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Energy-use modelling for residential buildings in the metropolitan area of Gran Mendoza (AR)

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ABSTRACT

Most of the world's population is concentrated in cities and there is necessary to intervene in the management of energy consumptions to ensure a high quality of people life with good air quality and thermal comfort and an overall livability of the urban environment. Anthropic activities are the main cause of greenhouse gas emissions and this suggests the need of a different management of energy consumptions especially of buildings, one of the principal contributor of GHG emissions.
The goal of this work is the evaluation of a simplified energy model that allows quantifying the spatial distribution of energy consumption at urban scale with a GIS tool. The case study is the metropolitan area of Gran Mendoza, an urban conglomerate comprising six *departamentos* in the central-western region of Argentina. The model estimates the energy consumption for space heating of residential buildings, after having classified the buildings according to their characteristics. This simplified model has been validated by the comparison with the real consumption data provided by the local company distributing natural gas. With this model, it is possible to elaborate energy strategies based on the real buildings heritage, identifying critical areas requiring a priority of intervention.

1. INTRODUCTION

The fifth assessment report of Intergovernmental Panel on Climate Change (IPCC) [1] shows that the temperature of the Earth can increase between 1.4 °C and 5.8 °C due to the high concentration of greenhouse gases (GHG) in the atmosphere, which is mainly an effect of anthropogenic activities. Among anthropogenic causes, mainly there is an increase in urban population, which leads to a strong expansion of the cities, especially in developing countries. Considering that since the year 2007 half of the world population resides in urban centers, globally the city has become the main cause of GHG emissions. In particular, the urban population is 54% of the world population and is expected to reach 66% in 2050 [2]; in particular, the urban population of Latin America represents 80% in 2014, while is 73% in Europe.

The most human activities are concentrated in cities, therefore these are a container on one hand of opportunities, on the other hand of critical issues, as the high impact on the environment. In fact, there is the need to act and plan over the medium-long term at international, national and local level, in order to determine valid strategies for: the reduction of GHG emissions, the optimization of the exploitation of energy resources, the evaluation of the economic impact of different energy systems to guaranty energy security for all population. The predictive energy models allow an analysis on a low-medium-long term, considering different scenarios and become important tools, as well as valid scientific analyses, also to determine and justify energy policies and actions in the decision-making field.

Specifically, this work deals with energy consumption of the residential sector due to space heating. Energy consumption was investigated for all the metropolitan city of Mendoza assuming that it varies according to the specific characteristics of buildings, population and neighborhoods.

The analysis conducted in this work starts from a previous research on the adoption of GIS-based assessment to evaluate buildings energy consumption at territorial scale [3-6].

After this introduction, paragraph 2 describes the energy situation in Argentina and paragraph 3 illustrates the case study of Mendoza and the used data collection. The approach of this work is explained in detail in paragraph 4 and the results are reported in paragraph 5. The discussion on the results is explained in paragraph 6 and the conclusions in paragraph 7.

2. ENERGY OVERVIEW OF ARGENTINA AND MENDOZA

The incorporation of renewable energies is a topic of global interest. China remains the main destination for clean energy projects (32%), followed by Europe (25%), the United States (19%), Asia and Oceania (excluding China and India, 11%), the Americas (6%), the Middle East (3%) and Africa (3%) [7-8].

In recent years, investments in clean energy have come from emerging states (China, India and Brazil), of the total added (2015), 46.5% was photovoltaic solar energy, 34.1% wind and 15.5% hydro, 4% biomass, biofuels, geothermal and thermosolar. A global investment slowdown occurred during 2016 [9]. In this context, within Latin America and the Caribbean the countries with the highest investments in renewable energies were Brazil, Mexico, Uruguay and Chile (the leader in solar energy in the subcontinent), followed by Honduras, Peru and Costa Rica [10].

In Argentina, renewable sources account for 1.9% of installed power [11], with an energy problem that worsened in 2011, when the country ceased to be an energy exporter and began to import it. In 2015, Law 27.191 [12] promoted the electricity generation from renewable sources, setting the goal of achieving 8% clean energy generation by the end of 2017 (postponed until 2018) and 20% by the end of 2025.

Oil and natural gas depict 85% on the primary energy matrix, while the rest of the sources (coal, hydropower, nuclear and others) share the remaining 15%. Thermoelectric plants supplied mainly by natural gas and to a lesser extent by diesel oil and fuel oil account for 60% of electricity generation, while hydroelectric and nuclear power plants do it for 31% and 9% respectively [13-14]. Therefore, Argentina is a very vulnerable country as it has an extremely unbalanced energy matrix and depending on hydrocarbons, having 0.3% of the world's oil reserves, 0.4% of natural gas reserves and 0.3% of coal reserves.

In Mendoza, the current energy system is mostly made up of the intensive use of fossil fuels, with harmful impacts on the environment so reduction of energy consumption and its progressive replacement by renewable energies is imperative. Excluding "own consumption" (energy consumption in hydrocarbon fields, refineries, and others and "non-energy consumption" (petroleum products not used as energy sources - oils, solvents, etc.), in the provincial full energy consumption, industry stands out explaining around 37.66% and residential sector is in second place with 30.97%; it is followed by transport sector with 16.39%, rural productive and services sectors show a lower participation of 10% with an efficiency of 55.6%, which means that almost half on consumed energy shows transformation, transportation, distribution and use losses.

Of the 100 % of the energy used in the domestic urban building sector, 37.8 % of the consumption corresponds to heating and 30.8 % to water heating, 6.5 % to food preservation, 9.3 % to food cooking, 9.3 % to refrigeration and ventilation, 0.7 % to lighting, 0.2 % and finally 11.7 % to other appliances (including water pumping and domestic motors) [15-17].

Regarding to the main source of consumption in urban domestic sector, the greatest value corresponds to natural gas distributed by network, which represents 67.7% of full sector consumption, followed in order of importance by electricity with 22.6% and liquefied gas with 7.2%. Input from other sources is practically marginal.

The largest uses of distributed gas are in heating (48% of the total), water heating (42%) and cooking (10%). Under these two conditions -heating and water heating- account for 90 % of full consumption of sources. In the residential zone on Metropolitan Area of Mendoza (AMM), predominant technology for space heating and water heating is based on natural gas [16, 18].

In this area there is great potential for solar energy development as an alternative source of energy since it has an average annual global solar radiation of 18.06 MJ/m^2 per day with a uniform distribution.

3. THE METROPOLITAN AREA OF GRAN MENDOZA (AR)

Mendoza is a city in Argentina located in the central West of the country and, together with the neighboring municipalities (*departamentos*) of Las Heras, Guaymallén, Maipú, Godoy Cruz and Luján de Cuyo, form the fourth largest conurbation of the Gran Mendoza with a population of 1,086,633 inhabitants [18]. The metropolitan city, is located at 827 m a.s.l. near the Andes Mountains and surrounded by desert on the other three cardinal directions; Mendoza seems like an oasis, thanks to the artificial irrigation system, originally created by the Inca people [20].

3.1 Georeferenced data collection

The energy consumption model for the Gran Mendoza urban area was developed with the use of three different databases.

The GIS database contains buildings information from the cadaster, referring to the year 2010, partially updated to the year 2012 (for Capital and Guaymallen); the data concerned both the volumetric units and the cadastral parcels. At the parcel level, the land use was known, so it was possible to recognize single-family houses, multi-family houses and condominiums; while in the volumetric unit there were indications about the number of floors, the area and the volume (assuming an average height per floor).

The second database consisted of census data referred to the year 2010 [21]. The information were collected for census section and grouped into three categories: population, family unit and housing.

The consumption of natural gas was provided by the local distribution company and referred to each *departamentos* of the Mendoza metropolitan area. The data referred to the 2010-2015 time frame were classified according to the type of use; in this work, only the quantity of gas for space heating of domestic sector was considered (in Figure 1). In Mendoza the heating season includes the months from April to October and the indoor comfort temperature is of 18 °C.

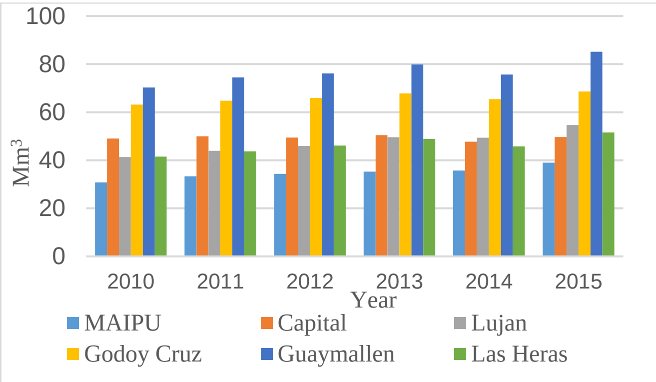

Figure 1. Natural gas consumptions for the 6 *departamentos* in the Metropolitan Area of Gran Mendoza

The Mendoza metropolitan area is served by the Ecogas company which distributes natural gas in the network on behalf of the company "Distribudora de gas Cuyana", on the provinces of Mendoza, San Luis and San Juan. Natural gas is distributed in the network with a lower calorific power of 10.81 kWh/m^3.

It was essential to converge the information on the three levels of scale (building, census section and district) for the creation of the model, then the common year 2010 was chosen as a reference year. The GIS-based assessment was also used for data adjustment and then the census section was considered as a reference territorial unit, adequate both for urban scale analysis and for data management of different type of buildings, population and surrounding context.

3.2 The climate in Gran Mendoza

The Metropolitan Area of Gran Mendoza is located in an arid region with intense solar irradiation, very wide air temperature amplitude and scarce rainfall.

In particular, the summers are hot with an average air temperature above 25 °C and the winters are cold and dry with temperature values below 8 °C. The climate of the city is strongly influenced by open-air irrigation channels allowing the presence of trees along all the roads; this affects the microclimate especially during the summer, making tolerable even the hottest hours of the day.

To evaluate the climate, the data of three weather stations in the metropolitan area of Mendoza have been collected for the years 2006-2016 [19]. The weather stations are located in the three suburbs areas and at different altitudes, with a temperature trend with differences up to 4 °C (in Figure 2).

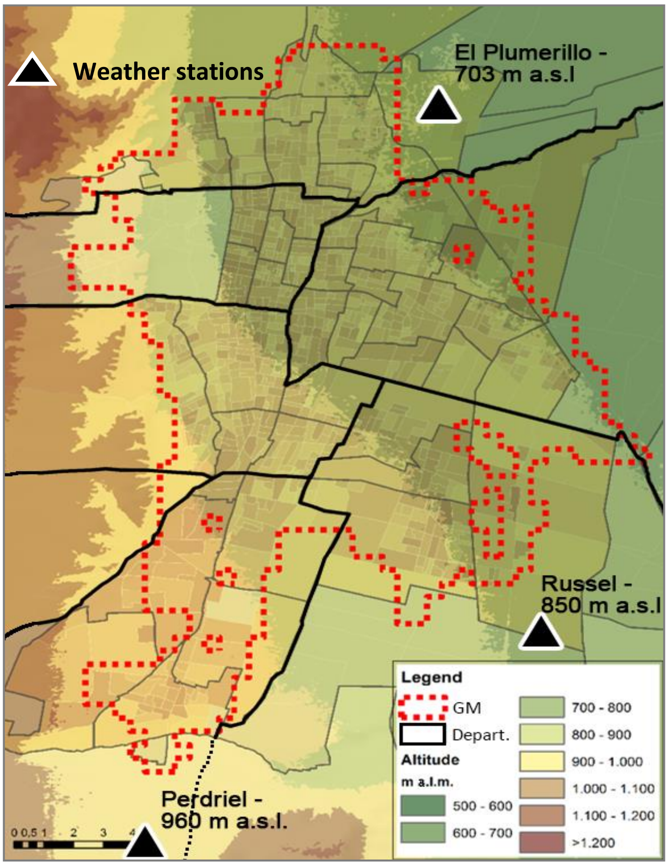

Figure 2. Weather stations in the metropolitan city of Gran Mendoza

In Table 1 the outdoor air temperatures and the HDDs at 18°C registered by the 3 weather stations are reported for the reference year 2010. As it is possible to observe, there is a difference in altitude up to 257 m.

To evaluate the energy consumption for space heating, each *departamento* has been assigned to the nearest weather station with similar altitude and differences in altitude have been taken into account.

Table 1. Air temperatures registered by the weather stations in Mendoza in the reference year 2010

	Altitude m a.s.l.	Tmean (°C)	Tmax (°C)	Tmin (°C)	HDD at 18°C in 2010
El Plumerillo (aeropuerto)	703	17.6	26.1	8.5	1171
Perdriel	960	14.0	22.6	4.8	1925
Russel	850	16.0	24.7	6.8	1540

4. MATERIALS AND METHODS

The introduction and the description of the energy system in Argentina and Mendoza indicate how it is necessary to intervene in the management of energy consumption to ensure the citizen a high level of quality of life related to air quality, thermal comfort and livability of the urban environment, where most of the world's population is concentrated.

The goal of the work is the application of an energy GIS-based assessment at urban scale that allows to quantify the energy consumption of the city. The proposed methodology estimates the energy consumption necessary for space heating of residential buildings, after having classified them according to their main characteristics in homogeneous groups and is validated by the comparison with the real consumptions provided by the local company that distributes natural gas. The results will identify the specific average consumption of the different types of residential buildings for the entire metropolitan area of Mendoza using a top-down model combined with a GIS-based assessment. From the model, it is possible to have an urban framework of the distribution of energy consumption and make assessments at urban scale, starting from the awareness of the cause of high consumptions on a specific area.

4.1 Analysis of the built environment

In this study a top-down model is applied starting from the energy consumptions at district scale, to obtain average consumptions of the census sections and then to evaluate simplified models of specific energy consumption for the different typologies of building to be applied at urban scale.

The Grand Mendoza and its six *departamentos* (Capital, Godoy Cruz, Guaymallen, Las Heras, Lujan de Cuyo and Maipù, in Figure 2) were represented with a GIS tool though a technical map and the heated volumes of buildings were compared with data of the census database with the identification of heated and non-heated volumes. This analysis has also allowed to analyze the built heritage that characterizes the different areas of Mendoza and its socio-economic differences. The analysis of the different areas of Mendoza has shown that some types of buildings are recurrent and then the different areas were listed and analyzed together with the main features that can affect the consumption of energy.

In the study area, four types of recurrent buildings were identified and for each one the percentage of heated volume was identified; the types of residential buildings are condominiums, condominiums with commercial activities on the ground floor, detached house, detached house with commercial activity.

Starting from the information of the blocks of buildings (census sections), a sample of types of blocks of buildings were identified according the recurring characteristics in order to obtain homogeneous situations as much as possible within the city; a tree scheme (Figure 3) was followed starting from the predominantly residential building typology. The first distinction is based on the prevalent type of residential building (detached house or condominium). The condominium sections were divided into "Entirely residential" or "Mixed", based on the percentage of commercial area within the condominium building compared to the actual residential area. However, the most sections have predominance of detached houses; to this category belong three sub-groups: central, peripheral and rural. The central sections are homogeneous with respect to the quality of the materials; this is one of the important energy variables useful for classifying buildings related to the thermal properties of their materials.

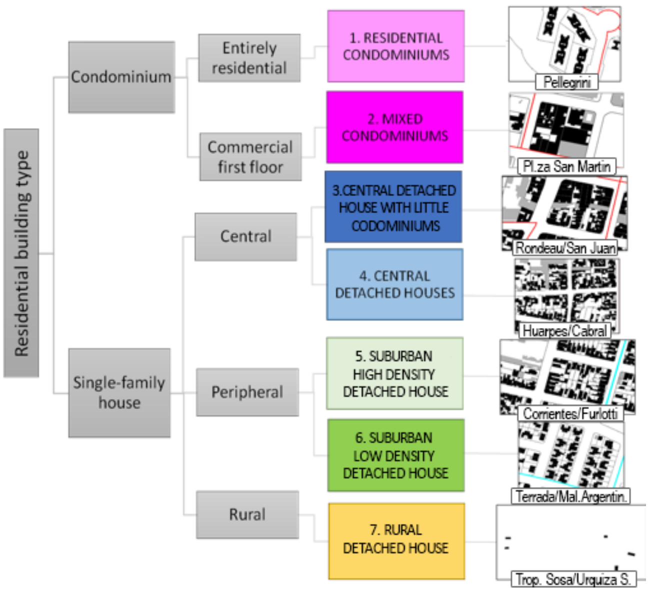

Figure 3. Recurrent groups of residential buildings

Specifically, the census database divided the buildings into four groups with respect to the quality of the materials (QM) and the level of finishing of the envelope:

QM1: resistant and solid materials with walls with an inner lining;

QM2: resistant and solid materials but without internal lining on walls or low quality of the floor;

QM3: low-quality materials for roof and floor;

QM4: very low quality materials.

The central sections all have a clear predominance of high class quality housing. From the point of view of the building typology they are the least homogeneous; within these there are a not negligible percentage of condominiums, for which they were further subdivided according to the prevalence of housing in an apartment or in an independent house.

The peripheral sections are uneven with respect to the quality of the materials present, but are homogeneous with the type of buildings as they all have high percentages of detached houses. The distinction within this category takes into account the relationship between the built-up area on the ground with the building coverage ratio (BCR) with low and high-density areas [22]. The limit value of BCR was set at 0.25 m^2/m^2, identified with respect to the statistical distribution of the data. Finally, the single-family rural houses were identified with respect to the extension of the section and are characterized by the single-family houses called "ranch".

Then, seven homogeneous recurrent groups of buildings were identified with respect to their characteristics.

Parallel to these physical characteristics of the city, there are also the socio-economic characteristics of population, as can be seen from Table 2. For example, the surface of the apartments and the number of occupants have an opposite trend, which indicates a situation of more poverty in the buildings groups 6 and 7; also the greater percentage of low-quality materials or the unemployment rate are indicators of the socio-economic factors of an area of the city.

Table 2 summarizes the characteristics for each group of buildings. As it is possible to observe the recurrent groups of buildings are very different as family size, house geometrical form (i.e. S/V), floor dimensions, percentage of commercial space, quality of construction materials, percentage of unemployed people, percentage of old people but also buildings density, buildings coverage ratio and height of buildings.

Table 2. Characteristics of the seven recurrent groups of residential building

Group	1	2	3	4	5	6	7
n. sections	49	9	48	213	317	418	7
persons/family	2.51	2.42	2.76	3.09	3.36	3.95	4.00
heated volume, %	632	50.7	72.8	84.1	89.8	89.0	86.1
S/V, m^{-1}	0.57	0.53	0.65	0.70	0.73	0.75	-
floor surface, m^2	120.8	133.1	80.3	70.3	47.6	40.7	-
commercial surface, %	3.4	12.2	2.2	1.3	1.6	0.3	0.0
QM_1 , %	85.4	81.3	84.7	85.6	66.5	48.1	22.6
QM_2 , %	13.6	18.1	13.5	12.2	26.5	38.6	37.0
QM_3 , %	0.9	0.6	0.9	0.9	1.9	4.4	5.7
QM_4 , %	0.1	0.0	0.9	1.4	5.0	8.6	34.7
unemployment rate, %	3	2	3	3	4	4	12
over 65 years, %	18	21	16	15	14	7	6
building height, m	11.3	14.4	6.4	4.0	3.4	3.1	-
buildings coverage ratio, m^2/m^2	0.36	0.48	0.32	0.31	0.33	0.10	<0.01
buildings density, m^3/m^2	2.4	3.9	1.4	1.1	1.1	0.3	<0.1

4.2 Analysis of energy consumption and climate data

The main variable influencing the energy consumption is the outdoor air temperature and its relative value of heating degree days (HDD). Then for each weather station, the HDD at 18°C has been calculated and also the altitudes differences of the various areas in Gran Mendoza areas (from a minimum of about 650 to a maximum of about 930 m a.s.l.). In particular, from the temperatures registered by the weather stations, a correction factor "d" was evaluated to consider the altitude differences of 1/105 °C/m in the evaluation of the HDD.

The average elevation of each district and census section was derived from the DTM (Digital Terrain Model), limited to the built area; the built area was obtained from satellite images, catching the urban area based on light pollution.

The average altitude for the urban area is 777 m a.s.l. and the HDD are those of the nearest meteorological station with similar altitude. Therefore, for every census section the average altitude was evaluated calculating the relative air temperature, HDD and consequently space heating energy consumption (in Figure 4). The factors that determine a low energy consumption for the *departamentos* of Capital and Godoy Cruz can be traced back to three. Firstly, both of them are characterized by apartments and therefore the prevailing buildings type is condominium (with a lower surface to volume ratio). Then, the prevalence of the buildings is built with good quality materials, completed with the finishes, and this allows a lower heat dispersion. Finally, over these years 2010-15, both *departamentos* have a limited buildings expansion because they are in the center of the metropolitan area.

The simplified energy model of residential buildings was then normalized with the altitude considering the reference year 2010, in order to depend only on the characteristics of the buildings, population and the urban context.

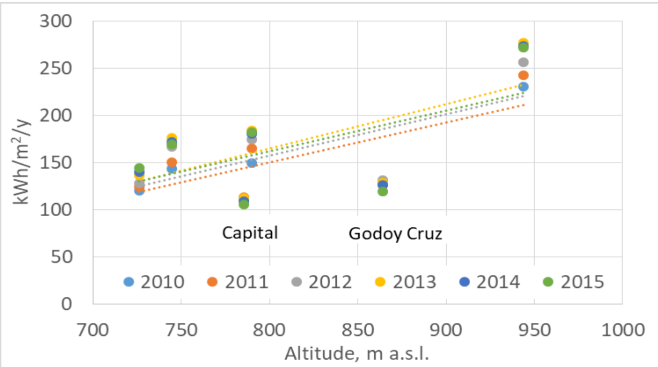

Figure 4. Altitude and specific annual energy consumption kWh/m^2/y by *departamentos*

4.3 Top-down model

The annual specific consumption (kWh/m²/y) was calculated from the districts consumption, through the number of users of natural gas and the evaluation of the heated volumes and the heated floors.

From the analysis of the built environment, the recurrent blocks of buildings typologies were subdivided in 7 homogeneous groups, in order to define the energy consumption classes. From the analysis of recurrent building typologies, the main following parameters have been considered for the energy consumption classes: the type of building, the quality of construction materials, the shape of buildings (with the surface to volume ratio S/V), the residential density but also the urban context conditions such as buildings density and solar exposition.

The energy classes were also subdivided as a function of the average value and standard deviation of S/V for every census section:

- S/V_1: 0.64- 0.33 m^2/m^3
- S/V_2: 0.64-0.72 m^2/m^3
- S/V_3: 0.72-0.80 m^2/m^3
- S/V_4: 0.80-1.29 m^2/m^3.

For condominiums, a further the class of S/Vc was considered with an average value of 0.58 m^2/m^3.

The residential density was calculated as the number of families on heated square meters for each census section; considering the different building typologies in Mendoza, three density classes were obtained: D1 <0.01 fam/m^2, D2 0.01-0.03 fam/m^2 and D3 >0.03 fam/m^2. This parameter was used to differentiate particular areas with higher consumptions and critical socio-economic conditions; in fact, a greater crowding of the sections leads to greater consumptions.

Then, loading the technical map of Gran Mendoza with a GIS tool, the specific energy consumption was evaluated with an iterative calculation for each group of buildings until the energy consumption of all districts was equal to the measured energy consumption data. This iterative calculation started from the districts with only a single group of buildings, then with districts with two groups and so on.

The characteristics of energy classes found in this analysis are illustrated in Table 3.

Table 3. Energy performance classes (EPC) for Condominiums "C" and Detached Houses "DH" (*prevalent)

EP class	Type of dwelling *	Quality of materials *	Surface to volume ratio	Residential density	N° of census sections
A	C	QM_1	S/V_c	D_1*	56
B	DH	QM_1	S/V_1	$D_{1\&2}$	58
C	DH	QM_1	S/V_2	$D_{1\&2}$	314
D	DH	QM_1	S/V_3	$D_{1\&2}$	352
E	DH	QM_1	S/V_4	$D_{1\&2}$	39
F	DH	QM_1	S/V_3*	D_3	19
G	DH	QM_2	S/V_3*	$D_{1\&2}$	95
H	DH	QM_2	S/V_4*	D_3	31
I	DH	$QM_{3\&4}$	S/V_4*	$D_{1\&2}$	15

4.4 Buildings inventory

The information collected for each census section was reported in an inventory; the data sheet of each section was divided into three parts. The upper part shows the identifier and the name of the section (represented by the name of the roads that cross it) and the energy class. The first part shows the general characteristics of the section; in the second part there are the data describing the urban configuration and in the third part the energy characteristics and the energy class. Finally, the annual consumption of gas in real and normalized kWh.

Energy consumption was calculated on the year 2010 because census database and the GIS cartography belong to the year 2010. Finally, in the lower part of the data sheet there is a space for notes, where specific information were reported also to identify different buildings in the GIS cartography.

The inventory also reported three images: one satellite imagine of the section, one enlargement of the picture on the block of buildings and another image with the GIS cartography that effectively indicates heated and not-heated spaces.

5. RESULTS

5.1 The built environment of Mendoza

From this analysis, the following 7 typologies of recurrent residential buildings have been identified (in Table 2 and in Figure 3): 1-residential condominiums, 2-mixed condominiums, 3-central detached houses with condominiums, 4-central detached houses, 5-suburban high density detached houses, 6-suburban low density detached houses, 7-rural houses.

As it is possible to observe in Figure 5, the center of the metropolitan city, Capital district, is characterized by apartments and then by condominiums that thin out from the central area until disappearing in the green sections. The recurring type of blocks is composed of single-family houses with one or two floors with their own relevance. The peripheral *departamentos* of Maipù, Lujan de Cuyo and Las Heras are almost entirely composed of single-family houses.

5.2 Energy performance classes and energy consumptions

From the analysis of the different building typologies in the *departamentos*, the 9 energy performance classes shown in Table 4 and Figure 4 have been identified. It can be noted that the energy class A is concentrated in the microcenter of the Capital municipality where the concentration of condominiums is higher (see Figure 5); a few scattered sections of the same typology indicate newly built districts that are entirely residential or mixed (directional centers with commercial and residential activities). Around the micro-center, a very jagged ring of energy class B that mixes with the class C can be recognized; these sections belong in part to the central detached house with the presence of few condominiums and in part to the denser peripheral areas (with building coverage ratio BCR > 0.25 m^2/m^2). The energy class C is lengthened and frayed, mixing with the class D along the north, east and south directions of expansion, with greater intensity in the northern area of Las Heras. Peripheral sections are characterized by higher consumptions with classes F, G, H, I; they are suburban or rural sections, as indicated by the lower density, with the presence of cultivated and uncultivated areas. Classes B and E are less frequent and are scattered throughout the metropolitan area of Mendoza; class B, as already indicated, is mainly present in the central zone around the microcenter, while class E is irregularly located in the periphery of the territory, in both urban and rural sections.

The nine classes can be divided into two groups with respect to the population density, on the basis of which consumption also strongly changes (in Table 4 and Figure 6).

Table 4. Characteristics of the 9 energy performance classes of residential buildings

Energy classes	A	B	C	D	E	F	G	H	I
n.sections	56	58	314	352	39	19	95	31	15
S/V, m^2/m^3	0.59	0.59	0.7	0.75	0.83	0.76	0.79	0.79	0.87
QM_1	0.85	0.81	0.75	0.68	0.63	0.59	0.35	0.3	0.18
QM_2	0.14	0.16	0.19	0.26	0.33	0.32	0.53	0.53	0.28
$QM_{3\&4}$	0.01	0.03	0.05	0.06	0.07	0.09	0.12	0.17	0.53
fam/m^2	0.008	0.009	0.01	0.013	0.016	0.047	0.019	0.047	0.029
kWh/m^2/y	91.1	94.5	115.4	140.0	165.8	472.5	187.9	446.2	363.5

Within the first group (A, B, C, D, E, G), consumption is very consistent with the information of each class. They have a growing trend, with an average value from 91 to 188 kWh/m^2/y and a small standard deviation compared to the second group (F, H, I); therefore, the variation of the data more concentrated around the average is index of more reliable average consumption values. The consumption of the second group is significantly higher and varies between the average values of 364-473 kWh/m^2/y. To these three classes (F, H, I) belongs a limited number of sections, 7%; these are sections in which the prevailing type of building, or rather the only one present, is the single-family house with a surface to volume ratio S/V greater than 0.76 m^2/m^3 and also a number of families much higher than for the other classes (number of families per gross floor of dwelling).

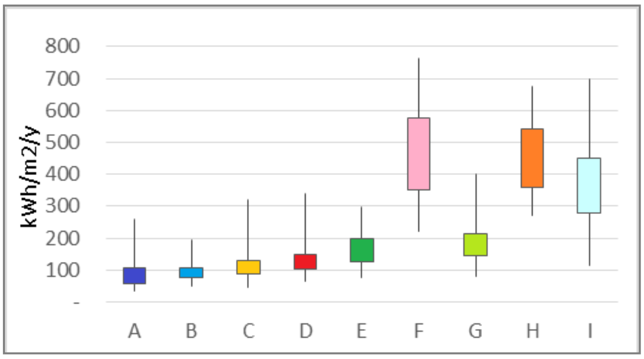

Figure 6. Space heating energy consumption (kWh/m^2/y) for each energy performance class. First quartile, third quartile, minimum value and maximum value for the reference year 2010

6. DISCUSSION

Applying the obtained energy model represented in Figure 6, it is possible to have a spatial representation of energy consumption in the metropolitan area. Furthermore, the causes and the critical issues were highlighted on the basis of which it was possible to elaborate strategies and guidelines for energy efficiency retrofit measures.

6.1 Urban energy consumption

Lower energy consumptions can be observed in the core of the metropolitan area confirming that a more compact urban built environment, characterized by the presence of condominiums, consumes less energy than a low buildings density areas with isolated single-family houses. This statement can however be contradicted by comparing the northern area of the metropolitan area of Las Heras (El Zapallar, El Resguardo, Ciudad LH) with the south of Luján (Chracras de Coria, Mayor Drummond, Vistalba); in the North, buildings density is higher (Figure 5) and, at the same time, higher energy consumptions (Figure 7). It is because of the houses in the South of the metropolitan area, although they are detached houses with very low density, consumes less because the quality of construction materials is better. The hypothesis is consistent with the social information of the individual sections, which show that the municipality of Las Heras has a higher rate of poverty than that of Luján.

Indicative elements derived from the census database are: the dissatisfied basic needs of people, the unemployment rate, and the overcrowding in the dwelling; moreover, in the southern area, there is a higher percentage of second houses (used for holidays or weekends), while the same use is essentially absent in the North.

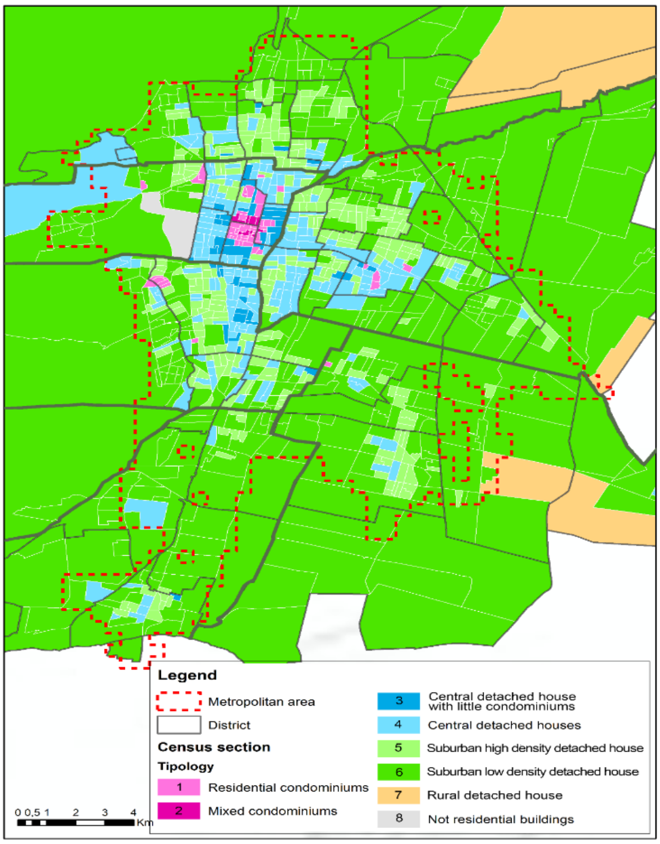

Figure 5. Classification of the built environment in buildings typologies

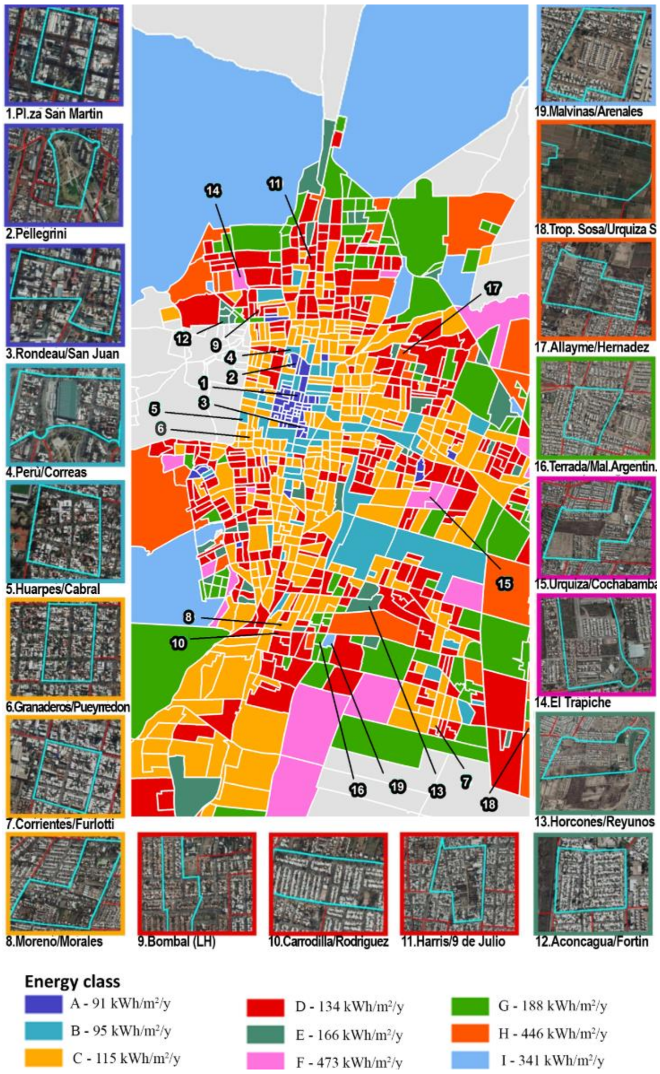

Figure 7. Energy performance classification of blocks of buildings for the year 2010 in Gran Mendoza

The quality of the materials is another considerable factor that influence energy consumptions; there is a correspondence between a good quality of construction materials and a lower consumption of energy, regardless of the position of the section (central or peripheral) and regardless of the buildings density.

Finally, it is possible to add that the peripheral situation (suburban and rural) is the most complex from an energetic point of view and not adequately represented by the typological classification, which tends to homogenize all the sections and flatten the information. To refine the representation and therefore the typological classification, it might be appropriate to better define the limits of the metropolitan area, for example based on the census sections and the population density. Furthermore, could be useful to increase information on the quality of materials throughout the area, to introduce other urban variables and to correlate them in order to obtain information on the configuration of the sections, as well as on the buildings.

Additionally, it might be appropriate to highlight the social discrepancies within the metropolitan area with greater force; in the typological classification, the different characteristics in the low-density typologies for the rich districts and less well-off ones are not effectively distinguished. In addition to the quality of the materials, the same configuration of the districts can vary with respect to the width of the streets, as well as the size of the apartments or the size of the houses; in this regard, urban variables should be included.

For the energy performance classes' map, a classification that takes into account social parameters can provide behavioral information that can be managed in an overall and transversal way, rather than with precise interventions on the single district.

6.2 The identification of critical areas

The energy consumptions for space heating of the residential buildings were compared through the Covey's management matrix with the annual consumptions and the specific annual consumptions for all the census sections in the Metropolitan City of Gran Mendoza. In this area, the average specific consumption was 152 kWh/m^2/y and the average annual consumption was 2719 MWh/y.

Through this graphical method also called "quadrant method", the priority of energy retrofit interventions was defined:

- "important" considering the specific energy consumption or the level of energy efficiency (or of GHG emissions) and
- "urgent" considering the annual energy consumption or the annual costs for space heating.

Then, in the quadrant 1 (top right) the important and urgent items are identified with higher specific energy consumption and higher annual energy consumptions than the average or median values. In the quadrant 3 (top left) there are important, but not urgent items. In the quadrant 2 (bottom right) there are urgent, but unimportant items. Finally, in quadrant 4 (bottom left), unimportant and also not urgent items.

Subsequently, with a cost-benefit analysis, higher specific consumptions were identified and a priority order of interventions were then assigned to every census section (from action 1 to action 4). In Figure 8 the critical sections with a priority of intervention were represented using a GIS tool. Those with higher priority are in peripheral areas, where a low quality of the material has already been observed, more crowded housing, lower urban density, and therefore greater heat dispersion. The south line is only partially highlighted by sections with priority 4; for the urban center five sections are highlighted characterized by single-family houses, but with a presence of condominiums.

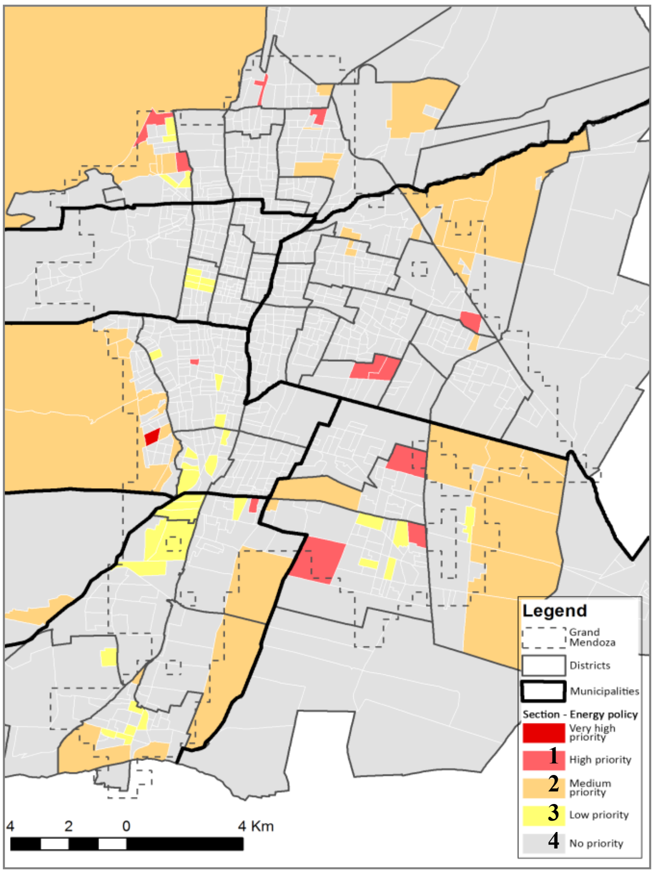

Figure 8. Critical areas with higher energy consumptions and higher priority of intervention

7. CONCLUSIONS

Argentina expects to consolidate into a leading country in the promotion of clean energy generation and to reach a level of renewable energy generation of 20% of the national electricity matrix by 2025. To this end, laws have been enacted: in 2015, for taxes and fiscal benefits (Law N.27,191); and, in December 2017, for the "Regime for the Promotion of Distributed Generation of Renewable Energy Integrated to the Public Electric Network" (Decree 1075). Both are designed to permit producers to inject energy into the national grid. The pending task in this field is to incorporate this complicated legal framework into the urban and building codes in force in the Metropolitan Area of Mendoza (MMA), and throughout the Province of Mendoza.

The results achieved with the work are specific contributions both to this subject and in the understanding of the relationships between urban habitat and energy at the local and regional scale. The produced maps of energy categorization and priority areas of intervention will contribute to the sustainability of local development, making possible in the future: the retrofit of existing buildings; the improvement of habitability conditions; the preservation of the physiognomy of the city; and, the maximum use of the solar resource for space heating, sanitary water heating and photovoltaic generation, through the control of urban morphology.

This top-down and GIS-based assessment was used to create two models of residential buildings in Mendoza that were spatially represented on a GIS cartography: the typological model and the energy model. In particular, the energy model was effective to describe energy consumption on a metropolitan scale. All the information resulting from the two models were collected in a GIS project and in datasheets that summarize the characteristics of the recurrent blocks of buildings, making the information of the maps clear, comparable and easy to update.

Knowing the built heritage and the energy map, specific retrofit interventions can be planned for district or the entire metropolitan area to evaluate the impact of different energy policies, for example combining retrofit interventions with the use of solar collectors and photovoltaic modules.

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