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Airtightness and ventilation in a mild climate country rehabilitated social housing buildings – What users want and what they get

Nuno M.M. Ramos [a,*], Ricardo M.S.F. Almeida [a,b], António Curado [c], Pedro F. Pereira [a], Sofia Manuel [a], Joana Maia [a]

[a] University of Porto, Faculty of Engineering, Department of Civil Engineering, Laboratory of Building Physics, Rua Dr. Roberto Frias s/n, 4200-465 Porto, Portugal

[b] Polytechnic Institute of Viseu, School of Technology and Management, Department of Civil Engineering, Campus Politécnico de Repeses, 3504-510 Viseu, Portugal

[c] Polytechnic Institute of Viana do Castelo, School of Technology and Management, Department of Engineering Sciences and Technology, Avenida do Atlântico, 4900-348 Viana do Castelo, Portugal

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ABSTRACT

Dwellings should be designed for users' wellbeing but frequently their actions seem to contradict the logic adopted in the design. The impact of users' actions and habits on buildings energy efficiency is well established and documented. However, there is a lack of available information concerning the relationship between user behaviour, building airtightness and ventilation. This paper explores the results of a large experimental campaign, which included: airtightness measurements by fan pressurization of flats; continuous CO_2 measurements, and a questionnaire regarding tenants' habits. Forty nine apartments from two different social housing neighbourhoods, one of them recently rehabilitated, were used as case study. Non-rehabilitated flats presented an average ACH_{50} of 8.9 h^{-1} while the rehabilitated flats presented an average of 6.8 h^{-1}. The impact of user behaviour in airtightness levels was investigated and, in the rehabilitated case study, the average ACH_{50} was 4.3 h^{-1} in modified flats and 7.7 h^{-1} in non-modified. This can have important consequences on the indoor environment as the average ACH found in a modified flat, ranged from 0.35 h^{-1}, in December to 1.01 h^{-1} in August, showing the importance of window opening in the actual ventilation rates. The standard methods for estimating average ventilation rates were applied to the sample and results compared with measurements, indicating a need to adapt currently used methodologies to adequately include user effect. The complexity of human behaviour is a challenge for designers and therefore increasing the knowledge of user actions and habits is decisive for building better homes.

1. Introduction

Sustainable building users' comfort can be accomplished with adequate energy efficient measures that include the minimization of heat loss through the building enclosure and the reduction of ventilation rates to minimal acceptable values. Recent studies indicate that in Southern European countries ventilation can represent 30–80% of the heating demand [1] and that the incidence of infiltration can vary from 10 to 27% [2]. In naturally ventilated buildings, airtightness will therefore play an important role in comfort and energy consumption, especially in mild climate countries where often dwellings' ventilation is adventitious and highly influenced by user behaviour [3,4]. Users can influence the ventilation patterns with different actions that include: opening/closing windows, changing settings of mechanical ventilation devices or acting on the airtightness itself by sealing ventilation inlets or upgrading windows. Several researchers studied the effect of occupancy and user behaviour on the energy use of residential buildings [5–10]. There is, however, little work regarding the importance of user behaviour in the variability of building airtightness.

Dwellings should be designed for user wellbeing but frequently user actions seem to contradict the logic adopted in the design. The result is a high variability of buildings' performance [5].

* Corresponding author. Tel.: +351 225081770; fax: +351 225081940.
E-mail address: nuno.ramos@fe.up.pt (N.M.M. Ramos).

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This problem grows in complexity for retrofitted buildings where the restrictions to the possible ventilation systems to be adopted have to be taken in consideration and hence, the ideal airtightness should be a topic for discussion.

In this work, the specific case of social housing projects located in Portugal, an example of a mild climate country is studied. The ventilation systems and airtightness levels of both original and rehabilitated buildings are characterized. At the same time, an enhanced knowledge of the user behaviour is pursued so that a clear view of their expectations and actions can arise from the study. The objective is to explore the links between users, airtightness and ventilation, contributing to rehabilitation strategies that can match users' expectations.

This paper presents results of a large experimental campaign to assess buildings' airtightness, window opening patterns and actual ventilation rates carried out in 49 units of two different social housing neighbourhoods, one of which was recently rehabilitated. The fan pressurization method was used, a questionnaire regarding tenants' habits and actions was implemented and CO_2 measurements were performed. Additionally, a standardized numerical estimation of expected ventilation rates was performed.

2. Background

2.1. Airtightness and ventilation

Residential ventilation can be provided by natural or mechanical means with infiltration caused by air leakage playing a role on the resulting air change rate (ACH). Sherman [11] addressed this subject, calling the attention for the importance of articulating standards that define ventilation requirements, airtightness levels and air flow estimation. The importance of airtightness in energy efficiency and thermal comfort is studied by different authors and addressed in cold countries regulations. In mild climates, such as Mediterranean countries, the topic is not so often approached [4] which may lead to undervaluing leakage in energy audits and not setting a focus on improving related aspects of building technology.

Yet, the continuous evolution of thermal regulations can be observed in Southern Europe countries of which Portugal is an example. The most recent version of the thermal code [12] adopted the EN 15242 [13] methodology for ACH estimation and 0.4 h^{-1} was adopted as lower limit for ventilation during the heating season. The lack of knowledge on airtightness of the Portuguese building stock and the fact that it's not thoroughly addressed in ventilation national standards [14] are problems that must be addressed. To do that, a reflection on target levels of airtightness for mild climate countries would be useful. The coupling between the air change rate with a pressure difference of 50 Pa (ACH_{50}) values to ventilation strategy was suggested by Liddament [15] and cited by Hens [16], according to Table 1. In mild climate countries the ventilation strategy in the residential sector is often adventitious, especially in existing buildings, very depending on window opening. This suggests caution for setting airtightness levels especially in rehabilitation context. This aspect was noted by Nantka [17] with in situ studies that showed how increasing airtightness led to degradation of indoor air quality.

Table 1
Airtightness vs. ventilation strategy.

ACH_{50}	Ventilation strategy
$ACH_{50} > 8\ h^{-1}$	Adventitious ventilation
$4\ h^{-1} < ACH_{50} < 8\ h^{-1}$	Natural ventilation (passive stack)
$1\ h^{-1} < ACH_{50} < 5\ h^{-1}$	Mechanical ventilation (exhaust)
$ACH_{50} < 1\ h^{-1}$	Balanced ventilation with heat recovery

2.2. Studies on airtightness variability

Many experimental studies on building airtightness, using the fan pressurization method, have been carried out in international context. Some of those studies tried to establish a relationship between airtightness and several construction related variables.

Kalamees [18] studied 32 detached dwellings in Estonia. The author compared the ones that were built under professional supervision and the ones built without professional supervision, since it is not rare in Estonia for a house owner to build a detached house on his own, with the help of some friends or a couple of workers without professional supervision. It was found that the airtightness of the dwellings without professional supervision is significantly worse. The mean ACH_{50} from the entire database was 4.9 h^{-1} and the respective air permeability (q_{50}) was 4.2 $m^3/(h\ m^2)$.

In a study carried out by Pan [19], the airtightness of 287 recently built dwellings in the U.K. was tested. The relationship between airtightness and several factors such as construction method, dwelling type, management context, design target, season, number of significant penetrations and envelope and floor area was evaluated. The airtightness of the dwellings averaged 5.97 $m^3/(h\ m^2)$ at 50 Pa. Results showed that dwellings built using precast concrete panels were significantly air tighter, whilst dwellings built by using more site-based labour-intensive construction methods were much more leaky.

Fernández-Agüera et al. [20] proposed and tested five specific protocols for carrying out pressurization/depressurization tests. Their sample included 10 Spanish dwellings and a large variability on the results was found. Authors pointed out manual processes used during construction as the cause for those variances.

Hens [16] determined the ACH50 of 14 dwellings of an estate in Belgium. Results showed a significant variance and, according to the author, one of the main reasons for that was the lazy workmanship at the contractor's side.

Air permeability of 28 Irish houses, built between 1944 and 2008, was tested by Sinnott and Dyer [21]. The effect of construction type, age, design details and retrofitting on air permeability was examined. Results indicate that newer dwellings are more airtight. It was concluded that good design, combined with high-quality workmanship, and rigorous control throughout construction are critical to ensure a good result.

Alfano et al. [4] carried out an experimental investigation on 20 Italian residential houses in order to evaluate their airtightness and the influence of floor area, envelope surface area, internal volume, typology, type of window frame and year of construction. An average experimental ACH_{50} of 7.3 h^{-1} was obtained. Windows, chimney and natural ventilation systems have been found as the most important components for buildings' airtightness.

A set of more than 120 apartments of 25 different Spanish buildings were tested by Tiberio and Branchi [22]. The average ACH50 was 3.40 h^{-1}. Houses with concrete walls revealed more airtight than those with plasterboard partitions. It was also concluded that an exhaustive control of execution in windows and façades sealing might result in an ACH below 2 h^{-1}.

Chan et al. [23] analysed the air permeability measurements of 134,000 single family detached homes in the U.S. Regression analysis was used to examine the relationship between permeability and various house characteristics. Year built and climate zone were found as the most useful parameters for predicting air permeability but a correlation with floor area and house height was also identified.

Meiss and Munoz [2] performed 13 fan pressurization tests in Spanish dwellings located in residential blocks and an average ACH_{50} of 6.26 h^{-1} was found.