Bioclimatic architecture and energy savings of the urban housing in arid environments

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ABSTRACT: The energy consumption for thermal conditioning of urban dwellings located in a zone of arid mesothermal climate is studied to identify its incidence in the household energy structure. The study's object is the city of San Juan (Argentina), located in the South American arid diagonal. The hypothetical consumption of natural/liquefied gas and electricity, per dwelling unit is estimated processing relieved data and calculating the bioclimatic design strategies, if it had been bioclimatically designed. It is concluded that the use of fossil energy for domestic thermal conditioning, constitutes about half of electricity and gas consumption in Winter and 60% of electricity in the Summer. If the housing had been bioclimatically designed, savings in electricity consumption would be 84% in winter and 46% in summer. For gas, the savings would reach 84%.

Keywords *Bioclimatic Architecture, Energy Savings, Houses, Arid Environments.*

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1. INTRODUCTION

Fossil fuels have been the drivers of the economy in the last 150 years, allowing that the world's population multiplied six times. Therefore, the virtual exhaustion of those reserves is currently one of the major problems with which the world civilization faces, originated in its indiscriminate use as generators of energy resources. In Argentina, according to INTI (2007), during 2002, 53% of the supply of primary energy was: natural gas (40%), oil (6%), hydropower (2%), nuclear power, and other sources (5%). From the supply with natural gas, 56% is consumed to condition buildings in the residential, industrial, commercial, public sector and transportation purposes. According to the same source, the main consumers of electricity are: industrial sector (44%), residential (29%) and commercial and public (25%). The latter constituted by public offices, hospitals, schools, shops and public lighting. According to ENARGAS (2005), the consumption of natural gas by sector is as follows: residential 21%; Commercial 3%; Industrial 33%; Energy Plants 31%; GNC (Compressed Natural Gas) 9%, others 3%. For 2006, the OLADE registered in Argentina a 53% of natural gas demand, while oil was 33%.

The World Development Bank (BMD, 2007), in the Latin America Regional analysis explicit that Argentina is the greatest consumer of household gas. This pressure generates the urgent need to optimize its use due to the inefficiency of the own hydrocarbon reserves. In line with the above, according to the CESLA - Centre for Latin American studies (2009), Argentina is the main consumer of household gas in Latin America, widely beating the second country (Venezuela) with 61% of the Latin American distribution (Argentina 308.4 Mill. TJ, Venezuela 45 Mill. TJ). In relation to the power consumption Argentina places in 3rd order with 109.4 Kv/h, after Brazil and Mexico. Comparing these values with the Latin American energy generation capacity, Argentina is the 4th country in production of oil and 2nd in gas generation.

According to statistics of the Ministry of Economy, Argentina (2008), oil reserves have fallen 25% in the period 2001-2005, in parallel to the fall in production. In the case of natural gas, the situation is even more serious, because in the same period was consumed 40% of the reserves increasing the production only by 18%. In the aforementioned report of 2006, OLADE refers to the natural gas consumption in Argentina by 2018 having an increase of 102% taking the 2003 as base; of the 41% in oil; and the 93% in electric power. On the other hand, the horizon of energy reserves in Argentina was for 2005 in the petroleum case of 9.1 years and natural gas, 8.87 years. In Argentina, approximately one third of the energy produced is consumed in and for the operation of buildings. Of this amount, half is used to meet the demand for heating and cooling (INTI, 2005). Furthermore, of the total demand of power according to the aforementioned OLADE report, gas accounts for a very high percentage, 73.93%, discriminated against in natural gas: 59.75% and liquefied petroleum gas: 14.18%. Argentina has increased the final per capita energy consumption in the decade 1997/2006 about 11.5%, value far higher than the Latin American average of 8.5%. Within this total and for the same period, residential consumption increased by 23%, having decreased the Latin American average about 2%.

The current environmental crisis with respect to the non-renewable natural resources, in combination with high levels of air pollution that affect the global climate change and in

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the creation of the heat island in the cities (Oke, 2006), generates inescapable social and governmental responsibilities in general, requiring actions that work together to reverse the serious effects. In this context of concepts, it is considered urgent the need to contribute to savings of fossil energy, refocusing its application to generating productive activities of capital goods or services and not to the residential sector, which is final and not generates added value. Within the residential sector the thermal conditioning is one of applications of conventional energy more easily replaceable, taking advantage of the climate in the architecture through passive or hybrid systems.

This work studies the energy consumption in the residential sector in a city of arid area located in the Centre-West of Argentina, identifies the structure of use and quantifies the possible energy savings on the assumption of a housing bioclimatically designed.

2. MATERIALS AND METHODS

2.1 Characterization of the Metropolitan Area of San Juan, Argentina

The arid ecosystems represent approximately 47% of the emerged lands of our planet and 14% of the world's population lives in them. In Argentina the arid zones make up 75% of the territory, have only 12% of surface water resources and its population is approximately 30% of the national total (Kurbán *et al*, 2015a). The Metropolitan Area of San Juan located to the southeast of the province of the same name (south latitude: 31° 32' 24", west longitude: 69° 31' 48”) in the Central-Western Argentina Republic, comprises Capital and the urban areas of Chimbas, Rawson, Rivadavia, Santa Lucia and Pocito departments. It has an extent of 127Km^2 (0.14% of the provincial territory), a population of 458,229 inhabitants (67% of the provincial total) and a population density of 37 inhabitants per km^2 (Papparelli *et al*, 2015). According to the characteristics of its spatial distribution, the city can be divided into Urban Characteristic Bands (BUC): eminently urban band (BUC EU), urban band (BUC UR), suburban band (BUC SU) and not urban band (BUC NU). These bands can be defined as: continuous and homogeneous portion of urban area, with urban index of similar value between two representative isolines of Land Occupation Factor (FOS), that identify its territorial limits and the state of spatial situation; it is presented as an area concentric to the main urban centre. (Papparelli *et al*, 2009). The Land Occupation Factor (FOS) corresponding to each band is as follows (Papparelli *et al*, 2015b): BUC EU: FOS ≥ 40%; BUC UR: 40%> FOS ≥ 20%; BUC SU: 20% > FOS ≥ 5%; BUC NU: 5%> FOS.

2.2 Population of each BUC of the San Juan Metropolitan Area (AMSJ)

The spatial distribution of the population in the AMSJ according to the Characteristic Urban Bands was obtained by overlapping a plane of such BUC with census 2010 radios (INDEC, 2010). The resulting population values were: BUC EU: 42,368 inhabitants, implying a population density of 38inhab/Ha; BUC UR: 253,415 inhabitants, implying a population density of 44inhab/Ha; BUC SU: 162,446 inhabitants, implying a population density of 28inhab/Ha. Figure 1 shows the isolines of spatial distribution of population density in the AMSJ overlapped with the Urban Characteristics Bands.

2.3 Urban Climate of the AMSJ

The anthropization process in urban areas involves an alteration of the natural climate due to the increasing changes in the conditions of the original physical support produced

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by building volumes, road infrastructure characteristics, urban afforestation and anthropogenic heat (by population, air pollution by cars, emission of heat into the atmosphere by use of environmental conditioning systems). Such changes influence the higrothermal conditions, both in the open spaces and the building interiors. This final state of the modified macro-scale climate is called *urban climate*.

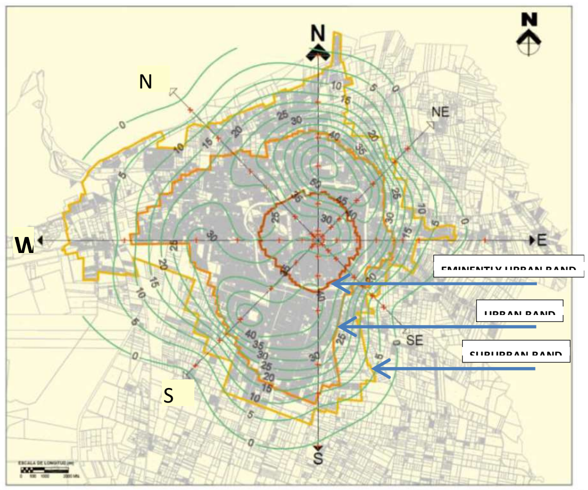

Figure 1: Isolines of population density in the AMSJ (Source: own elaboration)

The urban climate of the San Juan Metropolitan Area, is arid (Thornthwaite index = 0.0794) and Continental (Gorczynsky [K] index = 34.12), with high thermal amplitudes daily, seasonal and annual (17.3 °C). Low values of humidity (average = 40.92%). Low summer rainfall regimen (annual = 77.72mm). High solar radiation year-round (490W/m^2) as a result of a low and decreasing cloud cover level, and a water deficit of 979.28 mm. The most frequent wind throughout the year is from the south sector (average 7 km/h), with intense gusts associated with storms of dust in times of change of time. Prior to the changes of time usually appears a local wind known as "Zonda", which is a fohen effect, characterized by very dehydrated and torrid air that can last from some hours to several days (Kurbán *et al*, 2015b). One of the most important aspects of the urban climatology is the urban heat island phenomenon resulting from the alteration of four physical mechanisms (Mazzeo, 1984). For the AMSJ, the heat island for 2011, obtained from the processing of satellite images LANDSAT 5TM+, had a maximum intensity of 5.0 °C for summer and 4.5 °C for winter (Cúnsulo *et al*, 2013). The effects of the micro-climatic phenomenon are knit together with energy consumption, since in arid zones the urban heat island generates significant discomfort conditions particularly during the summer.

2.4 Bioclimatic Architecture

Despite the harshness of the arid climate of San Juan, the city has optimal climatic conditions for its use in the design of passive conditioning systems. In this regard, the statistics of the urban climate in the period 1995-2010 throws the following seasonal average values (Ortega *et al*, 2013): Global Solar Radiation: Summer 614.96W/m^2, Winter 349.92W/m^2; South Wind Frequency: Summer 64.89 %, Winter 47.90 %; Dry Bulb Temperature: Summer 32.59 °C, Winter 13.35 °C; Relative Humidity: Summer 41.40 %,

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Winter 41.90 %. The data show that for both seasons, the use of resources set up a very workable strategy: in summer, with high radiation and high temperatures, is also high the amount of hours a day in which blows the fresh wind of the southern quadrant with low relative humidity. In winter, with lower temperatures, remain an important global solar radiation and the frequency of winds from the South decreases markedly.

2.5 Structure by Use of the residential energy consumption in Argentina.

In Argentina, the residential sector consumed 9,890 ktep (1 tep: equivalent oil ton.) which accounted 21.8% of the total final consumption of energy in the country in 2004 (Ministry of economy, *op. cit*). The consumption in the same year differentiated by source was: Natural Gas: 61.9%; Electricity: 19.6%; Liquefied Gas: 13.3%; Vegetal Carbon: 2.2%; Kerosene: 1.4%; Wood: 1.0%; Wind: 0.6%. This indicates that the Natural Gas, Electricity and Liquefied Gas, totalize 95% of residential consumption. Of the above values, 92.2% correspond to urban households. According to the same source, in a "trend" scenario, i.e. without explicit policies of structural changes, the 2015 projection indicates that consumption will grow to 20,854 ktep. On the contrary, the increase would be 16,329 ktep in a "structural" scenario, i.e. adopting dispositions of UEE (efficient use of energy), to promote sustainability. Therefore, there would be savings of 21.7% compared with the "trend" scenario. The national energy Balance for 2012 (Secretaría de Energía de la Nación R.A., 2013) threw that the residential sector in Argentina consumed per type of energy (in miles of tep): Primary energy: Wood 0.003, Other primary 0.007; Secondary energy: Electricity 0.25, Natural Gas 0.63, Liquefied Gas 0.07, Vegetal Carbon 0.02, and Kerosene 0.03. Considering only electricity and Gas in the residential consumption, the values are: Electricity 0.32, Natural Gas 0.90, Network Gas 0.44, and Liquefied Gas 0.46.

2.6 Energy consumption in the Metropolitan Area of San Juan

a) Consumption of Electric Energy: Statistics 2013 from the company that provides the service of electrical energy in the AMSJ (Energía San Juan, 2014), breaks down the consumption, as follows: Annual province consumption: 1,748,189 Mwh; Annual residential consumption: 789,612 Mwh; Residential Users: 183,775 Users. For the AMSJ; Annual consumption: 1,586,044 Mwh; Annual residential consumption: 728,691 Mwh; Residential Users: 169,346.

b) Natural/liquefied Gas consumption: Distribuidora de Gas Cuyana S.A. 2011 statistics (Ecogas 2012), indicates that the annual volume of natural gas consumption in the residential sector was 92,828,040m^3. The Capital Department, totalized a consumption of 30,968,672m^3 corresponding to 34% of the total. In relation to the percentage consumption (Ecogas, 2014), the residential sector constituted in 2013 the 31.4% of the total delivered. According to the same source, the number of residential customers in the AMSJ with natural gas totalized 94,025 users.

2.7 Spatial distribution of the residential energy consumption in the AMSJ

A consumption survey was performed over homes located in 64 areas of the AMSJ. These areas were located in 64 urban nodes located in the AMSJ along the 16 main cardinal directions according to a geometrical-mathematic method (Papparelli *et al*, 2009). This method allows a representative sampling of the urban area through urban areas having

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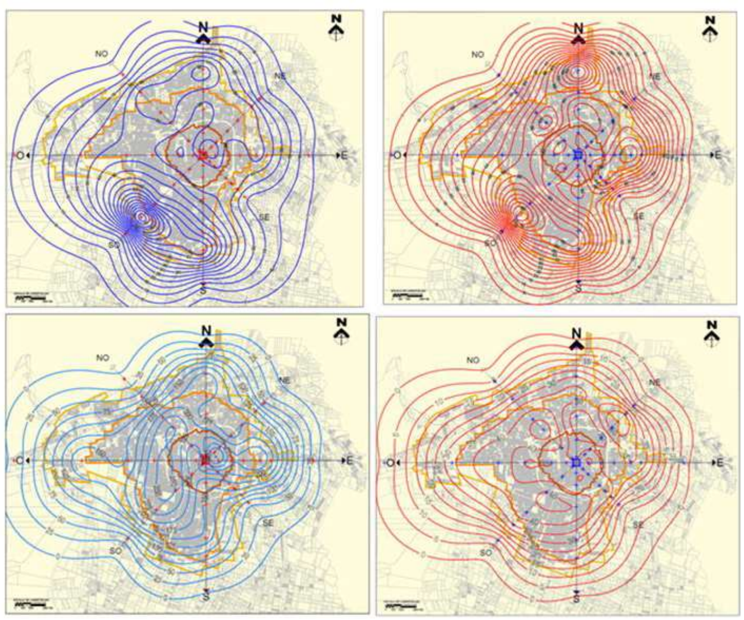
different urban index, randomly identified. According to the bioclimatic strategies for the city (Kurbán *et al*, 2013), July is the winter colder month and December the summer warmest one. Therefore, the survey collected information from both months as representative of the most extreme and rigorous by the arid climate seasons. For each urban node 2 samples were considered relieving consumption of electric energy (KWh), liquefied and natural gas (Kg or m^3).

The data were geo-referenced ("x" and "y" coordinates) to the centre of the city (25 of May square). The "z" coordinates corresponded to the value of energy consumption. To transform into continuous, the punctual information concerning each variable, a software that sits a soft surface on a grid of values x, y and z was used, and a three-dimensional model was performed. Horizontal cuts to the models at a convenient equidistance were made to obtain representative curves or isolines. Figure 2 shows the isolines of EE (Electric Energy) and Gas consumption per dwelling, in the AMSJ for winter and summer, overlapped to the cadaster of the city, with the three BUCs: predominantly urban, urban and suburban.

Figure 2. Winter (top) and summer (bottom)electric energy (left) and gas consumption (right). (Source: own elaboration)



Analysing the distribution of energy consumption for housing, according to the Urban Characteristic Bands, the averages per dwelling, according to each band were (Table 1):

Table 1. Energy consumption per dwelling and per BUC – AMSJ (Own elaboration)

BUC	Gas (m^3)		Electric Energy (KWh)	
	Summer	Winter	Summer	Winter
EU	41	231	409	260
UR	37	185	516	309
SU	20	104	424	292

2.8 Passive and Active Strategies of Bioclimatic Architecture

Using the temperature and relative humidity of the urban climate of the AMSJ for the same year in which there were developed the surveys of energy consumption (2013), the

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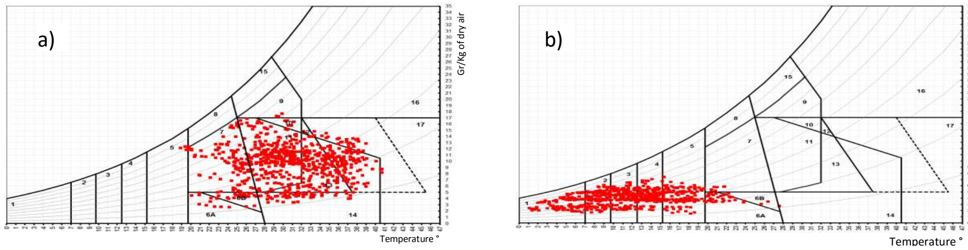
strategies of bioclimatic design were calculated applying the numerical-graphic method of Donald Watson (1983) through an analytic-mathematician adaptation of Mario Cúnsulo (Kurbán *et al*, 2014). (Figure 3).

Figure 3. Building bioclimatic Chart for AMSJ 2013: a) Dec.; b) Jul. (Source: Development on own statistics)



In Table 2 are shown the hours corresponding to each design strategy, calculated for the four seasons.

Table 2. Annual hours of bioclimatic design strategies by season in the AMSJ - year 2013. (Own elaboration)

	PASSIVE STRATEGIES				ACTIVE STRATEGIES						COMFORT		YEAR TOTAL	
Season	Hs of Passive Heating	Hs of Passive Cooling	% Hours of Passive Heating	% Hours of Passive Cooling	Hs of Active Heating	Hs of Active Cooling	% Hs of Active Heating	% Hs of Active Cooling	Hs of Mechanical Humidification	% Hs of Mechanical Humidification	Hs of Comfort	% Hs of Comfort	Annual Hs	% Annual Hs
Summer	43	838	**2.0**	**38.7**	0	639	**0.0**	**29.5**	48	**2.2**	596	**27.6**	2164	100
Fall	921	354	**41.3**	**15.9**	2	40	**0.1**	**1.8**	47	**2.1**	866	**38.8**	2230	100
Winter	1,684	34	**75.8**	**1.5**	198	0	**8.9**	**0.0**	253	**11.4**	54	**2.4**	2223	100
Spring	770	403	**35.3**	**18.4**	65	169	**3.0**	**7.7**	277	**12.7**	500	**22.9**	2184	100

2.8.1 Scenario 1(a): Structure of annual energy consumption for building thermal conditioning, in the Metropolitan Area of San Juan

The consumption was calculated from 2 types of data survey (Kurbán *et al*, 2015a): type and power of the appliance, and consumption checked for July, September and December. The universe studied consisted of 7 houses of similar technology and located at the different BUCs. The occupants varied from 1 to 6 people. The percentages of conventional energy used in thermal conditioning in such months, considered as scenario1, were: Heating: Natural/Liquefied Gas: 48%; Electric Energy: 42%; Cooling: 59%.

2.8.2 Scenario 1(b): Structure of seasonal energy consumption for building thermal conditioning, by BUC and season.

The relieved data consumption for summer and winter, were weighted according to the structure of energy consumption for thermal conditioning. These values were weighted with the percentages of monthly total bioclimatic strategies (active and passive, Table 2), obtaining the values of monthly energy consumption per dwelling for thermal conditioning, without bioclimatic principles. The results are shown in Table 3.

2.8.3 Scenario 2: Energy consumption of the AMSJ with bioclimatic design.

Processing the values of Table 3, with the percentages of annual hours of passive strategies (Table 2), the amount of gas and electricity that would be used if the architecture of the houses would have considered bioclimatic design strategies was calculated. This situation is called Scenario 2. The structures of consumption for this new scenario are shown in Table 4 and Table 5.

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Table 3. Scenario 1: without using bioclimatic architecture. Energy consumption by dwelling for each BUC, to get thermal conditioning in the AMSJ. (Own elaboration)

BUC	Season	Heating		Cooling	Total EE
		Gas (m³)	EE (KWh)	EE (KWh)	(KWh)
EU	Summer	7	7	610	617
	Fall	148	146	175	320
	Winter	281	277	113	390
	Spring	126	124	318	443
	Annual	562	554	1,216	1,770
UR	Summer	6	9	769	778
	Fall	118	173	220	393
	Winter	225	329	143	472
	Spring	101	148	402	549
	Annual	450	659	1,534	2,192
SU	Summer	3	8	632	640
	Fall	67	163	181	344
	Winter	127	127	118	244
	Spring	57	139	330	470
	Annual	254	437	1,261	1,698

Table 4. Scenario 2: using bioclimatic architecture. Energy consumption by dwelling

Season	Heating		Cooling
	Gas (m³)	EE (KWh)	EE (KWh)
Summer	1	1	429
Fall	24	19	77
Winter	90	71	133
Spring	35	28	256
Annual	151	118	894

Table 5. Scenario 2: using bioclimatic architecture. Energy seasonal consumption by housing of the AMSJ.

BUC	Season	Heating		Cooling	Total EE
		Gas (m³)	EE (KWh)	EE (KWh)	(KWh)
EU	Summer	7	7	378	385
	Fall	76	75	137	211
	Winter	87	86	111	197
	Spring	72	71	254	326
	Annual	243	239	880	1,119
UR	Summer	6	8	477	485
	Fall	61	89	172	261
	Winter	70	102	140	242
	Spring	58	85	321	406
	Annual	194	284	1,110	1,394
SU	Summer	3	8	392	400
	Fall	34	84	142	226
	Winter	39	96	115	212
	Spring	33	80	264	344
	Annual	109	268	912	1,181

2.9 Savings in the energy consumption of housing for annual and seasonal thermal conditioning in the AMSJ, using Bioclimatic Architecture.

From the Seasonal consumption in thermal conditioning in the city of San Juan and each Urban Characteristic Band, without taking into account design strategies bioclimatic and considering that housing have been designed bioclimatically, arise the following values of energy savings (Table 6: for the whole AMSJ and Table 7: by BUC).

3. RESULTS

The annual percentage of hours, in summer and winter seasons, for each bioclimatic architecture strategy, resulted:

Annual: HEATING 41.8%: Active 3.02%, Passive 38.78%; COMFORT 22.97%; COOLING: 35.23%: Active 18.44%, Passive 16.79%.

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Winter: HEATING 84.98%: Active 9.01%, Passive 75.97%; COMFORT 2.46%; PASSIVE COOLING 1.55%; ACTIVE HUMIDIFICATION 11.02%.

Summer: HEATING 1.99%: Active 0.00%, Passive 1.99%; COMFORT 27.54%; PASSIVE COOLING 38.72%; ACTIVE COOLING AND HUMIDIFICATION 31.75%.

Spring: HEATING 38.23%; Active 2.98%; Passive 35.26%; COMFORT 22.89; PASSIVE COOLING 18.45%; ACTIVE COOLING AND HUMIDIFICATION 29.42%

Fall: HEATING 41.39%; Active 0.09%; Passive 41.30%; COMFORT38.83%; PASSIVE COOLING 15.87%; ACTIVE COOLING AND HUMIDIFICATION 3.90%

The current values for total energy consumption per year, used for thermal conditioning of a house in the AMSJ, without using principles of bioclimatic architecture and the calculated according to the bioclimatic design strategies, if applied, were:

- Without Bioclimatic Architecture: Gas 933 m^3; Electric Energy 2283KWh
- With Bioclimatic Architecture: Gas 151m^3; Electric Energy 1013KWh

The above values show that the percentages of each type of energy savings, if homes were been designed following bioclimatic principles, result: Gas = 84%; EE = 56%.

Table 6. Seasonal and annual energy savings in the AMSJ using Bioclimatic Architecture. (Own elaboration)

Season	Heating		Cooling
	Gas (m^3)	EE (KWh)	EE (KWh)
Summer	11	9	350
Fall	221	173	146
Winter	376	295	12
Spring	174	136	151
Annual	782	613	658

Table 7. Annual and seasonal energy savings by BUC using Bioclimatic Architecture. (Own elaboration)

BUC	Season	Heating		Total EE	Cooling
		Gas (m^3)	EE (KWh)	EE (KWh)	(KWh)
EU	Summer	7	7	378	385
	Fall	76	75	137	211
	Winter	87	86	111	197
	Spring	72	71	254	326
	Annual	243	239	880	1,119
UR	Summer	6	8	477	485
	Fall	61	89	172	261
	Winter	70	102	140	242
	Spring	58	85	321	406
	Annual	194	284	1,110	1,394
SU	Summer	3	8	392	400
	Fall	34	84	142	226
	Winter	39	96	115	212
	Spring	33	80	264	344
	Annual	109	268	912	1,181

4. CONCLUSIONS

The study of the energy consumption for thermal conditioning of houses in a city of arid zone, such as the San Juan Metropolitan Area, indicates that during the winter, about half of the electric energy and Natural/Liquefied Gas is destined to such use. During the summer, that percentage amounts to 60% of the total electric energy consumption.

The savings in electric energy for conditioning of dwellings if bioclimatically designed would be 84% in winter and 46% in summer. In the case of the Natural/Liquefied Gas, the savings would reach 84%.

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Considering that the San Juan Metropolitan Area represents 0.14% of the provincial territory (127Km^2 of 89,651 Km^2) and has 67% of the total population of the province (458,230 inhabitants of 681,055 inhabitants) (Papparelli *et al*, 2015c), the contribution to the residential energy savings that would provide the use of bioclimatic architecture, would be highly significant.

If such energy savings were extrapolated to cities with similar urban conditions than San Juan located in arid meso-thermal and warm zones, the contribution that would be made to energy self-sufficiency, using bioclimatic architecture in their respective urban housing parks would be substantial.

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