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An approach to modelling envelope airtightness in multi-family social housing in Mediterranean Europe based on the situation in Spain

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ABSTRACT

Building hygrothermal performance, indoor air quality and energy consumption depend heavily on envelope airtightness. Over the last three decades, single-family dwellings have been amply studied in this respect by researchers in North Europe, the United States and Canada. However, very few studies have been conducted on airtightness in multi-family housing in warm climates such as Mediterranean Europe. This paper aims to enhance the understanding of building airtightness in early twenty-first-century multi-family buildings in southern Spain. Blower Door tests were conducted in 45 units in seven such buildings. The main airtightness parameter values found are reported and compared to the data for other buildings in southern Europe. The paper includes a statistical analysis of the findings, characterises building types and describes the protocol used to identify and quantify air leakage pathways. The conclusion drawn is that although a rough predictive model can be developed, the results are widely scattered due to the impact of the random component of manual construction, even in buildings with identical construction characteristics and types. The values recorded are nonetheless consistent with the findings for other European surveys.

1. Introduction

At this time, the residential sector accounts for 17% of Spain's final energy and 25% of its electric power consumption. Approximately 48% of that demand is estimated to be attributable to heating and cooling systems, values that are on the rise in Mediterranean areas [1]. As Spain is one of the largest countries, area-wise, in Mediterranean Europe, the hygrothermal performance, energy consumption and indoor air quality of its housing stock are sufficiently representative to be extrapolated to similar regions in southern Europe. In the wake of the transposition into Spanish Regulation (CTE, 2006) [2] of the European Energy Performance of Buildings Directive (EPBD) and its provisions on thermal envelope requirements, airtightness may be regarded as one of the factors with greatest impact on hygrothermal performance, energy consumption and indoor air quality in modern homes. Airtightness values and solar radiation-induced thermal loads (in both winter and summer) are instrumental in determining the actual energy demand in Mediterranean multi-family buildings. This applies to heating as well as cooling [3–5] and consequently to building energy strategies and performance labelling. Identification of air leakage pathways is a prerequisite to proposing construction solutions to improve building airtightness in compliance with the EU's 20-20-20 objectives [6].

Building envelope airtightness has become a standard area of research in the USA [7], where the most comprehensive databases and widest variety of infiltration models are available [8–11]. In particular, the LBNL air leakage measurements database developed by Chan et al. [12] and the DOE's Multifamily Envelope Leakage Model [12] are very widely used. Drawing from an exten-

Abbreviations: V_{50}, air leakage rate at 50 Pa across the building envelope including the flow rate through joints fissures and surface pores (m^3/h); Q_{env}, air flow (m^3/h) across the building envelope; Δp, pressure differential (Pa); n, air flow exponent; C_{env}, air flow (or leakage) coefficient; N, number of dwellings; Z, climate zone; FA, façade area (m^2); S, gross floor area (m^2); V, volume (m^3); WA, window area (m^2); WP, window contour (perimeter) (m); WIN, winter severity; SUM, summer severity; n_{50}, air change rate at 50 Pa (h^{-1}); w_{50}, specific leakage area at 50 Pa ($m^3/(h\,m^2)$); f_{50}, air leakage rate per unit of façade area at 50 Pa ($m^3/(h\,m^2)$); p_{50}, air leakage rate per unit of window perimeter at 50 Pa ($m^3/h\,m$); U-value, thermal transmission ($W/(m^2\,K)$); T, monthly mean temperature (°C); TM, monthly mean of daily maximum temperatures (°C); Tm, monthly mean of daily minimum temperatures (°C); H, monthly mean relative humidity (%); I, sunshine hours (h).

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sive review of measurements taken across the country, the former developed a revised model for single-family detached housing. The latter described a model for multi-family buildings which is, however, scantly applicable to southern Europe, where building types, construction techniques and climate vary immensely from the parameters for which the model was developed. Despite these constraints, both can be used a benchmarks for comparison.

Intense research is also underway in northern and central Europe [13–15], where building airtightness is extensively regulated. In southern Europe, dwelling airtightness and its relationship to the main air inlets has been studied more profusely in France than in any other country. There, multi-family units have been shown to be more airtight than single-family homes and the construction system used has been identified as one of the major factors affecting the results [16,17]. Legislation on airtightness is lacking in other southern European countries, although insightful papers have been published on conditions in Greece [18], Italy [19] and Portugal [20,21]. The Italian study covered 20 buildings of different types and in different seasons, while in Portugal the object of research was social housing, namely two multi-family buildings surveyed before and after retrofitting. The mean V_{50} values found by the latter for an area comparable to the region studied here were 8.9 h^{-1} prior to and 6.8 h^{-1} after refurbishment.

The most prominent infiltration studies conducted in Spain include research by Meiss and Feijo, who found a mean V_{50} of 6.26 h^{-1} [22] for the 13 homes measured and by Tiberio and Branchi, who ran the most extensive survey in the region to date, testing 150 recently built dwellings. Although the data were widely scattered, with a mean V_{50} of 3.50 h^{-1}, the distribution by low, medium and high airtightness showed that as a rule today's buildings lie in the medium category [23]. While the data reported in these papers are of interest from the standpoint of characterisation, they refer to north-central Spain, a region with a fairly cold continental climate reminiscent of central European construction techniques geared to airtightness, insulation and effective heating systems. Building conditions there consequently vary widely with respect to the warmer areas of the country. In contrast, a study by Montoya et al. addressing the less directly related issue of protection against air pollution due to toxic gas release, adopted an approach relevant to the present research [24]. Although that study involved no field tests and focused on single-family homes, it proposed a regional prediction model that differed from the Chan model and drew from a database of French tests (CETE Lyon). The authors also proposed a methodology for extrapolating the data based on housing type similarities.

Therefore, the studies conducted in southern Europe have yet to deliver a large body of data enough to identify the actual impact of airtightness on the energy efficiency of the residential buildings of the area, and the link with regional construction systems.

This article analyses a comprehensive suite of field data with the aim of enhancing the understanding of housing stock energy performance in an area highly representative of Mediterranean Europe. It focuses on multi-family units built in southern Spain in the first decade of the twenty-first century. The field campaign findings are set out, air leakage pathways are characterised, the scatter observed in envelope performance is discussed and a predictive model is proposed.

2. Context

Single-family dwellings account for 64% of the total European housing stock, although in the southern part of the continent, particularly in Italy and Spain, multi-family buildings prevail [25]. These countries also have a large stock of social housing, most of which adopts multi-family configurations [26] built to minimum construction quality standards [27]. While social housing can be defined in a number of ways, here it is meant in the broadest sense: housing that receives some manner of government subsidy or assistance [28].

Substantial improvements will be needed in these buildings in the years to come, both to improve indoor habitability and to comply with the energy efficiency standards for nearly zero energy buildings laid down in the EPBD [29] and in the EU's 20-20-20 objectives [31]. This is going to call for a huge effort in Spain and in other Mediterranean countries to improve the existing housing stock by means of effective, optimised energy intervention and refurbishment techniques. One of the main aims of refurbishment policy should be to optimise available public and private resources. Scantly effective retrofitting should be avoided to attain genuine energy savings while reaching the primary aim, the enhancement of indoor comfort.

These considerations are applicable to a significant portion of Europe: its entire Mediterranean flank, from southern Portugal to Turkey.

The area has a temperate climate, with mild temperatures that fluctuate only narrowly throughout the year. The winters are not very cold (with temperatures dipping below freezing only exceptionally), and although warm, the summers are not torrid. While the climate varies with the lay of the land, it is clearly distinct from conditions in central and northern Europe. The area is classified as Köppen Csa and Csb [31].

Albeit with regional variations, multi-family building architecture and construction are similar across the area [32] and differ widely from the solutions in place in central and northern European countries, especially where social housing is concerned [33]. Many of these solutions are a legacy inherited from the nineteen sixties and seventies residential construction boom [34]. The area's inhabitants share more than a similar climate, however, for social and cultural mores around housing use and occupancy are likewise analogous.

The reinforced concrete frame and continuous concrete slab construction that characterises medium-rise multi-dwelling housing, especially social housing, in Mediterranean cities, results in very airtight inter-storey compartmentation. The outer enclosures typically consist of brick or block (heavy- or medium-weight walls), usually with an inner cavity and several layers of plaster on the inside. Lightweight façades are uncommon.

As a rule this social buildings has been concibed as Natural Ventilated based on the understanding of the climate as benign, and generally lacks built-in heating or air conditioning systems. Users meet their heating needs with portable electrical radiators that in most cases are energetically inefficient and unable to provide for an even distribution of comfortable temperatures [35]. Nor is this housing fitted with ducted, whole-home cooling systems., despite the warm summers that characterise the area. As a result, homeowners tend to install room-size split AC-units a posteriori.

These buildings were not generally fitted with mechanically controlled ventilation systems until the entry into effect of the Technical Building Code in 2007 [2]. Prior to that date, bathroom and kitchen ventilation was based on the stack effect across static vents. Such extraction systems are often ineffective. Where indoor air quality in Mediterranean housing is not particularly poor it is thanks to the uncontrolled inflow of air through the building envelope (infiltration) or voluntary ventilation (manual operation of windows).

Envelope thermal-performance is average in such buildings, with medium-to-low thermal mass and wall thermal transmittance values on the order of 0.5–1.5 W/m^2 K. Artificial heating and cooling are needed to ensure comfortable indoor temperatures in the winter and summer under normal outdoor conditions. The absence