TESTING FOR BUILDING COMPONENTS CONTRIBUTION TO AIRTIGHTNESS ASSESSMENT

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ABSTRACT

When one intends to evaluate buildings energy efficiency their airtightness is a fundamental parameter. Airtightness is linked to undesirable and uncontrolled ventilation and, therefore, should be minimized. Quantitative characterization of expected leaks of common building elements would be useful for practitioners that intend to improve building enclosures for airtightness optimization. The most well accepted experimental procedure to evaluate in-situ buildings' airtightness is the fan pressurization method, typically making use of a "blower door" device. Individual components can be tested for air permeability in laboratory conditions according to well established standards. A systematic approach for components contribution to overall airtightness is lacking, especially due to insufficient measured data availability.
The paper presents a case study where in-situ blower door measurements were used to define the contribution of different building components to the airtightness of a small building. Several set-ups were established allowing for the individual effect of the components to be measured, namely: enclosure, windows, connection of the steel columns with the floor and ventilation ridge. An enclosure sample, including wall panel and one window, was built in the laboratory and air permeability tests were performed. The information from both in-situ and laboratory tests was combined in a methodology for airtightness prevision of a small building. The laboratory results, completed with air leakage values obtained from a published database, provide the base value for airtightness computation. That first value is then corrected and/or validated by the in-situ measurements of individual components.
Results indicate that the application of the methodology for Mediterranean countries, with the construction elements air leakage database available, could be questionable. A very different construction reality from the one in the countries that contribute for the database was found. The importance of a large number of studies in the Mediterranean countries, where constructions are less airtight, arises and should be the basis for a new database.

KEYWORDS

Airtightness, component leakage, laboratory tests, in-situ tests

1 INTRODUCTION

1.1 Motivation

Buildings airtightness represents a characteristic of the building which is fundamental for the quality of its indoor environment. Airtightness influences the heating load, the strategies of the ventilation system, the indoor air quality, the indoor acoustic comfort and, of course, the

energy efficiency of the building. Therefore, predicting airtightness is very important for both the design and the in service stages of a building (Iordache at al., 2011). The most well accepted experimental procedure to evaluate in-situ buildings' airtightness is the fan pressurization method, typically making use of a "blower door" device, which consists on an adjustable door that contains a reversible fan and that replaces one of the building's doors.
In cold climate countries, undesired ventilation, like the infiltration of air through the fabric of the building, might lead to a situation of energy waste and sometimes discomfort. Thus, an equilibrium between indoor air quality and energy efficiency must be achieved (Dimitroulopoulou, 2012).
In different climates, the desired airtightness may be different however. The values found in Italian dwellings (Alfano et al, 2012) are quite above the reference values found in EN 15242-2007 (CEN, 2007). If even warmer climates are considered, and depending on the adopted ventilation system, airtightness may even be undesirable.
Either airtightness is desirable or not, its estimation in design phase is important, and therefore a contribution to that is intended in this paper.

1.2 Airtightness estimation

The estimation of airtightness has been addressed by different authors, using different strategies to find an expected n_{50} value for a specific building or a type of building. The review by Relander et al (2012) grouped the different approaches into three categories: estimation based on multiple regression, estimation based on rough characteristics of the building and estimation based on component leakage and geometry of the building.
Component leakage can be assessed and quantified by different methods. The most common methodology is based on, step by step, artificially establishing a pressure difference (making use of the "blower door") between the two sides of the component and measure the resultant air flow. When applied for a component of a building, this methodology requires two tests, one with all the joints sealed and the other without any sealing. The flow rate difference between the tests corresponds to the component air permeability. Pinto (Pinto et al., 2011) applied this methodology to test air inlets, windows and doors of five dwellings. The studies by Relander et al (2010 and 2011) and Van den Bosshe et al. (2012) present examples of how laboratory tests were used in the assessment of component leakage and consequent influence on building airtightness.
In the present paper, the authors apply the estimation based on component leakage and geometry of the building to a very simple building used as a case study. An enclosure sample, including wall panel and one window, was built in the laboratory and air permeability tests were performed. In-situ "blower door" measurements were used to define the contribution of different building components to the overall airtightness. Several set-ups were established allowing for the individual effect of the components to be measured, namely: enclosure, window, window frame, enclosure defects and ventilation ridge. The information from both in-situ and laboratory tests is finally combined in a methodology that can estimate building airtightness.

2 IN SITU EXPERIMENTAL SET-UP

2.1 Case Study

The case study corresponds to a small building with light construction. The geometric properties are summarized in Table 1.

Table 1: Building geometric properties

Floor area [m^2]	Volume [m^3]	Envelope area [m^2]
48	150	178

The structural scheme of the building corresponds to a steel structure composed of tubular elements. Both the façade and the roof are clad with sandwich panels with 4 cm insulation in the interior, with mechanical fixation to the steel structure. The building includes a door and 4 aluminium frame windows, double glazed, distributed in pairs in two opposite façades. The building depends on natural ventilation and therefore a ventilation ridge was included in the roof.

2.2 Blower-door tests

The fan pressurization method for determination of air permeability of buildings consists of applying a known pressure difference between the two sides of a construction element or building and measure the resultant volume of air flow. This information his used to compute the "permeability law":

$$\dot{V}_{env} = C_{env} \cdot (\Delta p)^n \quad (1)$$

Where $\dot{V}_{env}$ is the is the air flow rate [m^3/h], C_{env} is the leakage coefficient [$m^3/(h.Pa^n)$], Δp is the pressure difference [Pa] and n is the air low exponent [-] which characterizes the flow regime (0.5 for turbulent flow and 1.0 for laminar flow).

Typically, the experimental determination of the "permeability law" is based on several measurements on the range 10 Pa to 50 Pa with increments of 10 Pa. The procedure is repeated twice, one for pressurization and the other for depressurization. The test is performed according to standard EN:13829-2000.

The air permeability measurements were carried out using the Retrotec 1000 blower door model (Figure 1). For each scenario, both pressurization and depressurization tests were performed.

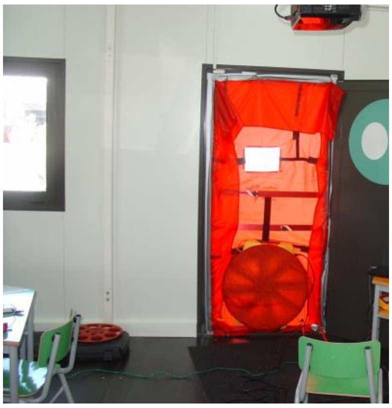


Figure 1: Experimental set-up

Exterior air temperature during tests ranged from 17.2 ºC to 19.0 ºC and the air velocity varied between 0.6 m/s and 0.8 m/s, which according to Beaufort scale corresponds to “1- light air” (EN:13829-2000).

2.3 Methodology

The methodology was based on the successive sealing of the following three building components: (a) ventilation ridge; (b) window frame; (c) connection of the steel columns with the floor. Therefore four testing scenarios were created as described in Figure 2 and Table 2.

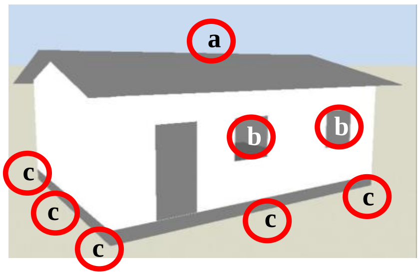


Figure 2: Building enclosure and components which were sealed

Table 2: Testing scenarios

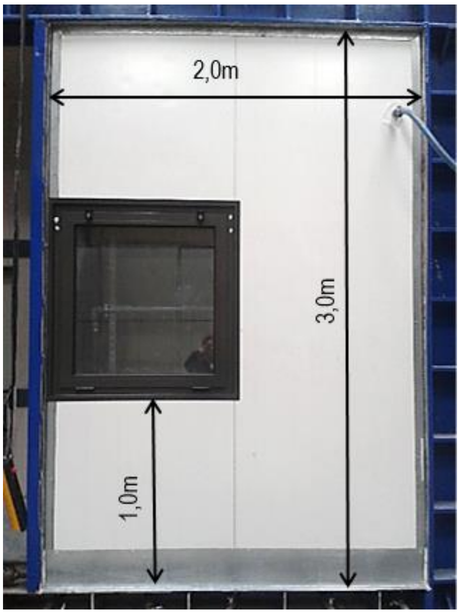
Scenario	**(a)**	**(b)**	**(c)**
1	NS	NS	NS
2	S	NS	NS
3	S	S	NS
4	S	S	S

NS: not sealed; S: sealed

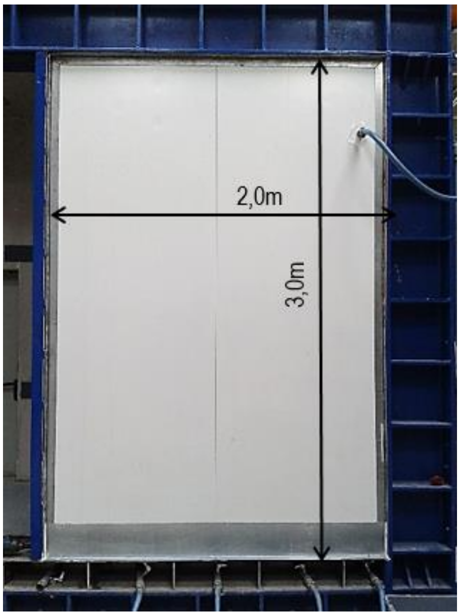
Consecutive differences between test scenarios allowed for the evaluation of the individual contribution of the building components for the building airtightness. In scenario 4, since the three building components were sealed, the airtightness of the enclosure is assessed.

3 LABORATORY TESTS

Two enclosure samples, one including wall panel and one window (Figure 3a)), and the other including only wall panel (Figure 3b)), were built in the laboratory and air permeability tests were performed.



a)



b)

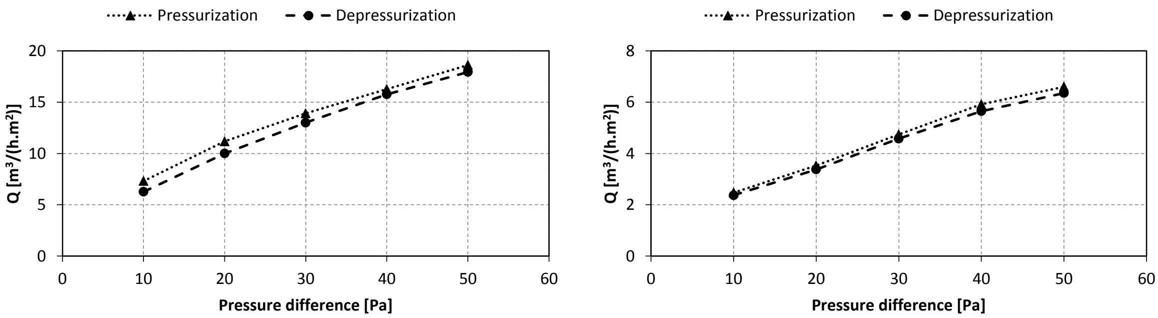
Figure 3: Laboratory enclosure samples. a) wall panel and one window; b) wall panel

These samples were tested according to EN 12114-2000. Samples were built in an uncontrolled environment in the laboratory and were tested with a temperature of 16 ºC and a relative humidity of 66%. Testes were carried both for positive and negative pressure differences, applying successive pressure levels starting at ±50 Pa and reaching a maximum level of ±500 Pa. In each pressure level the correspondent air flow throughout the samples was recorded.

4 RESULTS AND DISCUSSION

4.1 In-situ tests

Figure 4a) shows the result of the fan pressurization method, both for pressurization and depressurization, for scenario 1 and Figure 4b) for scenario 4. These are the two most extreme situations which were evaluated and correspond, respectively, to method A and method B described in EN:13829-2000.



a) b)

Figure 4: Air permeability tests. a) scenario 1; b) scenario 4

These results show that for a pressure difference of 10 Pa air flow rate ranges from 2.37 $m^3/(h.m^2)$, to 6.35 $m^3/(h.m^2)$, in depressurization, in the extreme scenarios. This difference is explained by the effect of the ventilation ridge, the window frame and connection of the steel columns with the floor. To evaluate their individual contribution the results of scenario 2 and 3 should also be taken into account and the consecutive differences between the test results must be computed. Figure 5 shows the individual contribution of each component for the building air permeability at 50 Pa (q_{50}).

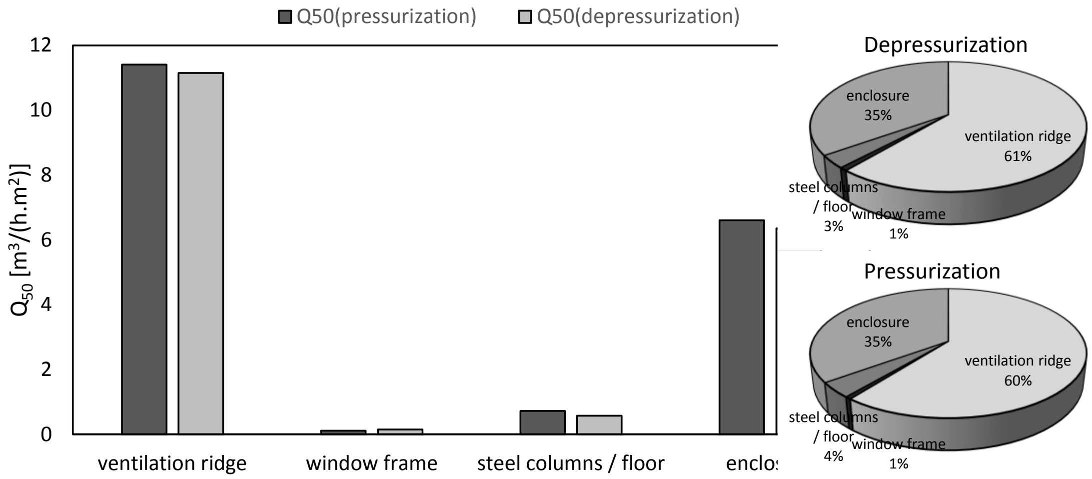


Figure 5: Contribution of the building components for the airtightness

Results revealed that the ventilation ridge is the most important component for the building permeability with a contribution of up to 61%. Building enclosure is responsible for 35% and the other two components have a residual impact (1% for the window frame and 3% for the connection of the steel columns with the floor). No significant differences between depressurization and pressurization test results were found.

Traditionally building airtightness is evaluated by the air change rate at a pressure difference of 50 Pa, n_{50}, which can be computed from the permeability law. Table 3 presents the results of n_{50} for the four scenarios.

Table 3: Results of the air change rate at a pressure difference of 50 Pa, n_{50} [h^{-1}]

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Depressurization	21.30	8.49	8.41	7.75
Pressurization	22.01	8.70	8.65	7.86

According to the current standards, regarding the energy efficiency of buildings, these are very high values of n_{50}, however it should be notice that this a small building with very specific characteristics, whose purpose is to be constructed in tropical countries and, therefore, the comfort conditions and the indoor air quality are the main preoccupation, rather than the energy efficiency.

4.2 Laboratory tests

Figure 6 shows the air permeability results of the two enclosure samples, with and without window.

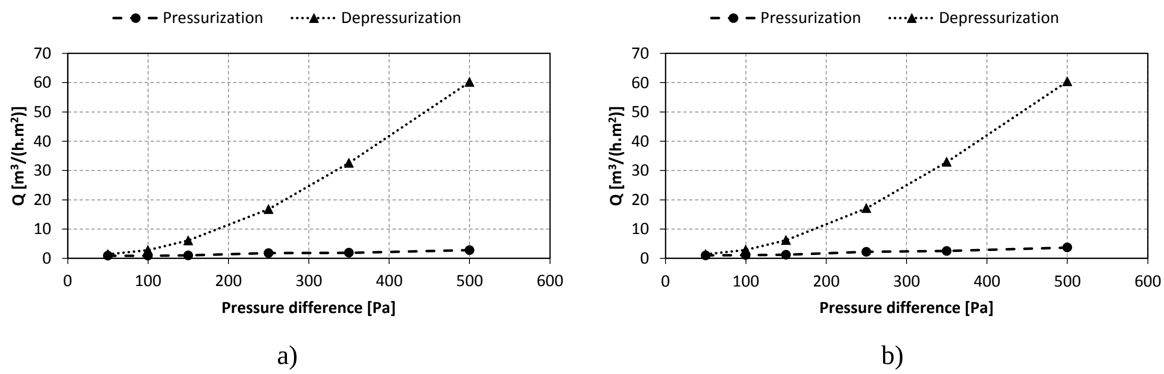


Figure 6: Wall panel air permeability tests. a) panel without window; b) panel with window

No significant differences between panels were found. This situation is in agreement with the fan pressurization tests, which indicated that windows are responsible for a very small contribution for the building airtightness. Another interesting conclusion is that results for pressurization and depressurization are very different. Additionally, this difference increases throughout the test and for the maximum pressure difference (500 Pa) reaches 59 $m^3/(h.m^2)$. However, for the lowest pressure difference (50 Pa) difference between tests was null. The explanation for this problem is related to a deformation in the wall panel connection with the steel structure (Figure 7).

Figure 7: Wall panel deformation due to the pressure difference in depressurization test

4.3 Discussion

The information from both in-situ and laboratory tests can be compared since both include an air permeability measurement for a pressure difference level of 50 Pa. Using both is possible to obtain an estimation of the building permeability by calculating the n_{50}. Equation 2 describes the method.

$$n_{50} = \frac{(Ql_{50,wnd} \cdot L_{wnd} + Ql_{50,ridge} \cdot L_{ridge} + Q_{50,enc} \cdot A_{enc} + \dot{V}_{50,fl\_con})}{V} \quad (2)$$

Where:

n_{50} – air change rate at 50 Pa $[h^{-1}]$

Ql_{50},wnd – air permeability of the metal panels with and without windows $[m^3.h^{-1}.m^{-1}]$

L_{wnd} – envelope area [m]

Ql_{50},ridge – air permeability of the ventilation ridge $[m^3.h^{-1}.m^{-1}]$

L_{ridge} – Ventilation ridge length [m]

$Q_{50,enc}$ – air permeability of the enclosure, which includes construction joints such as metal panels joints, wall to ceiling/floor and wall to wall joints $[m^3.h^{-1}.m^{-2}]$

A_{enc} – Construction joints length $[m^2]$

$\dot{V}_{50,fl\_con}$ – Air flow rate thought connections between columns and the floor $[m^3/h]$

V – Volume $[m^3]$

The laboratory sample doesn't include all the parts and components of the building, such as joints and connections between the elements (eg. wall/roof, wall/wall, wall/floor). Therefore, to properly apply this methodology additional data is required. Several studies regarding the individual effect of the components have been published and can be used to obtain the lacking data (Orme and Leksmono, 2002). Building enclosure was sub-divided in three parcels (metal panels joints, wall to ceiling/floor joints and wall to wall corner joints). Table 3 condensates the information.

Table 3: Q values from different building elements.

<table>
<tr><th></th><th>In situ</th><th>Laboratory</th><th>Literature</th></tr>
<tr><td>Ql_{50},wnd*</td><td>0.61</td><td>0.94</td><td>-</td></tr>
<tr><td>Ql_{50},ridge</td><td>244.88</td><td>-</td><td>-</td></tr>
<tr><td>Ql_{50},joint1</td><td rowspan="3">17.38</td><td>2.28</td><td>-</td></tr>
<tr><td>Ql_{50},joint2*</td><td>-</td><td>0.87</td></tr>
<tr><td>Ql_{50},joint3</td><td>-</td><td>-</td></tr>
<tr><td>Q_{50},col</td><td>108.75</td><td>-</td><td>-</td></tr>
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Ql_{50},joint1 – metal panels joints
Ql_{50},joint2 – wall to ceiling/floor joints
Ql_{50},joint3 – wall to wall joints (corners)
* - the literature value was obtained for timber constructions.

The air permeability of the ventilation ridge, of the wall to wall corner joints and of the columns connection with the floor couldn’t be found in the literature. Thus, only a rough approximation of the n_{50} can be established for this particular case. Table 4 shows the results.

Table 4: n_{50} values according to the two methodologies.

	In situ	Laboratory + literature
n_{50} [h^{-1}]	7.87	2.2

A large difference between the two methodologies was obtained. The approximations and limitations described previously help to explain it. A very different construction reality from the one in the countries that contribute for the database was found and the applicability of this methodology can be questioned. The importance of a large number of studies in the Mediterranean countries, where constructions are less airtight, arise and should be the basis for a new database.

5 CONCLUSIONS

The airtightness of a building can be tested using a blower door although an estimation procedure applicable in design phase could be very useful. The analysis of a small building whose components were simultaneously tested in laboratory conditions provided an opportunity to implement a strategy of airtightness estimation.

In the in-situ tests, it was found that the ventilation ridge was responsible for the highest percentage of airflow with a contribution of 61%. The permeability of the ventilation ridge was 11,0 $m^3/(h.m^2)$. The window frame and the connection of the steel columns with the floor have no significant impact on the airtightness as the permeability of the window frame and the connection of the steel columns with the floor was 0,66 $m^3/(h.m^2)$.

The laboratory tests proved that the window frame hasn’t got a significant influence as the result of the test sample with or without a windows lead to the same value. The laboratory tests showed that the panel joints permeability was 1,15 $m^3/(h.m^2)$. As laboratory tests couldn’t provide information for all the leakage components, information in the literature was added to the estimation process. The estimated value found was quite different from the measured one, proving that it could only be used as a lower limit n_{50} value.

To achieve the same n_{50} in the in situ tests than those achieved in laboratory, more set-ups should be made. However, some differences could occur because of problems related to construction defects and workmanship.

A very different construction reality from the one in the countries that contribute for the database was found and the applicability of this methodology can be questioned. The importance of a large number of studies in the Mediterranean countries, where constructions are less airtight, arises and should be the added to the database.

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