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Protocols for measuring the airtightness of multi-dwelling units in Southern Europe

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Abstract

The airtightness of building envelopes is one of the factors which most affects the hygrothermal conditions and the air quality of the indoor environment, as well as the energy consumption of the building. In multi-dwelling units this contributes significantly to the overall load for heating or air conditioning, making it possible to calculate the repercussion of infiltrations on the energy demand of a dwelling as between 20 to 50% of the total amount, depending on the climate zone and construction characteristics of the envelope. Hence the importance of knowing the parameters that characterise it. Pressurisation/depressurisation tests are the best method for characterisig these, but must be carried out in accordance with specific measurement procedures. The main objective of this paper is the proposal of five specific protocols for carrying out these tests in MDU, and their specific use in buildings in Southern European regions. In order to develop and validate this proposal we have carried out a series of multi test in ten dwelling units in a block recently built in the south of Spain. The results of these tests are presented and analysed here. These confirm the need for some protocols to distinguish between wet and dry spaces within the dwelling, given the difference in airtightness between them, and to expand the study indicators proposed by international regulations for a more accurate rendering of the behaviour of the envelope and the elements within it.

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*Keywords:*air leakage; air tightness; blower door; building energy conservation; fan pressurization test; indoor air quality; infiltration.

1. Introduction

The airtightness of building envelopes is one of the aspects which most affects hygrothermal performance, indoor air quality and energy consumption of the building. In multistories dwellings

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contributes significantly to the overall demand for heating or refrigeration.

Based on studies carried out in the USA by the Lawrence Berkeley National Laboratory (LBNL) [1,2,3], by the Institute for Diversification and Saving of Energy (IDAE) in Spain [4], and by our research group in the University Institute of Architecture and Building Science (IUACC) in the south of Spain [5], it must be considered that the repercussion of infiltrations on the energy demand of dwellings may constitute between 20 and 50% of the total, depending on the climate zone and construction characteristics of the envelope. Hence the importance of the parameters that characterise airtightness.

The best method for obtaining these parameters is usually pressurisation/depressurisation tests, generally using equipment such as Blower Doors, but these must be conducted in accordance with specific measurement procedures. The international regulations for these are very general, and at times especially vague, as they try to cover all sorts of buildings. It is necessary to generate specific protocols that incorporate the specific aspects of the ways of constructing and designing multi-storey buildings to Mediterranean Europe. The aim of this paper is to define these specific protocols to enable the establishment of such tests, objectively and rigorously, in order to obtain results for airtightness in housing which can be analysed to tackle any decision-making involved in rehabilitation processes for these buildings. This will allow us to focus on making the most of investment in the improvement of Energy Efficiency of blocks of flats. In order to validate and contrast the proposal a measurement campaign was carried out in March 2011, analysing 10 homes within a subsidised MDU, built in 2004 in the city of Seville, Spain.

2. European overview of pressurisation/depressurisation tests

The current regulations governing these tests are EN 13829 [6], ASTM E 1827-96 [7], ISO 9972 [8], EPB Regulations [9], as well as different variants in Europe [10,11], all of which have a common objective but different peculiarities. Their definition of the spaces to be measured states that ‘normally, the part of the building measured includes all deliberately conditioned rooms’. In general, two measurement procedures are proposed, named by the regulations stated previously as methods A and B:

- Method A is used to measure the airtightness of the building in use: the condition of the building envelope should represent its condition during the season in which heating or cooling systems are used.

-Method B is used to measure the airtightness of the building envelope: any intentional opening in the building envelope shall be closed or sealed.

Table 1 summarises the measurement conditions for both method A and method B, which mainly refer to the state of the openings of the ventilation systems and the openings through which air infiltrations can take place. In either case, all thermal or ventilation systems must be shut off.

Table 1. Table summarising Method A/B

Items	Belgium	Germany (DIN)	Germany (FLiB/ DIBt)	Netherlands	EPB Regulations	ASTM E1827	ISO 9972	UK (ATTMA)
Mechanical ventilation openings	◙/_	_/_	_/_	◙/_	◙/_	I/◙	◙/◙	_/◙
Natural openings/Permanently open natural ventilation openings	Φ/_	I/◙	I/◙	Φ/_	_/_	_/_	Φ/◙	_/◙
Fan inlet grills with motorised damper	_/_	_/_	_/_	_/_	Φ/_	Φ/Φ	_/_	_/Φ
Fan inlet grills without motorised damper	_/_	_/_	_/_	_/_	_/_	I/◙	_/_	_/_
Ventilators designed for continuous use	_/_	◙/◙	◙/◙	_/_	_/_	◙/◙	_/◙	_/_

Items	Belgium	Germany (DIN)	Germany (FLiB/ DIBt)	Netherlands	EPB Regulations	ASTM E1827	ISO 9972	UK (ATTMA)
Supply and exhaust ventilator dampers	_/_	Φ/◙	◙/◙	Φ/_	_/_	Φ/◙	_/_	_/_
Opening via fan, switched on for a short time only	_/_	I/◙	I/◙	_/_	_/_	_/_	_/_	_/_
Supply or exhaust openings for gas appliances	_/_	_/_	_/_	◙/_	_/_	_/_	_/_	_/_
Unsealable air inlet for an open combustion appliance,	_/_	_/_	_/_	_/_	O/_	_/_	_/_	_/_
Openings for electrical devices	_/_	Φ/Φ	Φ/Φ	_/_	_/_	_/_	Φ/◙	_/_
All incoming service penetrations	_/_	_/_	_/_	_/_	_/_	_/_	_/_	_/◙
All drainage traps	_/_	_/_	_/_	_/_	_/_	_/_	_/_	_/●
Other openings with closing device:	Φ/_	Φ/◙	Φ/◙	Φ/_	_/_	Φ/Φ	Φ/◙	_/_
Letter slot, cat-flap	_/_	Φ/◙	Φ/Φ	_/_	Φ/_	_/_	Φ/◙	_/_
Evacuation of used water	_/_	_/_	_/_	_/_	Φ/_	_/_	Φ/◙	_/_
Other openings without closing device:	_/_	_/_	_/_	_/_	O/_	●/●	O/◙	_/_
Aeration of waste water discharges	_/_	_/_	_/_	_/_	O/_	_/_	_/_	_/_
Lock, openings for the belts of the shutters	_/_	_/_	_/_	_/_	O/_	_/_	_/_	_/_
Kitchen Hoods	_/_	I/I	I/I	_/_	_/_	_/_	_/_	_/_
Chimney with/ without closing device	_/_	_/_	_/_	_/_	Φ/_	Φ/-	Φ/◙	_/_
Toilet Doors	_/_	_/_	_/_	_/_	Φ/_	_/_	_/_	_/_
Cupboards and closets	_/_	_/_	_/_	_/_	Φ/_	_/_	Φ/Φ	_/_
Doors to building parts outside the measured extent	_/_	_/_	_/_	_/_	_/_	_/_	_/_	_/◙
Door and trapdoor to a space outside of the measured zone: to a cellar, garage, an attic, a crawl space	_/_	_/_	_/_	_/_	Φ/_	_/_	Φ/Φ	_/_

Reading: O Open Φ Closed ◙ Sealed ● Filled I Do nothing _ Not specified

Note: The first column of each cell corresponds to method A and the second to B.

3. Proposal for measurement procedures: establishment of measurement protocols for housing

Five different protocols (M1 to M5) are proposed, in accordance with the desired objectives of the measurement. In order to do so, we have mainly used the European regulations mentioned previously, specifically EN 13829, as a base, adapting these for housing. There is a series of variables common to all five protocols, such as measurement time, meteorological conditions, difference in pressure, and sequence of pressure differences, all based on the above regulation.

3.1. Space to be analysed

When studying a multi-storey dwelling we do not measure it as a single space, as stairways and other elements constituting communal areas are not particularly airtight, well communicate with the exterior, and favour the formation of air currents as a result of differences in pressure and temperature. Including these communal spaces would distort the results obtained and prevent us from reaching conclusions on the airtightness of the envelopes of the individual dwellings. Therefore, measurements should be carried out on the individual homes (space with an energy demand which can be identified and put into an individual thermal conditioning context) measuring at least one flat situated on the lowest floor, another on an in-between floor, and another on the top floor [12,13,14].

The individual dwelling is a single space to be conditioned. In pressurisation/depressurisation tests it will be treated as a single zone, although in protocol M4 the kitchen is sealed, and in protocol M5 the bathrooms are also sealed. In buildings in the south of Europe bathrooms do not tend to be thermally conditioned and are usually depressurised in comparison with the rest of the dwelling as a result of air extraction systems.

3.2. Definition of the five measurement protocols

3.2.1. Protocol 1: M1

This measurement protocol reproduces method A, as defined by EN 13829, which aims to evaluate the airtightness of the envelope of the space to be measured for its real conditions in use.

3.2.2. Protocol 2: M2

Dwellings are usually ventilated by extracting air from the wet spaces (bathrooms and kitchens) in a controlled manner through a series of grills, whose operation is dependent on outdoor conditions, leading to an uncontrolled input of outdoor air through the envelope. With the M2 protocol the grills or openings through which air is extracted are sealed, mainly in kitchens and bathrooms. This is the most suitable protocol if we wish to evaluate the relationship between the airtightness of dwellings and their energy demand. In fact, ISO 9972[15], in agreement with the provisions of ISO 13790 [16], establishes that in order to calculate the rates of air renovation caused by uncontrolled infiltration/exfiltration through the building envelope, the 'natural system openings' must remain open when the pressurisation/depressurisation test is being carried out.

3.2.3. Protocol 3: M3

This measurement protocol reproduces method B, as defined by regulation EN 13829, which aims to evaluate the airtightness of the construction elements that constitute the building envelope and its joints or interfaces, sealing or closing all intentional openings, not only grills and air extraction openings (also sealed in M2), but others like the ventilation grills for gas installation when these have to installed in kitchens when this fuel is used for hobs, ovens, etc.

3.2.4. Protocol 4:M4

This protocol follows the guidelines of M3, but restricts the measurement space, as the kitchen is sealed. M4 (along with M5) is suitable for studying the differences between the building methods of wet areas and those of bedrooms and living areas (with acoustic protection) that are usually found in blocks of flats in Southern Europe. The carpentry work for these areas tends to differ, with different air permeability, as do the carpentry joints sometimes used on façades.

3.2.5. Protocol 5: M5

This protocol further restricts measurement space as, in addition to sealing the kitchen (like in M4), bathrooms are also sealed. In combination with M4, and as explained above, we are able to make a more detailed assessment of envelope airtightness, assigning responsibility for airtightness to the different parts of the dwelling and facilitating intervention in renovation and restoration work.

Table 2 provides a summary of the elements that have been sealed or closed for the different measurement protocols.

Table 2. Summary of protocols M1, M2, M3, M4 and M5

	M1	M2	M3	M4	M5
Kitchen hood	◙	◙	◙	◙	◙
Air conditioning units	◙	◙	◙	◙	◙
Kitchen gas ventilation grill	○	○	◙	I	I
Kitchen ventilation grill	○	◙	◙	I	I
Bathroom ventilation grill	○	◙	◙	◙	I
External windows and doors	Φ	Φ	Φ	Φ	Φ
Internal doors in measurement area	○	○	○	○	○
Kitchen door	○	○	○	◙	◙
Bathroom door	○	○	○	○	◙

Reading: O Open Φ Closed ◙ Sealed ● Filled I Do nothing

4. Case study

To validate and contrast the proposal an airtightness study was carried out on 10 units of a multi-storey building in Seville, using the proposed protocols.

4.1. Parameters defining the airtightness of dwellings

4.1.1. Defined by EN 13829:

Air Leakage rate at 50 Pascals, V_{50}, is of no use when comparing different homes. However, n50, air change rate at 50 Pascals, which expresses that value of the rate in relation to volume, is of interest.

In contrast, w_{50} and q_{50} are of no great use when evaluating the airtightness in MDU: w_{50} expresses the relationship between the rate of infiltrated air and the usable area, so that the value is proportional to another indicator, n_{50}, as ceiling height is very similar for dwellings. The relationship between this rate and the entire envelope area is expressed by q_{50}. This value does not provide us with much information either, given that the main air leakages occur in façades (not, for instance, in roofs, which are also part of the envelope) and mainly in the openings of these façades.

4.1.2. Parameters not defined by EN 13829:

As most uncontrolled air infiltrations that take place in buildings in the south of Europe are through exterior doors and windows and depend on the air permeability of fenestration features and blind boxes, where these are installed, and enclosures, along with plumbing, electrical and ventilation installations, we proposed three parameters as alternatives to the three parameters mentioned above, particularly to w_{50} and q_{50}, which as we already pointed out are not really suitable. The three parameters we chose were NL, used by Sherman [1] and two we are calling h_{50} and f_{50}.

- Normalized leakage area, NL. This could be considered an alternative to n50 and corresponds to the renovations/hour of air that takes place in the dwelling. It provides information on the suitability of planning the ventilation of dwellings taking infiltration into consideration.

- Air leakage rate by unit of window area at 50 Pa, h_{50}, or the relationship between V_{50} and the size of the openings, AH. This parameter provides information on infiltrations through the surface unit of openings, which is where most infiltrations occur.

- Air leakage rate by unit of facade area at 50 Pa, f_{50}, or the relationship between V_{50} and the area of the façade. This parameter provides information on infiltration through the surface unit of the entire façade, main element of the envelope through which infiltration occurs.

4.2. Expression and analysis of results

The assessment of the results for V_{50}, n_{50} or NL, f_{50}, and h_{50} is expressed in Figure 1.

Despite having carried out the measurements on the same types of building, which share construction processes and external variables, the results of the tests vary greatly, mainly due to the different envelopes resulting from the manual processes used during construction, a fact which reinforces the need to adopt these techniques for analysis and control tests that will ensure envelopes with a behaviour similar to that planned, as a first step towards guaranteeing energy efficiency.

Protocol M1, associated with Method A of EN 13829, has been defined as our reference protocol so we use it as a base for carrying of the remaining protocols which define this analysis methodology. The use of M1 is of no particular interest for the usual building types found in the south of Europe, as extraction grills in the wet areas of the dwelling (bathrooms and kitchen) do no function as additional openings in the usual use of the dwelling, but rather as outlets for the air that penetrates the rest of the envelope. Given that these were not sealed during the test, the results are distorted.

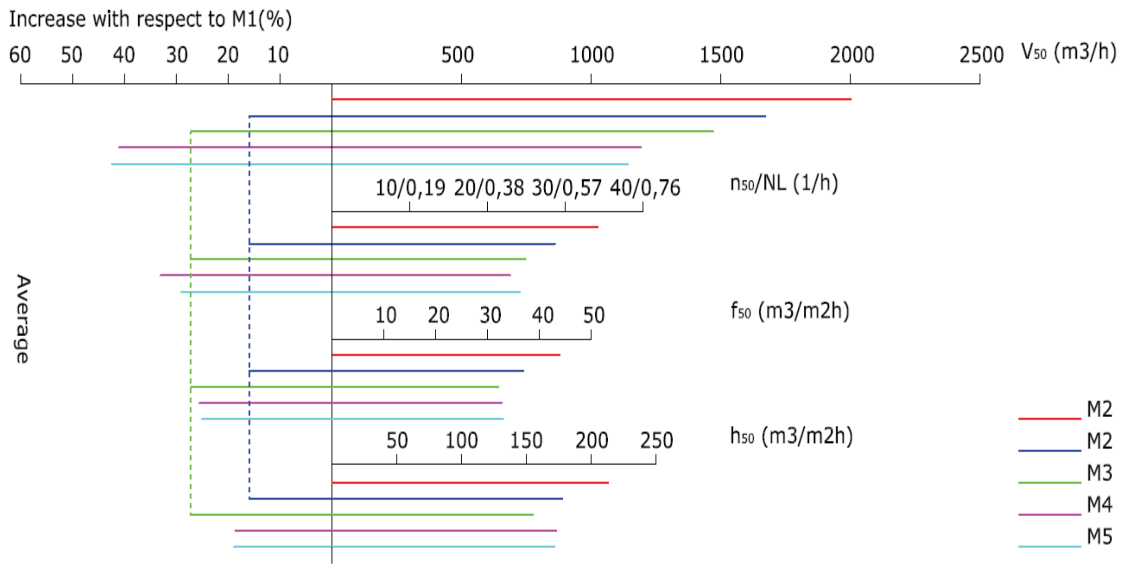

Fig. 1. Summary of measurements M1, M2, M3, M4 and M5

The execution of these five measurement protocols, while allowing a more detailed analysis and assessment, uses the starting point that in buildings in Southern Europe it is frequently not possible to consider homogeneous behaviour on the part of the envelope in relation to its airtightness. If we obtain the difference between the M2 and M3 measurements we can calculate the contribution of infiltration through the intentional openings in the envelope. If we compare M3 and M4 we obtain the contribution of uncontrolled openings in the bathroom to infiltration. In the case study included we have observed that the results for M4 and M5 are practically identical, as hardly any bathrooms have external wall openings.

5. Conclusions

Analyses have been carried out on the various European regulations on tests for the assessment of airtightness in buildings, verifying the diversity in treatments in relation to the external openings, as this is a fundamental factor for analysing the behaviour of the envelope and assigning responsibilities in terms of its airtightness. We were also able to verify the need to differentiate between dry and wet areas within the unit under study (dwelling), given the heterogeneous behaviour of the envelope in different spaces, and in some cases, with a variety of construction elements, as well as the incorporation of functional openings (vent openings, bathroom extractors, ventilation for gas installation, etc.).

In the case under study we can observe that when applying protocols M4 and M5 (discrimination of wet areas), the rate of air infiltration at 50 Pa is reduced by approximately 42% in relation to that obtained from the M1 base protocol (entire dwelling). It is therefore necessary to assign greater responsibility to the infiltration of these locations, despite the fact that they occupy the least usable surface. Hence the interest of parameter h50 when comparing the behaviour of locations, as this enables us to establish the repercussion that openings (of dry and wet locations) have on infiltration, either as a result of the fenestration features and glazing used in different cases, or because of the different solutions of the window joints to the façade.

When comparing the results of M2 and M3 in relation to M1, the rate of air infiltration at 50 Pa is reduced by 13.4%, showing the importance of the infiltration arising from intentional openings in the building envelope.

Applying the different protocols and expanding the study and assessment parameters allows us to have a more precise view of the behaviour of the envelope and each of its individual elements, and to assign priorities when generating correction and/or intervention operations on it, thus improving the usefulness of the pressurisation/depressurisation analysis method.

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