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A contribution for the quantification of the influence of windows on the airtightness of Southern European buildings

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ABSTRACT

Adequate airtightness levels are fundamental for the indoor environmental quality and energy efficiency of buildings. The quantitative characterization of expected leaks of common building elements is useful for practitioners that intend to improve building enclosures for airtightness optimization. This study intends to contribute to the quantification of the permeability of windows with a focus on the Southern European context of low airtightness in heavy construction buildings, where windows play an important role.

A large experimental investigation was therefore carried out in 23 spaces, establishing three possible set-ups (nothing sealed, window sealed and window and roller-shutter sealed), using the fan pressurization method. A total of 104 tests were performed.

Results revealed that the windows' permeability indices ranged from 4.8 to 96.4 $m^3/(h\,m^2)$ and from 1.2 to 30.8 $m^3/(h\,m)$, with average values of 28.7 $m^3/(h\,m^2)$ and 8.9 $m^3/(h\,m)$, the roller-shutter contribution can be highly variable; also the year of construction, the frame material and the opening system are the key parameters for the airtightness of windows.

1. Introduction

Airtightness represents a characteristic of a building that is fundamental for the quality of its indoor environment as it influences the heating load, the strategies of the ventilation system, the thermal comfort, the indoor air quality, the indoor acoustic comfort and, of course, the energy efficiency. Airtightness is linked to undesirable and uncontrolled ventilation, therefore it should be minimized from an energy standpoint [1]. Recent studies indicate that, in Southern European countries, the incidence of infiltration on the energy balance of buildings can vary from 10 to 27% [2]. Recently, the effect of infiltration and natural ventilation on the energy performance of buildings in Southern Europe has been studied by several researchers [3–5]. However, buildings with an increase in airtightness may face an increase of moisture-related problems, with consequences for both the durability of materials and indoor air quality [6].

Thus, the quantitative characterization of the expected leaks of common building elements is useful for practitioners who aim to improve building enclosures for airtightness optimization, both at the design and service stages of a building [7]. Irish case studies [8,9] showed that the adopted performance model overestimated in situ airtightness by up to 89%, while the works by Fernández-Agüera et al. [10,11] highlighted the difficulties of developing a reliable predictive model for airtightness in a specific building stock. The development of test protocols that allow the quantification of the contribution of components to air infiltration would be a strong foundation for more effective predicted models.

Windows are recognized as one of the most important sources of air infiltration. However, the different technologies found in the building stock may lead to a high variability of their actual performance. This study is therefore undertaken to contribute to the quantification of the permeability of windows, as well as their connections to the opaque envelope. It focuses on the Southern European context of low airtightness in heavy construction buildings where windows play an important role [10–12]. The intention is to fill a gap in the knowledge concerning the air leakage of windows, while, highlighting the large variability found when tested in situ, and to establish a methodology for ascertaining how such

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Nomenclature

n	Air flow exponent [−]
n_{pr}	Air change rate at the pressure difference ΔP_r [h^{-1}]
n_{50}	Air change rate at the pressure difference of 50 Pa [h^{-1}]
n_{100}	Air change rate at the pressure difference of 100 Pa [h^{-1}]
q_L	Air leakage rate [m^3/h]
q_{pr}	Air leakage rate at the pressure difference ΔP_r [m^3/h]
q_{50}	Air leakage rate at the pressure difference of 50 Pa [m^3/h]
q_{50_rs}	Roller-shutter permeability at the pressure difference of 50 Pa [m^3/h]
q_{50_win}	Windows permeability at the pressure difference of 50 Pa [m^3/h]
q_{100}	Air leakage rate at the pressure difference of 100 Pa [m^3/h]
q_{100_rs}	Roller-shutter permeability at the pressure difference of 100 Pa [m^3/h]
q_{100_win}	Windows permeability at the pressure difference of 100 Pa [m^3/h]
A	Window overall area [m^2]
A_{rs}	Area of the roller-shutter [m^2]
C_L	Air leakage coefficient [m^3/(h.Pa^n)]
FLF	Frame Length Factor [m/m^3]
L	Length of opening joints [m]
U_n	Test uncertainty [%]
V	Internal volume [m^3]
Δp	Induced pressure difference [Pa]

leakage occurs in existing buildings, which are candidates to rehabilitation.

2. Literature review

2.1. Building components versus airtightness

The airtightness of a building envelope depends on the permeability of its different components, connections and accidental leaks. There are databases [13] which include infiltration data for several building components, while others [14] refer not only infiltration data but also recommended values found in regulations and codes of practice, which can be considered for modelling purposes. Nevertheless, the numerous types of components, and their actual implementation conditions on the envelope, encouraged several studies on the quantification of their contribution to the overall airtightness of the building.

This procedure is frequently applied in the characterization of the permeability of industrial products [15] can be useful as a basis for the prediction of the on-site behaviour of specific building types, through the application of a component model [16]. Determining the airtightness of the window-wall interface in cavity brick walls [17] proved the importance of choosing the correct technique to avoid poor performance of this typical weak point in the envelope, delivering usable data for leakage quantification in each case. The importance of the correct assembly procedure of specific components in wood frame houses, namely window-wall connections [18], chimneys [19], basement walls [20] and wall-floor connection [21], was also explored based on laboratory set-ups, resulting on technical recommendations to drastically reduce permeability. Moreover, the analysis of commercial passive ventilation grilles [22] proved the importance of the development of standardized test methods for these devices, as large discrepancies were found between declared values and test results.

Conducting in-situ airtightness tests for the evaluation of contribution of components to the overall permeability of the building is another approach often found in literature. For instance, a survey identified the percentage contribution of each pathway to the global permeability, in low-rise multifamily buildings, pre and post refurbishment [23], with the tests being conducted by temporarily taping the components under observation. The retrofit actions lowered the average air flow rate at a pressure difference of 50 Pa, n_{50}, from 14.4 h^{-1} to 8.0 h^{-1}. In countries where the focus on airtightness has only begun, the in-situ tests provide the first approach for the creation of national databases. In another example, the Irish case [24], is was demonstrated that the airtightness evolution is not necessarily positive, as modern buildings are often poorly built, with defects found in the fitting of windows or passive vents that lead to undesired leaks. Italian dwellings [25], where an average n_{50} of 7.3 h^{-1} was found, also demonstrated excessive leakage in windows and fireplaces. Moreover, the growing interest in passive houses motivated the study of airtightness evolution in different construction phases [26], where it was found that airtightness would decrease from an intermediate stage to the final one due to the HVAC wall penetrations.

2.2. Contribution of windows to the airtightness of buildings

The windows and their connections to the opaque envelope are a relevant part of the overall airtightness of a building. The percentage of envelope permeability for which the windows are responsible is however quite variable. In one case [23], an average contribution to the resulting n_{50} of 7% was found, while in another [12] it was 25%.

Some research [27] analysed the impact of replacement windows on infiltration and IAQ in UK dwellings. It was concluded that the change of old windows would lead to a reduction of 0.1–0.3 h^{-1} of the background infiltration, which for typical dwellings in the UK would imply adding controllable background ventilation to prevent undesired low ventilation rates. In the case of Portugal [12], on the other hand, the increase of airtightness by window replacement combined with ventilation grilles would still be found insufficient by some users. The role of windows was considered decisive in other Southern European countries to characterize the overall airtightness of buildings [25,28]. In one case [28], a correlation between n_{50} and window frame length was found for a sample of 20 buildings. The permeability of windows, especially those with rolling-shutter boxes, was one of the reasons found for the lower airtightness levels found in Italian buildings when compared to existing literature.

From the aforementioned literature references, it becomes clear that it is important to add the knowledge of the airtightness of a building stock to the contribution of the different envelope components. Windows are very relevant, especially in Southern European buildings [12,25,28]. Although laboratory measurements can be applied in the evaluation of the contribution of windows to airtightness in specific technologies [17,27], a building stock with widespread window solutions requires an in-situ campaign.

3. Methodology

3.1. Air leakage measurements

The most common procedure to measure the air leakages through a building envelope is the fan pressurization method, commonly called the Blower Door Test. This method consists of applying a known pressure difference between the two sides of a