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An Analytical Approach to the Ventilation Effectiveness of Mediterranean Buildings.

Case Study: Existing Residential Building, Portugal

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Abstract

Building airtightness assumes an important role in the energy saving and the indoor thermal comfort. Ventilation rates bring significant impacts on energy usage in the constructions and indoor contaminant concentrations and also setting them as the key parameters in building performance.

Ventilation rate have been measured in building for a long time, and there are some developed measurement methodologies related to it in the research domains. However, most of the investigations in recent years have been done usually in the cold climate conditions, while Mediterranean construction are not deeply investigated in the literature.

In this paper, the authors present the obtained results of an experimental research which is carried out on the Portuguese residential buildings. The investigation is done by fan pressurization methods, also known as "Blower Door Test (BDT)" as the measurement method as well as Design Builder (DB) as the simulation software. The airtightness measurement of the existing buildings and the influence of air leakage on energy consumption and indoor comfort in different Portuguese construction typologies are focused on the aim of the research.

The important parameters of the building such as whole-building air change rates, building infiltration rates, and ventilation effectiveness rate in the residential building are also considered in this research.

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1. Introduction

Buildings require an adequate level of ventilation in order to maintain the health, comfort and well-being of the occupants and this involves the supply of fresh air and the removal of stale air and indoor air pollutants [1]. Ventilation can generate pressure difference, add or remove humidity, remove or dilute pollutants, control the thermal comfort, increase the building costs for air conditioning, and it is sufficient to maintain the building's integrity [2]. In Portugal natural ventilation, uncontrolled air movement into a building through cracks and small holes (infiltration) and through vents such as windows and doors, is the traditional method of allowing the renovation of the indoor air.

Nowadays, because of central heating and cooling, as well as the desire for privacy, people tend to make little use of windows for ventilation, so infiltration has become the main way of natural ventilation. Unfortunately, a home's natural infiltration rate is unpredictable and uncontrollable as it depends on its air tightness, outdoor temperatures, wind direction and other factors [3].

The implications of low levels of air tightness in buildings includes high infiltration rates, dryness caused by uncontrolled air leakage, as well as the annual energy consumption increment [4]. Air tightness has, therefore, a critical importance in improving the energy performance of buildings [5].

Many countries began air tightness researches and related measurement techniques since 1980s, and measurements were taken to find out the real air tightness performance of buildings, which are nowadays available in international literature. Most of them have been carried out in cold climatic conditions such as in Northern Europe [6], Canada and the US [7] and more strict standards were worked out for the air tightness performance.

The standards for air tightness performance in different countries have evolved [8] [9] and a variety of air-tightness levels among different countries can be found as well as criteria that have become more strict over time even in the same country [10].

Nowadays a reference database for the evaluation of air leakage in typical Mediterranean buildings, is not unfortunately available in technical literature, however an interesting reference for some building elements is given by ASHRAE, in the same way each country in Mediterranean region has defined a general minimum value for one or two parameters related to ventilation [11].

2. Research methodology

There are different methodologies to measure the leakage and air change rate of existing buildings. Measurement in-situ is a method in this field. Tracer Gas Tests and Blower Boor Tests (BDT) are two primary measurement methods which are used to measure the leakiness of a building and thereby predict the natural infiltration rate of the buildings' envelopes. Since in-situ measurement procedure involves high costs, simulation methods have appeared as a new way of analyzing building air tightness. This research is based on a comparative approach in order to calibrate the results of in-situ measurement by the simulation results.

In terms of envelope leakage measurement in existing residential buildings ISO-9972 [12] and EN-13829 [13] indicate the typical fan pressurization method. BDT is one-time assessment of the measured house leakage rate when the house is artificially pressurized. According to ISO-9972 Standard, there are three different methods of measurement for BDT and in this research method B was used in order to measure the air leakage rate that flows only through the building envelope. After the in-situ measurement the sample apartment was modeled in DB software to simulate its air change rate and its airflow circulation by Computational Fluid Dynamic (CFD) module. In the last step, all results of BDT and DB were compared in order to discuss the effectiveness and quality of the existing natural ventilation system in this sample apartment. However in order to develop this research more tests will be done and we are aware that the results from BDT can be changed in different floors, orientations, etc. But they can provide us some guidelines about buildings behavior according to the envelope characteristics which is a part of the research aim.

3. Field measurement

3.1. Field building overview

The research was developed in a retrofitted apartment. It is constructed in 1952 and is retrofitted in 2010. The apartment includes 25.4 m^2 floor area and 71.2 m^3 volume. It is located in the second floor of a 5-floor building where the first floor is parking. The building has one facade in the west side and the building has ventilated naturally. All the main structure of the building remains the original. The building is located in Rua de Fernandes Thomas, one of the oldest streets of Coimbra downtown, Portugal.

Fig. 1. The selected apartment as a case study.

3.2. Measurement procedure model of Blower Door

The fan pressurization approach in BDT method is commonly used in residential or small buildings. Envelope leakage is measured by pressurizing the building using a fan installed on the entrance door. The pressure inside the building is increased up to 50Pa by blower door fan and reduced gradually in 5Pa intervals by modulating the fan speed. By measuring the pressure difference and coincident blower door fan flow rate, the permeability of envelopes (n_{50}, q_{50}) of the building under test is assessed.

Table 1. Equations used to apply BDT method.

Parameters	Equations
Q_{50} air leakage rate, m^3h^{-1}. (The air flow rate across the building envelope including the flow rate through joints, fissures, and superficial porousness).	Q_{50}= CL.50n
n_{50}, air change rate h^{-1} (the infiltration air flow rate per internal volume).	$n_{50}= q_{50}/V$
qa_{50}, air permeability, (A_E is the envelop area: m^2), $m.h^{-1}$	$qa_{50}= q_{50}/A_E$

4. Result and discussion of BDT

Figure 2 demonstrates the tested apartment in the time of BDT. The results from BDT have been reported in airflow rate, and is associated with inducted building envelope pressure difference or in term of leakage area. There are two different methods for analysing the recorded data of BDT and this research is developed by the single point test method which makes the flow and inducted envelope pressure measurement at reference test pressure. This measurement is often repeated multiple times in order to calculate measurement uncertainty. Due to this method the building leakage curve is calculated by the variable coefficient and exponent in the following equation.

$$Q = C(\Delta P)^n \quad (1)$$

Where,
Q: is the airflow through the building leaks (CFM, m^3/h, h^{-1});

C: is the coefficient (airflow needed to change the building pressure by 1pa);
ΔP: is induced pressure difference between inside and outside of the building;
N: is the exponent (theoretically 0.5 to 1).

Fig. 2. The tested apartment in the time of BDT.

Figure 3 presents the building leakage curve due to the results of the BDT. It demonstrates the correlation between pressure and airflow rate in the induced pressure from 20 to 70Pa and it shows that as far as the pressure increases the rate of airflow also increases. It means that there is a constant relation between induced pressure and airflow rate in this building.

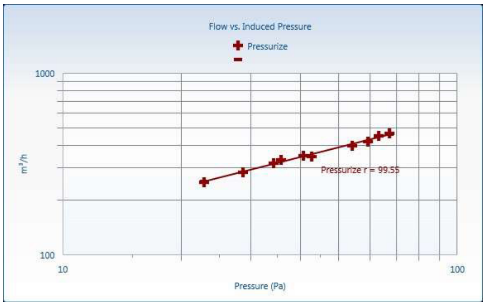

Figure 3: Relation between induced pressure and flow rate in pressurization test.

The measurement of the BDT is used in EU countries according to the EN-13829:2000. Table 2 illustrates the results of the pressurization test in BDT procedure inside of the selected building based on the equations presented in the regulation of EN-13829:2000.

Table 2. Results of BDT in the selected building based on the EN-13829:2000.

Parameters	Floor area (A_u, m^2)	Height of building (m)	Envelope area (A_e, m^2)	Building volume (m^3)	Permeability at 50Pa, (q_{50}, $m^3/h/m^2$)	Air Flow in 50 Pa (CFM)	Air change rate (n_{50}, h^{-1})
Reference Building	25.4	3.5	57.20	71.20	6.82	230	5.48

Often the airflow expresses in Air Changes per Hour (ACH) in referenced pressure. This is the number of times that the blower door flows at 50Pa to fill the total volume of the house in one hour. In the studied building this rate is equal to 5.48 h^{-1}. While the value of air change rate in different standards is absolutely smaller than the tested apartment. In ASHRAE standard the air change rate is 0.35h^{-1} and according to the PASSIVE HOUSE standards is

0.6 h^{-1}. This large difference between the ASHRAE and PASSIVE HOUSE standards with the existing condition of the tested apartment demonstrated the air tightness and air permeability condition of the case study.

5. Results and discussion of DB simulation

As it was already explained in the Research Methodology, one of the new ways to predict building air leakage and infiltration is simulation method. Figure 4 shows the results of the simulation of the referenced building in DB software, considering its leakage and infiltration on a weekly period in the cooling season. As figure 4 shows, the air change rate of the building varies between 2-7 h^{-1} under a 50Pa pressure. We can also see that when the air change rate of the building is high and more than 5 renovations per hour the operative temperature of the building decreases based on the air circulation in the interior spaces. However, in most simulation periods, the operative temperature, and the inside surface temperature are higher than the air temperature which it means the interior spaces of the building are warmer than outside in the summer period. Based on the first chart of figure 4, we can see that besides exterior surface temperature and interior surface temperature being higher than air temperature and operative temperature, there is also no difference between these two parameters (interior and exterior surfaces temperature) and even they are overlapped in some periods of the simulation. Which it means that the thermal resistance of building envelope is weak. As the last chart of Figure 4 demonstrates, there is a correlation between airflow in/out with the infiltration rate of the buildings. When the transferred air between inside and outside, by flow, is high the air change rate of the buildings (infiltration) is also high and, on the other hand the building has the lower operative temperature.

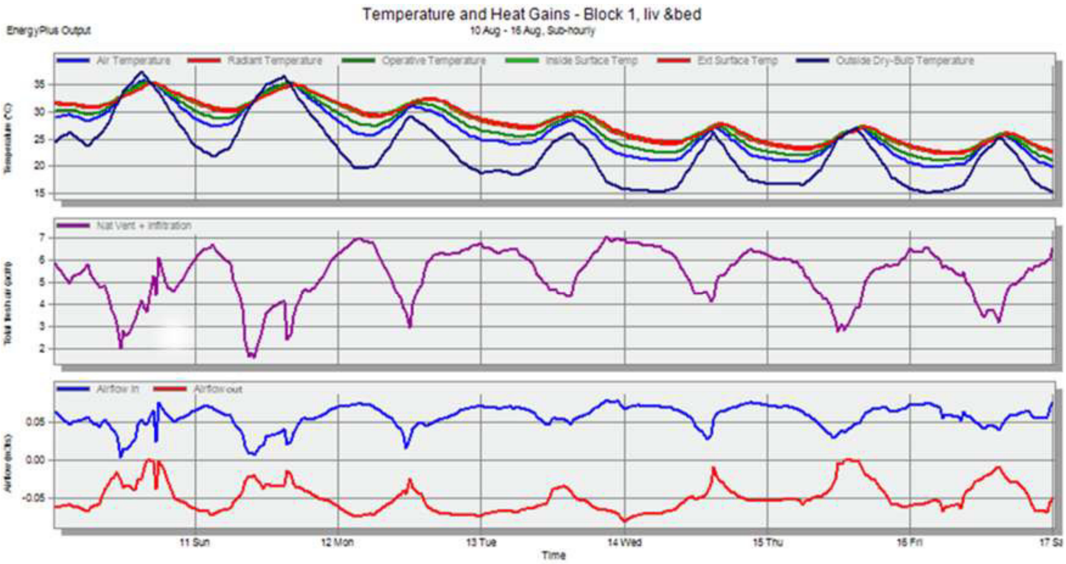

Figure 4: The analysis of air leakage of the naturally ventilated building by DBS in a weekly period in the cooling season.

Since there are some openings in the building envelopes for intake and exhaust of the airflow and air circulation, Figure 5 illustrates the air distribution in the interior spaces of the reference building simulated by the CFD module of DBS. According to this figure, it is possible to observe the air distribution in the interior spaces based on the position and geometry of the openings.

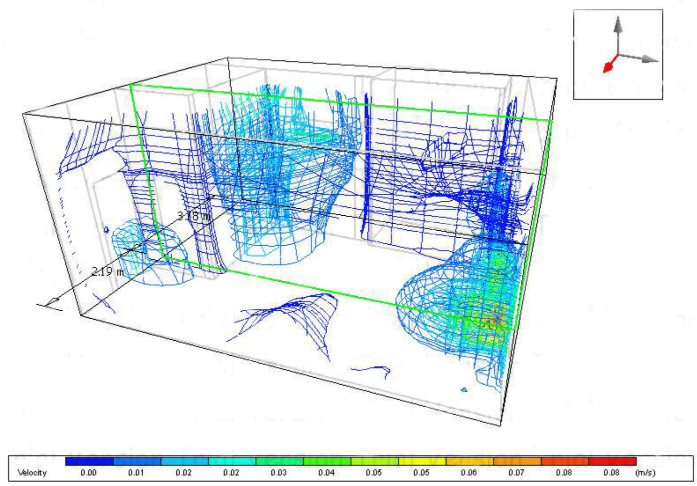

Figure 5: Analysis of air distribution in the reference building with DBS.

6. Conclusion

Taking into account the aim of this research and based on the presented results of the BDT in the reference building and the results of the DBS about the air change rate of the building and also the distribution of the air in the interior spaces, it is observed that the air change rate of the building in both methods is almost similar and near, which is generally between 5-7 h^{-1}. With this values, and based on the international classification of Passive House Institute and also Air Barrier Association of America, the building is placed in the class of standard existing home (based on Field data). Since the building is a retrofitted building, the air change rate of the building is acceptable in the existing condition. However, the thermal resistance of the building envelope is very weak, based on the overlapped of the interior and exterior surface temperature as it was shown in Figure 4, which it needs to improve.

On the other hand, the answer of the question about how much the obtained air change rate of the building is effective, will be the next phase of this research.

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