Energy efficiency, indoor thermal comfort and influence of user habits in retrofitting of social housing blocks: Case study in the Metropolitan Area of Barcelona

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1. INTRODUCTION

The Mediterranean seaside cities like the towns placed at the Metropolitan region of Barcelona have soft winters and variable summers which change from hot to very hot. Historically, summer comfort in dwellings was reached through passive cooling strategies and reducing the activity of the citizens during the hottest hours (the *siesta*). At the beginning of the 20^{th} and until the building regulations appear, most of the constructed buildings were designed without any energy saving criteria, therefore, summer and winter passive were scrapped.

Figure 1. –Site overall view and pilot tower detail

Since the 90s, the mechanical air conditioning systems replaced the deficit of summer comfort strategies on buildings and caused a huge increase of the energy consumption and the peak loads in the summer season. In 2007 a new Spanish Building Code (CTE, 2007), aiming to improve the rational use of energy in new buildings and assuming the requirements defined in the EPDB [1] and [2], was officially set up. Along 2010 this new building regulation is supposed to be extended to the existing building stock. This extension, aims at becoming a driver for the revival of the construction sector and for the uptake of innovative systems and cost effective energy services linked to retrofitting.

This article aims to present a valid methodology to evaluate the existing summer comfort, the annual energy demand and the influence of tenant's behaviour in 820 households of a working class district that will be retrofitted within the next two years. The methodology combines dynamic energy hourly simulations and monitoring of real energy consumption data. Moreover, a comparison of several passive retrofitting measures is then carried out.

2. METHODOLOGY FOR VALID ENERGY DEMAND AND COMFORT ANALYSIS.

Six apartments in one of the fifteen storey towers of the district were modelled and monitored. Their annual energy loads for heating and cooling as well as their indoor thermal comfort and electricity consumption levels were assessed. Two of the studied dwellings were air-conditioned in the summer and have gas boilers for heating, while the others had no cooling systems and gas or electrical stoves for heating. After literature review, two different methods will be used within this study: the (ASHRAE)[5] for energy modelling and calibration of existing buildings, and an application example reported by Pedrini, Westphal and Lamberts [6]. The model calibration was carried at the indoor temperature level. A comparison of the measured indoor temperature and the simulated one was carried out.

Difference between them is used as the parameter for model acceptance. The requirement for model acceptance was defined in ASHRAE [4]. The available calibrated computer models allowed for the comparison of eleven simulation scenarios of retrofitting measures with seven orientations and several users' behaviour scenarios.

Concerning to the energy consumption analysis, a combination of electricity consumption monitoring of 6 dwellings and monthly electricity and gas bills collection of 50 dwellings was carried out.

3. RESULTS

3.1 Calibration Model of the non air-conditioned dwellings

Energy audits, on–site tests and monitored electricity consumption data provided reliable data which were used to refine internal gains rates as well as sources of heat losses. Additional refinements of the model provided accurate ventilation rates as well. Results for indoor temperature and error accuracy simulation are shown in figs. 2 and 3. Results show that error was above 10% only the 0.94% of the total monitoring time. As shown in Figure 3 there is a large decrease of error accuracy when considering afternoon and night ventilation in summer. The adjustment of night ventilation rate was finally 1,5 ACH for May, June and September; 3 ACH for July; 1,5 A CH for August , and 4 ACH from October to April. The averaged indoor temperature in summer is around 26 ºC for the day and 23 ºC for the night. In winter, the averaged measured temperature is 20ºC for all the day. As shown in Figure 4 and in Table 2, the tenants are in comfortable conditions (considering comfort with no air movement), only in 52,7% of the overall number of occupied hours in the summer season.

3.2 Calibration Model Air-Conditioned Dwellings

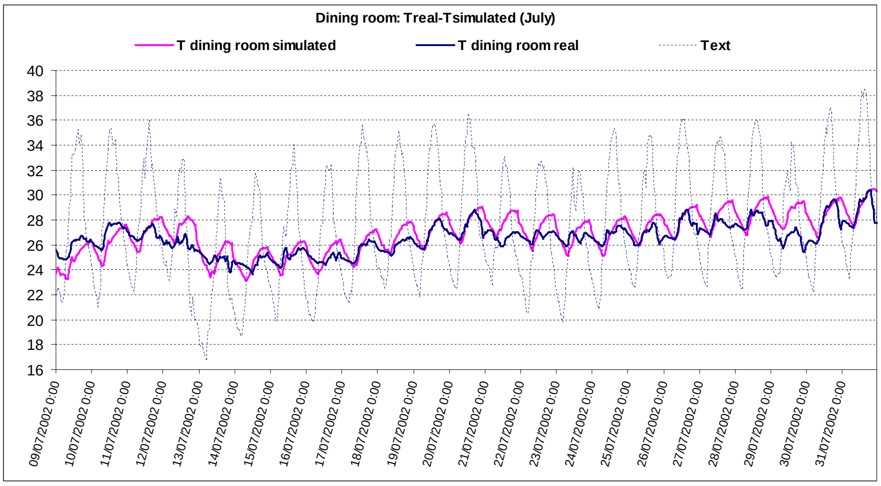
The monitoring devices installed in each dwelling, only measured overall electrical consumption. A segregation of the total consumption in permanent (PC), air conditioning (AC), and electrical equipment consumption (GC) was undertaken. PC was estimated by calculating the average consumption of non occupied days; the GC was obtained considering the hourly consumption curve for a representative day without AC use. After analyzing summer season data, the conditions defining the AC working schedule were: if indoor temperature (T)>24ºC, or ΔT(out-in)> 3ºC, and electricity consumption is higher than a typical daily electricity consumption. Based on these boundary conditions, an automated step by step method to segregate the energy consumption was implemented. The cases when the method could not well identify cooling consumption represented the 3.8% of the whole monitoring period, therefore results were representative enough for AC dwelling use. Results in Table 1 show that cooling (AC) and general consumptions (GC) were the two main causes of electricity consumption during summer, with 34% and 41% of total energy consumption respectively. However, this high energy consumption only causes a very small improvement in the summer comfort, leading to an average indoor temperature of 25,5 ºC. As shown in Figure 4 and in Table 2, the tenants are in comfortable conditions (considering comfort with air movement) in 89% of overall number of occupied hours in the summer. Thermal energy demands for dwellings in these comfort conditions are 61,24 kWh/m2·yr for heating and 3,1Kwh/m2·yr for cooling, as shown in Tables 3 and 4.

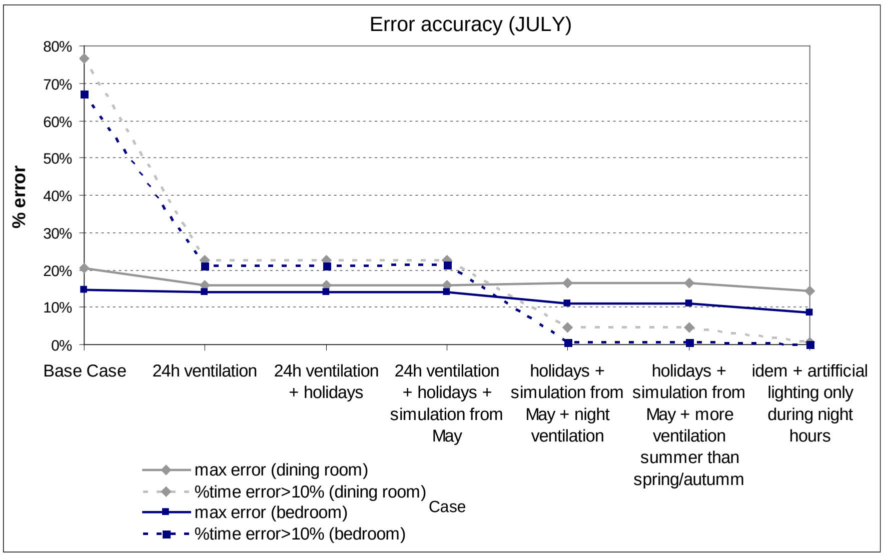
3.3 Results of simulated retrofitting scenarios

The defined retrofitting scenarios are shown in Table 2. The results of the simulations are shown in Tables 3 and 4. Table 3 shows the effect The reduction of cooling loads and the improvement of indoor comfort levels in summer through the proper use of night cross ventilation is reflected in the table 3. It causes 23% and 34% of comfort improvement in AC and non-AC dwellings respectively. The effect of solar protections was 8% and 16% of comfort improvement in AC and non AC dwellings respectively. Concerning to cooling demand, the impact of natural ventilation and solar protections is 100% and 54% of improvement in AC dwellings, and 16% and 37% in non-AC dwellings. In AC dwellings, a reduction of 1,5ºC in the cooling set point temperature causes an increase of 122% of cooling energy demand and small improvement of only 4% in summer comfort. The impact on reducing 1ºC of heating set point temperature in heating demand was 15% of improvement, but caused 35% of reduction of comfort levels. Concerning to the envelope retrofitting scenarios (see Table 4), it was found that summer comfort levels did not highly increase in both type of dwelling for any of the simulated retrofitting scenarios. The envelope retrofitting measures have a crucial impact in the heating demands reduction and in the improvement of winter comfort conditions. In table 4, it can be appreciated that the Proposed retrofitted and the Alternative 1 gave very similar results. The alternative 3 was very low cost efficient. The reduction of heating demand and the improvement of comfort levels were very small in comparison with the high costs due to the replacement of existing windows. Therefore, the Alternative 2 was selected as the best option for the retrofitting process to be implemented.

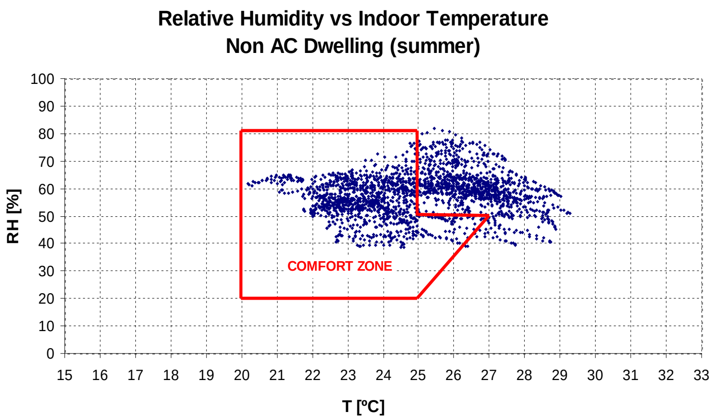
4. Conclusions

After data analysis and results processing it can be drawn that the calibration method developed within this study is a quite simple and reliable method. Calibrated models allowed for the evaluation of the suggested retrofitting measures and impact of tenants' behaviour. Results showed that good use of balcony's protection and air-crossed night ventilation achieves much lower cooling demand than increasing insulation. Only heating demand and comfort in winter improvements justify envelope retrofitting measures implementation. Design parameters scenarios and analysis of the user's behaviour revealed that other actions such as innovative ventilation systems may represent significant improvements with low or even negligible economical costs. Taking into account the high cost of the envelope retrofitting measures proposed, further research work is needed in finding other more cost effective measures such as boilers replacement and a good energy practice campaign.





Figures 2 and 3.- Si mulation Results and error accuracy for the Non Air-Conditioned Dwelling's Calibrated Model in July



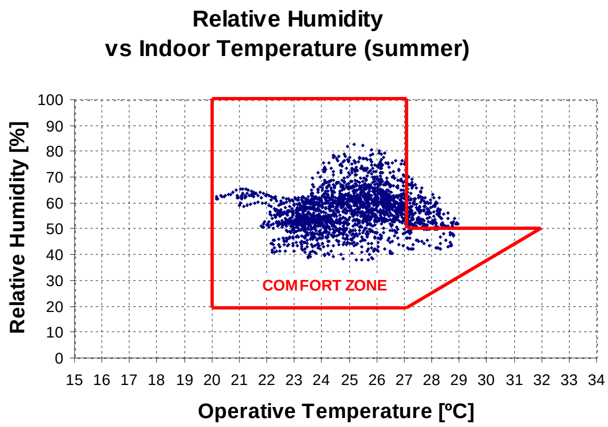


Figure 4.- Comfort result in summer: left)non AC dwelling, right)AC dwelling

	Total Electricity Consumption	Permanent Consumption	General Consumption	Air-Conditioning Consumption
AUGUST Consumption (kWh)	704	182	291	231
JULY Consumption (kWh)	876	212	363	308
AVERAGE Consumption (kWh)	790	197	327	269.5
AVERAGE Consumption (kWh/m2)	8.88	2.21	3.67	3.03

Table 1.- Monthly Electricity Consumption disaggregated for summer.

	Retrofitting Scenarios
Current Dwelling	Current real dwelling.
Proposed Retrofitting	Suggested retrofitting measures for both façades and openings implemented. Overall heat transfer coefficient (U-value) was 30% smaller than those stated by national regulations.
Alternative 1	Suggested retrofitting measures considering an insulation thickness that exactly met national regulations.
Alternative 2	Alternative 1 without windows renovation (only façade renovation implemented).
Alternative 3	Only windows renovation implemented.

	Design Parameters and Users' Behaviour Scenarios
South-East Orientation	Simulation of the air-conditioned dwelling (oriented North-West) in a South East Orientation.
North-West Orientation	Simulation of the non air-conditioned dwelling (oriented South-East) in a North-West Orientation.
No Solar Protection	Supression of the existing solar protections: canopy in the air-conditioned dwelling and the upper story's balcony for both dwellings.
Heating Set Point 20°C	Reducing the air-conditioned residence's heating set point temperature from the current 21°C down to 20°C.
Cooling Set Point 20°C	Reducing the air-conditioned residence's cooling set point temperature from the current 25.5°C down to 24°C (national standards for indoor thermal comfort)
No Use of Natural Ventilation	No use of natural ventilation in none of the apartments.
No Use of Air-Conditioning	Supression of the air-conditioned system in the air-conditioned dwelling.

Table 2.- Description of simulation scenarios.

				Current dwelling:	No Solar Protections	heating Set Point Temperature 20ºC	Cooling Set Point Temperature 24ºC	No use of air conditioning	No use of natural ventilation
Air Conditioned dwelling	Energy savings	Heating Loads	(Kwh/m2·year)	61,24	68,83	52,11	61,39	61,24	61,21
			% Decrease		12,39%	-14,91%	0,24%	0,00%	-0,05%
		Cooling Loads	(Kwh/m2·year)	-3,1	-4,79	-3,1	-6,86	0,00	-6,43
			% Decrease		54,52%	0,00%	121,29%	-100,00%	107,42%
	Thermal Comfort	Winter comfort	% hours with comfort	47,40%	72,72%	30,61%	47,40%	51,61%	52,64%
			% Increase		53,42%	-35,42%	0,00%	8,88%	11,05%
		Summer comfort	% hours with comfort	88,91%	82,24%	88,91%	92,39%	46,22%	68,57%
			% Increase		-7,51%	0,00%	3,91%	-48,02%	-22,88%
		Annual comfort	% hours with comfort	62,15%	75,16%	45,56%	62,97%	50,23%	56,72%
			% Increase		20,94%	-26,69%	1,32%	-19,18%	-8,73%
Non air conditioning dwelling	Thermal Comfort	Winter comfort	% hours with comfort	18,22%	21,66%				20,06%
			% Increase		18,88%				10,12%
		Summer comfort	% hours with comfort	52,67%	44,38%				33,70%
			% Increase		-15,74%				-36,01%
		Annual comfort	% hours with comfort	28,63%	28,28%				23,56%
			% Increase		-1,24%				-17,70%

Table 3.-Simulation results of design parameters and users' behaviour:

				Current dwelling:	Proposed retrofitting	Alternative 1	Alternative 2	Alternative 3
Air Conditioned dwelling	Energy savings	Heating Loads	(Kwh/m2·year)	61,24	23,58	28,43	42,37	49,59
			% Decrease		-61,50%	-53,58%	-30,81%	-19,02%
		Cooling Loads	(Kwh/m2·year)	-3,1	-1,89	-2,02	-2,2	-2,85
			% Decrease		-39,03%	-34,84%	-29,03%	-8,06%
	Thermal Comfort	Winter comfort	% hours with comfort	47,40%	78,57%	75,13%	66,23%	59,56%
			% Increase		65,75%	58,50%	39,72%	25,66%
		Summer comfort	% hours with comfort	88,91%	92,97%	92,34%	92,74%	89,05%
			% Increase		4,56%	3,86%	4,31%	0,15%
		Annual comfort	% hours with comfort	62,15%	82,26%	79,54%	73,03%	67,12%
			% Increase		32,37%	27,99%	17,51%	8,01%
	Thermal Comfort	Winter comfort	% hours with comfort	18,22%	23,46%	23,06%	24,76%	21,78%
			% Increase		28,74%	26,55%	35,90%	19,56%
		Summer comfort	% hours with comfort	52,67%	60,95%	58,77%	54,10%	52,94%
			% Increase		15,72%	11,58%	2,70%	0,51%
		Annual comfort	% hours with comfort	28,63%	33,07%	32,21%	32,28%	29,77%
			% Increase		15,51%	12,52%	12,76%	3,99%

Table 4.- Retrofitting scenarios: simulation results.

5. References

[1] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.

[2] CTE, Código Técnico de la Edificación. RD 1371/2007, de 19 de octubre (BOE 23/10/2007) www.codigotecnico.org/
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[4] American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE Pocket Guide for Air Conditioning, Heating, Ventilation, Refrigeration (SI Edition), 2005.

[5] American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE Handbook HVAC Applications,1999, chapter 38, pp. 8-9.

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