Air permeability measurements of dwellings and building components in Portugal

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ABSTRACT

Ventilation represents a significant part of heat loss in winter, leading to the need to minimize airflow. However, it is absolutely necessary to ensure indoor air quality and the safety of the users and to control the risk of condensation. Ventilation is responsible on average for 30–40% of energy consumption in air conditioning in Western European buildings. There is great variability in air change rates (ACH [h⁻¹]) from country to country and the minimum value takes into account comfort, sensory and hygrothermal criteria. In Portugal improvements have been made in the air permeability of window frames, but despite the improvements also made in installing mechanical extraction ventilation devices in kitchens and toilets, these often do not guarantee the minimum number of air change rates required.

Air permeability tests were recently carried out in five flats with identical construction characteristics, in the same building, with the aim of characterizing the air permeability of buildings and components, in Portugal. These data are particularly useful for improving the design of building components (e.g., windows and roller shutter boxes) and to perform simulations with reliable data.

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1. Introduction

Ventilation systems play a major role in defining hygrothermal conditions of comfort and air quality inside buildings. They are absolutely necessary for removing pollutants and moisture produced by the use of buildings and to ensure the oxygen levels required for human metabolism and efficient work of combustion devices. According to studies published in Europe, ventilation represents approximately 30–40% of the energy consumed for heating buildings and in Portugal the variation may be from 30% to 80% [1,2].

Quantifying infiltration through cracks and joints is difficult or even impossible. It is difficult to identify and characterize all the cracks in a building. In order to overcome this difficulty, building components (e.g., window or door) are often tested in situ or in a laboratory. In Portugal, the air permeability of windows, doors and self-adjustable inlets has rarely been tested [3].

The air permeability coefficients of different components and construction elements (e.g. windows, doors, walls, floors, ceilings, joints between elements and chimneys) may be found in the specialized literature and in current international standards or regulations [4,5].

Various quantitative methods can be used to assess the air permeability of components [6]. The simplest one just uses a ventilator to establish, step by step, a pressure difference between the interior of a compartment and the exterior. The test is carried out twice; in the first time the air flow rate blown into the compartment is measured for every pressure step; for the second time the joints of the windows are made impermeable with an adhesive tape and the air flow rate blown into the compartment is recorded again. The air permeability of the window is thus given by the flow rate difference between tests for every pressure step. This is called the indirect method. A “Blower door” can be used for this test and it implies that one of the building doors should be replaced by an adjustable door fitted with a reversible fan whose characteristics (q, Δp) must be known beforehand.

Furthermore, another application of this method is to predict average air infiltration rates (ACH). The average local climate should first be characterized in terms of wind and temperature. Afterward it is usually assumed that [7]:

\[
ACH_{\text{annual, average}} = \frac{ACH_{h0}}{N}
\]

At European level several studies [8–11] show that air permeability strongly depends on the type of building. On average, terraced
The pressure test consists of applying a known pressure difference between the two sides of a crack, construction element or building. The volume of air flow rate is measured and plotted in function of the pressure (q, Δp).

The pressurization and depressurization curves can be defined as:

\[ q = C \Delta p^n \]  

where the air flow exponent, \( n \), characterizes the flow regime and varies between 0.5 for turbulent flow and 1.0 for laminar flow [15]. For a significant international sample of dwellings, an average value of \( n \) equal to 0.66 was obtained [14].
- main entrance door of solid wood with rubber weather strips in the top and side joints and threshold lowered by 1 cm on the inside;
- expanded polystyrene (EPS) roller shutter box with a horizontal particleboard lid in the bedrooms and living room;
- sliding single-glazed windows with air permeability of class 2 according to EN 1026: 2000.

The tests were performed in five flats (flats 1 and 3: 1st floor; flats 2 and 5: 4th floor; flat 2: 2nd floor). The volumes of the flats were approximately 160 m³ (see Fig. 2). Fig. 2 shows the flat type and the location of the ventilation system inlets.

3.2. Experiments

The aim of the experimental campaign was to characterize the installed ventilation devices and building components, both in the laboratory (National Laboratory of Civil Engineering - LNEC) and in situ. A comparative analysis of the results (including some test results obtained by the manufacturers) was carried out.

The in situ tests lasted from February to March 2006 and were carried out using a blowing door (Minneapolis Blower Door model). The air permeability of the components was determined by the indirect method.

In the results presented below, in the case of depressurization the air is flowing from the outside to inside the flat.

During all the tests carried out in situ, the weather conditions were measured (wind speed and direction, air temperature and relative humidity) at the roof of the building, as well as the
Fig. 4. Static ventilators on the bathroom ducts.

Fig. 5. Aerodynamic performance of the self-regulated air inlet.
3.2.1. Aerodynamic performance of the self-regulated air inlet

Fig. 5 shows the aerodynamic performance of the “module” 30 self-regulated air inlet - French made. These inlets must conform to the requirements set out in standard NF E 51-732: 2005 [19].

From the comparative analysis of the results presented by the manufacturer and the laboratory test results, it may be concluded that at low pressure (0–20 Pa), which is more common in natural ventilation or mechanical ventilation systems, the flow rates are quite close since the opening essentially behaves like a constant section opening. Moving toward the highest range of pressures, where the effect of the self-regulating membrane is sensitive, a different performance is found between manufacturer tests and laboratory tests. A difference between flow rates at high pressures may therefore result from a malfunctioning of the regulating membrane.

The in situ air permeability of the self-regulated air inlets was determined for the group of 4 inlets (Fig. 6) installed in the flat, which, in the case of depressurizing the flats (air intake), should reach approximately 98 m³/h (24.5 m³/h × 4) for a pressure difference of 10 Pa (Fig. 5).

All the results obtained from the in situ air permeability tests of the inlets can be found in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Flat</th>
<th>Test date</th>
<th>Test</th>
<th>Air permeability [m³/h]</th>
<th>Flow rate for 10 Pa [m³/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>7th March</td>
<td>Pressure</td>
<td>q = 34.818Δp^0.1044</td>
<td>70.2</td>
</tr>
<tr>
<td>4</td>
<td>7th March</td>
<td>Depressurization</td>
<td>q = 38.236Δp^0.6015</td>
<td>96.9*</td>
</tr>
<tr>
<td>5</td>
<td>14th March</td>
<td>Pressure</td>
<td>q = 32.382Δp^0.3460</td>
<td>71.8</td>
</tr>
<tr>
<td>5</td>
<td>14th March</td>
<td>Depressurization</td>
<td>q = 27.925Δp^0.4752</td>
<td>83.4</td>
</tr>
</tbody>
</table>

* For one air inlet is 24.2 m³/h.

3.2.2. Air permeability of the current window

The European standards EN 1026: 2000 [20] and EN 12207: 1999 [5] were followed in the laboratory tests (conducted on the window manufacturer’s prototype). The window had the following characteristics: total area of 1.80(m²) × 1.00(m²) m²; length of the moveable external joint of 6.60 m; thickness of the simple window glass pane of 4 mm.

Under European standard EN 12207: 1999 [5], the window’s air permeability belongs to class 2 (the best class obtained among the pressure and depressurization partial tests). The equations obtained as a function of the air permeability trials (adjusted results for standard conditions of 20 °C and 101.3 kPa) are summarized in Table 2. The accuracy required in accordance with the international test standard EN 1026: 2000 is 10% [20].

Compared with the Initial Type Tests carried out under the responsibility of the window assembly designer ("system house"), the tests carried out on the window manufacturer’s prototype showed a significant increase in air permeability (over 100% for 10 Pa), thereby lowering the air permeability class from 3–4 to 2. These results show the mismatch between the best assembly practice developed by the assembly designer and the real assembly practice of the window manufacturer (Fig. 8).

The air permeability test results obtained in situ for the windows, both together and separately, are found in Table 3. The

Table 2

<table>
<thead>
<tr>
<th>Test</th>
<th>Flow rate as a function of total area [m³/h m²]</th>
<th>Flow rate for 10 Pa [m³/h m²]</th>
<th>Flow rate as a function of the length of the moveable joint [m³/h m]</th>
<th>Flow rate for 10 Pa [m³/h m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>q = 0.853Δp^0.1581</td>
<td>3.2</td>
<td>q = 0.232Δp^0.1581</td>
<td>0.9</td>
</tr>
<tr>
<td>Depressurization</td>
<td>q = 0.1975Δp^0.1485</td>
<td>1.4</td>
<td>q = 0.0485Δp^0.1485</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Fig. 6. Aerodynamic performance of the self-regulated air inlet (7th March 2006).

Fig. 7. Comparative analysis of the aerodynamic performance of a self-regulated air inlet (depressurization, comparison for 7th March 2006).

Table 1 shows some variability in the results. This may be explained by fluctuating wind speed. When the under depressurization is 10 Pa the flow rate is slightly below the expected rate.

The comparative analysis between the tests carried out in situ and those carried out in the laboratory in Fig. 7 shows that these values are close at pressures below 20 Pa. Nevertheless, there is still some discrepancy in the results at higher pressures, showing that a malfunction of the self-regulating membrane occurs also in situ measurements.
size of the windows was as follows: living room window area of \(2.70 (w) \times 2.00 (h) \text{m}^2\), kitchen window area of \(1.80 (w) \times 1.10 (h) \text{m}^2\) and bedrooms window area of \(1.80 (w) \times 1.00 (h) \text{m}^2\) (total area of \(10.98 \text{m}^2\)). Considering the similarity of test methods, the pressure and the flow rate determined \textit{in situ} may be compared with the pressure and the flow rate determined in the laboratory. Care should be taken when interpreting laboratory tests because the outer face of the window is placed inside the test rig; therefore, pressure inside this test rig corresponds to a flow from outside to inside the compartment, which is comparable to depressurization site tests. In these tests, the air permeability (flow rate) would be expected to be lower for the pressure test (air flowing out of the flat) because some windows (kitchen outside door) are of the type single side-hung casement, opening inwards; therefore, a higher pressure inside the flat compresses the casement against the joint, reducing the gaps and thus the air permeability. However, this was only found to be the case for the test held on 8th February 2006.

A comparative analysis per unit of area between the bedroom window laboratory test and the \textit{in situ} living room window test is shown in Fig. 9. Given the discrepancy of results, mainly at high pressures, it may be concluded that the extrapolation of tests to larger windows as mentioned in [21] is not recommended. In this case an overestimation of approximately 200\% is obtained for 600 Pa (this pressure is under the range of the standard EN 12207: 1999 [5], but having in mind the comparisons of test results, here the air permeability is only presented up to 60 Pa).

### 3.2.3. Aerodynamic performance of the bathroom exhaust device

The tests were carried out in accordance with standard NP EN 13141-1: 2006 and the respective aerodynamic performance is shown in Fig. 10. The accuracy obtained is smaller than 5\% of the measured value [22].

The extraction pressure loss coefficient of the exhaust device \((\zeta = 2 \times \Delta p/1.2 \times (A/[q/3600])^2\) is 2.8, which is equivalent to a pressure drop of 40 Pa for 45 m\(^3/h\). This figure greatly exceeds the pressure loss recommended by NP 1037-1: 2002 [23], 3 Pa, thus implying a drastic reduction in bathroom air extraction rates in Portugal today, where the use of this type of device is common.

In the flats with improved ventilation systems, an aluminum exhaust device with the following size was used: exterior \(= 196(b) \times 150(h) \text{mm}^2\), interior: \(\phi 120 \text{mm}\). The manufacturer’s aerodynamic performance rating is shown in Fig. 10.

### Table 3

<table>
<thead>
<tr>
<th>Flat Test date</th>
<th>Test (Global)</th>
<th>Flow rate at 10 Pa [m(^3)/h]</th>
<th>Flow rate for 10 Pa [m(^3)/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 8th February 2006</td>
<td>Pressure (Global) (q = 4.333\Delta p^{0.862})</td>
<td>24.3</td>
<td>2.21</td>
</tr>
<tr>
<td>1 8th February 2006</td>
<td>Depressurization (Global) (q = 10.324\Delta p^{0.489})</td>
<td>32.6</td>
<td>2.97</td>
</tr>
<tr>
<td>2 21st February 2006</td>
<td>Pressure (Global) (q = 7.576\Delta p^{0.407})</td>
<td>23.5</td>
<td>2.14</td>
</tr>
<tr>
<td>3 21st February 2006</td>
<td>Depressurization (Global) (q = 1.100\Delta p^{0.015})</td>
<td>11.0</td>
<td>1.00</td>
</tr>
<tr>
<td>4 7th March 2006</td>
<td>Pressure (living room window) (q = 7.734\Delta p^{0.402})</td>
<td>19.6</td>
<td>3.63</td>
</tr>
</tbody>
</table>
Table 4
Roller shutter box air permeability.

<table>
<thead>
<tr>
<th>Flat</th>
<th>Test date</th>
<th>Test</th>
<th>Flow rate as a function of the length of the moveable joint [m^2/h]</th>
<th>Flow rate for 10 Pa [m^3/h]]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8th February 2006</td>
<td>Pressure</td>
<td>[q = 107.044\Delta p^{0.5712}]</td>
<td>251.6</td>
</tr>
<tr>
<td>1</td>
<td>8th February 2006</td>
<td>Depressurization</td>
<td>[q = 81.117\Delta p^{0.4458}]</td>
<td>264.1</td>
</tr>
<tr>
<td>3</td>
<td>21st February 2006</td>
<td>Depressurization</td>
<td>[q = 99.602\Delta p^{0.4458}]</td>
<td>278.0</td>
</tr>
</tbody>
</table>

The extraction pressure loss coefficient of this device is 0.77, which is equivalent to a pressure drop of 2 Pa for 45 m³/h. So, it does not surpass the pressure loss recommended by NP 1037-1: 2002 [23].

3.2.4. Pressure loss and pressure factor of the static ventilator (cowl)

The static ventilator was tested in the laboratory in accordance with standard prEN 13141-5: 1998. The wind tunnel test took place at LNEC. The determined parameters were the pressure loss coefficient \(\zeta = 1.5\); the nominal value claimed by the manufacturer is \(\zeta = 1.51\) and the pressure factor.

The static ventilator’s performance obtained by the manufacturer was graded in accordance with standard NF P 50-413: 1993 (this standard was recently withdrawn; its content is now in DTU 24.2.P1-1: 2006 [24]). This document grouped the static ventilators in 2 classes. Class B (Good), the classification obtained by this ventilator, had the following specifications:

- pressure loss coefficient, \(\zeta\), less than 2;
- pressure factor less than \(-0.65\) for wind directions of \(\pm 30^\circ\) with respect to the horizontal axis;
- pressure factor less than \(-0.50\) for wind directions in ranges \([-60^\circ; -30^\circ]\) or \([+30^\circ; +60^\circ]\);
- pressure factor less than 0 for other wind directions.

Fig. 11 shows the comparative analysis for the two tests, from which it is possible to conclude that the ventilator is of class B. However, the results obtained in the laboratory give lower (better) values for the pressure factor.

3.2.5. Air permeability of the roller shutter boxes

Fig. 12 shows a typical detail of a roller shutter box in Portugal. The roller shutter boxes were not tested in the laboratory since their performance in terms of air permeability depends, to a great extent, on their installation. Only the in situ test results are presented (Table 4). As shown in Section 4, the air permeability of the overall roller shutter box is higher than that of the window.

To reduce the air permeability of the roller shutter box, the following recommendations on the design should be retained:

- to seal the whole fixed joint between the walls, windows and the roller shutters with, for example, mastic;
- to improve the connection between the frame of the roller shutter box and the horizontal particleboard (that encloses the box) with a “male-female” joint.

3.2.6. Air permeability of the doors

The performance of the doors is detailed in the tables below. The size of the doors was as follows: area of interior doors 0.75(w) \(\times\) 2.00(h) m², area of kitchen external door

Table 6
Air permeability of the flat’s main entrance door.

<table>
<thead>
<tr>
<th>Flat</th>
<th>Test date</th>
<th>Test</th>
<th>Flow rate as a function of the length of the moveable joint [m^2/h]</th>
<th>Flow rate for 10 Pa [m^3/h]]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14th March 2006</td>
<td>Pressure</td>
<td>[q = 0.792\Delta p^{0.5547}]</td>
<td>30.6</td>
</tr>
<tr>
<td>5</td>
<td>14th March 2006</td>
<td>Depressurization</td>
<td>[q = 0.618\Delta p^{0.3402}]</td>
<td>113.1</td>
</tr>
</tbody>
</table>

a Length of the moveable joint: 5.40 m.

Table 5
Air permeability of the interior doors of the flat (bedrooms and kitchen).

<table>
<thead>
<tr>
<th>Flat</th>
<th>Test date</th>
<th>Test</th>
<th>Flow rate as a function of the length of the moveable joint [m^2/h]</th>
<th>Flow rate for 10 Pa [m^3/h]]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 doors</td>
<td>7th March 2006</td>
<td>Pressure</td>
<td>[q = 3.974\Delta p^{0.4031}]</td>
<td>68.0</td>
</tr>
<tr>
<td>3 doors</td>
<td>7th March 2006</td>
<td>Depressurization</td>
<td>[q = 4.739\Delta p^{0.3943}]</td>
<td>64.6</td>
</tr>
<tr>
<td>1 door</td>
<td>14th March 2006</td>
<td>Pressure</td>
<td>[q = 1.744\Delta p^{0.7999}]</td>
<td>52.7</td>
</tr>
<tr>
<td>1 door</td>
<td>14th March 2006</td>
<td>Depressurization</td>
<td>[q = 2.374\Delta p^{0.6024}]</td>
<td>52.3</td>
</tr>
</tbody>
</table>

Table 7
Air permeability of the external kitchen door.

<table>
<thead>
<tr>
<th>Flat</th>
<th>Test date</th>
<th>Test</th>
<th>Flow rate as a function of the length of the moveable joint [m^2/h]</th>
<th>Flow rate for 10 Pa [m^3/h]]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8th February 2006</td>
<td>Pressure</td>
<td>[q = 0.538\Delta p^{0.6099}]</td>
<td>13.4</td>
</tr>
<tr>
<td>1</td>
<td>8th February 2006</td>
<td>Depressurization</td>
<td>[q = 1.016\Delta p^{0.7714}]</td>
<td>29.4</td>
</tr>
<tr>
<td>4</td>
<td>7th February 2006</td>
<td>Pressure</td>
<td>[q = 0.819\Delta p^{0.6056}]</td>
<td>20.0</td>
</tr>
</tbody>
</table>

a Length of the moveable joint: 5.36 m.
Table 8  Comparative analysis of the various sources of the results.

<table>
<thead>
<tr>
<th>Source</th>
<th>Manufacturer - base value</th>
<th>Laboratory</th>
<th>In situ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-regulated air inlet</td>
<td>q for 10 Pa = 23.2 m$^3$/h (Fig. 5)</td>
<td>q for 10 Pa = 24.5 m$^3$/h (Fig. 5)</td>
<td>q for 10 Pa = 24.2 m$^3$/h (Fig. 6; Table 1)</td>
</tr>
<tr>
<td>Static Ventilator</td>
<td>q for 50 Pa = 36.0 m$^3$/h (Fig. 5)</td>
<td>q for 50 Pa = 52.6 m$^3$/h (Fig. 5)</td>
<td>q for 50 Pa = 46.4 m$^3$/h (Fig. 6; Table 1)</td>
</tr>
<tr>
<td></td>
<td>Pressure factor for 0$^\circ$ = – 0.91 (Fig. 11)</td>
<td>Pressure factor for 0$^\circ$ = – 1.11 (Fig. 11)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pressure loss = 1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Window assembly designer - base value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Window manufacturer - Laboratory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Window manufacturer - In situ</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9

<table>
<thead>
<tr>
<th>Component</th>
<th>Test date</th>
<th>Flat</th>
<th>Flow rate for 50 Pa [m$^3$/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roller shutter boxes</td>
<td>8th and 21st Feb. 2006 (Table 2; Average)</td>
<td>1 and 3</td>
<td>586.3</td>
</tr>
<tr>
<td>Windows</td>
<td>8th and 21st Feb. 2006 (Table 4; Average)</td>
<td>1 and 3</td>
<td>64.0</td>
</tr>
<tr>
<td>Main entrance door</td>
<td>14th March 2006 (Table 6)</td>
<td>5</td>
<td>269.8</td>
</tr>
<tr>
<td>Kitchen external door</td>
<td>8th Feb. 2006 (Table 7)</td>
<td>1</td>
<td>95.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total air flow rate [m$^3$/h]</td>
<td>1015.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$ACH_{50}$ [h$^{-1}$]</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Fig. 13. Overall air permeability of flats.
difference of 50 Pa, previously measured and presented in Section 3, are summed and presented in Table 9. The obtained flow rate corresponds to a \( ACH_{50} = 6.3 \), that is equal to the average \( ACH_{50} \) obtained at the overall air permeability tests presented in Fig. 13. This agreement shows that these building components have the most influence in the overall air permeability of the flat. It shows also that these measurements are reliable, because similar results are obtained by following two different test methods (measurement of overall air permeability of the flat, versus individual measurement of the air permeability of each of the building components).

5. Conclusions

In this paper tests of air permeability of every building component and tests of the overall flat air permeability were carried out. With respect to the individual characterization of the components, the following may be concluded:

- In general, there is some discrepancy between the test results from different sources. In the case of the self-regulated air inlet (Figs. 5 and 7), the test results of the aerodynamic characteristics presented by the manufacturer and those obtained in the laboratory and in situ tests do not agree for higher pressure differences (which, in the case of natural ventilation, is not too important because the pressure differences are usually small). This is due to malfunction of the self-regulating membrane.
- The example of the bedroom window also shows that the real window has higher air permeability than initial Type Test results presented by the window assembly designer (in this case by 200% - Fig. 8). This shows the deterioration in the quality of window installation carried out by the window manufacturer because the construction rules issued by the window assembly designer are not completely followed. Recommendations should be issued in order that window manufacturers fully follow the technical instructions prepared by the window assembly designer.
- The high air permeability of the kitchen external door and main entrance door, confirmed the expectations (Table 9): faulty configuration of the bottom horizontal joint. In light of the requirements set out in NP 1037-1: 2002 [23] this is one of the components which should be given the most attention at the design and execution stages.
- The low air permeability of the interior doors (Table 5) as compared to the values cited in the Portuguese literature highlights the potential restriction of air flow inherent to a ventilation system and shows that bigger gaps indoor joints or ventilation air transfer devices are needed in order to avoid ventilation restriction.
- The high pressure drop characteristic for a “current” exhaust air terminal device installed in the bathroom exhaust duct (Fig. 10) shows the importance of proper component selection.
- The data obtained from the roller shutter box confirm that this is the component making the greatest percentage contribution to the overall air permeability in flats (Tables 4 and 9). It also highlights the need to improve their performance, along with that of external doors.

As regarding to the overall air permeability of the flats, the following may be concluded:

- Although the flats tested were of the same size, with the same components and apparently with the same construction processes, the overall air permeability shows wide variation. This is probably due to the variation of the dimension of the gaps surrounding the roller shutter boxes and the gaps in the lower opening joint of the external doors (altogether these correspond to more than 90% of the overall air permeability of the flat, according to Table 9), that strongly depends on the local installation work. Nevertheless, the average value is similar to that shown in the Portuguese literature. The overall flat air permeability should be reduced by improving the quality of roller shutter boxes and external doors manufacturing and installation.
- Good agreement between the air permeability obtained in the individual component test (Table 9) and the overall air permeability (Fig. 13), can be concluded and indicate the reliability of the results.

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References


