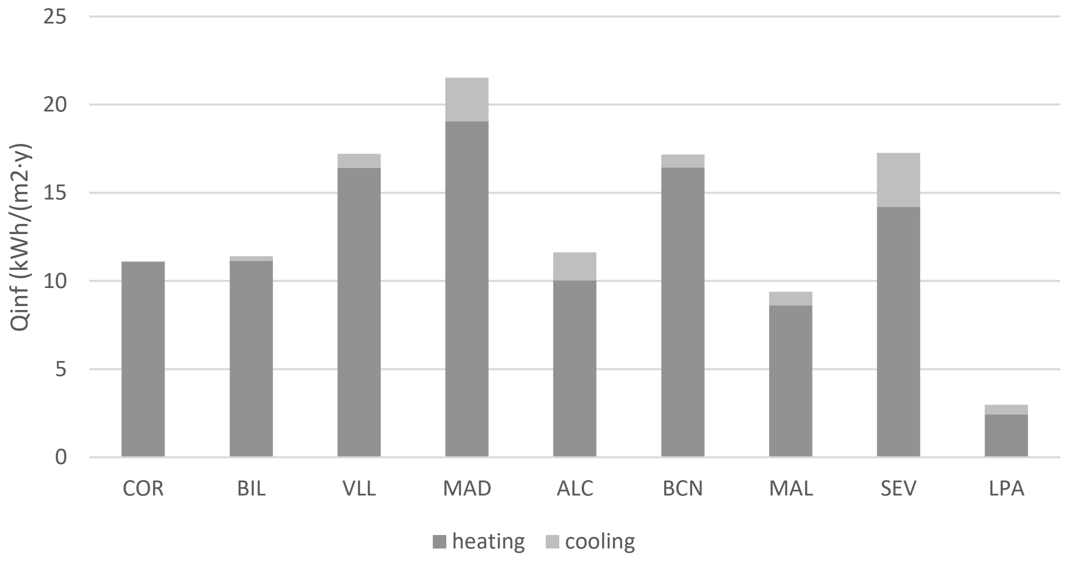
3 RESULTS AND DISCUSSION

Averaged main results sorted by location of the dwellings are shown in Table 1. The energy impact estimation of the air infiltration was obtained, both for the heating and cooling demand (Figure 1). Furthermore, the relative impact of air infiltration on the heating and cooling demand has been approached based on reference demand values used in energy certification of existing buildings (IDAE 2011) (Figure 2).

Table 1: Airtightness results and energy impact due to air infiltration

Parameter	unit	COR	BIL	VLL	MAD	BCN	ALC	MAL	SEV	LPA
n_{50}	h^{-1}	4.61	4.67	4.99	7.29	9.73	7.78	6.89	8.88	5.43
q_{50}	m^3/(h·m^2)	3.58	3.47	3.76	5.93	7.49	6.26	5.16	6.81	4.60
n	-	0.62	0.62	0.64	0.61	0.59	0.61	0.60	0.58	0.59
Q_{inf-H}	kWh/(m^2·y)	11.10	11.15	16.41	19.07	16.44	10.02	8.61	14.21	2.43
Q_{inf-C}	kWh/(m^2·y)	0.02	0.26	0.80	2.47	0.73	1.60	0.78	3.06	0.54
$\%_{-H}$	%	11	11	10	15	18	18	20	25	0
$\%_{-c}$	%	0	0	9	12	5	5	2	6	2

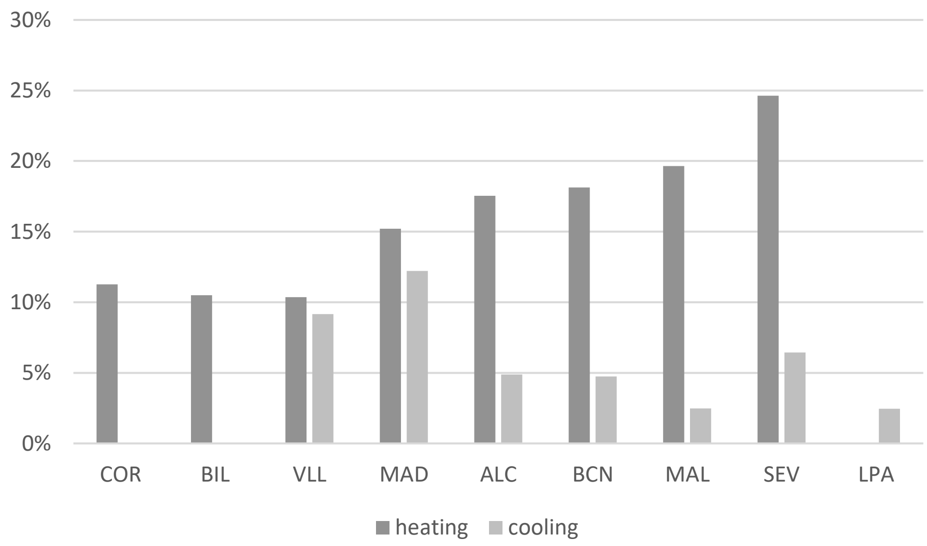
Figure 1: Anual energy impact due to air infiltration



Maximum permeability values (q_{50}) were found in Mediterranean areas such as Barcelona, Sevilla and Alicante, whereas dwellings with a better airtightness performance were located in the north of the country (A Coruña, Bilbao and Valladolid). The pressure exponent, n, is in all the locations close to 0.6.

Air infiltration has a greater impact on the heating demand, especially in cities with a continental climate such as Madrid or Valladolid. Values of up to 19.07 kWh/(m^2·y) have been obtained in the case of Madrid, while in cities with a milder climate such as Las Palmas de Gran Canaria, the value is reduced to 2.43 kWh/(m^2·y). In the case of the cooling demand, the energy impact of air infiltration is lower, with maximum values of 3.06 kWh/(m^2·y) in the case of Sevilla. In other locations such as A Coruña or Bilbao, the impact on the demand for refrigeration becomes residual.

Figure 2: Relative impact of air infiltration on the heating and cooling demand



Regarding the relative impact of air infiltration, values up to 25% corresponding to the heating demand or 12% for cooling demand were obtained.

4 CONCLUSIONS

In Mediterranean countries with mild climates and where ventilation has traditionally been done in a natural way, the concern regarding airtightness is still scarce. However, air infiltration cannot be ignored any more in a context where huge efforts are being made to transform the existing stock into nZEB. It seems to be time to face a change in building construction traditions and regulations, addressing airtightness properly.

From the results obtained in the present study, it can be derived the enormous impact that air infiltration through the building envelope has in Spain. The impact is greater on the heating demand, while the impact for cooling can be residual in Atlantic areas. Maximum values of up to 19.07 kWh/(m^2·y) for the heating demand have been obtained in the case of Madrid, or up to 3.06 kWh/(m^2·y) in the case of the cooling demand in Sevilla. In relative terms, air leakage entails up to 25% of the heating demand and up to 12% of the cooling demand. These results are in line with the values previously stated in other studies.

Therefore, the energy impact of air infiltration in existing residential buildings of Spain is a question to consider necessarily given its demonstrated relevance. Consequently, compliance with the European Directive 2018/844 seems only possible by paying special attention to airtightness, implementing limitations in this respect applicable both to the design of new buildings and to the renovation of the existing housing stock.

Nevertheless, a larger sample and a deeper analysis of the data should be considered in order to draw more accurate conclusions.

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