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Air permeability measurements of dwellings and building components in Portugal

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A R T I C L E I N F O

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A B S T R A C T

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.

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]:

$$ACH_{\text{annual average}} = \frac{ACH_{50}}{N} \tag{1}$$

At European level several studies [8–11] show that air permeability strongly depends on the type of building. On average, terraced

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Nomenclature

A	area of opening perpendicular to air flow, [m^2]
ACH	air change rate, [h^{-1}]
w	width of an exhaust device/door/window, [m]
C	leakage coefficient, [$m^3\ h^{-1}\ m^{-2}\ Pa^{-n}$] or [$m^3\ h^{-1}\ m^{-1} \cdot Pa^{-n}$] or [$m^3\ h^{-1}\ Pa^{-n}$]
h	height of an exhaust device/door/window, [m]
N	constant, which depends on the local climate, type and location of the building, [-]
n	air flow exponent, [-]
q	air flow rate, [m^3/h]
Greek symbols	
Δp	pressure difference, [Pa]
ζ	pressure loss coefficient, [-]
Subscripts	
infilt	infiltration
syst	system
annual average	average annual air change rate
50	air change rate at 50 Pa

houses are less permeable than semi-detached or detached houses, but more permeable than flats.

The document CEN/TR 14788: 2006 [12] also gives ACH_{50} limits as a function of the type of the ventilation system and the shielding of the dwelling in order to achieve $q_{\text{infilt}} < 0.25 \cdot q_{\text{syst}}$.

So, in order to optimize energy efficiency in accordance with the European Directive on Energy Performance of Buildings (EPBD - 2002/91/CE) [13], the air permeability of buildings has to be assessed and the components which play the most important part in that air permeability must be identified. Given the difficulty in finding published data on the overall air permeability in dwellings (ACH_{50}) with similar construction characteristics and similar components (e.g. air permeability of interior doors) to Portuguese housing stock in Mediterranean countries [4,14], a wide-ranging experimental campaign was carried out with tests performed in five flats with identical construction characteristics and building components.

These data are particularly useful for improving the design of building components (e.g., windows and roller shutter boxes) and to perform reliable simulations.

2. Methodology of pressure tests

2.1. Principle

The pressure test consists of applying a known pressure differential 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:

$$q = C \Delta p^n \tag{2}$$

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].

2.2. Procedures and standards for determining ACH_{50}

The measurement range is typically between 10 Pa and 60 Pa with increments of between 5 Pa and 10 Pa and a minimum of 5 measurement points [16,17]. Flow rates are not measured for outside/inside pressure differences below 10 Pa, in order to minimize the influence created by the wind and by thermal differentials during the tests (for normal climate conditions, pressure induced by the combined effect of temperature differences and wind is in the range of $\pm$10 Pa) [6]. It is also recommended that the windows and doors of adjacent flats are open [18] so that the pressure difference between the exterior and the flat under study is as uniform as possible.

As mentioned above, the tests are influenced by external weather conditions so they should only be carried out when the product of the difference between the exterior and interior air temperature by the height of the building is not higher than 200 m °C [16] or not higher than 500 m K [17] (the test criteria vary according to the standard). Test conditions are most favorable when the wind speed is between 0 m/s and 2 m/s and the exterior air temperature is between 5 °C and 35 °C [16].

2.3. Uncertainty

For standard equipment, uncertainty in determining the various parameters that may be obtained with this test are below 15% in most cases [17]. Uncertainty in determining values for C and n may be obtained by the methods described in various documents [17], likewise the uncertainty of flow rate measurements [15].

3. Test results - experimental characterization of building components and ventilation devices

3.1. Description of the building and ventilation system tested

A four-story multifamily building located in the neighborhood of Porto was chosen (Fig. 1). The flats had a ceiling height of approximately 2.5 m.

The natural ventilation system proposed by the designer had the following characteristics and locations (Fig. 2):

- air self-adjustable inlet device located above the roller shutter box at an approximate height of 2 m; one self-regulated air inlet per room (the characteristic air flow rate is 30 m^3/h at the pressure difference of 20 Pa) and two in the living-room (Fig. 3); this is a so-called “module 30” air inlet;
- air fixed inlet device on the external kitchen door (with an adjoining balcony) installed in the lower portion of the door; its overall size is 55 × 16.5 cm^2 (an effective area of 247.5 cm^2);
- extraction from toilet with a fixed plastic “current” outlet positioned approximately 2.1 m above the floor (gross area of 15 × 15 cm^2 and effective area of approximately 26 cm^2) and a static ventilator (cowl) at the end of the duct on the roof (Fig. 4).

The elements that are not a direct part of the ventilation system, but influence it nonetheless, had the following characteristics:

- particleboard bedroom doors with rubber weather strips in the top and side joints and a bottom gap of an average height of 0.4 cm when the door is closed;
- particleboard kitchen and bathroom doors with rubber weather strips in the top and side joints and a bottom gap of an average height of 0.8 cm;