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Energy consumption of bioclimatic buildings in Argentina during the period 2001–2008

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ABSTRACT

The energy performance of two bioclimatic buildings located in Santa Rosa city, a temperate semi-arid agricultural region of central Argentina, is analysed. The bioclimatic design included direct solar gain, thermal inertia, natural ventilation, thermal insulation, external shading, building orientation, and dwelling grouping. Each double-story building is aligned on an East–West axis and it has a compact shape with 350 m^2 of useful floor area (58 m^2/apartment). The solar collection area is around 18% of the apartment's useful area on the ground floor and 14% on the upper floor. This paper describes the energy performance of the buildings during the period 2001–2008. The analysis includes: (a) the energy consumption (natural gas and electricity) during 2001–2007 (natural gas: annually, bimonthly; electricity: monthly); (b) the natural gas consumption and the thermal behaviour during the winters of year 2001 (between July 27 and August 3) and 2008 (between August 8 and 13); (c) the daily natural gas consumption and the thermal behaviour during 2001 and 2008 winters; (d) the comparison between the energy consumption for heating in bioclimatic and conventional buildings. The authors concluded that the results confirm the large potential of solar buildings design to reach significant levels of energy saving. The comparison of solar and conventional buildings in terms of natural gas consumption demonstrates the magnitude of such potential.

Contents

1. Introduction

Climate change could have significant effects on the energy sector in many countries. Rising temperatures, changes in the amount of precipitations and variation in humidity, wind patterns,

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and the number of sunny days per year could affect both consumption and production of energy. In some countries, the impact could be a major one. The nature and magnitude of this impact may not be easy to predict, owing to counteracting effects and uncertainty surrounding both climate change and baseline projections of energy use. The energy sector is sensitive to climate change and the sub-sectors most likely to be significantly affected are space heating, space cooling, and hydroelectric generation [1]. There is a need to integrate the different policy areas where energy efficiency, demand response, and climate change programs are discussed and developed, and there are positive signs that this integration is starting to occur [2].

Several countries, including those in the European Union (EU) and many environmental non-governmental organisations, have agreed that the global average temperature increase should be limited to 2 °C above pre-industrial levels to avoid such dangerous interference, agreement which is reaffirmed by the international negotiation processes in 2006 [3]. The predicted effects of climate change present a number of primary challenges for buildings, increased demand for cooling in summer, and increased thermal discomfort in buildings [4].

Buildings, worldwide, account for as much as 45% of energy consumption, and similar share of greenhouse gas emissions that makes buildings the biggest single contributors to anthropogenic climate change [5]. Compelling and cost-effective opportunities to reduce energy consumption in buildings exist both in IEA (International Energy Agency) member countries and in developing countries. William Ramsay, Deputy Executive Director of IEA, remarked that, in order to ensure sustainable development, a policy to minimize energy consumption and greenhouse gas emissions has to include measures to reduce the end use of energy in buildings. Consequently, policies for buildings are an important component of the IEA package of recommendations for the G8 [6].

Energy consumption in the residential sector (depending strongly on the climate of a region) is a main portion of the total energy consumption in most countries. In order to promote energy conservation in the residential sector and to estimate the CO_2 emissions, it is important to examine the residential energy consumption in different countries and to exchange information about this area, so that policy-makers and energy experts can learn from each other in devising policies related to residential energy standards [7].

In the EU, the residential and tertiary sector buildings consume roughly 40% of the total final energy use. Space heating accounts for more than 50% of the primary energy demand of residential and service buildings [8]; similar percentages are observed for the other developed countries. In France, the building industry contributes with a 25% of greenhouse gases emission and 43% of total energy consumption, making it the biggest energy consumer of all the economy sectors. The energy for space heating in the residential sector represents more than 40% of the total energy demand (electricity, hot-water and air-conditioning) [9]. Since a period of restructuring of the industrial base in the late 1970s and early 1980s, UK energy consumption has been on an upward trend. The built environment accounts for approximately 50% of energy use. The domestic sector accounts for almost 34% of the UK energy consumption. Governments have made a series of efforts to reduce this consumption through a significant tightening of the Building Regulations. One important aspect of the UK domestic energy use is the relatively poor state of houses [10].

According to the United States Environmental Protection Agency, the reason because buildings have a considerable impact on energy consumption and also in the environmental quality, is due to the low construction requirements. In this country, during 2007 the residential sector consumed around 21% of the total energy (Transport = 29%; Commerce = 18%, Industry = 32%) [11]. The Canadian building sector consumed 31% of the total energy use during 2007. The residential sector (single detached homes, single attached homes, apartments and mobile homes) used energy primarily for space and water heating, the operation of appliances, lighting and space cooling, representing 17% during 2004 [12].

México's buildings consume around 23% of the total energy use (residential buildings = 83.8%, commercial and public buildings = 16.2%) [13]. At present, there are several simultaneous energy transitions, which reflect changes in the energy resources portfolio, in the types of technology used, and most importantly, in the way society and institutions understand the benefits and impacts produced by energy [14]. While in Mexico energy consumption in the residential sector decreased 2.06% (period 2004–2006) in Argentina and Brazil it increased 0.58 and 2% respectively (period 2004–2006) [15].

In Argentina the building sector constitutes 37% of the primary energy consumption (residential buildings = 53%) [16]. Residential energy consumption increased 0.58% during the period 2004–2006. Energy consumption is strongly related to dweller's behaviour, whose energy demands are linked to temperature variations. Thus, electricity consumption in times of extreme cold or hot weather is 50% higher and gas consumption in winter increases up to eight times the usual values. Residential energy consumption of gas in summer amounts between 8 and 10% of the total delivered volume; in winter it concentrates up to 45% of the required total. During 2007 – year that showed an important difference in seasonal consumption due to unusually low winter temperatures – while in January residential buildings consumed less than 8% of the monthly total, in July they consumed 8 times more. Such a difference, whatever the cautions taken in these cases, shows that what is surplus in summer is scarce in winter. From November to December, there is enough gas to supply it to the industrial sector and the electric power stations, but in winter, when housing consumption increases up to even half of the required total, industries and power stations must resign between 20 and 50% of their summer consumption to favour top priority residential users. The Argentinean energy consumption matrix depends more than 50% on natural gas. The electricity consumed in the residential sector is more uniform during the year than that of gas, because it is used, on average, for artificial lighting, refrigerators and freezers. Thus, significant variations occur in very cold or hot days, when dwellers make a massive use of air conditioners [17].

Argentina's main problem in terms of energy lies in the systematic reduction of its natural reserves, a fact that forces the country to import more heavily and to depend on international prices. Having an energy matrix strongly dependant on natural gas, between 2001 and 2008, there was a 34% increase in its demand and a 39% decrease of the natural reserves [18]. Through low-energy architecture and sustainable urban design, regulations and energy control, energy consumption and CO_2 emissions in Argentina's building residential sector could be reduced around 76% [19].

The final draft of the Intergovernmental Panel on Climate Change describes the design strategies for energy-efficient buildings which include reducing heating, cooling and lighting loads; increasing efficiency of appliances, heating and cooling equipments and ventilation; improving operations and maintenance, considering building shape, orientation, related attributes, thermal envelope, etc. The latest report from the IPCC estimates that improvement in the energy efficiency of buildings could potentially reduce projected global carbon emissions up to 29% by 2020, and up to 40% by 2030 [20].

The new EU Action Plan on energy-efficiency aims to limit the rise of the global average temperature to 2 °C compared to pre-industrial level. To achieve this, the EU is promoting a goal of 30% reduction in greenhouse gas emissions by 2020, compared to 1990 levels, in developed countries [21]. The European Directive on

Energy Performance of Building (EPBD) which came into force in 2002 to be implemented in the legislation of Member States in 2006, aims to improve the overall energy efficiency of new buildings and large refurbished existing buildings in order to reach the level of saving required by the Kioto Agreement [6].

In China, energy-efficiency efforts began in the early 1980s when, with support of the State Economic and State Planning Commissions, the Ministry of Public Works approved projects to investigate the amount of energy consumed by space heating and to develop an energy-efficient design standard for residential buildings in the very cold and cold zones (large amounts of energy was being consumed for heating). By the end of 2000, unfortunately, the total floor area of residential buildings designed according to energy-efficient standards represented only 8% of the total area of residential buildings in very cold and cold zones [7,22].

In this context, during the last years low-energy consumption buildings were constructed around the world and particularly in Argentina, with passive solar strategies design: direct heat gain, thermal storage, cross ventilation, high envelope's thermal resistance [23–26].

Many buildings designed under Leadership Energy Environment Design have now been occupied and it is reasonable to ask: are these buildings living up to expectations? To answer this questions post-occupancy evaluations need to be undertaken to measure the building's performance [27]. Torcellini et al. [28] conducted an overview of sustainable buildings in the USA. Their analysis showed that all buildings performed worse than predicted, but all managed a substantial saving compared to comparable code-compliant buildings. The authors suggested that deviation from the predicted savings was due to higher than expected occupant loads and to systems not performing together as designed. Further, hours of operation and building space temperatures varied from the initial design. They concluded that the designers were optimistic about the behaviour of the occupants and their acceptance of systems. Diamont et al. [29] investigated 21 LEED-certified buildings. On overage, for the 18 buildings that had both simulated whole building design and actual energy use data, energy use was 1% lower than modelling predictions. However, there was large variability, and some performed better than predicted while others performed worse. The authors recommended that a comprehensive collection and publication of modelled vs. actual energy use data was needed, allowing for a closing of the gap between design simulation and as-built performance.

Filippín and Beascochea [30], Filippín [31] and Flores Larsen et al. [32] describes the post-occupancy evaluation of energy and thermal performance of residential and non-residential low-energy buildings that were designed to minimize fossil energy use. All analysed buildings are located in the province of La Pampa, central Argentina, in a temperate semi-arid continental climate that shows extreme hot and cold records during the summer and winter seasons, respectively. In La Pampa, the Gas Company, based on historical records, reports that 67% of the gas consumed during the year is used for heating purposes. The record reaches 75% during winter [33].

The present paper analyses the energy performance of two multi-family bioclimatic buildings located in Santa Rosa city, La Pampa, during the period 2001–2008. The analysis includes the energy consumption (natural gas and electricity) during 2001–2007, the natural gas consumption and the thermal behaviour during a winter week of year 2001 and 2007, and the daily natural gas consumption and the thermal behaviour during 2001 and 2008 winters. The electricity and gas consumptions are analysed in different periods of time (annually, bimonthly, monthly, daily, and hourly) to account for stationality and dweller' behaviour. A comparison between the energy consumption for heating in the bioclimatic building and its conventional layout is performed.

2. Building description

The two multi-family buildings are located in Santa Rosa city, La Pampa (South latitude 36°6, longitude 74.4° and 189 m above sea level), in a temperate semi-arid agricultural region of central Argentina. Fig. 1 shows the location of Santa Rosa. Climate information is presented in Table 1. An Olgyay analysis indicates that 83% of the days in the year fall outside the thermal comfort area [34]. Passive solar systems, thermal inertia, natural ventilation, thermal insulation, external shading, building orientation and dwelling grouping are suggested techniques to improve the thermal comfort along the year [35–37].

The distance between the two blocks (A and B, Fig. 2) is long enough to reduce overshadowing and to maximize solar gains in winter. Each double-story building is aligned on an East–West axis and it has a compact shape with 350 m^2 of useful floor area (useful area/apartment = 58 m^2). There are six apartments (from East to West, apartments 1–3 on the ground floor; apartments 4–6 on the first floor), each one having two bedrooms and a dining room with a kitchen on the northern side, and services facing the south. The solar collection area is around 18 and 14% of the apartment's useful area on the ground floor and upper floor, respectively.

The apartments, without mechanical cooling system, have a heater in the corridor (2900 W). The design harmonises the benefits of compactness and the requirements of natural daylighting, heating, and ventilation. Fig. 2 shows the design of the building and its technology (for more details see Filippín et al. [38]). The apartments are occupied by university students of low economic resources that come from different places of the region.

Filippín et al. [38] describe the hygrothermal performance of 12 apartments which were studied during the period December 13, 2000–January 15, 2002. Six apartments in one of the blocks (Block

Fig. 1. Location of Santa Rosa city in the province of La Pampa (Argentina).

Table 1
Climatic data of Santa Rosa, La Pampa, Argentina (36°57′S, 64°27′W, 189 m o.s.l.).

Annual values	Maximum mean	Temperature	23.4 °C
	Minimum mean		8.1 °C
	Mean		15.5 °C
	Global horizontal irradiance		16.3 MJ/m^2
	Relative humidity		68%
July	Minimum mean	Temperature	1.5 °C
	Mean		7.6 °C
	Maximum mean		13.5 °C
	Thermal amplitude		12.0 °C
	Mean wind velocity		2.8 m/s
	Global horizontal irradiance		8.1 MJ/m^2
	Mean ground temperature (−1.00 m)		10.0 °C
January	Maximum mean	Temperature	31.9 °C
	Mean		23.8 °C
	Minimum mean		15 °C
	Thermal amplitude		16.9 °C
	Mean wind velocity		3.9 m/s
	Global horizontal irradiance		24.0 MJ/m^2
	Mean ground temperature (−1.00 m)		23.8 °C
Annual heating degree-days (Tb = 16 °C)			1136
Annual heating degree-days (Tb = 18 °C)			1545
July–August heating degree-days (Tb = 16 °C)			939
Annual cooling degree-days (Tb = 23 °C)			128

Source: Servicio Meteorológico Nacional – Fuerza Aérea Argentina.

B) were monitored in detail, comprising both hygrothermal and gas consumption measures. The monitoring of the apartments under real living conditions gave a solid base to understand the building thermal behaviour and the influence of dwellers' habits. The potential of solar buildings design to reach significant levels of energy saving was confirmed. The comparison of solar and conventional buildings in terms of natural gas consumption demonstrates the magnitude of such potential.

On the basis of thermal and energy behaviour previous results, during 2001, the present paper describes the post-occupancy evaluation of energy performance during the period 2001–2007 in the bioclimatic multi-family buildings. During the period, Block A was occupied by women who lived there for one or two years, except for one student who lived for 6 years in apartment 3. Block B was occupied by men and women. The students would not be the same in the period, except for apartments 3 and 4 (60% of the students lived there for 6 years).

The specific aims are:

(a) To analyse energy consumption (natural gas and electricity) of 12 apartments during 2001–2007 (natural gas: annually, bimonthly; electricity: monthly);
(b) To study the natural gas consumption and the thermal behaviour during the year 2001 (between July 27 and August 3) and 2007 (between August 8 and 13) winters;
(c) To evaluate the daily natural gas consumption and the thermal behaviour during 2001 and 2008 winters;
(d) To compare the heating energy in low-energy consumption and conventional buildings (without bioclimatic design strategies).

3. Results and analysis

Table 2 shows mean climatic conditions for the period 2001 and 2007. The coldest year was 2007, showing mean minimum temperatures of −0.7, −1.1 and −0.1 °C for June, July and August, respectively. Values for 2007 were found to be below the historical ones.

3.1. Natural gas consumption (2001–2007)

3.1.1. Annual consumption

Table 3 shows the total annual natural gas consumption per apartment and per building (Blocks A and B in accordance with Fig. 2).

3.1.1.1. Block A. The annual average gas consumption in Block A, occupied by women, was 873 m^3, with a variability of 10% among apartments. If apartments are considered by floors, it is observed that the average was 847 m^3 on the ground floor and 898 m^3 on the first floor. The apartments located in the eastern side consumed, on average, 945 m^3 and those on the western side 899 m^3. The apartments located in the central areas consumed less gas (apartment 2 consumed 772 m^3 and apartment 5, 775 m^3). In these cases, apartments' envelopes have less contact with the exterior air so the thermal losses are lower. Consumption variability among the different years of the period is related to differences in annual outdoor climatic conditions and/or changes in the apartment's occupancy by groups of student dwellers. For the period 2001–2007 the variability (CV) in each apartment ranges from a minimum value of 12.4% (apartment 1, the same group of four students did not stay for the whole period but the number of dwellers was kept the same) to a maximum value of 27% (apartment 5, the same group of students did not stay for more than one year and the number of dwellers varied from 3 to 4, except for 2003 in which only one dweller occupied it).

3.1.1.2. Block B. The annual average gas consumption in Block B, occupied mainly by men, was a little bit lower than that of Block A (829 m^3) with a variability among apartments of 12.5% for the whole period. On the ground floor the average annual consumption was 883 m^3 and on the first floor it was 774 m^3. The lower consumption of the first floor apartments can be explained by the heat dissipation through the ventilation ducts of the heaters and the heat transfer through the mezzanine. This was not observed in Block A since, as it will be shown in the winter consumption analysis described in the following section, students living on the ground floor apartments maximized the use of direct solar gain and minimized the use of heaters. The apartments located on the eastern and western sides consumed, on average, 868 and 794 m^3, respectively. The central apartments showed an average consumption of 824 m^3. Consumption variability in each apartment for the study period ranges from a minimum of 13% (apartment 3, same group of students, one student stayed from 2002 until 2007, another from 2004 to 2007) to a maximum of 25% (apartment 2, the group of three or four students changed every year).

Table 4 shows consumption variability within the year, which points to seasonality in gas consumption. Values show that during 2001 (building inauguration year) the average variability coefficient for the six apartments is 47.6 and 45% for Blocks A and B, respectively. From that year onwards, period during which the flats were monitored and audited, an increase in consumption variability within each year (apartment 2A, CV = 89%; apartment 2B, CV = 90%, both in 2004) is observed. It might be inferred that seasonal variability could be associated to users' interpretation of natural climatization strategies. During 2001 the buildings were frequently visited by project members that developed a strong campaign among users providing them with a Good Practice Guide. The interruption of these campaigns and the fact that the same students would not stay in the same apartments might surely have affected the right use of the buildings by maximizing solar gain during winter.

For both buildings and for the study period, the total natural gas consumption might be showing the following:

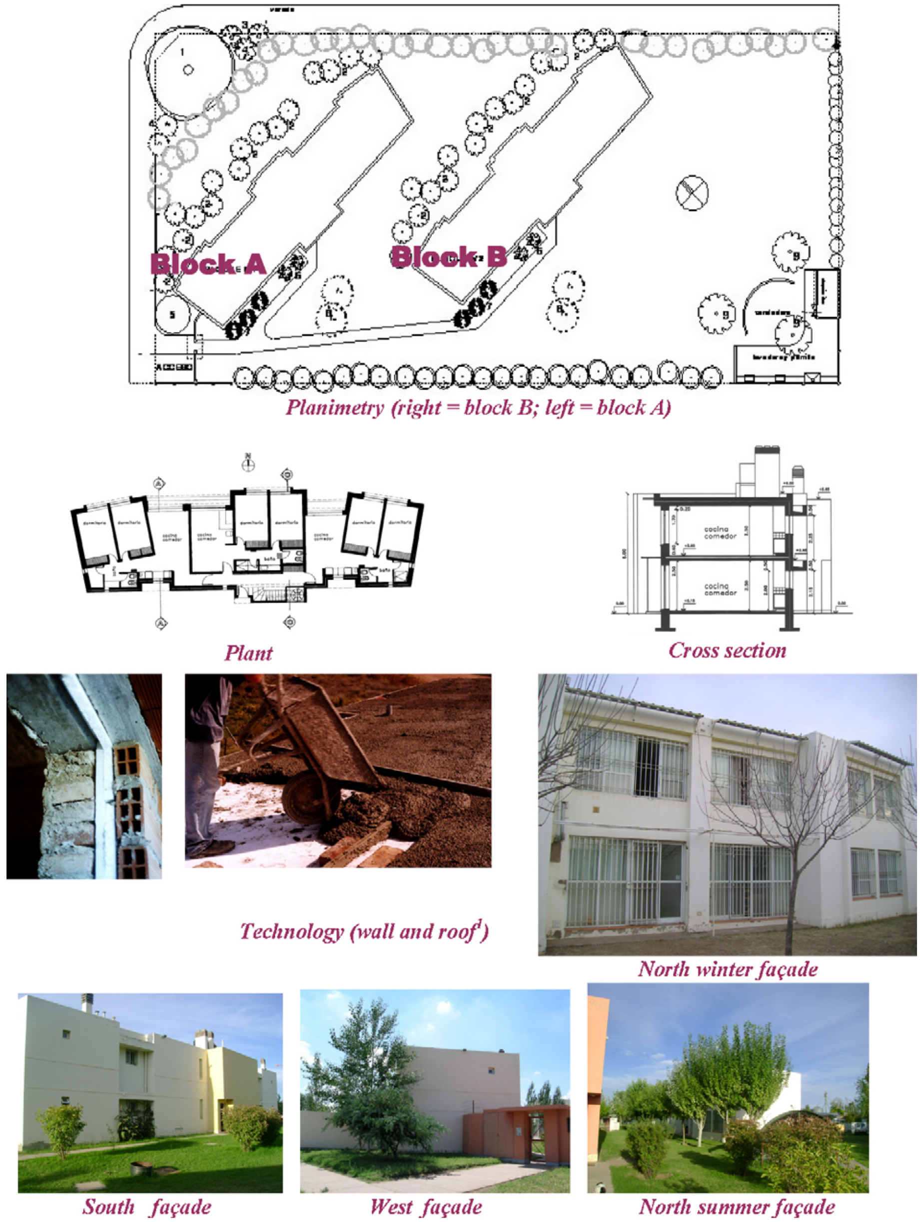

Fig. 2. Building's pictures. (1) The external walls have three layers: an inner 180 mm brick wall to provide inner thermal mass, a 50 mm thermal insulation layer, and an external ceramic wall with concrete to protect the insulation layer. Roofs were insulated with a 70 mm polystyrene sheet and a light subfloor with a waterproof layer. Hermetic aluminium frames and double glazing of windows allow to reduce heat losses and to regulate natural ventilation and daylighting. Overheating is reduced by eaves and black-out curtains.

(a) the annual average consumption for the period (2001–2007) per useful surface area is around 15.7 m^3/m^2 (useful area = 54 m^2),
(b) there are different dwellers' habits and also there are differences in the stay periods (maximum variation coefficients between 27% (apartment 5A) and 25% (apartment 2B). Variability can be due to students' mobility,

Table 2
Mean temperatures during the period.

Mean temperature (°C)	2001	2002	2003	2004	2005	2006	2007
Annual	21.4	21.5	23.3	21.9	22.6	23.5	21.9
Winter	14.2	14.1	15.1	14.9	14.2	16.6	14.0
Summer	30.8	28.0	31.5	29.2	30.2	30.7	30.2

(c) although all the apartments on the ground floor (18% of the transparent area facing North with respect to the useful area) and all those on the first floor (14% of the transparent area facing North with respect to the useful area) show the same direct solar gain, it is possible that not always all the curtains are completely open to let the sun in,
(d) the central apartments with less exposure to the exterior show less consumption followed by apartments facing west. This is the same for both Blocks,
(e) the apartments on the ground floor, Block B, with even more direct gain area, consume more gas than those on the ground floor; there might be a heat flow towards the upper floor (heat transfer through the mezzanine and/or through the heaters' ventilation ducts),
(f) the apartments located in the western side might be naturally warmer due to outdoor temperature and solar radiation, facts

Table 3
Annual natural gas consumption and variability during the period 2001–2007 (SD = standard deviation; CV = coefficient of variability).

Apartment	Years							Period 2001–2007		
	2001	2002	2003	2004	2005	2006	2007	Average (m^3)	SD	CV (%)
1A	818	1017	931	1188	894	983	1081	987	123	12
2A	944	748	698	673	755	685	900	772	108	14
3A	1079	950	889	1064	796	771	994	935	122	13
	Average on the ground floor during the period 2001–2007								847 m^3	
4A	884	740	964	909	954	803	761	859	155	17
5A	564	975	584	1066	653	662	924	775	206	27
6A	760	720	576	789	1065	977	1156	863	208	24
	Average on the first floor during the period 2001–2007								898 m^3	
	Average in the building during the period 2001–2007							873	87	10
1B	976	808	974	1062	781	1258	1202	1009	181	18
2B	580	976	850	1015	777	481	862	792	197	25
3B	1029	984	761	806	797	764	803	849	110	13
	Average on the ground floor during the period 2001–2007								883 m^3	
4B	575	643	668	782	800	659	962	727	130	18
5B	902	999	730	726	947	770	926	857	112	13
6B	578	663	895	689	902	550	892	738	155	21
	Average on the first floor during the period 2001–2007								774 m^3	
	Average in the building during the period 2001–2007							829	103	12.5

Table 4
Bimonthly average natural consumption (m^3) and variability (%) (2001–2007).

Apartment	Statistic indicators	Years						
		2001	2002	2003	2004	2005	2006	2007
1A	Average	164	169	155	198	149	164	180
	SD	71	119	97	131	99	113	123
	CV	43	70	62	66	67	69	68
2A	Average	189	125	116	112	126	114	150
	SD	98	90	85	100	111	92	108
	CV	52	72	73	89	88	81	72
3A	Average	216	158	148	177	133	128	166
	SD	118	108	117	111	91	106	118
	CV	55	68	79	63	68	82	71
4A	Average	177	123	161	151	159	134	127
	SD	79	70	113	88	97	87	85
	CV	45	57	71	58	61	65	67
5A	Average	113	162	97	178	109	110	154
	SD	59	101	51	101	57	76	120
	CV	52	62	52	57	52	69	78
6A	Average	152	120	96	131	177	163	193
	SD	57	76	56	95	102	87	130
	CV	38	64	59	72	57	54	67
1B	Average	195	135	162	177	130	210	200
	SD	104	88	112	129	79	144	128
	CV	53	65	69	73	61	69	64
2B	Average	116	163	142	169	129	80	144
	SD	58	134	87	152	1001	40	101
	CV	50	83	61	90	78	50	70
3B	Average	206	164	127	134	133	127	134
	SD	101	107	90	117	96	81	97
	CV	49	65	71	87	73	64	73
4B	Average	115	107	111	130	133	110	160
	SD	38	68	77	98	97	70	131
	CV	33	64	70	75	73	63	82
5B	Average	180	166	122	121	158	128	154
	SD	85	112	87	75	120	80	136
	CV	47	67	71	62	76	62	88
6B	Average	116	110	149	115	150	92	149
	SD	43	78	116	69	97	51	98
	CV	37	71	78	60	64	56	66

Table 5
Natural gas consumption during July and August (2001–2007).

Apartment and natural gas consumption		Years							Period 2001–2007		
		2001	2002	2003	2004	2005	2006	2007	Average (m^3)	SD	CV (%)
1A	July–August natural gas consumption	254	322	242	293	246	296	331	283	36	13
2A		295	246	217	271	299	278	317	275	34	12
3A		336	319	292	301	259	289	356	307	32	10
4A		212	175	301	219	282	254	238	240	43	18
5A		201	266	146	278	165	114	372	220	90	41
6A		232	217	161	251	302	268	334	252	57	22
1B		314	255	298	276	218	408	397	309	71	23
2B		176	366	260	320	286	143	287	263	78	30
3B		346	273	213	292	232	238	297	270	46	17
4B		145	188	195	236	273	216	356	230	68	30
5B		263	285	121	223	318	250	419	268	91	34
6B		165	220	282	189	280	176	287	228	54	23

that could account for lower consumption with respect to those in the eastern side,

(g) there is a strong incidence of seasonality in consumption (high variability within the year), with higher consumption rates during July–August. Variability is quite different among apartments and also among the different years considered, which could be associated with dwellers' habits in each case.

3.1.2. Winter consumption (2001–2007)

The highest bimonthly consumption corresponds to the months of July and August. Table 5 shows the consumption corresponding to the bimonthly period in each apartment and for each of the study years. Apartment 5A shows a consumption variability coefficient among years of 41% (the highest value observed in the Block A). In previous sections, we pointed out that in this apartment, the group of student dwellers was never the same, they did not stay for longer than a year and the number of dwellers varied from three to four, except for the year 2003 during which only one student lived in the apartment. In Block B the greatest consumption variability is observed in apartment 5 (34%), showing a similar situation to the one previously described. The average consumption value for Blocks A and B and for the whole period is 263 and 261 m^3, respectively, that is, around 4.85 m^3/m^2 (useful area = 54 m^2). In both cases, variability among apartments goes between 12 and 11.5% (see Table 6). In the same table it can be observed that higher levels of consumption correspond to 2007. According to weather reports, the mean minimum temperature in July (−1.1 °C) and August (−0.1 °C) was under the mean minimum temperature for the period 1997–2001 (July = 1.5 °C; August = 2.9 °C).

3.2. Thermal behaviour and annual natural gas consumption

3.2.1. Block B, year 2001

During 2001, thermal monitoring was carried out in Block B. This activity was described in detail in different articles [38,39]. During the first monitoring period (between April 5 and June 5) daily mean indoor temperatures in the apartments varied between 17.5 and 24.5 °C. This temperature was 1 °C higher in apartment 1 (ground floor), east side of the building, than apartment 4 (upper floor), rising to 3.2 °C for western apartments 3 and 6, and with a similar behaviour for central apartments 2 and 5. As a general trend, apartments 1 and 3 on the ground floor were warmer than others, presenting the highest gas consumption rates. During the second monitoring period (from July 9, 2001 to January 15, 2002) the mean outdoor temperature increased from 7 to 23 °C as summer approached. During the hotter period (December and January) the upper floor apartments had higher indoor temperatures than ground floor ones, exceeding 25 °C, because of high sol-air temperatures on the roof of upper floor apartments (4, 5 and 6).

Fig. 3 shows gas consumption during 2001 (obtained from Table 3) and average temperature in each apartment obtained from the monitoring data. It is observed that the Block's average temperature was 22.3 °C (average outdoor temperature = 13.2 °C). Average temperature in each apartment varies from 21.3 and 23.2 °C, with indoor thermal variations of 5 °C which shows that thermal comfort is guaranteed. The annual average consumption was 773 m^3 natural gas for the six apartments.

According to the reports of the Gas Company, 67% of the annually consumed natural gas per user in the study region is destined to space heating. In this case, the average would be 518 m^3 (average useful area: 54 m^2 = 9.6 m^3/m^2). The relation consumption/m^2 is equivalent to 99.5 kWh/m^2 to reach an average temperature of 22.3 °C (considering heat contribution from dwellers, food cooking, water heating and electric gadgets). From all the apartments evaluated from a thermal and energy-use perspective, we analysed apartment 4B (eastern end, first floor). In this particular case, since 2001 the dwellers followed certain use habits that guaranteed the success of the bioclimatic design strategies implemented (opening curtains to maximize direct solar gain, rational use of heater, opening windows to ventilate during adequate times). This apartment reached a temperature of 22.1 °C showing a total annual consumption of 575 m^3 natural gas within which heating takes 67% (385 m^3) i.e. 7 m^3/m^2. The annual consumption per m^2 of useful area in 2001 was 74 kWh/m^2; about 35% higher than the value established by the German Guidelines for multi-family low-energy housing to reach comfort,

Table 6
Average and variability natural gas consumption during July and August in the buildings (2001–2007).

Building		Years							Period 2001–2007		
		2001	2002	2003	2004	2005	2006	2007	Average (m^3)	SD	CV (%)
A	Average between apartments	255	257	226	269	259	250	325	263	32	12
	SD	52	58	65	30	51	68	47			
	CV	20	22	29	11	20	27	14			
B	Average between apartments	235	264	228	256	268	238	340	261	30	11.5
	DS	85	61	36	48	37	92	59			
	CV	30	23	29	19	14	39	17			

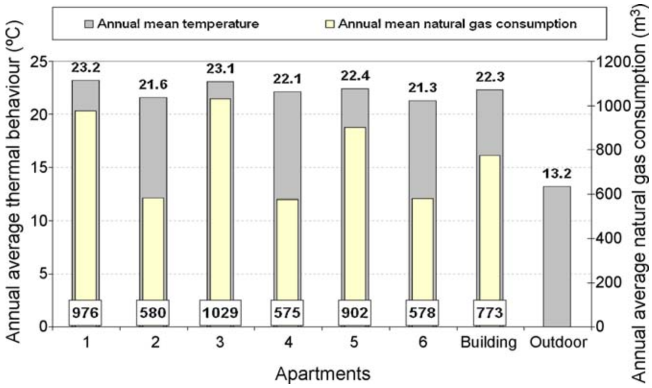

Fig. 3. Thermal behaviour (°C) and natural gas consumption (m^3) during 2001 in Block B.

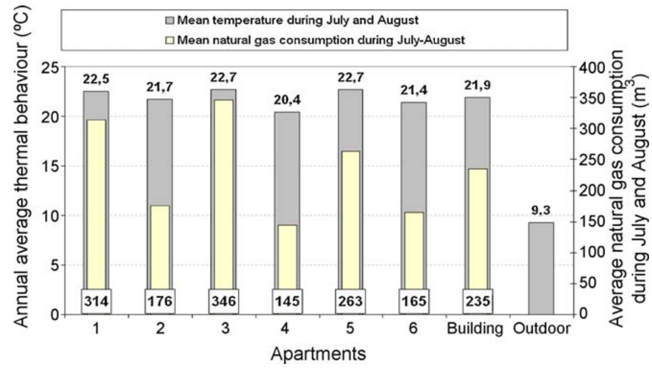

Fig. 4. Thermal behaviour (°C) and natural gas consumption (m^3) during July and August 2001 in Block B.

which do not specify an average temperature to reach (55 kWh/m^2). The average consumption of the apartments in Block A was 841.5 m^3, rather higher in relation to that of Block B. It is possible to infer that, under the same climatic conditions, these apartments reached comfort levels.

It may be interesting to know whether the resulting average consumption for the period July–August 2001 in the monitored building was enough to reach comfort levels. The recorded average temperature for each apartment can be observed in Fig. 5.

According to Fig. 4, the average consumption for the period July–August 2001 to reach an average indoor temperature of 21.9 °C (average outdoor temperature = 9.3 °C) was 235 m^3. Except for 2003, the consumed volume of gas was always higher than 235 m^3. The values obtained for Block A are above the reference value (value for 2001). Again during 2003, gas consumption was lower, July was hotter than usual, with a mean maximum temperature (14.6 °C) above the historical record (13.5 °C) and predominant clear sky days. It may be possible that both these facts (higher solar irradiance and higher temperatures) determined the decrease in gas consumption. As it was previously said, during 2007 consumption increased; the mean minimum temperatures recorded in July (−1.1 °C) and August (−0.1 °C) were lower than the historical ones (July = 1.5 °C; August = 2.9 °C). The absolute minimum temperatures for July 2007 (−10 °C) were also higher than the historical records (−5.9 °C). We can infer that recorded consumption values in the following years allowed reaching a comfort indoor temperature.

3.2.2. *Daily thermal behaviour of Block B during a winter week in 2001 and natural gas consumption in both blocks*

Table 7 shows the daily natural gas consumption, the outdoor climatic conditions (temperature and solar irradiance) and the

Table 7
Daily natural gas consumption, mean indoor and outdoor temperatures in Block B, and solar irradiance on horizontal surface during the period July 27th–August 2nd (2001).

Apartment		Days							Period between July 27 and 3 August 2001		
		July					August		Average (m^3)	DS	CV (%)
		27	28	29	30	31	1	2			
1B	Daily natural gas consumption (m^3)	7.35	5.72	8.15	6.93	5.96	2.96	4.65	6.0	1.8	29.4
2B		4.55	5.65	6.79	1.39	0.55	1.25	3.53	3.4	2.4	71.0
3B		4.72	7.77	8.29	8.48	5.20	8.42	5.98	6.9	1.6	22.9
4B		3.58	2.33	3.54	2.87	1.61	2.20	1.48	2.5	0.8	33.8
5B		2.34	0.25	0.96	4.54	3.75	1.29	0.52	2.0	1.7	84.9
6B		2.69	3.61	2.94	2.38	0.86	1.95	1.23	2.2	1.0	43.2
Building	Average	4.2	4.2	5.1	4.4	3.0	3.0	2.9	3.8	2.11	55.00
	DS	1.8	2.7	3.1	2.8	2.3	2.6	2.2			
	CV	43.9	64.1	59.7	62.6	77.3	88.0	74.7			
1B	Daily mean indoor temperature (°C)	23.1	23.1	22.2	23.7	24.0	23.5	22.0	23.1	0.7	3.2
2B		21.2	21.3	22.5	22.5	21.0	19.9	20.7	21.3	0.9	4.4
3B		21.9	21.8	22.7	23.0	23.2	23.4	23.2	22.7	0.6	2.8
4B		20.9	19.8	19.2	20.0	20.5	20.4	20.9	20.2	0.6	3.1
5B		24.0	19.3	17.7	19.5	21.3	21.5	20.4	20.5	2.0	9.8
6B		20.4	20.4	20.6	20.6	20.6	20.6	21.1	20.6	0.2	1.1
Building	Average	21.9	21.0	20.8	21.6	21.8	21.6	21.4	21.4	0.9	4.1
	DS	1.4	1.4	2.0	1.7	1.5	1.6	1.0			
	CV	6.3	6.7	9.8	8.1	6.8	7.2	4.9			
Mean outdoor temperature (°C)		3.7	6	6.6	7.7	11.7	11.7	17.7	Average = 8.9 °C		
Daily irradiance on horizontal surface (W/m^2)		13.9	12.3	10.9	10.2	12.1	10.0	8.1	Average = 11.1 MJ/m^2		
1A	Daily natural gas consumption (m^3)	6.00	5.58	6.13	2.07	7.20	6.44	4.59	5.43	1.68	31.01
2A		7.61	6.07	6.59	6.05	7.07	7.47	6.26	6.73	0.65	9.72
3A		7.61	6.00	5.95	5.96	6.22	7.40	2.62	5.97	1.63	27.39
4A		3.73	3.14	5.00	6.73	0.39	0.23	0.00	2.75	2.63	95.73
5A		2.93	4.47	3.23	4.37	5.26	1.39	1.79	3.35	1.44	42.86
6A		4.48	5.45	7.35	7.41	4.50	2.30	3.19	4.95	1.94	39.15
Building	Average	5.39	5.12	5.71	5.43	5.11	4.21	3.08	4.9	1.54	31.59
	DS	1.99	1.12	1.44	1.93	2.54	3.26	2.18			
	CV	36.96	21.97	25.19	35.62	49.65	77.50	70.83			

Table 8
Daily natural gas consumption during the period between August 8 and 13 (2008).

Apartment		Period between 8 and 13 (August 2008)							
		8–9	9–10	10–11	11–12	12–13	Average	DS	CV
1B	Daily natural gas consumption (m^3)	4.273	6.133	7.946	6.28	4.355	5.80	1.53	26.39
2B		2.501	2.954	3.295	4.806	5.055	3.72	1.14	30.68
3B		2.377	4.963	3.559	3.977	5.714	4.12	1.29	31.25
4B		2.470	2.633	2.592	4.199	2.860	2.95	0.71	24.13
5B		2.151	3.511	3.638	4.885	7.243	4.29	1.92	44.70
6B		3.561	5.399	1.704	1.960	3.665	3.26	1.50	45.89
Building	Average	2.89	4.27	3.79	4.35	4.82	4	1	25
	DS	0.84	1.43	2.16	1.42	1.56			
	CV	28.96	33.51	57.07	32.65	32.33			
Mean outdoor temperature (°C)		12.2	8.5	10.4	10.5	7.7			9.9
Daily irradiance over horizontal surface (MJ/m^2)		12.4	11.8	10.4	6.2	5.8	Average = 9.3 MJ/m^2		
1A	Daily natural gas consumption (m^3)	3.47	1.74	7.82	4.86	6.74	4.93	2.45	49.66
2A		2.44	0.88	1.10	2.59	1.78	1.76	0.77	43.71
3A		3.57	4.76	8.23	4.28	6.38	5.44	1.87	34.33
4A		4.81	5.52	5.48	5.88	4.18	5.17	0.68	13.08
5A		6.92	4.67	2.21	6.25	5.22	5.05	1.81	35.91
6A		6.13	6.57	5.13	8.63	7.92	6.88	1.40	20.39
Building	Average	4.56	4.02	5.00	5.42	5.37	4.9	1.7	34
	DS	1.72	2.23	2.89	2.04	2.18			
	CV	37.71	55.33	57.76	37.69	40.57			

mean indoor temperature of apartments in Block B for the July 27–August 2, 2001 winter week. This week can be representative of the whole winter period due to the fact that daily consumption in each Block during this week is similar to the daily average consumption calculated on the basis of bimonthly data. This conclusion can be arrived at from the following analysis: the average consumption for the period July–August 2001 (Table 6) is 255 m^3 (Block A) and 235 m^3 (Block B), that is, a daily average consumption of 4.1 and 3.8 m^3, respectively. These values are similar to the daily averages of 4.9 and 3.8 m^3 recorded between July 27 and August 2, 2001 (Table 7) which allow us to consider that this week is representative of the winter season.

The analysis of the mean indoor temperature in each apartment and of outdoor climatic conditions along the period (Table 7) shows the dispersion among the daily recorded values and also among daily values recorded in each of the apartments and blocks. In the Block B apartments, thermally monitored, the average consumption of 3.8 m^3 guaranteed an average indoor temperature of 21.4 °C (mean outdoor temperature = 8.9 °C; solar irradiance = 11.1 MJ/m^2 over horizontal surface).

In Block B gas consumption and thermal behaviour during the night were analysed in two apartments: 1 and 5. The first one reached an average temperature of 23.3 °C, the second one, 19.9 °C (night outdoor temperature = 9.4 °C). Apartment 1 (higher daily consumption, 6 m^3) had the heater on (high) during the night and showed a consumption of almost 4 m^3 per day for heating purposes. Apartment 5 (lower daily consumption, 2 m^3) consumed almost 0.9 m^3 for heating purposes, with the heater on (low) during the whole day. In the case of the monitored Block, the recorded daily average consumption allowed to reach an average daily temperature of 21.4 °C. It is possible to infer that the apartments in Block A also reached a comfort temperature during the week.

3.3. Natural gas consumption and daily and hourly thermal behaviour in the winter of 2008

According to the daily monitoring carried out during 2008, results are similar to those in 2001 (see Table 8). The average daily consumption was 4.9 and 4 m^3 for Blocks A and B respectively, values that would guarantee indoor comfort (the mean maximum temperature in August was 1.6 °C higher than that of 2001; the mean minimum temperature was 3.6 °C lower than that of 2001). The daily consumption is variable among apartments (25 and 34%), variability that is associated mainly with the use of heaters during the season. Some students let the heater on during the night, others turn it to pilot and others turn it to pilot all over the day-24 h. Some users maximize direct solar gain by opening all the curtains (Fig. 5).

Fig. 5. Direct solar gain during winter 2008.

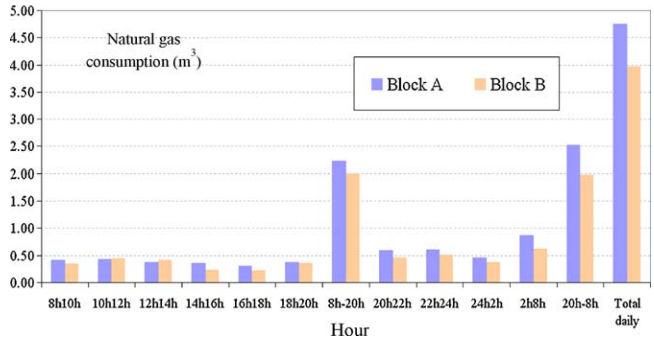

Fig. 6. Hourly average NGC during the periods between 8 and 11 August.

There is also variability among the days recorded in each apartment, surely associated with solar irradiance availability. Apartment 4A shows a variability of 13% (the lowest value considering all the apartments) with a daily average consumption 57% higher than 4B.

Fig. 6 shows the hourly average consumption for each Block. Night and day were studied. In Block B (thermally monitored) and according to the questionnaires given to users, the heater is turned to low between 8 pm and 12 pm; it is turned to pilot between 12 pm and 6 am and then turned to high during the first 2 h in the morning (consumption ≅ 1 m^3 during night/day). During the day, the heater is turned to pilot (consumption ≅ 0.7 m^3/day). In order to continue with the study, a daily average consumption for Block B of 1.7 m^3 (42% of the daily total) to keep an average indoor temperature of 22 °C is adopted. In Block A the heater is between high and low during the whole day (heating absorbs about 66% of the daily consumption = 3.2 m^3).

Gas consumption allows to infer that the building reached an indoor temperature higher than 22 °C. Under winter climatic conditions (mean outdoor temperature = 8.9 °C; irradiance over horizontal surface = 11.8 MJ/m^2) results show that an apartment would need, on average, about 2.45 m^3 natural gas per day to keep comfort conditions (0.51 kWh/m^2).

In accordance with the daily value and for the complete period July–August, the heating consumption would be 152 m^3. According to Table 9, the average consumption for both Blocks during the period is 262 m^3. On the basis of these records in both buildings, the percentage of gas consumed for space heating (guaranteeing comfort) is 58%. This value is quite lower than the 75% estimated by the Gas Company for winter in the region. This daily consumption is used to develop the last part of the present study, which has as one of its aims to compare the building energy consumption for heating, with and without bioclimatic design strategies.

3.4. Electricity consumption

The apartments analysed in this study have neither air conditioner nor fan. Except for one (3B) which has a music centre with amplifier, loudspeaker and electric guitar, the others have the ordinary furniture and fittings: fridge, television set and personal computer. Table 9 shows the annual electricity consumption between 2002 and 2007. Block B (mainly occupied by men) consumes, on average and per year, 6% per more electricity than Block A (occupied by women) contrary to what happens with natural gas consumption (Block A consumes 6% more gas than Block B). In both Blocks the upper floor (less glazed area in the kitchen-dining room) consumes, on average, 15% more electricity than the ground floor. For the whole period the variability coefficient shows that electricity consumption was more variable than that of natural gas. For example, in Block A, apartment 3 shows a CV = 54%; natural gas consumption for the same period showed a variability of 13%. In Block B, apartment 1 shows an electricity CV = 51% whereas for natural gas variability was 189% (Table 10).

On average, electricity consumption for the period 2002–2007 (695 kWh), was about 12.8 kWh/m^2 of useful area (54 m^2), that is, 46 MJ/m^2.

On the one hand, it is possible to associate electricity consumption to users' renewal and to the equipment which each unit has, and on the other, greater or lesser opening of black-out curtains would be conditioning the greater or lesser lighting energy use. For example, apartment 3B with an average consumption of 1011 kWh (period 2002–2007) shows diversity of equipment as compared to apartment 5B, with an annual average consumption of 546 kWh.

3.5. Total energy consumption

Fig. 7 shows the total energy consumption in MJ (1 m^3 of natural gas = 37,300 MJ). In both Blocks it is observed that higher consumption levels relate to natural gas (90%). This situation is a characteristic of buildings' energy use (traditional construction) in the study region.

Table 9
Annual electricity consumption (kWh) during the period 2002–2007.

Apartments	Years						Period 2002–2007		
	2002	2003	2004	2005	2006	2007	Average (kWh)	SD	CV (%)
1A	265	598	602	529	600	848	574	187	33
2A	677	885	936	869	341	770	746	219	29
3A	751	260	388	431	459	1079	561	301	54
Average on the ground floor during the period 2001–2007									627
4A	545	578	524	335	929	1155	678	303	45
5A	856	632	1284	638	677	793	813	247	30
6A	652	220	591	796	622	1126	668	295	44
Average on the first floor during the period 2002–2007									720
Average in the building									673
1B	788	182	536	192	597	638	489	248	51
2B	677	288	809	268	293	715	508	251	49
3B	1116	730	630	1049	1168	1372	1011	280	27.7
Average on the ground floor during the period 2002–2007									669
4B	609	730	1011	1060	1156	1228	966	244	25
5B	431	163	588	570	794	732	546	227	42
6B	919	286	354	852	1111	1177	783	379	48
Average on the first floor during the period 2002–2007									765
Average in the building									717

Table 10
Electricity average consumption and variability (kWh).

Apartments	Statistic indicators	Years					
		2002	2003	2004	2005	2006	2007
1A	Average	22	50	50	44	50	71
	DS	21	23	18	12	18	23
	CV	95	47	37	27	37	32
2A	Average	56	74	78	72	28	64
	DS	22	25	33	18	9	34
	CV	40	35	43	25	32	53
3A	Average	63	22	32	36	38	90
	DS	22	8	14	17	17	14
	CV	36	37	44	49	46	16
4A	Average	45	48	44	28	77	96
	DS	19	20	13	12	36	22
	CV	42	41	31	42	46	23
5A	Average	71	53	107	53	56	66
	DS	14	26	58	15	17	20
	CV	20	49	54	29	31	30
6A	Average	54	18	49	66	52	94
	DS	34	11	24	30	27	12
	CV	63	58	49	45	51	13
1B	Average	66	15	45	16	50	53
	DS	25	8	24	8	18	14
	CV	38	51	53	52	37	26
2B	Average	56	24	67	22	24	65
	DS	33	83	23	8	8	11
	CV	59	34	34	35	34	17
3B	Average	93	61	52	87	97	114
	DS	21	16	18	29	26	18
	CV	23	26	33	33	27	16
4B	Average	51	61	84	88	96	102
	DS	27	23	31	20	13	34
	CV	54	37	37	23	13	33
5B	Average	36	14	49	47	66	61
	DS	49	8	24	22	18	15
	CV	136	58	49	47	27	24
6B	Average	77	24	29	71	93	98
	DS	46	17	14	21	15	7
	CV	61	70	46	29	17	7

4. Bioclimatic building–conventional building

The code used to simulate the designed buildings in Santa Rosa was SIMEDIF *for Windows* [40], a free software developed at INENCO (Non Conventional Energy Research Institute, Argentina). In a previous work, the thermal simulation of the studied buildings performed with this software was shown [38,39]. SIMEDIF simulates the transient thermal behaviour of *multi-room* buildings with natural and passive air-conditioning systems and indoor heat gains. The code calculates the transient indoor temperatures of the different zones of a building under defined climatic conditions. It has been largely validated throughout years of experimental work in Argentina by numerous groups that have used it for research, design, and simulation of the thermal behaviour of buildings [41–43,39,32]. In all cases, comparison between the simulated temperatures and the experimental data confirmed the reliability of the software.

In order to determine heating energy saving between the bioclimatic buildings under study, and considering that the buildings have a conventional design, once calibration is performed, simulation takes place varying design strategies in accordance with:

(A) Same glazed area, but with single-glazed windows, without thermal insulation in the vertical envelope, and with 0.03 m thick thermal insulation in the horizontal envelope (this thickness was used in some particular cases in the study region).
(B) Glazed area reduced to 50% and without thermal insulation in the vertical and horizontal envelopes (this reduced glazed area is closer to window sizes per useful area of low-income housing, generally with no thermal insulation of the envelope).

Simulations were carried out for July average climatic conditions (minimum, mean and maximum temperatures of 1.5, 7.6 and 13.5 °C, respectively and solar irradiance over horizontal surface of 8.1 MJ/m^2). Curtains were supposed completely open in each room. The simulation results for the bioclimatic building show that under these climatic conditions, each apartment would consume, on average, 2.94 m^3 of natural gas per day to keep an indoor average temperature of 22 °C.

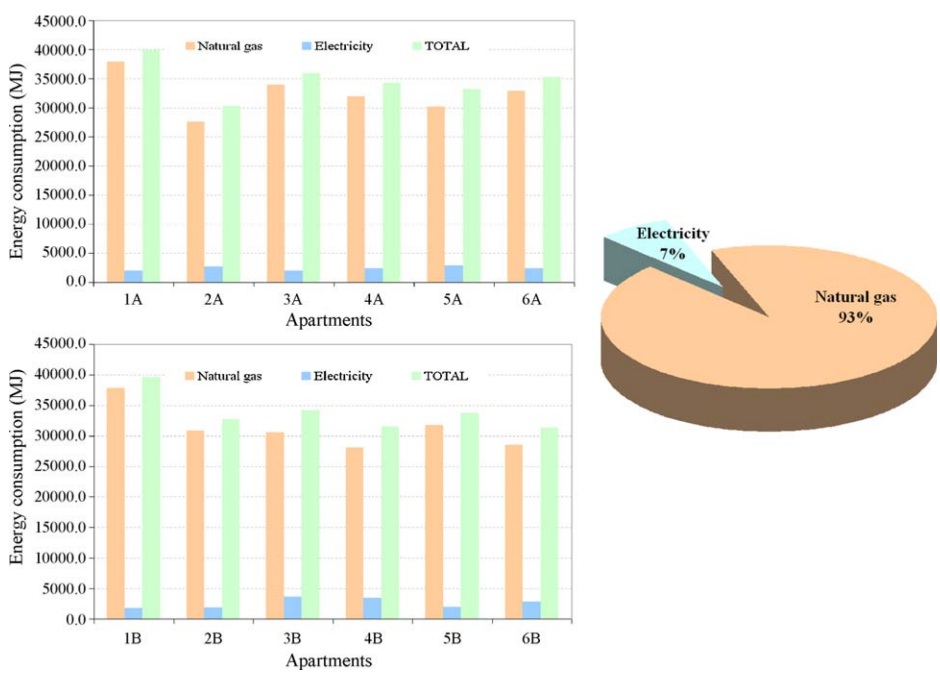

Fig. 7. Total annual energy consumption average during the period 2002–2007.

Table 11
Simulated daily heating energy consumption and energy saving.

Multi-family block building		Simulated heating energy consumption (m^3)	Energy saving (%)
Bioclimatic		2.9	
Conventional	A	5.9	50
	B	11.6	75

This value is comparable to the 2.45 m^3 daily natural gas consumption per apartment (mean indoor temperature = 22 °C; minimum, mean and maximum outdoor temperatures 4, 8.9 and 14 °C, respectively and irradiance over horizontal surface around 11.8 MJ/m^2), value obtained through daily and hourly monitoring carried out in winter 2001 and 2008, periods during which users were not the same but heating energy consumption was similar. This last value corresponds with real consumption under more favourable climatic conditions, what accounts for the small difference between both values. Due to the fact that the results of the hourly indoor temperature in each room, obtained from the thermal simulation with SIMEDIF, were adjusted with experimental data, if technology modifications were performed the results obtained from the simulation would be highly reliable. Thus, in order to analyse the heating energy saving on the basis of the implementation of bioclimatic design strategies, simulations were carried out of the same building with both design situations previously described and we calculated the necessary energy to keep an indoor mean temperature of 22 °C under equal climatic conditions. Table 9 shows the results obtained in each case.

In Table 11 it can be observed that the implementation of the bioclimatic design strategies resulted in a heating energy saving (for this case and to keep the indoor temperature of 22 °C, under average climatic conditions) of about 50 and 75%.

5. Conclusions

This work allowed for an exhaustive analysis of energy consumption along a period of 7 years in two Blocks of bioclimatic buildings situated in central Argentina, in a moderate-cold climate. Climatic conditions during the period were similar (except that in 2007 winter was colder), but dwellers mobility was considerable (students, in general, did not stay for more than 2 years). We must also remark that students come from different parts of the country – colder or hotter regions – and that their life-styles and habits are different.

The annual average gas consumption per square metre for the period 2001–2007 was 15.7 m^3/m^2, (585.6 MJ/m^2), out of which 4.8 m^3/m^2 are consumed in the period July–August. The analysis of winter consumption shows that in the bioclimatic buildings, the 75% heating gas share estimated for winter in the study region by the Gas Company, was reduced to a real 58%, a value that, at the same time, guarantees the thermal comfort for users. The heating energy average during winter of around 29.2 kWh/m^2 (mean indoor temperature = 22 °C) was 49% higher than that of the European Passive House (15 kwh/m^2) characterized by a *U*-value of the envelope that does not exceed 0.15 W/m^2 K (in our case U = 0.48 W/m^2 K). The total energy consumption was 175.6 kWh/m^2/year (heating – hot water – cooking – appliances – lighting).

The record was 32% higher than that of the European Passive House (120 kWh/m^2/year). This is a promising fact in a country in which the energy scenario is quite complex. Applying these design strategies to all buildings would decrease the risk of lacking the necessary natural gas for winter use.

Regarding electricity consumption, for the period 2002–2007 the average consumption is 12.8 kWh/m^2 (46.3 MJ/m^2). Thus, in all cases, gas consumption shows a strong seasonal component and absorbs, on average, 93% of the total annual consumed energy.

Results obtained and their analysis allowed us to observe that, even though apartments on the ground floor (18% of the useful area) and those on the first floor (14% of the useful area) have the same glazed area that generates direct solar gain and helps to naturally heat rooms, not all users maximize this advantage (some do not draw completely the black-out curtain during the times of greater irradiance in winter).

Natural gas consumed annually during the whole study period, even with different users and life-styles, guaranteed comfort. The designed buildings, under monitoring conditions (indoor temperature = 22 °C; outdoor temperature = 9 °C) would have a 75% heating energy saving if compared to the same typology but with less glazed areas facing North and without thermal insulation in the envelope (the usual technology in the region). In reference to electricity consumption, it seems that it is highly associated to the furniture and fittings in each apartment.

These results confirm the benefits of the design strategies implemented in these experimental buildings with an insulated envelope (U_{wall} = 0.50 W/m^2 °C and U_{roof} = 0.46 W/m^2 °C), passive solar heating, daylighting and natural ventilation. In each of these apartments, occupied by different users (variable in number, 4 people/unit) with different life-styles, the energy consumption remained within the estimated values during the thermal predesign stage in 1999. Results obtained from this study can be considered highly satisfactory: students lived under comfort conditions and energy consumption was low. To these facts it can be added that when they were built in 2000, the over-cost due to solarisation and conservation was lower than 3%.

Agreeing with Newsham et al. [27] we emphasize the importance of studying the post-occupancy performance of buildings. Thermal performance evaluation under real conditions of use allowed to close the gap between design simulation and as-built performance.

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