INFLUENCE OF IMPROVEMENT OF AIR-TIGHTNESS ON ENERGY RETROFIT OF SOCIAL HOUSING, A CASE STUDY IN A MEDITERRANEAN CLIMATE

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ABSTRACT

In Spain, the residential sector is the third principal source of energy consumption; many of these dwellings are obsolete and do not have optimal conditions of comfort. For this reason, their energy retrofitting means an enormous step towards the energy efficiency. Under the general intervention strategies, the study and analysis of the air-tightness of the building envelope (as measured by the degree of infiltration) is a fundamental factor, because of its impact on energy efficiency, thermal comfort of occupants and indoor air quality. For this purpose, it has become a regular research field in other European countries and the USA. However, there is a lack of studies with adequate roominess to allow a proper analysis and interpretation of what happens in our regional climate and construction typology.

The aims of this paper is presenting a case study for the energy retrofit of 68 social multi-dwelling units in Cordoba (Southern Spain) evaluating their global energy demand and analysing the importance of air-tightness.

An in-situ air-tightness measurement campaign was carried out in these multi-dwelling units, before and after retrofitting, using Blower Door equipment. The best method for obtaining these parameters is pressurization/depressurization tests. It has been effectuated some modifications on façades and windows in order to obtain a better air-tightness.

The energy consumption was evaluated for the different levels of air-tightness by some tests which have allowed models to be generated. These models have been analyzed using Design Builder Energy Simulation software program, based on the DOE 2.2 calculation engine, obtaining predictive energy consumption, before and after retrofitting, including only air tightness changes and other retrofitting improvements (insulation, solar protection, U-transmittance in windows and facades) for the dwelling-units during a typical year.

KEYWORDS
Energy efficiency; building retrofitting, social housing buildings; energy consumption; air-tightness.

INTRODUCTION

In Spain, construction and operation of residential buildings accounts for the third highest energy consumption, after traffic and industry. The increased consumption that occurs in homes built in Spain is due to the climate. According to sources at the Institute for Diversification and Saving of Energy [1] air-conditioning accounts for approximately 49% of that consumption.

Social housing represents a significant proportion of the residential building stock of Southern Europe, which, when added to the socioeconomic characteristics of their occupants, necessitates special consideration of the methods to be used for the reduction of their energy consumption, especially that associated with their thermal comfort.

The most effective route for the reduction of energy consumption derived from the control of the energy demand associated with the transfers through the envelope using passive strategies. This intervention can be approached in two ways: the efficient construction of new buildings and the energy retrofit of existing residential buildings, a field of action that presents great potential for energy saving due to the importance of the housing stock built, and in use, in the last 50 years, it is also encouraged by the recent release of the Energy Performance of Buildings Directive, EPBD [2].

The air-tightness of building envelopes is one of the aspects which most affects the hygrothermal performance, indoor air quality and energy consumption of the building. In multi-story dwellings it contributes significantly to the overall demand for heating or cooling. The magnitude of the effects of air-tightness depends on many factors such as weather conditions (temperature, wind speed and direction), the design and geometry of the building and especially the quality of construction (design and execution), which complicates the analysis procedure [3,4,5].

As a result of the impact of the air-tightness of the building envelope (as measured by the degree of infiltration) on energy efficiency, thermal comfort of occupants and the indoor air quality, its study and analysis has become a regular field of research in other European countries and the USA. However, in our regional area, studies lack adequate breadth to allow a proper analysis and interpretation of the impact of air-tightness, in the context of the climate and construction types of the region.

The work of M. Sherman and the Lawrence Berkeley National Laboratory (LBNL) must be highlighted as a main reference in this field. It was associated with construction programmes in the USA which focused, primarily, on the housing field, and carried out extensive characterization campaigns and the development of predictive and calculation models for the phenomena of natural ventilation and uncontrolled infiltration processes. Our goal is to transfer and adapt these techniques and methodologies to our constructional reality and building processes in Spain.

To establish correlations between air flow and the energy performance of residential buildings, reference is again made to Sherman's work, with the Energy Performance of Buildings group of the LBNL [6] and those of Liddament [7] from the Air Infiltration and Ventilation Centre. This work investigates how current levels of ventilation affect energy demand and the estimated energy savings involved in adapting that ventilation to an appropriate indoor air quality, using the ASHRAE Standards 62, 119 and 136 to estimate the ventilation requirements and energy consumption.

The objective of this work was to analyze the importance of the infiltration in the energy demand reduction included in the residencial retrofit sector, analyzing a case study of multi dwelling units in the Mediterranean area. This was carried out on a building for which architect Rafael Suarez, co-author of this paper, designed a recently completed retrofit, boosting saving and energy efficiency.

CASE STUDY

The object of the study and analysis is a building of 68 social housing units, all of them rented, located in the city of Córdoba (Figure 1) in the south of Spain.

This building is a symmetrical U-shaped block five stories high, with housing units and an underground car park. Its construction dates from 1994 and it was retroffited in 2011. The retrofit project was promoted by the Córdoba Town Council and financed by the State Fund for Employment and Local Sustainability [8].

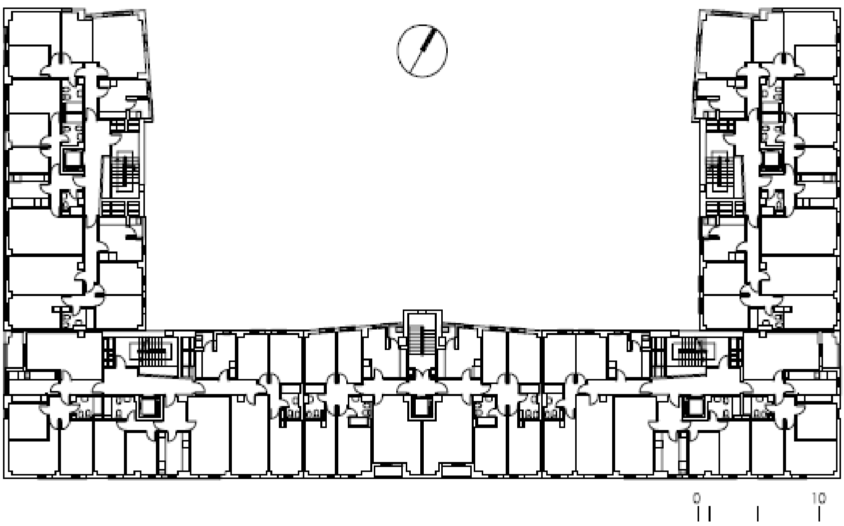

Figure 1. Floor plan

The thermal envelope of the building (table 1) presents low insulation levels, particularly on façades and floors in contact with the exterior, without any type of insulation, and in openings with single glazing.

Building element		U(W/m2K)		Retrofit improvement
		Original	Retrofitting	
Facades	24 cm porous ceramics bricks with exterior rendering and interior plastering	0.94	0.33	Ventilated facade with 6cm Mineral Wood
Openings	Anodised aluminium frames with 5mm single glazing	5.70	3.8	Double glazed 4+6+4
Roof in contact with outdoor	Ceramic tiles, key mortar, brick board bedded on sand, slopes formed with 10 cm cellular concrete and 5 cm extruded polystyrene.	0.47	0.47	
Floor in contact with car parking	Unidirectional framework 25+5 semi-resistant joists finished with terrazo flooring and plaster	2.25	0.54	5cm extruded polystyrene insulation, air chamber and metal false ceiling.

Table 1. Characterization of the thermal envelope

Climate

The climatic profile used comes from the EnergyPlus weather files (EPW) database, part of the energy simulation software created by the U.S. Department of Energy. The file selected for Córdoba, CÓRDOBA SWEC (Spanish Weather for Energy Calculations), was created from the data originating from the Spanish National Institute of Meteorology (table 2)
Location: Córdoba (Spain) (N 37º 53 ') (W 4º 54 ') (GMT +1.0 Hour)
Elevation: 90 m above sea level: Standard atmospheric pressure: 100953 Pa

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average monthly temperature (^{0}C)	9.2	10.9	13.5	15.4	19	23.5	27.3	27.2	24	18.5	13.2	10.2
Average monthly wind velocity (km/h)	8	8	9.6	10.6	8.9	9.6	9.5	9.6	8.7	8.5	8	8.3

Table 2. Climate values in Cordoba

The climate is sub-continental Mediterranean with warm summers, very high temperatures (maximum average temperatures of 36 °C) and an average of over 300 hours of sun per month from June to September. The winters are mild and last from November to March, with short springs and autumns.

METHODS

Passive strategies through the envelope are the most effective strategies to reduce the energy demand in the residencial buildings. The original state of the building performance must be known to calculate the potential reduction of the energy demand.

In the analysis of the original state of the building the solar radiation was studied with Ecotect Analysis version 5.50, the thermal bridges and common air leakage paths with an infrared camera, the air tightness with the blower door , the air and superficial temperature with a data logger and energy analysis with Desing Builder. Based on the study of data obtained, it is possible to elaborate a profile of the energy demand and set strategies to improve the energy consumption and thermal conditions. The most efficient strategies was chosen and their demand energy reduction was calculated.

Air tightness measurements using Blower Door

To know the original and retrofitting air tightness of the residential building, pressurization and depressurization tests were carried out using Blower Door equipment, which provides airtightness to the dwelling unit, the Air Leakage rate at 50 Pascals which take place as a result of the infiltrations through the building envelope.

Figure 2. Blower Door Test

In order to carry out these tests a blower door fan was placed at the external door of the housing unit, in order to extract (depressurization) or introduce (pressurization) air into the unit until a negative or positive pressure of 50 Pa was reached and the airflow was measured.

As this was a multifamily residential building, it was not measured as a single space, since staircases, lifts and other elements of the communal areas are not airtight and create air currents that are too large to ensure reliable measurements. Measurements were carried out on individual dwelling units, measuring at least one of them on the top floor, one on an intermediate floor and another on the ground floor.

These tests were executed in the original conditions to locate the main routes of air leakage with infrared thermography. After the retrofitting the tests were carried out in order to prove their improvement.

Energy models

To establish the energy performance of the original and retrofitted building the computer program Design Builder version 2.2.5.004 was used, whose simulation engine, Energy Plus, methodology developed by the United States Department of Energy and recognized by the International Energy Agency, enabled the authors to obtain precise data on annual or monthly demand for its original condition and for the retrofit project.

Each dwelling unit in the model was considered as a single space to be climatized. The official protocol for conditions of use and operation in Spain for the use of alternative energy simulation programs was followed [9].

<table>
<tr><th rowspan="2">Activity</th><th rowspan="2">Period</th><th rowspan="2">Value</th><th colspan="6">Schedule</th></tr>
<tr><th colspan="2">Weekdays</th><th colspan="2">Weekends</th><th colspan="2">Holidays</th></tr>
<tr><td rowspan="2">Occupation</td><td>Winter</td><td rowspan="2">0.056 pers/m2</td><td rowspan="2">00:00 a 07:00
07:00 a 16:00
16:00 a 23:00</td><td rowspan="2">100%
25%
50%</td><td colspan="2">00:00 a 24:00</td><td colspan="2">50%</td></tr>
<tr><td>Summer</td><td>00:00 a 24:00</td><td>100%</td><td>00:00 a 24:00</td><td>0 %</td></tr>
<tr><td rowspan="2">Equipment & Lighting</td><td>Winter</td><td rowspan="2">8.88 W/m2 (4.44x2)</td><td colspan="3" rowspan="2">00:00 a 08:00
08:00 a 19:00
19:00 a 20:00
20:00 a 23:00
23:00 a 24:00</td><td colspan="3" rowspan="2">10%
30%
50%
100%
50%</td></tr>
<tr><td>Summer</td></tr>
<tr><td rowspan="2">Ventilation</td><td>Winter</td><td rowspan="2">3 ac/h</td><td colspan="3">00:00 a 24:00</td><td colspan="3">0%</td></tr>
<tr><td>Summer</td><td colspan="3">00:00 a 08:00
08:00 a 24:00</td><td colspan="3">100%
0%</td></tr>
</table>

Table 3. Protocol for conditions of use and operation in Spain.

RESULTS AND DISCUSSION

Retrofitting

Simulations were produced for the original conditions as well as for each of the intervention solutions proposed in order to obtain increased improvements in the energy demand of the building for its retrofit [10].

The program calibration was carried out in the EFFICACIA Project [11].

After analyzing the original state of the case study, the principal paths and factors where the building was losing energy were found and the main strategies in the retrofit proposal were:

- Encouragement of airflow, mainly through natural ventilation at night during the summer depending on exterior conditions.
- Energy conservation, improving insulation, and the accumulation of energy through thermal inertia. To guarantee complete efficiency in the summer time the thermal mass must be in contact with the night airflow to ensure passive cooling, while in winter the wall must receive solar radiation.
- Solar Radiation and Solar Control, capturing solar radiation in winter and ensuring suitable protection from radiation in summer (solar protection of the openings with the most solar exposure, depending on orientation, using sliding, folding, or fixed slat systems. East and west windows are protected by external movable shading devices which are activated during the cooling period).
- Thermal envelope insulation (Table 1) using a ventilated façade system, with a ceramic or metal finish. This system reduces thermal bridges in beams and pillars and along the joints between bricks and load-bearing structure.
- Thermal transmittance of windows, incorporating double glazing and improving insulation on external framework.

Figure 3. Case study, before and after retrofit.

Air tightness retrofitting

The values of the Blower Door tests can not be used directly for determining the annual infiltration value, because it responds to conditions of depression and pressure differential inside / outside very high, wich fundamental mission is the determination of Air-Tighness at 50 Pa.

Attributed to (and often denied by) Kronvall [12] and Persily [13], there was a rule of thumb that seemed to relate Blower-Door data to seasonal air change data in spite of its simplicity

$$ACH= ACH_{50}/20 \quad (1)$$

That is, the seasonal amount of natural air exchange could be related to air flow necessary to pressurize the building to 50 Pascals, where “ACH” is the natural air changes per hour and “ACH50 ” are the air changes induced by a 50 Pa pressure using a fan. We assume the uncertainty in the calculations using the following correction factors [14]:

-Dwelling units are 1 storie, their height correction factor is 1.

-Dwelling units are situated in the city, surrounding of other buildings, their shielding correction factor is 1.

-N of leakages is about 0,7, their lakiness correction factor is 1

V_{50} and ACH_{50} values obtained from the Blower Door tests and MDU characteristics, before and after retrofitting are represented in table 4.

Before retrofitting, ACH varies between 0.500 and 0.638, its averages is 0,550 and its standard desviation is 0.054. Although the construction system is the same, there are a significant degree of dispersion in air tightness tests, it can be due to constructive problems.

In most European countries the minimum ventilation standard ranges between 0.35 and 0.5 air changes per hour. However, in Spain, from the approval of the Technical Building Code in 2006, the requirements are much higher and the amount increases to 0.9-1 air changes per hour in new residential buildings.

After retrofitting, ACH varies between 0.426 and 0.536, its averages is 0.467 and its standard desviation is 0.041.
It is observed that the dispersion is lower than before retrofitting.
In both cases there was not relation of facade area and window area with air tightness.

These infiltration values aren´t for envelope, they are for whole dwelling units.

	Volume (m^3)	**Facades**	**Facade Area (m^2)**	**Window Area (m^2)**	**Indoor Temperature (ºC)**	**Outdoor Temperature (ºC)**	**V_{50}**	**ACH_{50}**	**ACH**
P1-V1	177,72	3(N,W,E)	64,16	12,61	32 (30)	34 (35)	1825 (1529)	10,27 (8,60)	0,513 (0,430)
P3-V2	176,53	1(0)	34,69	7,92	30 (29)	30 (36)	1966 (1695)	11,14 (9,60)	0,557 (0,480)
P3-V3	178,98	2(E,O)	39,94	10,33	32 (31)	32 (37)	2019 (1713)	11,28 (9,57)	0,564 (0,479)
P4-V12	177,72	3(N,W,E)	64,16	12,61	36 (31)	37 (34)	1778 (1513)	10,01 (8,51)	0,500 (0,426)
P4-V13	176,53	1(E)	34,69	7,92	(36)	(39)	(1603)	(9,08)	(0,454)
P5-V1	133,78	3(N,W,E)	58,31	9,28	32 (33)	33 (35)	1707 (1433)	12,76 (10,71)	0,638 (0,536)
Average							1859 (1631)	11,09 (9,35)	0,550 (0,467)
Desvest							130 (109,7)	1,08 (0,81)	0,054 (0,041)

Table 4. Multi dwelling unit characteristics and Blower Door test before and (after retrofitting)

This infiltration reduction is due to the thermal insulation that seal the joint between the facade and the window frame (figure 4) and the sustitution of the simple glass from the window for a double glass 4+6+4 and the improvement of the lock of the frame

Figure 4. Envelope retrofit

Energy demand

The study and analysis of the demand of the existing building revealed major energy losses in winter, due mainly to infiltrations, glazing and lack of insulation on façades,while in summer the main gains resulted from transmissions through openings and infiltrations. Windows play a very important role in thermal operation as they are elements for direct solar capture, natural ventilation and let in daylight.

Of the calculated overall annual demands, most correspond to heating (58% vs. 42% of cooling) resulting from the building orientation, the generation of its own shade, its shape (0.30) and the deficient insulation of the thermal envelope which translate into major energy losses. This demand differs considerably in relation to orientation, so that correction measures take this factor into account.

After retrofitting, the total energy demand reduction varies between 34 % and 46%, while the heating demand reduction is bigger varies between 7% and 41% , the cooling energy demand is lower varies between 1,6% and 16%.

There is a notable improvement of the energy efficiency after the energy retrofit. That is entailed in a consumption energy reduction of 42% respect to the initial stay, while a reduction of 17% respect to original conditions is due to actions that influence the air-tightness level of multi-dwellings. This fact emphasizes the importance of this parameter on consumption reduction.

Uncertainly and errors in calculations are due to the simplify transfer from ACH 50 to ACH, as discussed above, but this affects both states, before and after retrofitting. The airtightness change is due only to the improvement of the envelope.

	Multi Dwelling Units	P1-V1	P3-V1	P3-V2	P3-V3	P4-V12	P4-V13	P5-V1	Average
Total (kWh/m2)	Original conditions	67	73	68	63	82	96	91	77
	Infiltration retrofit	63	62	55	52	65	68	79	63
	Additional retrofit measures	41	40	38	35	48	52	60	45
Cooling (kWh/m2)	Original conditions	21	30	41	29	36	41	31	33
	Infiltration reftofit	20	27	37	26	31	34	28	29
	Additional retrofit measures	14	21	25	19	25	29	24	23
Heating (kWh/m2)	Original conditions	46	43	26	34	47	58	60	45
	Infiltration retrofit	43	35	18	26	34	34	51	34
	Additional retrofit measures	27	19	12	15	23	23	35	22
Increasing about total original conditions (%)	Infiltration retrofit	-5	-15	-19	-18	-20	-29	-12	-17
	Additional retrofit measures	-39	-45	-44	-45	-42	-46	-34	-42
Increasing about cooling original conditions (%)	Infiltration retrofit	-2	-9	-11	-10	-12	-16	-9	-10
	Additional retrofit measures	-34	-29	-38	-32	-31	-30	-20	-31
Increasing about heating original conditions (%)	Infiltration retrofit	-7	-19	-32	-24	-28	-41	-14	-24
	Additional retrofit measures	-42	-56	-53	-55	-51	-60	-41	-51

Table 5. Energy demand based on calculations

Energy demand results was obteined with Desing Builder because their retrofit works have just finished, but a monitoring campaigne is planned for the building.

CONCLUSION

Following the intervention proposal considerable improvement was observed in the thermal behaviour of the building for all energy models simulated and analyzed, more so in winter conditions, with a 51% reduction in demand, contrasting with a reduction of the demand for cooling of 31%, with an estimated reduction of total demand of 42%. Moreover, this reduction in demand translates into an improvement of thermal stability and reduction of temperature oscillations, with considerable repercussions on the increase of internal thermal comfort [10].

A great part of this energy demand reduction is due to an improvement in the air tightness after retroftting, a 40% on the total reduction, it is most important in heating 46% than in cooling 32%. For this reason, testing and review processes are essential to identify the common leakaege paths trought the envelope. This studies have to be presented in such a way that they can be easily put into practice as protocols to control the construction quality and reduce the energy demand in residential buildings.

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