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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 ofventilation systems and to avoid excessive energy consumption. Previous studies have estimated an energy impact of infiltration on the heating demand between 2 and 20 kW h/(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 airflows through the envelope in residential buildings in Spain. For this purpose, airtightness results of more than 400 blower door tests have been analysed. Multi-family and single-family dwellings built in several periods and located in nine regions with different climate characteristics have been studied. Infiltration was found to have an energy impact in the range 2.43–19.07 kW h/(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.

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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 EU is used for heating and cooling. Eighty percent (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 has a great impact is the presence of air infiltration.

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 supply. It has already been estimated that the energy impact of air infiltration on the heating demand can account for around 10 kW h/(m^2 y) in regions with a moderately cold climate (2500 degrees-day) (Carrié & Wouters, 2013), or an increase on the heating demand from 5 to 20 kW h/(m^2 y) in countries with temperate climate (Spiekman, 2010).

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National building regulations in Spain are gathered in the National Building Code (CTE), which was first released in 2006 and has been updated several times so far (Ministerio de Fomento del Gobierno de España, 2017). Requirements regarding the limitation of the energy demand in dwellings are gathered in its Basic Document "Energy saving" (DB HE). Concerning airtightness, there is only a limitation on the permeability of windows depending on the climate zone, not considering global airtightness. That means that the energy impact of air infiltration has increased its weight on the overall energy performance of buildings, given the constant improvement of the thermal transmittance of the building envelope without concern on airtightness. A new update of CTE is expected to be released in 2020. 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. Since tests performance is not mandatory, global permeability is calculated based on the permeability of doors and windows (from default values depending on its classification), the permeability of the opaque part of the envelope (from default values depending on building typology) and air inlets (default value).

Given the relevance of airtightness from an energy point of view, the purpose of this paper is to analyse 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 there are no building airtightness requirements in Spain, testing is not mandatory and therefore there is a lack of data in this regard. 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 focussed on a specific type of dwelling have already been carried out in Spain so far (Fernández-Agüera et al., 2016; Jiménez Tiberio & Branchi, 2013; Meiss & Feijó-Muñoz, 2015). 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 several 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 representative 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 vintage of the cases tested was proportional to the existing building stock, being the periods 1960–1979 (37%) and 1980–2006 (39.5%) the most representative 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 pressurisation 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)):

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

where V_{env} is the airflow rate through the envelope of the dwelling (m^3/h), C_{env} the airflow coefficient (m^3/(h Pa^n)), Δp the induced pressure difference (Pa), n the pressure exponent (–).

In order to compare air leakage rates, the values of the airflow rate were normalised by the building envelope area, A_E (m^2) and internal volume V (m^3), and reported at a normalised pressure difference of 50 Pa, q_{50} (m^3/(h m^2)) and n_{50} (h^{-1}), respectively, interpolated from measurements.

However, operational pressure differences are typically an order of magnitude around 4 Pa, much lower than 50 Pa (Jones et al., 2015). There have been many studies in this regard so far. The studies that first assessed the relationship between n_{50} and n_{nat} (air change rate under natural conditions) were carried out in the 70′ and 80′ (Kronvall, 1978; Persily & Linteris, 1983). Subsequently, Sherman (1987) reported a linear relationship considering an empirical correction factor N scaling it according to local climate, air leakage path size, dwelling height and shielding (Equation (2))

$$n_{nat} = \frac{n_{50}}{N} \tag{2}$$

This model has been broadly applied in national building codes and standards, although it must be emphasised that the use of a scaling factor is a simplified treatment of a complex reality (Chan et al., 2005).

2.3. Energy impact assessment

Infiltration can contribute significantly to the overall heating or cooling load of a building (Buchanan & 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 (3)).

It is obtained as a product of the air infiltration flow, the volumetric 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 emphasised 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 et al., 2012)

$$Q_{inf} = C_p \cdot G_t \cdot V_{inf} \tag{3}$$

where Q_{inf} is the annual energy loss (kW h/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 volumetric heat capacity of the air, which is 0.34 W h/(m^3 K), G_t are the annual degree days (kK h/y), both for heating

(G_{t-H}) with a base comfort temperature of 21 °C, and for cooling (G_{t-C}) with a base comfort temperature of 25 °C. V_{inf} is the air leakage rate (m^3/h), defined according to Equation (4):

$$V_{inf} = n_{nat} \cdot V \tag{4}$$

Furthermore, it is worth mentioning that the non-guarded pressurisation testing method used does not allow to distinguish the origin of air infiltration in the case of apartments in buildings. It has been estimated in previous studies that inter-zonal leakages can account for a wide range between 2% and more than 60% of the total air leakage (Villi et al., 2013). 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 through the surface in contact with the outdoor environment.

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 (Figure 2). These values were obtained with the software LIDER, using representative typologies and construction systems (IDAE, 2011). Given that reference values are given by typology, they were averaged.

A widespread of the airtightness results was found within the range 1.19–39.42 h^{-1} for the air change rate n_{50} and from 0.96 to 29.92 m^3/(h m^2) in the case of the air permeability rate q_{50}. The distribution of the data was found to be non-normal, according to Kolmogorov–Smirnov normality test using the extended tool IBM SPSS Statistics. Considering the air change rate (n_{50}) of the whole sample, a mean value of 7.52 h^{-1}, a median of 6.39 h^{-1} and a standard deviation of 4.91 were found. Maximum values were found in Mediterranean areas such as Barcelona ($n_{50} = 9.73$ h^{-1}), Sevilla ($n_{50} = 8.88$ h^{-1}) and Alicante ($n_{50} = 7.78$ h^{-1}), whereas dwellings with better airtightness performance were located in the north of the country: A Coruña ($n_{50} = 4.61$ h^{-1}), Bilbao ($n_{50} = 4.67$ h^{-1}) and Valladolid ($n_{50} = 4.99$ h^{-1}).

From a regulatory point of view, since, as already mentioned, there are no requirements in Spain, a comparison has been made with other countries' standards. Most of the cases tested would comply with regulations in the UK or Ireland, where limitations have been implemented for new dwellings: $q_{50} < 10$ or 7 m^3/(h m^2), respectively. However, results are above regulations in other countries such as Germany ($n_{50} < 3$ h^{-1} in buildings with natural ventilation). On the other hand, as it could be expected, the results obtained are in any case far from LEED puncturable values (1.5–4.25 h^{-1}, depending on the climate zone) or Passivhaus airtightness requirement ($n_{50} < 0.6$ h^{-1}), which seems to have become the target value in some areas like Sweden or

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

Parameter	Unit	COR	BIL	VLL	MAD	ALC	BCN	MAL	SEV	LPA
n_{50}	h^{-1}	4.61	4.67	4.99	7.29	7.78	9.73	6.89	8.88	5.43
q_{50}	m^3/(h m^2)	3.58	3.47	3.76	5.93	6.26	7.49	5.16	6.81	4.60
n	–	0.62	0.62	0.64	0.61	0.61	0.59	0.60	0.58	0.59
A_E	m^2	331.3	235.5	310.3	288.2	296.49	286.1	274.5	275.2	457.2
V	m^3	255.7	176.1	244.6	244.9	250.8	231.3	209.8	226.9	412.2
G_{t-H}	kK h/y	54.89	56.86	80.09	63.48	33.24	44.90	34.46	38.50	9.86
G_{t-C}	kK h/y	0.12	1.32	3.91	8.21	5.30	1.99	3.12	8.30	
Q_{inf-H}	kW h/(m^2 y)	11.10	11.15	16.41	19.07	10.02	16.44	8.61	14.21	2.43
Q_{inf-C}	kW h/(m^2 y)	0.02	0.26	0.80	2.47	1.60	0.73	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

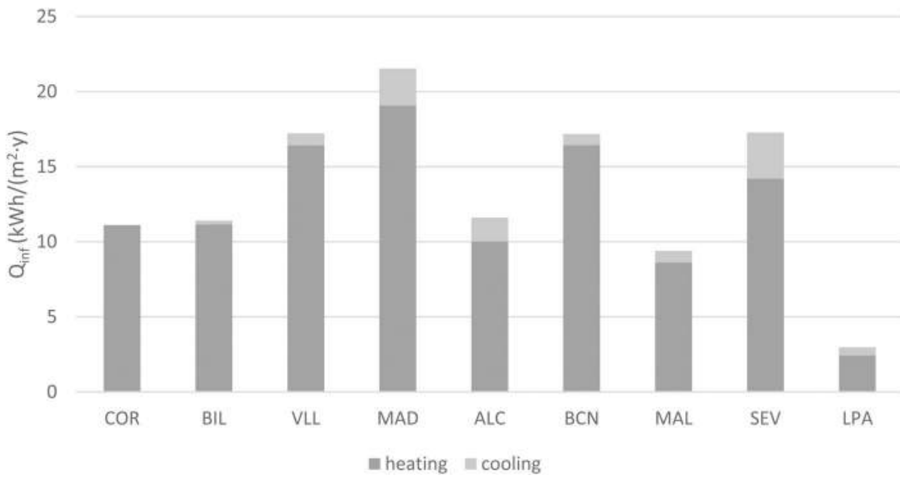

Figure 1. Annual energy impact due to air infiltration.

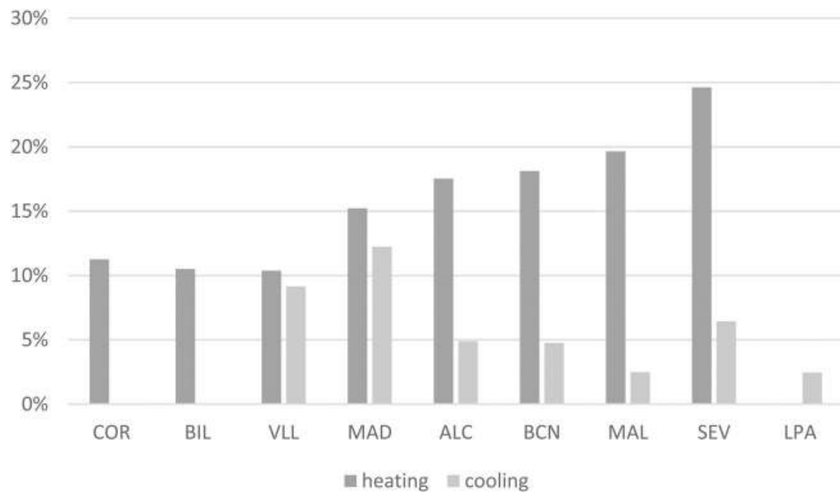

Figure 2. Relative impact of the air infiltration on the heating and cooling demand.

Brussels. However, it must be taken into account that regulations usually refer to new buildings and the scope of this study was to characterise existing dwellings built on different periods.

Considering the energy assessment, air infiltration has a greater impact on the heating demand, especially in cities with a continental climate such as Madrid or Valladolid. Values up to 19.07 kW h/(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 kW h/(m^2 y). In the case of the cooling demand, the energy impact of air infiltration is lower, with maximum values of 3.06 kW h/(m^2 y) in the case of Sevilla. In other locations such as A Coruña or Bilbao, the impact on the cooling demand becomes negligible.

Regarding the relative impact of air infiltration, values up to 25% corresponding to the heating demand in the case of Sevilla or 12% for the cooling demand in Madrid were obtained. These relative values must be interpreted taking into account the airtightness results and the energy demand. In the case of Sevilla or Málaga, the high share of the energy impact of infiltration can be explained given the low heating demand (57.70 and 43.84 kW h/(m^2 y), respectively) and, at the same time, a high air change rate.

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 building 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 is possible to conclude that air infiltration through the building envelope has an enormous impact in Spain. The impact is greater on the heating demand, while the impact for cooling can be negligible in Atlantic areas. Maximum values up to 19.07 kW h/(m^2 y) for the heating demand have been obtained in the case of Madrid, or up to 3.06 kW h/(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 matter 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.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Buchanan, C. R., & Sherman, M. H. (1998). CFD *simulation of infiltration heat recovery* (pp. 1–10) [Paper presentation]. 19th AIVC Annual Conference, Oslo, Norway.

Carrié, R., & Wouters, P. (2013). Building and ductwork airtightness. *REHVA European HVAC Journal*. http://tightvent.eu/wp-content/uploads/2012/02/TightVent-book2013-REHVA-TOC1.pdf

Chan, W. R., Nazaroff, W. W., Price, P. N., Sohn, M. D., & Gadgil, A. J. (2005). Analyzing a database of residential air leakage in the United States. *Atmospheric Environment*, *39*(19), 3445–3455. https://doi.org/10.1016/j.atmosenv.2005.01.062

European Parliament. (2018). European Directive 2018/844 Amending Directive 2010/31/EU on the Energy Performance of Buildings and Directive 2012/27/EU on Energy Efficiency. Official Journal of the European Union (Vol. 156).

Feijó-Muñoz, J., Pardal, C., Echarri, V., Fernández-Agüera, J., Assiego de Larriva, R., Montesdeoca Calderín, M., Poza-Casado, I., Padilla-Marcos, M. Á., & Meiss, A. (2019). Energy impact of the air infiltration in residential buildings in the Mediterranean area of Spain and the Canary Islands. *Energy and Buildings*, *188–189*, 226–238. https://doi.org/10.1016/j.enbuild.2019.02.023

Feijó-Muñoz, J., Poza-Casado, I., González-Lezcano, R. A., Pardal, C., Echarri, V., Assiego De Larriva, R., Fernández-Agüera, J., Dios-Viéitez, M. J., Del Campo-Díaz, V. J., Montesdeoca Calderín, M., Padilla-Marcos, M. Á., & Meiss, A. (2018). Methodology for the study of the envelope airtightness of residential buildings in Spain: A case study. *Energies*, *11*(4), 704. https://doi.org/10.3390/en11040704

Fernández-Agüera, J., Domínguez-Amarillo, S., Sendra, J. J., & Suárez, R. (2016). An approach to modelling envelope airtightness in multi-family social housing in Mediterranean Europe based on the situation in Spain. *Energy and Buildings*, *128*, 236–253. https://doi.org/10.1016/j.enbuild.2016.06.074

Instituto para la Diversificación y Ahorro de la Energía. Gobierno de España. (2011). Escala de Calificación Energética Para Edificios Existentes.

International Organization for Standardization. (2015). *ISO 9972:2015 Thermal performance of buildings. Determination of air permeability of buildings. Fan pressurization method*.

Jiménez Tiberio, A., & Branchi, P. (2013). A study *of air leakage in residential buildings* [Paper presentation]. 2013 International Conference on New Concepts in Smart Cities: Fostering Public and Private Alliances (SmartMILE), Gijón (pp. 1–4). https://doi.org/10.1109/SmartMILE.2013.6708180

Jones, B., Das, P., Chalabi, Z., Davies, M., Hamilton, I., Lowe, R., Mavrogianni, A., Robinson, D., & Taylor, J. (2015). Assessing uncertainty in housing stock infiltration rates and associated heat loss: English and UK case studies. *Building and Environment*, *92*, 644–656. https://doi.org/10.1016/j.buildenv.2015.05.033

Kronvall, J. (1978). Testing of houses for air leakage using a pressure method. *ASHRAE Transactions*, *84*(1), 72–79.

Meiss, A., & Feijó-Muñoz, J. (2015). The energy impact of infiltration: A study on buildings located in north central Spain. *Energy Efficiency*, *8*(1), 51–64. https://doi.org/10.1007/s12053-014-9270-x

Ministerio de Fomento. Gobierno de España. (2017). *Código Técnico de La Edificación (CTE)*.

Persily, A. K., Linteris, G. T. (1983). A comparison of measured and predicted infiltration rates. *ASHRAE Trans.* 89 (June). https://www.osti.gov/biblio/6499412-comparison-measured-predicted-infiltration-rates

Sherman, M. H. (1987). Estimation of infiltration from leakage and climate indicators. *Energy and Buildings*, *10*(1), 81–86. https://doi.org/10.1016/0378-7788(87)90008-9

Spiekman, M. (2010). *ASIEPI. The final recommendations of the ASIEPI project: How to make EPB-regulations more effective?*

Villi, G., Peretti, C., Graci, S., & De Carli, M. (2013). Building leakage analysis and infiltration modelling for an Italian multi-family building. *Journal of Building Performance Simulation*, *6*(2), 98–118. https://doi.org/10.1080/19401493.2012.699981

Younes, C., Shdid, C. A., & Bitsuamlak, G. (2012). Air infiltration through building envelopes: A review. *Journal of Building Physics*, *35*(3), 267–302. https://doi.org/10.1177/1744259111423085