Verification of the thermal behaviour of dwellings designed with bioclimatic criteria:

Case study on balcony conservatory energetic efficiency

AURORA MONGE BARRIO[1], ANA SANCHEZ-OSTIZ GUTIERREZ[1],
SILVIA DOMINGO IRIGOYEN[1], PURIFICACION GONZALEZ MARTINEZ[1]

[1]School of Architecture, University of Navarra, Pamplona, Spain

ABSTRACT: A study of the energy performance of two rental residential buildings belonging to the Government of Navarra (Spain), through monitoring and modelling, has been carried out. The buildings consist of two towers, with 5 dwellings per floor, built in 2006 according to bioclimatic criteria. In every floor, three of the dwellings have a bioclimatic attached balcony conservatory facing south.

The study of the thermal and energy performance of the buildings consists on: in-situ monitoring and testing (thermographs and blower-door essay), analysis of heating consumption, energetic simulations of dwellings and survey of users.

Among the findings of the study, it was confirmed that flats with attached balcony conservatory have a greater potential for energy efficiency, reaching a lower than 10 kWh/m2.year in one of the typologies. Some major problems have been detected, such as deficiencies in construction (considerable air-infiltrations due to assembly between the opaque facade and window frames), in the design of the dwellings (summer ventilation and solar protection problems, mainly in sun-spaces) and incorrect use by dwellers (both summer and winter).

Regarding Directives 2010/31/EU and 2012/27/UE on Energy Efficiency in Buildings (EPDB2010), with the efficiency targets set for 2020, where the Administration must retrofit a certain percentage of their public buildings and at the same time "set an example", we believe that it is necessary that buildings designed and built with bioclimatic and/or energy efficiency criteria, are checked after several years to find out whether the initial goals have been achieved, to analyse possible deviations and their origin, to suggest improvements and to disseminate the results. The aim of this paper is to present these issues and the results obtained on the example of these two buildings..

Keywords: Energy Efficiency, verification of energy performance, monitoring, energy simulation.

INTRODUCTION

The importance of serious environmental problems and the weak equilibrium amongst the needs of our techno-industrial society and our ecosystem, show a necessity of reducing the energy consumption in our cities diminishing in this way, environmental consequences.

The 2010/31/UE directive, “on the energy performance of buildings” (EPBD2010), establishes the aim of reducing energy dependency and greenhouse gas emissions. Buyers and tenants must hold an energy efficiency certificate and have the necessary information to improve it. The administration ought to apply efficiency recommendations as well in order to set an example.

CASE STUDY

Two residential buildings, owned by a housing society belonging to the Government of Navarre, built in 2006 in Pamplona (Spain), with bio-climatic criteria are studied. The dwellings are aimed for social rental. The study has been carried out during 2011 and 2012.

Figure 1. Aerial view of residential buildings RA1 y RA3 (SITNA) [1]

Pamplona’s climate is Cf2b according to Köppen-Geiger’s climate classification. It is therefore a warm humid climate, with cold winters and cool summers, and rainfall falling down evenly throughout the year, except for two dry months (number 2).

The annual average is around 12ºC, 5ºC in the coldest month (January) and 20,9ºC in the warmest (August). Global solar radiation on horizontal surface daily average is 3,88 – 4,04 kWh/m2.day (according to different sources), with a direct to global radiation of 48-58%. Predominant wind in Pamplona is North and Northwest, with an annual speed average of 3,4m/s, and a 40% calm.

According to the Spanish Technical Code of Edification, document "Energy savings" (CTE-HE1) [2], Pamplona stands in a D1 climatic zone, which ensures harsh winters with need of heating, and cool summers without need for air conditioning, in the household.

A hardening of the climatic conditions in relation to the average has been verified in the years of the analysis (2011 and 2012), and although "climatic change" is not the aim of this paper, the response of dwellings and users to this new situation should be studied. The monitoring has shown that February 2012 was much colder (3ºC less than average temperature), and August 2011 and 2012, was much warmer (2ºC and 3,6ºC, over average historic temperature).

According to the mentioned Spanish Code, conditions for winter thermal comfort inside the dwellings are established in 17-20ºC (night-day). The authors consider inadequate the lower temperature, and therefore establish a minimum of 18ºC in this paper. For the summer, the dwellings are studied according to adaptive comfort methodology UNE EN 25251 [3]

GENERAL DESCRIPTION

The two residential buildings are named RA1 and RA3. The first one has a south looking facade with an azimuth deviation of 25ºW, and 5ºW for the second one. Both blocks are almost identical, with a commercial and common spaces ground floor, and standing eight floors high with five dwellings per floor.

In each floor, three of the dwellings have a south looking balcony conservatory coming from the main room into the dwelling, having two of them two orientations (B and D), and only one orientation the third (type C). The other two dwellings do not count with a balcony conservatory, and have North and West orientation (type A) and North and East (type E). Each dwelling has between 63-68m^2, counts with heating, and the standard is one sitting-room, two bedrooms, kitchen, bathroom and hall.

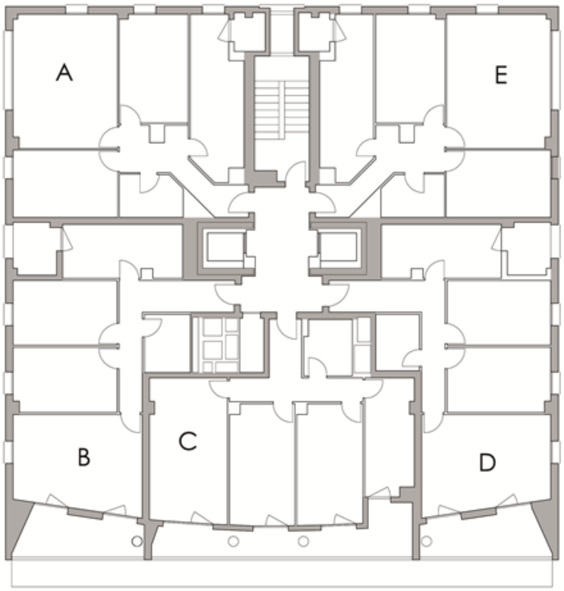

Figure 2. Residential buildings RA1 and RA3 standard layout.

The facade in the West, North and East orientations is ventilated with 11cm of thermal insulation (U=0,30W/m^2.K) and the south façade is totally made up with the conservatories. The closure between the balcony conservatory and the dwellings is an opaque wall with 4cm thermal insulation (U=0,61W/m^2.K). The carpentry is thermally broken steel frames, except the balcony conservatory's exterior sheet that is non-thermally broken steel, and the standard glass is 4.12.5mm (U=2,8W/m^2.K), except the balcony conservatory's exterior sheet, which is 6mm (U=5,7W/m^2.K). Darkening and solar protection of the windows and the balcony conservatory's interior sheet (HI) is made by a system of rolling blinds, with the box in the inside of the dwelling, typical in Spain. The balcony conservatory exterior sheet (HE) is protected with an exterior concrete 1m overhang.

The balcony conservatory works differently winter and summer, as well as day and night. In Pamplona, in winter conditions during the day, the balcony conservatory's HE and HI must be closed, with no obstacle to solar radiation (blinds, shades, etc.) and during the night, the balcony conservatory must be protected as much as possible, lowering the HI exterior blinds. In summer conditions in Pamplona, during the day the balcony conservatory shall be protected from solar radiation and high temperatures, lowering the HI blinds, and ventilating the balcony conservatory (opening HE, at least a 25%). During the night, considering the exterior temperatures are lower than the interior ones, HE and HI should be opened, as well as all other windows in the dwelling, in order to cool it through night cooling cross ventilation.

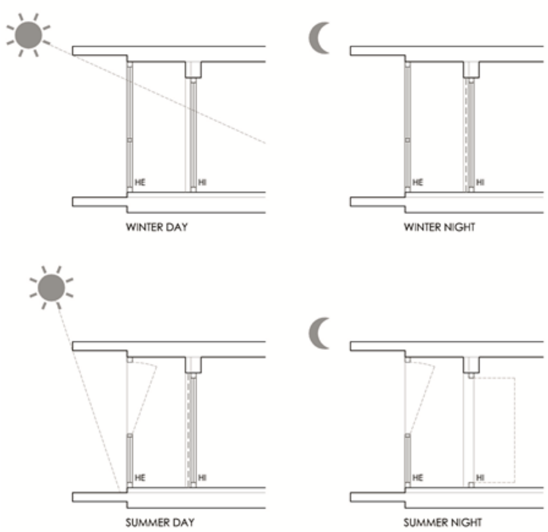

Figure 3. Plan of balcony conservatory RA1 and RA3

Both residential buildings, RA1 and RA3, count with a sole boiler room with natural gas for heating and domestic hot water (DHW), with solar panels. Each dwelling has its own energy´s counter and a thermostat. RA1 has conventional radiators, and RA3 has a radiant floor heating system.

When the tenants sign the contract, they are given some explanation about the use of the balcony conservatory and the radiant floor.

As shown in table 1, heating consumption is higher in RA1 than in RA3, when it ought to be otherwise, due to ignorance on using the radiant floor, among other factors. We can also see a notable increase in the percentage of loss on heating distribution, a decrease in the efficiency of the boiler (due to not working full capacity) and in DHW.

Studying the heating demand in each dwelling, from the individual counters, (see Figure 1, example of heating demand in Winter season 2011-12), we can see that the first and last floors in each block have a great percentage of dwellings with a higher than average heating demand, which indicates an insufficient insulation.

In figure 4, in another color, we can see the monitored dwellings´ gas consumption.

We can observe that heating demands for type C dwellings (south orientation and balcony conservatory), is less than 10 kWh/m^2.year, except in first and last floor dwellings. Besides, we see that the heating demand difference between southbound dwellings with two orientations (type B and D), are not less than the ones between the northbound dwellings with two orientations (type A and E).

Lastly, we have been informed that presently, there is a 30% defaults, to which we add the detected less than average heating consumption, (see figure 4), that may explain cases of “fuel poverty”. It was firstly defined by Brenda Boardman in the 1990s, as the incapability of a home to obtain the adequate quantity of energy with the 10% of income, and this definition was later enlarged to mean the ability of having a minimum thermal regime at home of 21ºC in the sitting room and 18ºC in the rest of the dwelling [4].

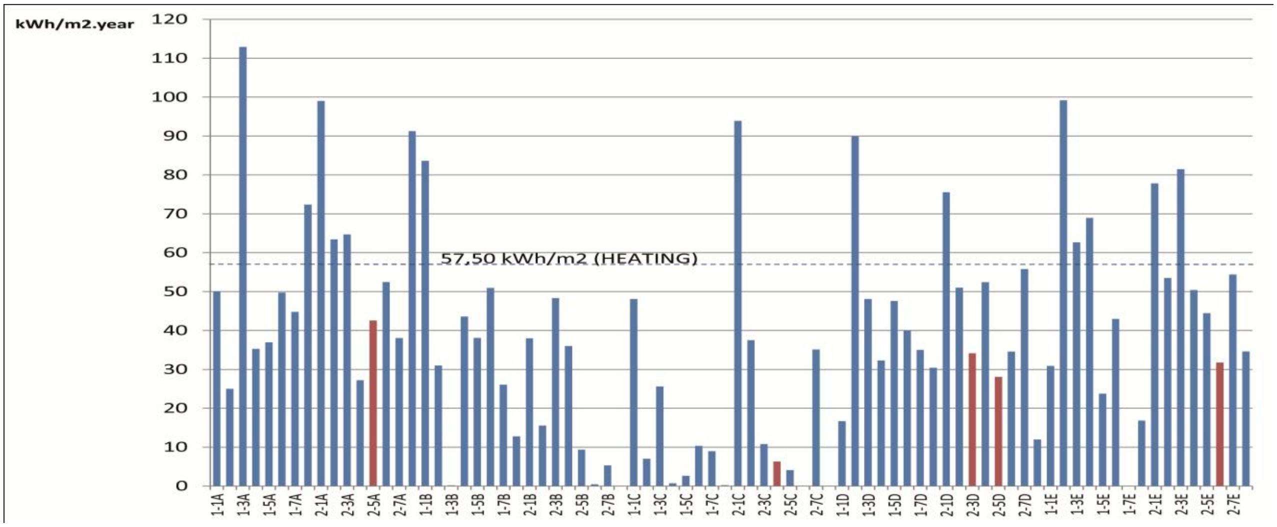

Figure 4. 2011-12 RA1 (1) and RA3 (2) heating demand

RA1 & RA3 GAS CONSUMPTION				
	RA1 (Counter reading)	RA3 (Counter reading)	Instalation Losses + DHW	TOTAL GAS (kWh)
WINTER 2008-2009	84.000 (43%)	109.000 (57%)	137.000 (41,5%)	330.000
AÑO 2009	89.790 (44%)	114.145 (56%)	81.261 (28,5%)	285.197
AÑO 2010	131.129 (45%)	157.225 (55%)	70.766 (20%)	359.121
AÑO 2011	77.357 (46%)	91.901 (54%)	147.064 (46,5%)	316.323
WINTER 2011-12	99.647 (48%)	105.859 (52%)	189.646 (48%)	395.154

Table 1: Natural Gas Consumption in RA1 and RA3

MONITORING AND OTHER TESTS

Firstly a blower door test was carried out in one of the block RA1, type D dwelling, at 50pa, and resulted in n50=6,28r/h, that is, much higher than the average we find in Pamplona (n50=2-5). It was discovered, counting also with a thermographic study, that the main problem in the dwellings was the infiltrations due to the quality of the carpentry, their union with the facades, and the boxes for the blinds. Also thermal bridges are observed, from the system of gypsum plasterboard, plugs in facade, etc. To illustrate this point, we can see the image of the carpentry in an eastbound sitting room, at a normal pressure (figure 5).

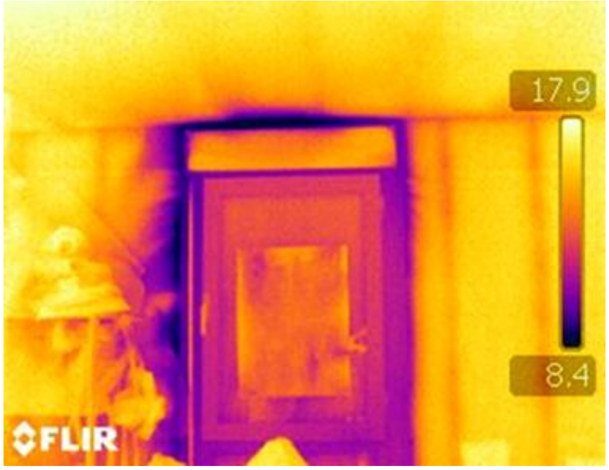

Figure 5. Thermographic image of RA3 type D dwelling

RA3 dwellings, as described in table 2, were monitored. No type B dwelling could be monitored. The thermal sensation in general, in winter is normal, due to use of heating, although was very hot in the summer in every dwelling with balcony conservatory. There is also a low demand in dwelling type C, with a normal even warm winter thermal sensation.

	Orientation	Balcony Conservatory	Winter Thermal Sensation	Summer Thermal Sensation	Demanda de calefacción (kWh/m^2.año)
5A	N-W		N-C	N	42,58
4C	S	SI	N-C	MC	6,32
3D	S-E	SI	MF	MC	34,14
5D	S-E	SI	N	MC	28,07
6E	N-E		N	N-C	31,77
MC (very hot), C (hot), N (neutral), F (cold), MF (very cold)					

Table 2: Resumen de características de viviendas monitorizadas de RA3, en la campaña de invierno 2011-12

A winter monitoring campaign was undertaken during 17 days (December 2011), and a summer campaign during 45 days (June - August 2012), leaving temperature and humidity data loggers (that registered every 10 minutes) in the dwelling's sitting rooms.

The main results of the winter monitoring were that dwelling 4C, with a lower heating demand, had a better thermal comfort (higher average temperatures and less thermal oscillation). Dwelling 5A, with a higher heating demand turned out to be the coldest dwelling, due mostly to an inadequate use of ventilation. Finally, dwelling 6E demands less heating than 3D, with similar inside thermal conditions, having the latter south orientation, due to an inadequate use of the balcony not having the latter south orientation, due to an inadequate use of the balcony conservatory (HE always open, due to a dog living there).

The main results of the summer monitoring are that dwellings stay within a range of comfort, although with disconfort situations due to an insufficient design for summer conditions and an incorrect use.

Firstly, the balcony conservatory has a 1m overhang and HI has a blind on the exterior, but some sort of solar protection system would be required for HE (preferably on the exterior). Secondly, the aperture system for the HE (tilt and turn) only allows a 5% opening, which is inadequate (a 25% would be necessary, which would allow the opening of HE).

It has also been detected that at moments of maximum temperatures and solar radiation, the balcony's conservatory HE remains closed or with a minimum aperture, and the HI and some windows remain open without the necessary conditions for ventilation (lack of cold focus). Therefore important overheating takes place in the dwellings.

The main conclusions of this monitoring phase were: balcony conservatories contribute to energy efficiency in winter conditions, using direct and indirect solar radiation, and through the "buffer" effect produced during the day, an insufficient design in the balcony conservatories is detected, mostly in summer conditions (minimum aperture in HE, lack of solar protection in HE), as well as an incorrect use of the dwellings in winter and summer. It has also been verified that the dwellings enclosures are deficient, and the energy gain through the balcony conservatories is not properly saved.

ENERGY SIMULATION

With the information gathered at the buildings, the monitoring results and conclusions, and the thermographic and blower door tests, a simulation was carried out with Design Builder software, that works with Energy Plus, developed, the latter by the U.S. Department of Energy, from BLAST and DOE2. The RA3 balcony conservatories' residential buildings' simulation models have been undertaken with "compact HVAC" and "crossed ventilation models". The latter makes possible to calculate air flows, according to the infiltrations, the aperture of doors, windows and grilles, the chimney effect, and the difference in pressure due to wind. The simulation has been carried out with the climatic year 2011-12, during which the monitoring has taken place, in order to compare the results of heating demand and the thermal behaviour of dwellings.

With energy simulation, we can test the potential of balcony conservatories in dwellings, since the repercussion of heating demand in rooms that count with a balcony conservatory is a 10% of the dwelling's demand, considering a correct use. The thermal behavior in winter, using the same amount of heating in every home (heating times and setpoints), gives approximately 4ºC more in dwellings with balcony conservatory (B, C and D type), comparing to dwellings without it (A and E types), due to the thermal gain of the southbound dwelling counting with balcony conservatory, and the buffer effect produced. Improving the building's enclosure, the heating demand in 2011-12 could be less than 15kWh/m^2.year.

Improvements have been done in the balcony conservatory to optimize its behaviour during winter. The importance of improving the exterior sheet from a simple glass to a double glass has been highlighted, and a double glass with low-e and extra clear glasses. However the most important improvement comes from making better the air tightness characteristics of the carpentry and blind boxes in the balcony conservatory, reducing original demand by a 25-30% (see table 2).

During the summer, the improvement in the balcony conservatory's HE aperture (25%), and the existing solar protection systems are not sufficient to avoid overheating in the hottest summer days in Pamplona. It is therefore necessary to add solar protection in the exterior sheet. An exterior protection, with a blind of mobile and adjustable slats will avoid disconfort periods, according to Category I of adaptive comfort in UNE EN 25251. A blind could be incorporated in the interior of the exterior sheet, a more simple and economic system to install, with less implications on the image of the building, and with a better durability and maintenance. A fan would be required however, to reach comfort using this system, reducing operational temperature in approximately 3ºC, as stated in UNE EN ISO7730, figure G1 [5].

DISCUSSION

Users' actions are fundamental in the real demand for energy in buildings, both in conventional and in energy efficient ones. If the user is not aware or does not know how to use the building, he/she may use more energy and even have greater discomfort conditions than in a conventional building.

This research has detected that in general passive resources in homes are not used. The incidence of orientations in different seasons are ignored, negative uses such as the installing of curtains in windows prone to solar gains, the importance of the distribution of the heat gain in the home is not acknowledged, etc. Other times, although information is at the reach of the user, the design does not permit a good use (e.g. inadequate retention systems in the windows to facilitate the secure ventilation of the balcony conservatory).

This is of special importance in balcony conservatories, as complex elements that require actions, in the winter aimed at solar gain during the day and at saving the heat during the night or when there is not enough radiation, and in the summer to achieve an adequate ventilation and shading. It must also be acknowledged that it is a transition space, with a temperature range not suitable as a living space, and so it shall not be used as such.

It is therefore fundamental, on the first place, to save in the building's book all the instructions of use for every passive and active elements that may affect energy efficiency, and secondly inform users with clear and continued actions about the buildings' and specially about the balcony conservatories' use, more often when the climate conditions are harsher than usual. As has been seen, more conscious and active ecological users in the balcony conservatories get very positive results during the year.

Three fundamental components are included in the concept of "fuel poverty": family income, energy prices and the dwelling's energy efficiency.

Spain is currently going through a serious economic crisis with a 26,2% unemployment rate, according to the 4th quarter 2012 study (EPA), nearly 6 million of persons in Spain. Furthermore, there are more than 1,8 million homes with every family member unemployed (from a total of 17,4 million homes in Spain). Navarre, community with Pamplona as capital city, presents an unemployment rate of 17,4%, with a total of 52.600 unemployed [6]. On the other hand, energy prices have gone up notably, and this tendency is expected to continue.

For this reason, the increase of energy efficiency may be the only aspect to enforce towards the erradication of "fuel poverty" in the short term. As seen, there are two main fields of improvement, the first one a low cost one, that improves the conditions of use in dwellings (and at certain moments the only one we will be able to enforce) through information activities, etc, [7,8], and a second one, adding to this good use, where an improvement in the design of the balcony conservatory and in the enclosure of the dwelling is made, that requires an economic expense, but has great potential for energy saving.

We think the Public Administration must promote and foment high energy efficient buildings, aimed at the most vulnerable communities, to achieve the lowest possible energy costs from use of the dwellings. Currently, actions must target the rehabilitation of existing residential buildings.

The buildings, property of the Public Administration, aimed at social rent, must be energetically rehabilitated. In this way, and following the requirements of EPBD2010, the Administration would set an example, and it would also start a wide reaching public information system spreading information about energy efficiency. An immediate example would be the dwellings studied on this paper, RA1 and RA3, originally designed with bioclimatic concepts, that have a great potential for improvement in the field of energy efficiency, and applied to a very vulnerable population.

CONCLUSION

Two residential buildings, aimed at social rent, with south looking balcony conservatories have been studied. Some important problems have been detected in the buildings, due to a deficient quality in the buildings´ enclosures, and to an insufficient design and protection of the exterior sheet of the balcony, adding to an incorrect use of the balcony conservatory and the dwelling, both in summer and winter.

We believe that this detailed study in recent buildings designed as bioclimatic, after some years of use, is interesting in the path to the zero emissions building objective, not only for detecting the building's own problems, but to extrapolate its care and solutions to other buildings.

Although the EPDB does not mention public buildings with a residential and social use, we think the directive should include them, for its great implication in the defense of a quality of life for more vulnerable communities.

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