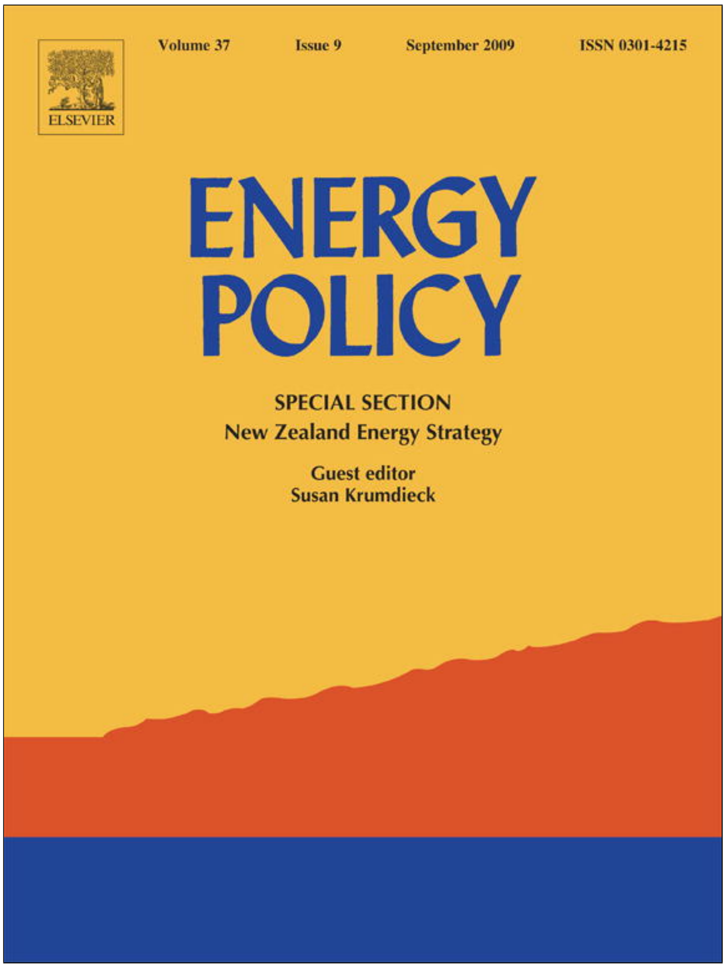
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Analysis of energy consumption patterns in multi-family housing in a moderate cold climate

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ABSTRACT

This paper analyzes the energy consumption during the period 2001–2006 of 192 flats distributed in three-storey buildings, in order to understand how current policies related to energy use could be improved for increased residential energy efficiency in Argentina. The buildings (1, 2 and 3 bedrooms) are located in La Pampa, central Argentina, in a moderate cold climate. The dimensional and energy-consumption variables are studied (area, envelope's area, FAEP = envelope's area/floor area; envelope's thermal resistance R, volumetric heat loss G and auxiliary heating Q_{aux}). The natural gas consumption is analyzed at annual and seasonal levels. Consumption variability among buildings, storeys and flats is calculated. The quantitative analysis is coupled to a qualitative description through direct observation of the buildings. The results show: (a) a high incidence of natural gas consumption in the total annual energy consumption (natural gas+electricity), (b) seasonality of natural gas consumption, with a maximum value in the cold period July–August (variability = 80%), (c) little variability among buildings of the annual natural gas consumption (4.17%), (d) the lowest average energy consumption at the first floor, (e) high variability among flats on each storey, (f) winter consumption of a multi-family dwelling lower than a single-family dwelling of similar area and (g) little seasonal variability of the electricity consumption.

1. Introduction

At present, about 50% of the human population lives in urban areas, and estimates show that around 2025 this figure could reach 75%. The energy pattern followed in the past 150 years has led to cities extremely dependent on energy resources that are pollutants, fact that turns them more and more vulnerable to interferences in the supply. In the near future, cities will have to assume the worst part in the many problems carried out by systems based on non-sustainable energies. These problems include air and water contamination, CO_2 emissions, and climatic change. Reducing the cities' energy dependence is, then, vital (García, 2007). Nowadays, cities use more than 70% of the total energy consumed by human beings (Ruano, 2002). Even though cities only occupy 0.4% of the earth's area (García, 2007), they are responsible for the greatest part of CO_2 emissions, which turns them into a key element to mitigate the global climate crisis. The unplanned urbanizing process is causing serious damages to human health and the environment, contributing to social, ecologic and economic instability in many countries (CIP, 2007).

According to Ganem et al (2005), the built area is a valuable cultural resource which constitutes the city's fabric and image, and which contributes to conform the identity of its inhabitants. It also represents huge amounts of material resources and built-in energy. Buildings are unique in their longevity compared with other industrial products (OECD, 2004). The energy problem plays an important role in their design and operation, so careful and long-term decisions taken at the design stage can significantly improve their thermal performance and reduce their energy consumption (Mohammad and Al-Homoud, 2001). Buildings consume energy in many different ways, i.e. through construction materials, components and systems (built-in energy) and during the distribution and transportation stage of materials to the construction site (grey energy). Also buildings consume energy as a result of the construction process (induced energy) and through their installed equipment (operative energy). Additionally, they consume energy as a result of maintenance, remodelling and final distribution. Thus, in order to be energy efficient, a building should try to reduce its consumption by all means (Jones, 2002). Morillón Gálvez (2008) states that construction processes that consume natural resources along time, cause different environmental impacts, for instance, popular architecture and high-tech

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architecture have a minimum impact (10^{14} ergs) and a severe one (10^{24} ergs), respectively.

Buildings, worldwide, account for as much as 45% of primary energy resources, and a similar share of greenhouse-gas emissions, that makes buildings the biggest single contributors to anthropogenic climate change (Nature Publishing Group, 2008). In Europe, the building sector is responsible for about 40% of the total energy consumption. The European Directive on energy performance of buildings (EPBD) aims at improving the overall energy efficiency of new buildings and large existing buildings during significant renovation (Eurima, 2007). For instance, Sweden has regulating and subsidising investment in energy-efficient buildings: there are building codes for thermal insulation that have been applied since 1960, and recently, the government subsidised information and advisory services at municipal level, according to the International Energy Agency.

In the European Union, the average consumption/dwelling has decreased between 2000 and 2004 of around −0.5% (Lapillonne and Pollier, 2007). The same authors report that Spain and Greece show a growth of 2.5% whereas Portugal shows a negative rate (−2.5%). In Mexico 23% of the delivered energy consumption corresponds to buildings (83.8% corresponds to consumption in housing), according to the Energy Secretariat of Mexico (2004). In this country, the energy consumption in the residential sector between 1998 and 2005 increased 0.12% with a negative rate (−1.55%) of growth of CO_2 emissions (CONAFOVI, 2006). This negative rate is explained by switching from fossil fuel electricity to the use of gas. In China, the building sector accounts for nearly one quarter (25%) of the total energy consumption and it has been growing steadily (Qingyuan, 2004).

In Argentina, between 35% and 40% of all used primary energy resources are destined for the environmental conditioning of the built habitat (53% corresponds to the residential sector) (OLADE, 2006). According to the 2005 Energy Statistics, residential consumption increased 2.5% between 1996 and 2004, with a growth rate of CO_2 around 2.18% (Evans, 2005). The main fuel for residential use is natural gas: 60% of households are connected to the gas network and their consumption accounts for 24% of the total gas consumed in the country, according to the Energy Secretariat of Argentina. In the southern part of the country, the climate is as cool as in northern Europe, but policies for reducing heat consumption have not been developed yet. In Argentina, the IRAM Norm 11604 (2001) regulate the building envelope's thermal transmittance and the limit values of the volumetric heat loss coefficient G^2, which captures both fabric and ventilation losses in one term. We used this coefficient throughout this research to serve as a basis of future discussions trending to change the Argentinean regulations. Because the ceiling heights of the flats under consideration are similar for all flats, this coefficient is directly related to the envelope area exposed to the outdoor environment.

The last report from the Intergovernmental Panel on Climate Change states that improvement in the energy efficiency of buildings could potentially reduce projected global emissions up to 29% by 2020, and up to 40% by 2030 (IPCC, 2007). Furthermore, energy efficiency is seen as the most effective way of improving availability of energy supply, reducing carbon emissions and increasing competitiveness while enforcing these energy-saving measures. The major obstacles to increase energy efficiency in the building sector are institutional barriers and market failures rather than technical problems (Nature Publishing Group, 2008).

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

Annual values	Maximum mean temperature	23.4 °C
	Minimum mean temperature	8.1 °C
	Mean temperature	15.5 °C
	Global horizontal irradiance	16.3 MJ/m^2
	Relative humidity	68%
July	Minimum mean temperature	1.5 °C
	Mean temperature	7.6 °C
	Maximum mean temperature	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 temperature	23.8 °C
	Minimum mean temperature	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.

To promote energy conservation in the residential sector, and to mitigate the CO_2 emissions, it is important to examine the residential energy consumption pattern. The total energy use in households was studied in developed and developing countries: Biesiot and Noorman (1999) studied the consumption of households in Netherland, Reinders et al. (2003) performed the study for households in the European Unions, Cohen et al. (2005) described the energy requirements of dwellings in Brazil, Pachauri and Spreng (2002) studied the case of India, Carlsson-Kanyama et al. (2005) performed a similar study for Sweden. In Argentina, the residential energy use of one-family households was described by González et al. (2007). At present, the authors do not have knowledge of studies related to the energy consumption of multi-family buildings in Argentina. Within this framework, the present paper has as a general aim to analyze the energy-consumption pattern (period 2001–2006) in a group of multi-family houses (192 flats in 8 blocks), located in the city of Santa Rosa. This analysis is made to understand how current policies related to energy use could be improved for increased residential energy efficiency in Argentina. Specific objectives comprise the following: (a) to analyze energy consumption, depending on flats' vertical location (ground, first, second floor) and orientation (north, south, east, west); (b) to evaluate the seasonal consumption, (c) to study the influence of the surrounding environment on energy consumption, (d) to compare energy consumption patterns of multi-family and single-family dwellings with the same area; (e) to propose an approach for improving energy efficiency.

2. Climate and building description

There is an important diversity of climates in Argentina, i.e. degree-days (DD) between 2730 and 690 (IRAM Norm 11603, 1996). The city of Santa Rosa (capital of the province of La Pampa)

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[2] *G*-value: volumetric heat loss coefficient: the total heat loss of a dwelling (through the fabric and ventilation) divided by the heated volume and the temperature at which the loss occurs (Goulding et al., 1994). ($G\text{-value} = \Sigma AU/V + 0.35 * n$; ΣAU is the area weighted summation$*U$-values of all external surfaces; V is the volume of the building, m^3; n is the average ventilation rate in air changes per hour).

is located in a moderate cold climate (Table 1) and it has a population of about 100,000 inhabitants. In the last few years, the construction of multi-family buildings had a remarkable increase. The design of these buildings commonly included big single-glazed areas without solar protection. Between 2005 and 2007, 32,400 m^2 had been accepted to be built, of which 27,520 m^2 are multi-storey buildings (Región, 2007). These multi-family buildings are placed downtown. Toward the periphery, also with a significant growth in the past years, an important percentage of family houses are being built by the government to satisfy low mid income families' housing needs. The greatest energy consumption in the city (electricity and natural gas) derives from residential areas, as reported by the Energy Secretariat of Argentina (2009).

Fig. 1. North view of one of the studied blocks.

The multi-family buildings analyzed in this paper were built in the 1960s. There are 192 flats distributed in 8 blocks of three storeys along a SE–NW axis. The flats have 1, 2 and 3 bedrooms: around 25% of flats have 1 bedroom, 25%—3 bedrooms and 50%—2 bedrooms. There are 8 flats on each floor (ground floor, first and second floor). Fig. 1 shows a photograph of one of the studied blocks. Fig. 2 shows the buildings' floor plans and their cross-section. The north facade azimuth is 150° (south = 0°). The building has an independent structure of reinforced concrete. The external walls are of ceramic block (U-value = 1.84 W m^{-2} K^{-1}) without thermal insulation. Windows are single-glazed with metal frames and external roller shutters (U-value = 5.82 W m^{-2} K^{-1}). The roof does not have thermal insulation (U-value = 1.80 W m^{-2} K^{-1}). Table 2 shows some dimensional

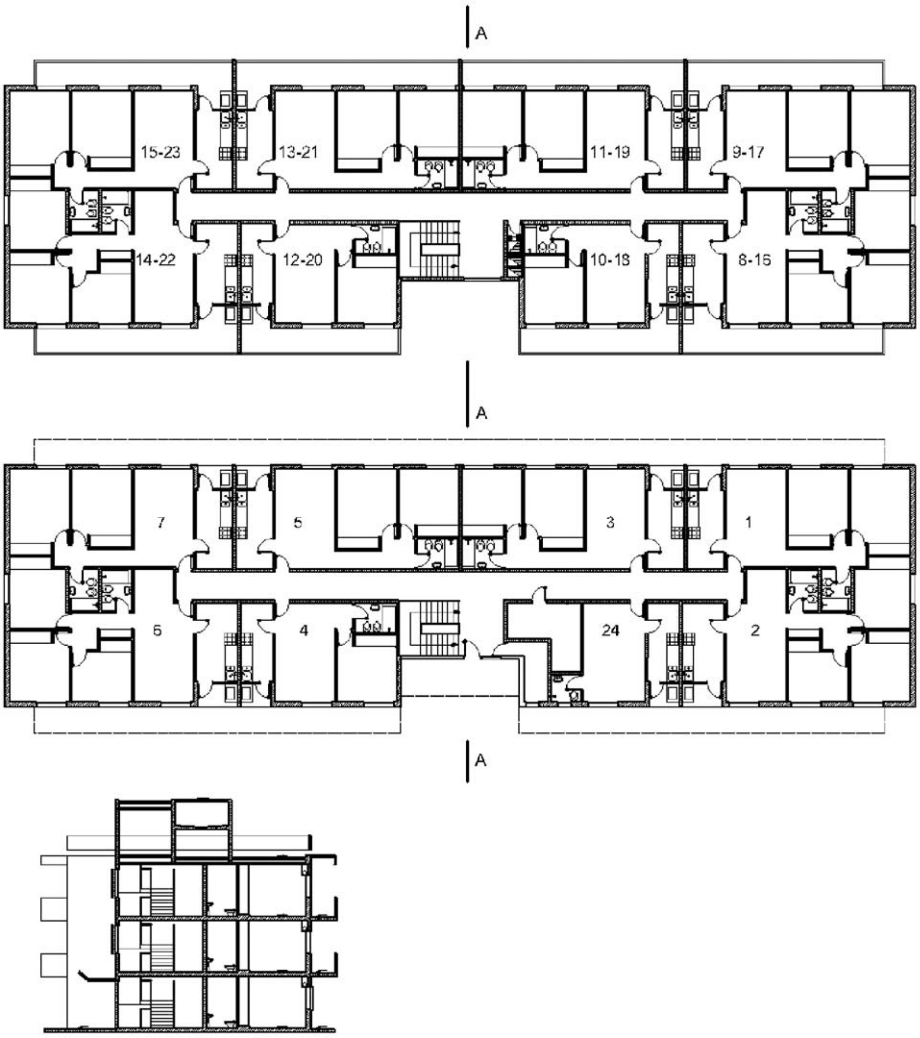

Fig. 2. Plan view and section of the studied blocks. The azimuth of northern façade is 150° (south = 0°).

Table 2
Dimensional, morphological and energy markers: FAEP (envelope surface area/floor area) volumetric heat loss coefficient G and calculated auxiliary heating Q (estimated according to G-value, degree-days and base temperature T_{base}).

Level	Flats	Area (m^2)	Envelope (m^2)	Volume (m^3)	FAEP	G ($W/m^3\,K$)	Q annual T_{base}(°C)				Q July–August T_{base}(°C)	
							18 °C		16 °C		16 °C	
							GJ	m^3	GJ	m^3	GJ	m^3
Ground floor	1–6	65.8	41.6	171.1	0.63	2.46	56.2	1506	41.3	1107	16.4	441
	2–7	50.2	35.4	130.5	0.70	2.42	42.1	1130	31.0	830	12.3	331
	3–4	50.8	24.2	132.0	0.48	2.31	40.7	1091	29.9	802	11.9	319
	5–24	36.5	18.2	95.0	0.50	2.15	27.3	731	20.0	537	8.0	214
						Total	166.3	4458	122.2	3276	48.6	1305
First floor	8–14	65.8	41.6	171.1	0.63	2.54	58.0	1555	42.6	1143	17.0	455
	9–15	50.2	35.4	130.5	0.70	2.55	44.4	1191	32.6	875	13.0	349
	11–13	50.8	24.2	132.0	0.48	2.52	44.4	1190	32.6	875	13.0	348
	10–12	36.5	18.2	95.0	0.50	2.4	30.4	816	22.4	600	8.9	239
						Total	177.2	4752	130.2	3493	51.9	1391
Second floor	16–22	65.8	107.4	171.1	1.63	2.9	66.2	1776	48.7	1305	19.4	520
	17–23	50.2	85.6	130.5	1.70	2.89	50.3	1350	37.0	992	14.7	395
	19–21	50.8	75.0	132.0	1.48	2.87	50.5	1356	37.1	996	14.8	397
	18–20	36.5	54.7	95.0	1.50	2.76	35.0	938	25.7	689	10.2	275
						Total	202.0	5420	148.5	3982	59.1	1587
						Block total	545.5	14630	400.9	10751	160	4283

and energy coefficients. The FAEP value[3] increases towards the top floor; the volumetric heat loss coefficient 'G'[2] varies between 2.15 and $2.90\,W\,m^{-3}\,K^{-1}$ from ground to top floor. Also estimated annual auxiliary heating (Q_{aux})[4] increases towards the top. This is explained by a greater exposure to the exterior environment of the top floor envelope's. The G values are higher than those allowed by IRAM Norm 11604 (2001).

3. Results

3.1. Natural gas consumption

In Argentina, 58% of the consumed residential energy is used for heating (OLADE, 2006). In La Pampa, the gas company reports that 67% of the gas consumed during the year is used for heating purposes, based on historical records. Different authors in Argentina have analyzed energy consumption in the residential sector and under different climatic conditions. The total energy consumption and the relative consumption of electricity versus gas consumption in public housing varied with climate (Rosenfeld and Czajkowski, 1992; Filippín, 1999; Blasco et al., 2000; González et al., 2007), i.e. in colder zones the relative consumption of gas is higher due the spread use of gas heaters, which are cheaper than electric ones. This situation will be discussed later in this paper together with the results found in our study.

Measured total natural gas consumption (to heat water, to cook and to heat rooms) is summarized in Table 3 by block and by floor. A relative variability between 12% and 17% among blocks is observed for different floors. The top floor shows the highest average annual consumption and the lowest variability among blocks. The relative variability of the total consumption among blocks is 4.17%, an insignificant figure if it were considered that the analysis involves 192 flats with different spatial locations and areas, different dwellers' lifestyles, some units are rented, others have been refurbished. The availability of solar radiation in this region is high, with prevailing clear sky during winter. Because the sun is an important energy source in those flats that have access to solar gains, the aperture percentage of external roller shutters and internal curtains can increase or decrease conventional energy consumption. We can compare the measured gas consumption for heating with the estimated auxiliary heating (Q-value) to keep an indoor temperature of 16 °C. The first figure is obtained from Table 3, by considering the statistics of the gas company indicating that a 67% of dwelling *annual* gas consumption is destined to heat the indoor environment, and a 75% of dwelling *winter* gas consumption is destined for heating. Then, from Table 3: $6626\,m^3*67/100 = 4439\,m^3$, $6523\,m^3*67/100 = 4370\,m^3$ and $8209\,m^3*67/100 = 5500\,m^3$. These values are

Table 3
Statistical indicators of the total annual natural gas consumption (m^3) in each block and level (SD: standard deviation; CV: coefficient of variability % = SD/average *100).

Block	Ground floor	Upper floor		Total/block
		1°	2°	
44	6667.6	6956.4	7602.8	21226.8
74	6398.2	8117.0	7127.6	21642.8
126	7957.2	5907.5	9175.1	23039.8
174	7943.7	6141.3	7969.1	21687.8
244	6553.4	6681.5	7169.8	20404.7
274	5690.5	7450.9	8327.4	21468.8
326	6156.3	4417.2	9518.4	20091.9
374	5643.8	6513.0	9155.3	21312.1
Average	6626.3	6523.1	8209.9	21359.3
SD	896.6	1106.7	966.7	891.4
CV(%)	13.5	16.97	11.97	4.17

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[3] FAEP-value: the ratio between the envelope surface and the floor area (Esteves et al., 1997).

[4] Q_{aux}-value: conventional (i.e. non-solar) contribution to the total load (Goulding et al., 1994).$Q_{aux} = 24\,h*\text{degree-days}*G\text{-value}*V/1000$.

Table 4
Statistical indicators of the average total annual natural gas consumption in each block and level (m^3) between 2001 and 2006.

Block	Ground floor		First floor		Second floor	
	Average	CV (%)	Average	CV (%)	Average	CV (%)
44	833.4	49.0	869.5	34.8	950.3	17.7
74	799.8	30.1	1014.6	39.9	890.9	36.9
126	994.6	21.4	738.4	23.2	1027.3	19.8
174	798.5	25.3	825.4	41.1	1132.9	42.8
244	936.2	30.9	835.2	39.8	896.2	22.8
274	711.3	31.7	931.4	36.9	1040.9	27.5
326	879.5	34.8	552.1	47.6	1189.8	42.9
374	705.5	31.1	814.1	40.7	1144.4	22.1
Average	832.3	31.8	822.6	38.0	1034.1	29.1
SD	101.6		137.0		115.1	
CV (%)	12.2		16.6		11.1	

similar to those of the estimated annual auxiliary heating (*Q*-value in Table 2) for each block level. Tables 2 and 3 also show that the ground floor (with less energy loss) consumes more gas than the first floor. Direct observation of flats shows that external roller shutters in flats are not closed (perhaps for safety reasons) and/or there are plants near windows that reduce solar gains. Since the slab is not insulated, the ground acts as a heat sink. Flats at the second floor have high heat losses due to the uninsulated roof.

Table 4 shows the standard deviation (SD) of average consumption in flats, which is higher in the intermediate level (first floor) (137.0 m^3). This level also has the lowest average consumption per flat (this could be associated to less energy loss through the envelope). The relative variability between the average consumption (period 2001–2006) of each of the 8 flats on each floor, would show the effect of the orientation and useful area and variations among dwellers' lifestyles (for example: external rollers drawn or not drawn, indoor temperature, etc.). In three blocks (126–244–326) the average consumptions per flat on the ground floor are higher than on the first floor, because at ground floor solar irradiance is lowered by medium and big-size plants (NE sector, block 126, and SW sector, block 174). On the north facade second floor of all blocks, there are no obstructions (solar aperture[5] depends solely on dwellers' habits).

Fig. 3 shows the average value and consumption variability for the period 2001–2006, per flat, floor, and block. For most flats, there are no variations of the annual average consumption along the period. Those cases, in which variability is significant, correspond to flats unoccupied for some years or rented flats. It was observed that 7% of balconies in flats had been closed with aluminium carpentry (thus increasing the useful area by 12 m^2). Gas consumption increased when the balcony is closed (i.e. flat 23 of block 174), or when new heaters were installed (the ventilation pipe can be observed on the facades). The owners closed the balcony to increase the useful area, without any consideration about the passive solar heating that could be provided by this sunspace in northern facades.

All flats show important bimonthly relative variability (values higher than 70%), which indicates that energy consumption is seasonal. Also a strong incidence of heating in relation to gas consumption is found. Fig. 3 also shows that there are blocks whose flats show greater energy consumption variability between 2001 and 2006, such as block 244, whose dwellers are employees of the province government who do not usually stay for more than one year. Other blocks show a relative variability below 10%.

Fig. 4 provides some examples that confirm gas consumption seasonality: the greatest consumptions correspond to period 4 (July–August, the coldest months in the region). The average consumption and variability vary between 200 and 400 m^3, and between 5% and 15%, respectively. It represents 0.5–0.7 $m^3\,day^{-1}$, i.e. 1.3 h of an 'on' oven. The spatial location (ground, first, second floor) and its orientation (north: taking advantage of solar radiation to provide natural heating; south, or on both ends of blocks: greater heat losses through the envelope) define consumption/m^2. For instance, in the second floor of block 174, Fig. 4 shows that flat 22 (at NE end side, FAEP $= 1.63$), with a higher FAEP factor but having windows facing north, consumes less gas/m^2 than flat 19 (south, FAEP $= 1.48$). The same situation is found in block 74: flat 17 (at SW end, FAEP $= 1.70$) consumes 34% more gas in winter than flat 20 (facing north, FAEP $= 1.50$). Other example is block 126: flat 6 (ground floor, at NE end side, FAEP $= 0.63$) has a lower consumption than that of flat 17 (second floor, at SW end, FAEP $= 1.70$).

To analyze heating gas consumption, we selected those flats with relative variability below 12% in energy consumption, amounting 69 flats of a total of 192. These flats with low variability were permanently occupied by a given family along a six-year study, so there was no interruption of electricity and gas supply. High-variability values were observed in those flats where the occupancy was not permanent along the period (i.e. rented flats), and they were not included in this analysis.

Fig. 5 shows the *heating* energy consumption during July–August, obtained from multiplying the gas consumption by 75% (which is the percentage heating consumption/total consumption estimated by the gas company for winter). The highest consumption corresponds to flats facing south, on one end of the building, and also to those on the second (top) floor that have higher values of volumetric heat loss coefficient *G*. For instance: flat 23 of block 174 (second floor, at SE end, $G = 2.89\,W\,m^{-3}\,K^{-1}$), has a heating gas consumption of about 460.5 m^3, while flat 20 of block 126 (first floor, facing north, $G = 2.76\,W\,m^{-3}\,K^{-1}$) has about half of this value (235 m^3). Thus, gas consumption for heating correlates both with energy losses through the envelope and with solar irradiation availability.

Fig. 6 shows a regression analysis among the energy consumption in heating (bills) and the value calculated from degree-days, *G*-value and a base temperature (set-point temperature) of 16 °C. The heaters were used along a 2 h period (between 11 and 13 h, according to occupants' information). The efficiency of the heaters is around 65% (González et al., 2007). Neither internal loads nor solar gain (62% of the flats analyzed face south, others on the ground floor do not lift the curtains for privacy) are accounted for. The results of Fig. 6 suggest that consumed natural gas should guarantee an indoor temperature around 16 °C. Evans (2003) estimates an increment of 4 °C for the effect of the internal gains, Mohammad and Al-Homoud (2004) consider an increment of 6 °C for the effect of the main operational parameters of occupancy, lighting, and equipment in each flat. As a consequence, the flats would reach an indoor temperature between 20 and 22 °C.

3.2. *Electricity consumption*

The electricity consumption of flats whose annual consumption has little variation is analyzed. The studied period is 1996–2006 for some flats and 2000–2006 for others. Flats that have air-conditioning equipment are studied and the seasonal variations in electricity consumption are analyzed. Table 5 shows

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[5] Solar aperture: openings in the building's envelope that permit solar irradiation.

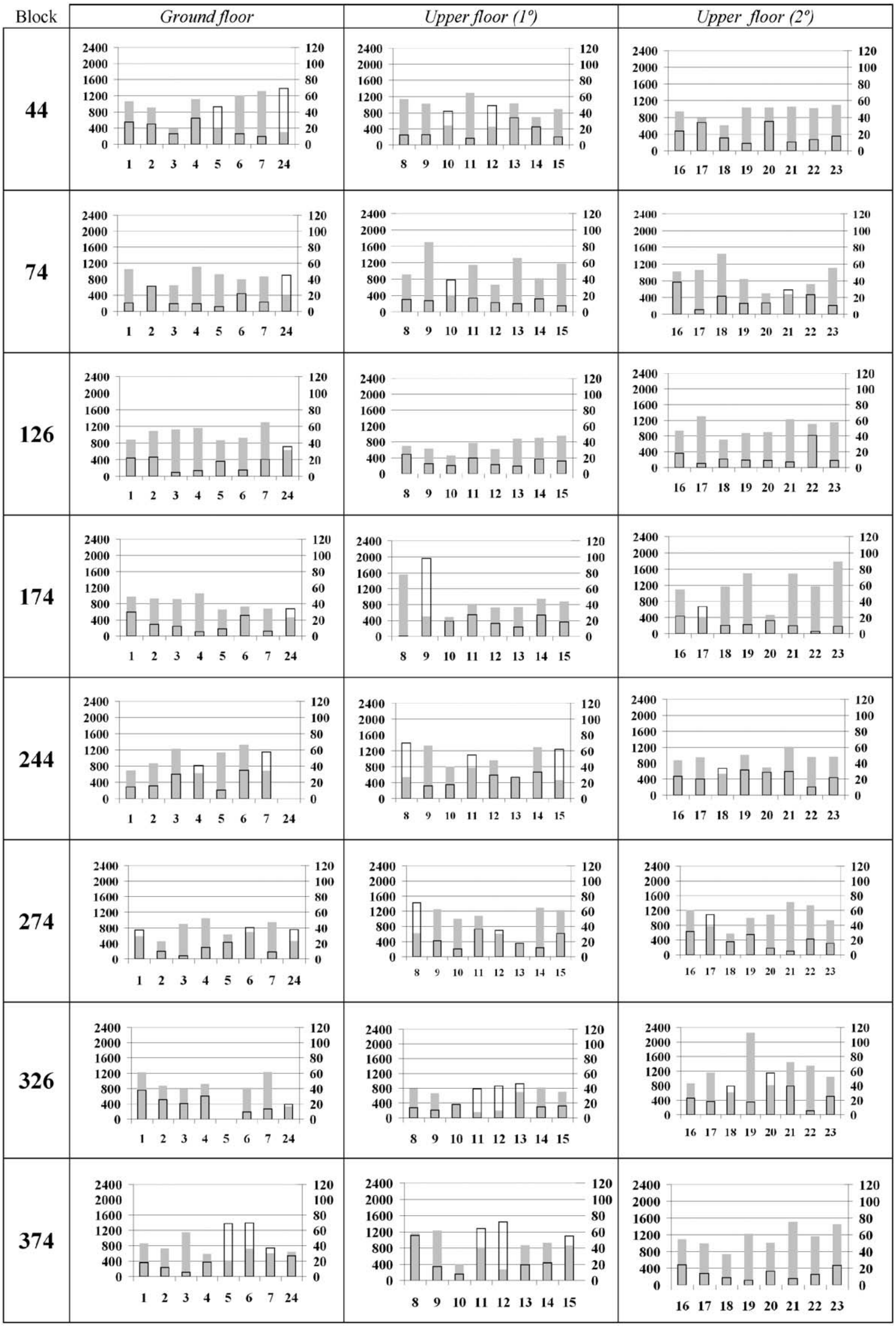

Fig. 3. Average annual gas consumption (grey) per apartment and block and variability coefficient (dark thick line) (%). Period: 2001–2006.

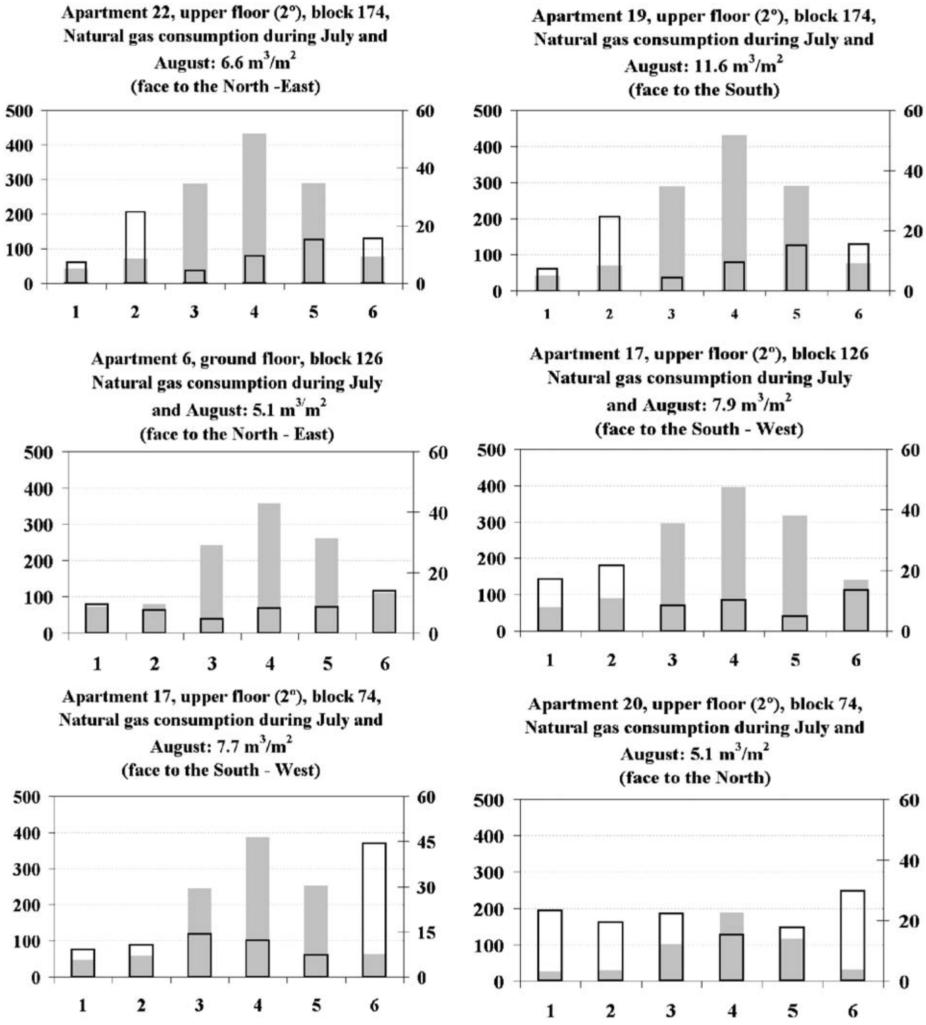

Fig. 4. Two-month period natural gas consumption in some apartments. Principal vertical axis: natural gas consumption in m^3 (grey); secondary vertical axis: coefficient of variability in % (dark thick line).

the average monthly and annual electricity consumption and variability per flat. In most flats the monthly variability of electricity consumption is lower than 15%, even in flats with air-conditioning (for gas consumption these values were about 70%). The only exceptions are flat 2 (block 44), flat 10 (block 374) and flat 19 (block 374). Flat 2 of block 44 has a relative variability in monthly consumption around 49%: the records show high electricity consumption in winter, during which values range between 200 and 250 kWh/month. This increase in the electricity consumption is due to a more intense use of the heating/cooling air conditioner in months with less availability of sunlight and with the negative effect of obstructive vegetation. Flat 10 (block 374) shows a monthly variability of 26%, with winter consumptions ranging from 100 to 120 kWh/month, which could be associated to the fact that the balcony was closed with aluminium carpentry and black-out curtains. In flat 19 (block 374) facing south, the highest consumption is observed in winter and spring and it could be related to less availability of sunlight. Table 5 also shows that flats with air-conditioning has variabilities between 3.4% in flat 21 facing south (block 126) – what might be showing that the equipment is cold/hot with an average consumption between 310 and 350 kWh/month – and 12.3% in flat 10 facing north (block 44) with low consumption in January and February. Most of the flats that have air-conditioning systems are located on the top floor, fact that can be foreseen since the heat loads are greater through the roofs.

3.3. *Total energy consumption*

To analyze the total annual energy consumption (total consumption = gas consumption+electricity consumption) for each flat, we considered only those in which gas and electricity consumption showed relative variability values below 12%. Gas and electricity consumption records were converted into GJ (1000 m^3 of natural gas = 37,300 MJ). Fig. 7 shows a ranking of total energy consumption in the analyzed flats. It categorically shows a greater incidence of the gas consumption in the total energy consumption. The average total consumption of 47 flats is 43.6 GJ, from which 38.5 GJ corresponds to natural gas consumption (88%) and 5.1 GJ to electricity consumption (12%).

Flat 9 on the SW end of block 74 shows the highest annual energy consumption (69.5 GJ) due to its plant location (block end with a high FAEP factor), windows facing south, and little availability of solar irradiation and daylighting during winter due to shading from evergreen vegetation (see Fig. 8). Flat 23 of

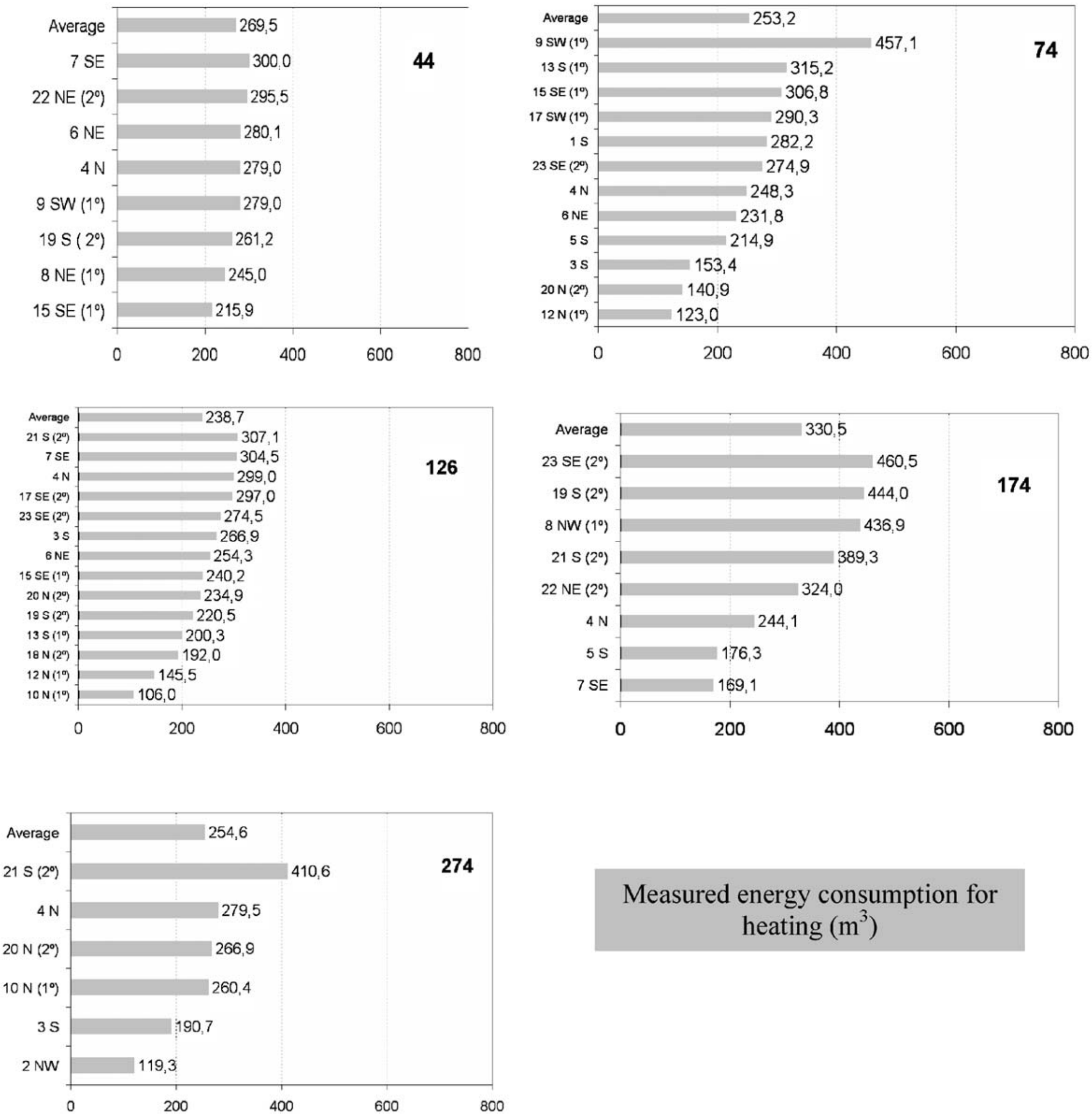

Fig. 5. Average natural gas consumption for heating. Period: 2001–2006. Vertical axis: flat; horizontal axis: natural gas consumption in m^3.

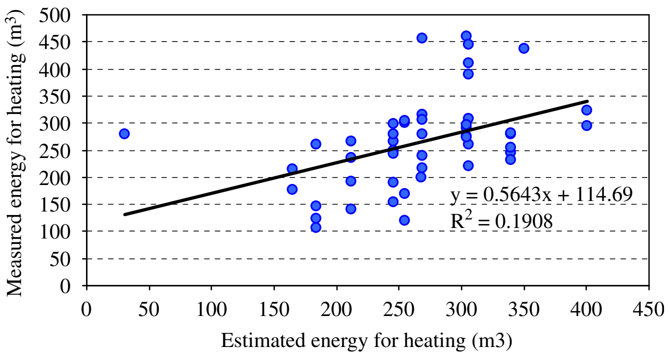

Fig. 6. Measured energy heating during July and August versus estimated energy heating according to: degree-days (base temperature = 16 °C); heater efficiency = 65%; flat's schedule use = between 11 and 13 h in 47 flats.

block 174, at the SE end side of the ground floor, shows an annual total energy consumption of 68.9 GJ. Flat 20 (block 44) located on the top floor and facing north, with less area exposed to the exterior, shows an annual consumption of 57.7 GJ (the flat has an air conditioner).

No significant differences between the average annual electricity consumption in multi-family housing and public housing for lower-mid income families in the study region were observed (54.6 GJ according to Filippín, 1999). Annual gas consumption in multi-family housing is about 30% of that recorded for public housing whose *G*-value is between 1.95 and 1.31 W m^{-3} K^{-1} (Filippín, 1999). When we compare these values with the energy consumption of housing in other Argentinean climates we find that in colder climates both electricity and gas consumptions are higher while in warmer climates electricity consumption is higher and gas consumption is a little lower. As an example, in the Patagonian Andean region (cold climate, mean annual temperature around 8.3 °C) the annual gas consumption of a housing is 169 GJ and its electricity consumption is 8 GJ (González et al., 2007). These values can be explained by a higher use of the gas and electrical air heaters due to lower outdoor temperatures. On the other hand, San Juan is an arid region in the west of Argentina, with a warmer climate (1042 degree-days, with a base temperature of 18 °C) and we find an average annual gas consumption around 24.7 and 9.6 GJ of

Table 5
Average annual and monthly electricity consumption in kWh (References: S/A = without cooling system: C/A = with cooling system).

			Annual consumption			Monthly consumption	
			Period	Average	Variability coefficient (%)	Average	Variability coefficient (%)
44	S/A	2	1996–2006	1582.0	13.6	131.8	49.2
		5	1996–2006	720.8	14.3	52.8	18.7
		6	1996–2006	1661.1	12.3	139.4	8.3
		7	1996–2006	1713.0	11.5	144.0	6.9
		8	2000–2006	1807.0	4.9	157	15.0
		11	2000–2006	772.4	4.5	64.4	6.5
		15	2002–2006	1175.4	11.75	98.0	17.7
		16	2002–2006	1078.8	14.8	91.4	5.8
	C/A	10	1996–2006	692.8	9.7	55.9	11.5
		17	2000–2004	1128.2	15.0	94.1	6.8
		19	2005–2006	1663.0	5.3	138.6	11.1
		20	2005–2006	1887.5	2.0	157.3	9.2
		21	2006	1705.0		155.0	12.3
		22	2000–2004	2055.0	3.9	171.3	5.8
74	S/A	1	2000–2006	1715.0	7.1	163.9	2.4
		3	2000–2006	881.8	12.4	73.8	4.3
		4	2000–2006	1540.0	10.1	128.8	8.7
		5	2000–2006	1518.0	4.2	126.5	10.8
		8	2000–2006	2870.6	12.0	239.2	2.6
		9	2000–2006	1715.9	12.5	143.0	4.4
		11	2000–2006	713.3	9.8	59.4	5.9
		13	2000–2006	1119.4	9.8	93.3	5.6
		14	2000–2006	1282.3	15.0	106.9	14.2
	C/A	7	2000–2006	2379.0	10.9	196.2	5.1
		15	1996–2006	2460.7	13.0	227.3	10.2
126	S/A	3	1996–2006	939.7	5.5	79.0	3.3
		6	1996–2006	1052.4	15.8	88.3	14.0
		12	1996–2006	1024.0	14.4	73.7	9.15
		13	1996–2006	837.0	11.1	91.0	5.4
		14	1999–2006	2348.1	6.8	173.7	13.3
		17	1996–2006	1534.6	7.8	128.9	4.7
		18	1996–2006	687.0	9.9	57.7	7.2
		19	1996–2006	1561.0	8.6	135.0	12.5
		20	2003–2006	1368.7	13.4	330.7	4.3
	C/A	10	1996–2006	1028.0	13.1	87.2	8.2
		15	1996–2006	1833.7	13.9	154.0	10.1
		21	2000–2006	1859.0	12.2	331.4	3.4
		23	2000–2006	1861.0	11.5	365.1	13.0
174	S/A	3	1996–2006	1654.1	8.04	139.0	4.85
		5	2000–2006	1227.8	10.6	281.5	1.8
		8	2005–2006	1277.0	10.2	365.5	1.2
		13	1996–2006	1293.0	10.5	117.3	4.7
		16	1996–2006	1080.0	10.5	90.6	9.9
		18	1996–2006	904.6	11.2	76.1	13.6
		21	1996–2006	2308.9	10.2	194.0	6.4
		23	2000–2006	699.6	9.4	246.1	3.4
	C/A	15	1996–2006	2362.2	8.4	198.6	9.1
274	S/A	1	1996–2006	879.9	8.3	74.0	8.1
		2	1996–2006	499.7	7.7	42.0	9.6
		3	1996–2006	743.0	7.9	75.1	8.1
		5	1996–2006	874.3	15.1	73.4	4.6
		7	2000–2005	1620.0	3.5	337.5	2.0
		9	2000–2006	629.8	5.9	257.4	2.1
		12	2000–2006	930.8	12.4	283.0	3.3
		14	2000–2006	2086.3	6.9	146.0	8.0
		19	2000–2005	1025.5	14.7	74.2	16.1
		20	1996–2006	901.8	2.9	77.6	3.7
	C/A	4	2000–2006	1032.9	8.4	262.5	1.7
		22	2000–2004	2153.6	9.3	150.6	4.8
326	S/A	2	1996–2006	1281.0	7.8	107.5	5.4
		6	1997–2006	1320.0	3.9	110.0	11.8
		14	1996–2006	1516.0	4.2	127.5	8.9
		15	1996–2006	1173.0	12.9	98.3	11.7
		17	1996–2006	1468.0	12.9	123.5	11.4
		24	2001–2004	563.0	14.5	61.4	6.5
374	S/A	2	1996–2006	2268.4	1.1	190.6	6.5
		3	1996–2006	962.0	13.1	80.8	7.5
		10	1997–2006	1008.8	7.3	84.1	25.8
		14	1996–2006	1072.0	16.7	90.1	7.9
		17	1996–2006	1484.7	10.5	124.7	4.2

Table 5 (*continued*)

		Annual consumption			Monthly consumption	
		Period	Average	Variability coefficient (%)	Average	Variability coefficient (%)
	19	2001–2004	670.3	14.1	55.9	22.7
	21	2000–2006	2273.1	8.6	189.4	3.4
C/A	4	1996–2006	1123.7	15.3	94.3	10.7

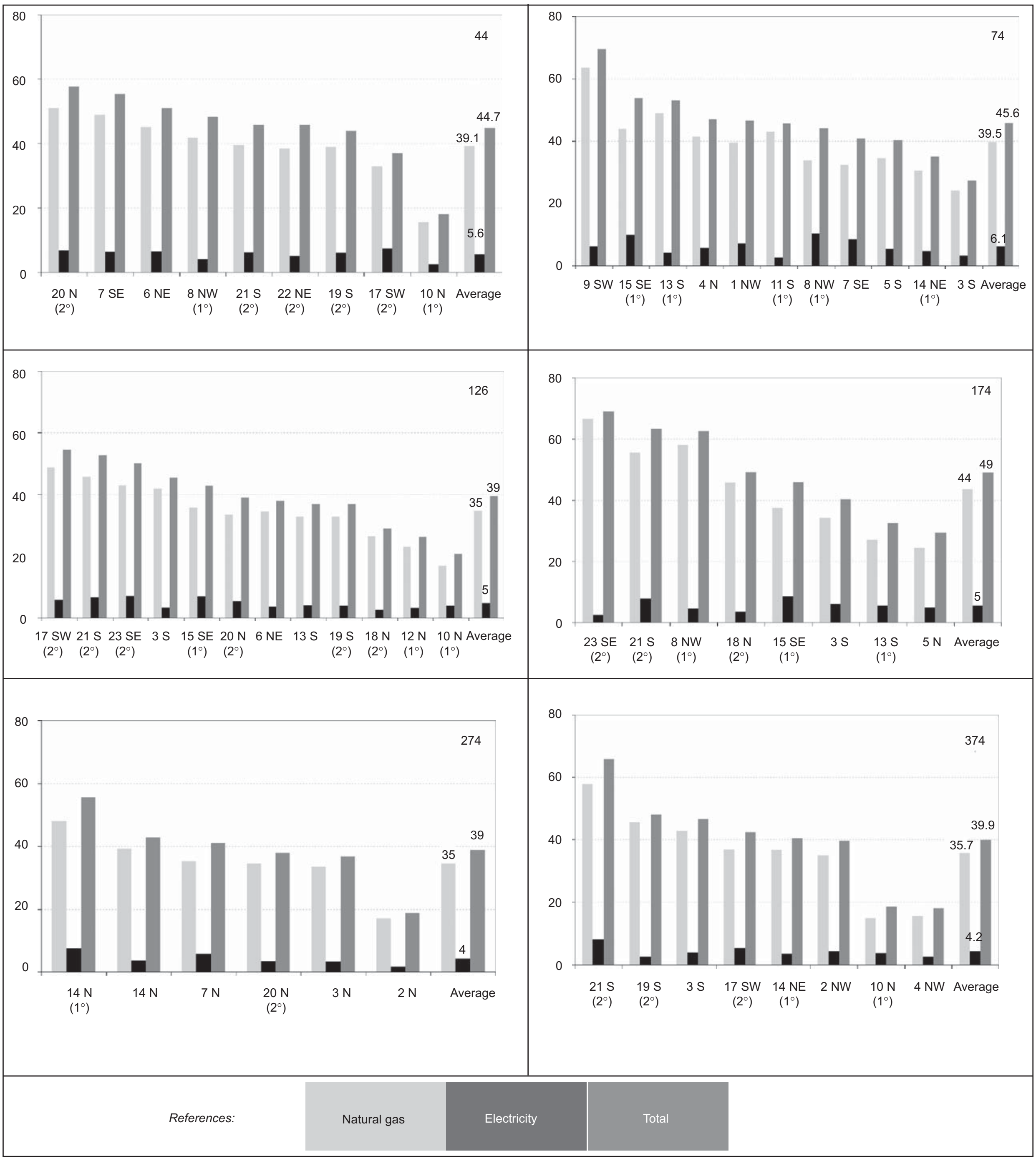

Fig. 7. Total annual energy consumption (GJ). Horizontal axis: flat; vertical axis: energy consumption (GJ).

annual electricity consumption in public housing (Blasco et al., 2000). These values are explained by a higher use of the air-conditioning equipment in summer and lower needs of heating in winter. In the next paragraphs, we will analyze the energy situation in Argentina and how the use of thermal insulation in buildings would decrease the total energy consumption in both climates.

Fig. 8. Building's south facade (block 74).

4. Thermal improvement guidelines

Energy efficiency improvement and energy saving are important targets to be achieved in every society as a whole and in residential buildings in particular. The major impediments to increase energy efficiency in the building sector are institutional barriers and market failures rather than technical problems, as pointed out by Nature Publishing Group (2008). Among these, Santamouris (2005) includes: lack of owners' awareness of energy efficiency benefits, insufficient awareness and training of property managers, builders and engineers, low-energy cost, lack of specialized professionals to perform energy audits and ratings.

When analyzing energy consumption in housing, several factors are interrelated. In the research carried out by Lopes et al. (2005), they propose the '3-star' concept that presents three main axes representing the surrounding environment (trees and plants around the house that shade it properly, total heat gains will be reduced for the same typical day), residents' action (occupants' interaction with housing) and technology matters (characteristics of the housing materials and of the equipment).

Mohammad and Al-Homoud (2005a) said that significant energy saving could be realized in buildings if they are properly designed and operated. Therefore, building designers can contribute to solving the energy problem if proper early design decisions are made regarding the selection and integration of building components. Thermal insulation is a major contributor and obvious practical and logical first step towards achieving energy efficiency. A holistic approach of all the important features required, for the best building thermal performance design, can prevent the irrational waste of natural energy resources while it may form a sustainable building scheme that can utilize adequately the benefits of the surrounding environment (Kontoleon and Eumorfopoulou, 2008).

At present, there are no technological barriers to achieve the thermal improvement of a building. In our region, the market offers the necessary resources to carry out a retrofitting. There are many benefits derived from using thermal insulation, which can be summarized as follows: (a) great energy saving can be achieved, thus reducing the required size of the HVAC equipment, (b) associated emitted pollutants are reduced, (c) the periods of indoor thermal comfort, especially between seasons, are extended, (d) the lifetime of the building structure is increased, (e) vapour condensation on the buildings' surface is prevented, and (f) thermal bridging is reduced (Mohammad and Al-Homoud, 2005b).

Filippín and Beascochea (2007) stated during 2007: "our 10-year experience gained from designing and monitoring low-energy buildings in central Argentina demonstrates that in our comparison of conventional and low-energy designs, a 25% reduction of the energy-loss coefficient (*G*-value) was observed in the case of solar buildings". Besides, the authors found that the implementation of bioclimatic design strategies represented, on average, a 50–90% saving of the energy budget used for heating. In parallel, this also means a significant reduction in CO_2 emissions to the atmosphere. The thermal performance analysis and the patterns of gas consumption suggest that while our design and construction achievements are already well suited to face the winter period, the summer time still represents a challenge to be faced and overcome by future research. For that reason we assume and confirm that in our country there are no technical barriers to design and to construct buildings with low energy consumption, not only residential buildings but also educational and other non-residential buildings. An example of a non-residential energy efficient building, is described in Flores Larsen et al. (2008), where the design and thermal behaviour of a bioclimatic auditorium at the National University of La Pampa used for teaching activities in Santa Rosa, La Pampa (Argentina) is compared with a conventional layout. Without additional cost, the energy-saving of the whole building was 50% in heating requirements with respect to the conventional layout, and 70% in requirements of conventional energy for cooling.

In this context, for an energy improvement of the building, the insulation of the roof is the most feasible alternative to be implemented. We considered that technical aspects are not barriers for the improvement of energy use. The inclusion of a 0.075-m-thick layer of expanded polystyrene would allow, for example, a *G*-value reduction of 17% (as a consequence, the heating and refrigeration loads would also be reduced). The improvement of the *U*-value of the external walls (with a 0.05-m-thick layer of expanded polystyrene) would allow a further reduction of *G*-value (around 12%). Therefore if the original *G*-value was $2.90\,\mathrm{W\,m^{-3}\,K^{-1}}$ and the retrofitting *G*-value is $2.12\,\mathrm{W\,m^{-3}\,K^{-1}}$), heating energy saving would be around 29%.

Another alternative could be changing single glazing to double glazing, even if the substitution of the carpentry for another hermetic one (they diminish the infiltration rate, and as a consequence the *G*-value and auxiliary heating are reduced). We believe that the barrier is the lack of incentives and subsidies for the owners to implement the improvements. An appropriate and economic decision would be a redesign of the buildings surroundings (pruning trees) to increase the use of the passive solar energy to heat the indoor environment.

5. Energy situation in Argentina

About 60% of the primary energy in the world is supplied by petroleum and natural gas. At the current consumption rate, the petroleum supply is estimated to last as long as 36–38 years (Freda and De Dicco, 2004) and the natural gas around 60 years. In Latin America, the proved petroleum resources are scarce when related to the world resources: only 12% of the petroleum resources and 5.2% of natural gas resources. Argentina has 0.3% of the world's petroleum resources, and the same value for natural gas.

Argentina is a very vulnerable country due to its high dependency on fossil fuels: petroleum and natural gas provides around 90% of the total energy consumed in Argentina. Besides, there is a strong dependency on natural gas in the electricity production. Energy supply is a crucial issue in the government agenda. Since 2005, several power shortages and shutdowns have been reported in critical summer days, because the load for air-conditioning was growing faster than the electricity supply.

The residential sector in Argentina uses several energy resources, depending on location, connection to gas and electricity networks and incomes of the owners. The energy resources are natural gas, bottled liquefied petroleum gas (LPG), electricity, diesel, kerosene and firewood. A recent research shows that similar amounts of energy per medium salary (i.e. USD 387, according to the government's official statistics center INDEC, 2008). This value applies to the registered workers, and is somewhat higher than that considering also unregistered salaries were obtained when diesel, kerosene, electricity and bottled gas were purchased (De Cicco, 2005). In this research work, the authors explain that, even though electricity seems to be more expensive for households, its higher end-use efficiency compensates for a similar final cost with respect to LPG, wood, diesel and kerosene. The situation is very different when natural gas is used, because when buying natural gas, the households in Argentina obtain 5–15 times more energy for the same salary than with other energy resources. Because Argentina has fuel prices set by various agreements between government and companies, natural gas for the residential sector is sold below the international price and often the government offers subsidies for gas consumption in zones with cold climates.

The previously described analysis on the natural gas consumption and electricity consumption shows that a high percentage of the total annual energy consumption corresponds to natural gas consumption (around 90%). Even though this situation is similar in other cold and temperate zones of the country, the energy-saving programs promoted by the government are focused mainly on electricity. Some examples are the change in the official hour to gain of one hour of daylighting in summer (of doubtful effectiveness), and the list of recommendations including the use of energy-efficient lamp bulbs and awareness in the use of lights. The gas regulation authority recommends to cook on low heat and to correctly regulate the temperature of water heaters for bath and wash, with some prevention tips to reduce the accidents related to gas use. Regulations related to house insulation and building thermal quality, efficiencies of space and water heating device efficiencies, are still lacking. The availability of cheap gas is certainly not a motivation for improving insulation. But this situation will not last longer in time—at the current production rate, the petroleum and natural gas resources in Argentina will not last beyond 2012 and 2015, respectively (Freda and De Dicco, 2004; De Cicco, 2005). Thus, there is an urgent need of serious energy policies to deal with this problem. Particular policy measurements to improve building insulation must be gradual, because it strongly depends on the availability of construction materials and methods, training of builders and households, economic incomes of the owners, culture and education, environmental awareness, and so on. The regulations should be applied in the whole country, including warm climates where a good insulation standard could significantly reduce the energy consumption for air-conditioning equipment.

6. Conclusions

This study allowed for the evaluation of annual and seasonal natural gas consumption in multi-family dwellings displayed in blocks. The analysis revealed that no variation on annual total consumption among the 8 blocks was observed. Results showed that in the cases with equal useful area but less FAEP, the first floor of each block showed less natural gas consumption. Climatic conditions of the region determine a strong incidence of seasonality on natural gas consumption and greater share of gas for heating purposes. When the useful area and the technology of walls are similar, the winter energy consumption of the multi-family dwelling (200–400 m^3) is lower than that of a single-family dwelling (500 m^3). Variations in gas consumption for heating can be clearly observed in relation to orientation and spatial location, for example, flats located on both ends on the ground floor, with greater outdoor exposure (block 326; $FAEP = 0.63$) consume 25% more gas than those on the first floor ($FAEP = 0.48$). Flats receiving solar contribution from the north consume 36% less energy for heating than those facing south. For this reason, an economic proposal to improve sunlight entrance during winter would be a redesign of the landscape in each building's immediate environment that would diminish the effect of plant obstructions.

Monthly electricity consumption did not show variation in most of the cases. Most of the air conditioners are located in flats on the top floor, which is compatible with the important heat load through the roof, without thermal insulation and with a solar radiation in summer and at midday of $1000\,W\,m^{-2}$.

With respect to the total energy consumption, 90% was consumed as natural gas. The flats that consume more energy are located on the block's top floor, facing south (less availability of solar resources to heat and light naturally all spaces) and on the ends (greater envelope area in contact with the exterior).

The high relative variability of annual average consumption of gas and electricity for the period 1996–2006 and 2001–2006 could be related, in particular cases such as that of rented flats, to the change of user and living habits (endogenous factors), situation that will be analyzed in future studies. In a new stage and in view of the results obtained in this study, we will monitor some of the flats identified as representative, with or without air-conditioning systems for summer.

Energy-efficient buildings are not a promise in the study region, they are a reality. We are convinced that users and designers need an impulse and greater knowledge of the benefits of energy saving to reduce institutional barriers. There is a need of education of the public on current energy status. Also the government should promote research on low-cost building materials, policy instruments for improving efficiency in gas and electricity consumption, inclusion of insulation standards in building codes, and spreading of information directed at builders and households. Architects and professionals must be aware that energy efficiency in buildings and its relation to the future energy stage in Argentina (natural gas depletion for the next decade) (Baragatti, 2004; De Dicco, 2005) must constitute the priority guidelines in architectural design. We believe that promoting incentives and subsidies for energy-efficient materials and equipment, rather than on gas consumption, might convince more owners to join this trend that aims at saving energy and preserving the environment.

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