Evaluation of air leakage and its influence on thermal demands of office buildings in Madrid

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Introduction

The major consequences of infiltration are the thermal losses derived from it, which account, in some instances, for high percentages of the total building's thermal demands [1] and therefore, in energy intensive buildings, cause important economic losses. However, air leakage careful analysis and management is usually the exception rather than the norm.

Four office buildings in Madrid have been analysed at two different levels: air leakage tests and mathematical modelling. In this way real *ELA*, and the instantaneous and mean infiltration values have been determined, as well as its effects on the heating and cooling demands. This process highlighted different recurring building pathologies, which, although only tested in this small simple, lead to belief this could be a clear picture of the current situation.

This analysis is a part of a bigger project on the multidisciplinary study of the energy behaviour of commercial buildings in Madrid, under the umbrella of the major commercial district development "Desarrollo Urbanístico de Chamartín (DUCH)".

Development

The methodology used is structured in two separate steps: firstly, the air leakage tests to determine the main parameters of the case study buildings. Secondly, modelling of infiltration allowing the characterisation of the transient model and the resulting data analysis.

Air leakage test

The different air leakage test standards consist in pressurizing and de-pressurizing the study zone using ventilators (usually placing a BlowerDoor [2]) and determining the necessary airflow to achieve a set pressure. In the present case the tests were carried out in the four buildings at store level.

This technique yields the Effective Leakage Area (*ELA*). Assuming the total building's air leakage through the different cracks can be represented as the infiltration through a mouthpiece of equivalent area, the cracks' dimensions can be represented as a single effective area [3], or *ELA*. Thus, the *ELA* is usually used, at a set reference pressure, to represent the leakage through the envelope.

However, as some previous studies have shown [4], and for a couple of the current analysed buildings, substantial infiltration occurs between the study zones and some adjacent ones, some of which are unconditioned, con-

Table 1. Characterisation of the analysed buildings.

Parameter	Units	Description	Building A	Building B	Building C
Year	year	Year of building	2010	2008	2009
N_plan	Storey	Number of storeys	6	10	4
Type	–	Type of construction	Heavy	Light	Light
Per_window	%	Percentage of window	> 90%	> 90%	> 90%
Surf_bui	m^2	Building's total envelope	5 398	10 632	7 448
Vol_bui	m^3	Building's total volume	25 147	93 600	36 689
Height_bui	m	Building height	23	42	15

Table 2. Summary results of the air leakage tests.

	Building A	Building B	Building C
ELA_{test} (cm^2)	7.479	5.483	1.295
ELA_{ZPD} (cm^2)	3.739	0	0
ELA (cm^2)	3.739	5.483	1.295
ELA (cm^2/m^2 facade)	6.36	17.69	4.56
Roof and slab infiltration ratio over the total (R)	0.23	0.02	0.04

sequence of a deficient building process. Thus, it becomes necessary to differentiate between external and internal air leakage. To achieve this, the Zone Pressure Diagnostic (ZPD) was used, which indicates what the corresponding *ELA* is for the analysis zone with regards to the adjacent and non-external surfaces, and so the *ELA* for the external ones [5].

Infiltration modelling

Infiltration can be broken down into a climate independent component (*ELA*), and another dependent on climate conditions, in a non-lineal effect. The climate independent component can be partially quantified by the field tests, whilst the climate interaction requires of a model to calculate its effect. The ASHRAE's [6] recommended Lawrence Berkeley Laboratory (LBL) have been used for this purpose. This model establishes that air infiltrations are a function of permeability of the building and the pressure differences through its envelope. These pressure differences are induced by air temperature differences (Stack effect) and the wind's pressure.

The above-described methodology has been implemented in TRNSYS, considering weather and monitored data, with the aim of achieving transitory infiltration values, and the determination of the effect of air leakage in the buildings' thermal behaviour.

Results and discussion

The exposed methodology has only been implemented in three of the four buildings originally selected. In the remaining one, although the air leakage test was tried, the required pressure differential values (50 Pa) were not achieved due to the construction pathologies. Both the influence of the pathologies in the building envelope and the ones in the internal partitions adjacent to unconditioned spaces posed too high an obstacle for the consecution of reliable results.

The characterisation of the three analysed buildings is determined through the parameters on **Table 1**.

Out of the field test undertaken for the three buildings, **Table 2** shows their characteristic values.

It can be observed that the infiltration levels between floors are only relevant in Building A, and that the ELA of building B is greater than for the other two buildings. These parameters are the ones used in the equations of the LBL methodology implemented.

The shown results, although being one of the objectives of the analysis, are not very intuitive. In order to make them clearer, they are applied to the different conditions and TRNSYS [7] models for the buildings, so that the air renovations due to infiltration and their effect on the buildings' thermal demands can be obtained. As an example, the infiltration instantaneous values for the same week in April are shown for the three buildings (**Figure 1**).

The results were synthesized into a weighted average value for infiltration (average infiltration values for the considered time interval, based on wind speed ratios for each orientation), a variation in demands and power on the Spanish regulatory reference (variation of thermal demands with calculated instantaneous infiltration vs. infiltration derived from the interpretation of the

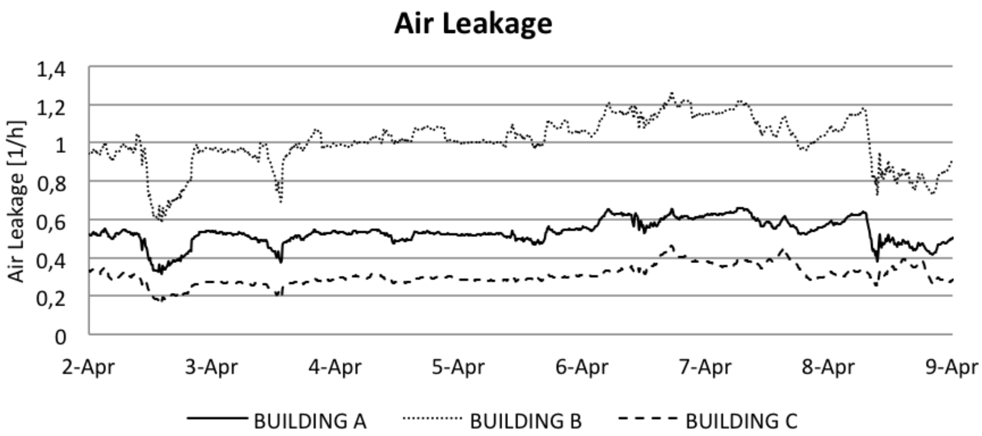

Figure 1. Instantaneous values of infiltration in the three buildings, for a week in April.

Spanish regulation [4-8]), and variation in demands and power supposing no infiltration (variation of thermal demands with calculated instantaneous infiltration vs. no infiltration). **Table 3** shows values obtained using monitored climate data from February to September.

Where the variations on demands are obtained by comparing the excess (positive) or the default (negative) of the integrated temporal values of the reference case over the entire period, versus the integrated temporal values of the real case over the entire period. By following the same procedure, positive values for Power means that reference case have a bigger value, while negative one's means the opposite. The variables whose values are 100, indicate that in the reference case, the values of demand or power are zero.

In the data can be observed the proportion of the weighted infiltrations and, most importantly, the great variation in demands and powers between the models based on real data and those based on regulations. Also the weight of the infiltration on energy demands and powers can be noticed through the comparisons with no infiltration scenarios. The major influence on heating demands vs. cooling ones could be due to a combination of the high internal loads of these buildings, and because of minor infiltrations in summer season when, at the same time, non-occupancy periods exists.

It is worth mentioning, based on the established values and the singularities observed during the field tests, that, mainly in the A and B buildings, the result is a reflection of a poor quality in the construction process, rather than not meeting the current regulatory standards. Equally, comparing the results obtained with other references for office buildings in the US [1] or Australia [9], the magnitude order is very similar.

Table 3. Summary of transitory results of the infiltration models.

Parameter	Units	Description	Building A	Building B	Building C
$\dot{Q}_f\_ave$	1/h	Weighted average infiltration value	0,44	0,81	0,27
ΔQC_{SPAREG}	%	Cooling demand variation percentage on Spanish regulation reference	1	14	1
ΔQH_{SPAREG}	%	Heating demand variation percentage on Spanish regulation reference	−79	−100	−78
PC_{SPAREG}	%	Cooling power variation percentage on Spanish regulation reference	−4	−11	−4
PH_{SPAREG}	%	Heating power variation percentage on Spanish regulation reference	−72	−100	−83
$\Delta QC_{NOINFIL}$	%	Cooling demand variation percentage on no infiltration	3	17	3
$\Delta QH_{NOINFIL}$	%	Heating demand variation percentage on no infiltration	−94	−100	−91
$PC_{NOINFIL}$	%	Cooling power variation percentage on no infiltration	−6	−13	−6
$PH_{NOINFIL}$	%	Heating power variation percentage on no infiltration	−100	−100	−100

However, it is very complicate to compare the results for the three different buildings, as those have very different characteristic parameters. That is why the results were normalised based on the buildings' height (parameter affecting the wind speed directly), the *ELA* (air tightness level for the façade), and the form factor for the building (ratio envelope surface/volume). Normalizing each of these parameters for Building A the following are obtained:

Figure 2 is a graphic representation, hourly based and for a week in April, of the values in **Table 4**.

It is seen that the *ELA* is the main factor in the models. The second one is the height which conditions the wind on the façades. The form factor appears as a second order derivative influenced for the other two parameters.

Conclusions

The main conclusions refer to the feasibility, necessity and interest in undertaking this type of test, both in new construction and in existing buildings. It is also necessary to integrate detailed models in the design tools, verification and buildings' intelligent energy management, as well as in certification tools. Implementing such analysis in the building process would detect building pathologies, enabling the improvement of the construction processes by establishing priorities depending on the constructive solutions adopted. It would also allow the design process

Table 4. Infiltrations for the comparative analysis between buildings and on key parameters.

Infiltrations		Building A	Building B	Building C
Base Results	1/h	0.44	0.81	0.27
Normalization by height	1/h	0.44	0.62	0.32
Normalization by form factor	1/h	0.44	1.18	0.34
Normalization by ELA	1/h	0.44	0.56	0.77

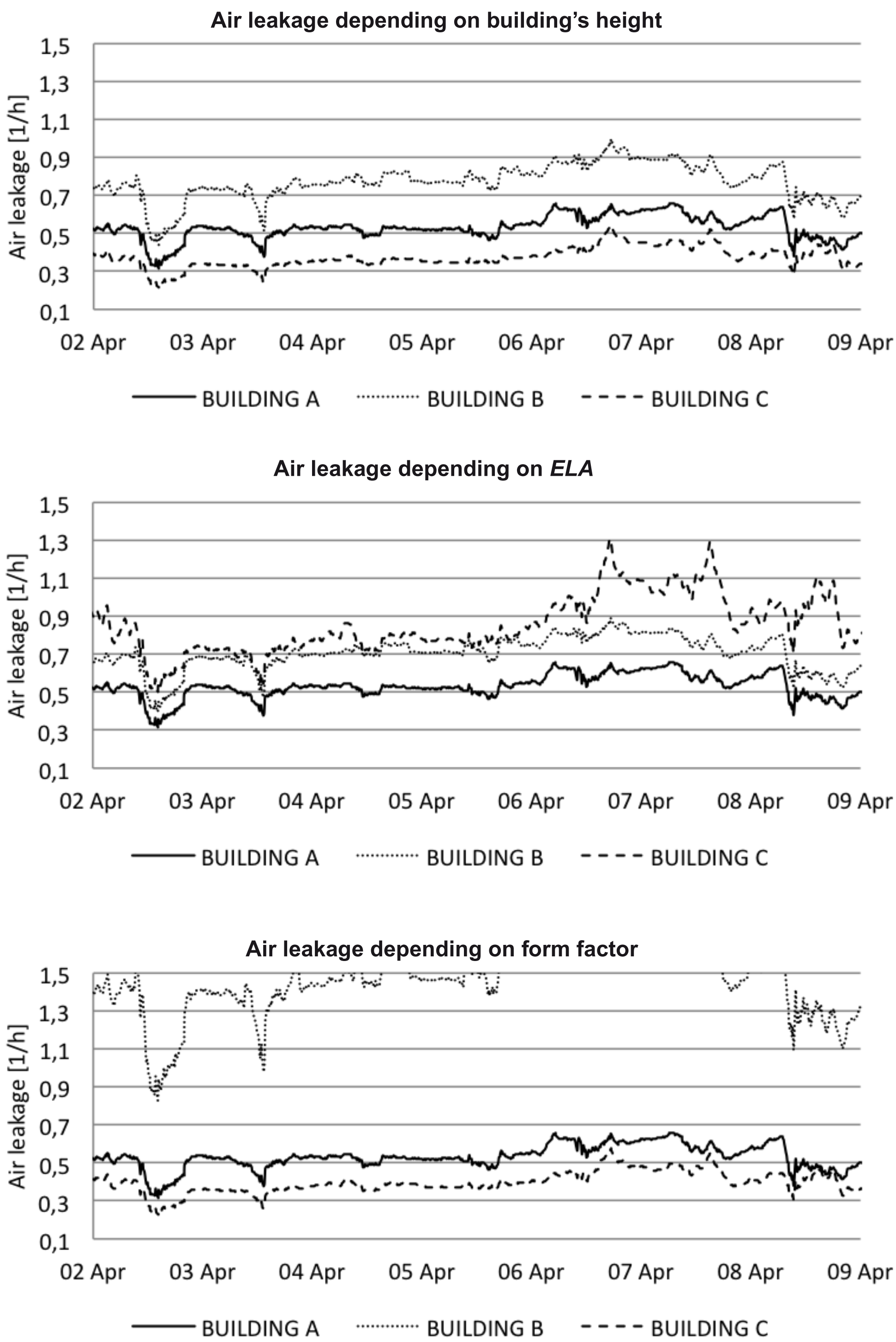

Figure 2. Infiltrations, for a week in April, of the three buildings considering B and C normalised to A-building's height (top), ELA (centre), and form factor (bottom).

Zone sealing for airtigthness testing (two first ones) and bottom one BlowerDoor installation for tightness testing

to be informed under cost-efficiency parameters, closer to reality certifications, as well as a more accurate intelligent building management. Equally, and taking into account other similar projects undertaken in different latitudes [10], a more deep analysis and from a stronger architectural point of view could relate constructive pathologies and architectural solutions, with different values for the present latitudes.

For the analysed buildings, their infiltration values are considerably high, with the consequent effect on the thermal demands and high-energy bills. This is mainly due to a poor construction process and practice, although having small form factors, or being low buildings, helps minimizing such effect. Equally, the order of magnitude in the variation of demands with respect to the normative case would justify, in terms of running costs, undertaking the necessary reforms to fix these problems. The strongest evidence lies in the building where the test could not be successfully completed due to the elevated air leakage both with the outside and the adjacent spaces. One should question if this is just an exception or the norm in old enough buildings (1992) in this geographical location.

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