

Evaluation of heating energy consumption patterns in the residential building sector using stepwise selection and multivariate analysis

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ABSTRACT

The aim of the present study is to evaluate historical consumption of natural gas for heating, between 1996 and 2009, in multifamily buildings, using stepwise selection and multivariate analysis. 72 apartments of the capital of the province of La Pampa, Argentina, were studied. Some apartments were previously monitored, thus information about their thermal and energy behaviour is available. There are many variables that could influence the winter energy and annual consumption of the apartments. Based on the characteristics of buildings in Argentina and on previous research, ten variables were selected, from which the most representative ones were selected by using a stepwise method. Then, the apartments were grouped by applying clustering techniques, and the *centroids* for each cluster were determined by averaging the variables that describe the cluster. It was shown that the apartments monitored in previous works, having good thermal behaviour, are close to the *centroids* of the group to which they belong and could be taken as references of their group. The annual heating energy consumption average for the sample is 118.2 kWh/m²/y. However, a significant percentage of apartments showed energy consumptions lower than 70 kWh/m²/y, which is a widely accepted value to define a building as a "low-energy" one. Thus, some apartments could be classified as "low-energy", but for the actual Argentinean Norm they do not qualify even for the worst energy level label. The results make evident a strong disagreement between the Argentinean standard label and the real energy consumption for heating. This fact should be considered as fundamental in order to review the Norm.

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1. Introduction

Energy use plays an important role in building design and operation. Careful and long-term decisions made during the design stage of a building can significantly improve its thermal performance and reduce its energy consumption [1]. Yu et al. [2] claim that the identification and knowledge of the main variables influencing the energy consumption of a building could help to improve construction and energy efficiency while reducing its emissions of greenhouse gases.

Several authors have worked on the assessment of energy consumption and its association with different variables including building geometry and orientation, solar availability, thermal properties of the building materials, level of thermal insulation, etc. Caldera et al. [3], consider that the energy demand of buildings has become a topic of great importance due mainly to the growing interest in energy sustainability, which increased after the enactment of the 2002 European directive. These authors

proposed a methodology that led to establishing simplified correlations between geometric characteristics, thermal and physical variables and energy performance for space heating. They obtained a very good correlation between useful area, solar availability/m² and power consumption. Catalina et al. [4] conclude that there is a close relationship between the shape of a building and its energy consumption, and that a significant reduction of this consumption could be obtained if the building was adequately designed.

In order to promote energy conservation in the residential sector, and to mitigate CO₂ emissions, it is important to examine the residential energy consumption pattern. Biesiot and Noorman [5] studied the consumption of households in the Netherlands; Reinders et al. [6] performed the study for households in the European Union; Cohen et al. [7] described the energy requirements of dwellings in Brazil; Pachauri and Spreng [8] studied the case of India, while Carlsson-Kanyama [9] performed a similar study for Sweden. In Argentina, many authors focussed on the evaluation of residential buildings in order to analyze the thermal – energy behaviour, comfort conditions, energy consumption and Argentinean users/dwellers' behaviour [10–25].

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Argentina has a large variety of climates. IRAM Norm 11603 (1996) [26] considers different bio-environmental regions and suggests specific building design strategies for each one, and IRAM Norm 11900 E₁ (2009) [27] defines buildings' heating energy efficiency labels in agreement with the thermal transmittance of the envelope. The current energy perspective and the use of non-conventional energy sources turned Argentina into a vulnerable country due to its high dependency on fossil fuels, with oil and natural gas providing around 90% of the total energy consumption. Some 22.5% of the delivered gas in Argentina is destined to the residential sector, and 60% of households are connected to the gas network. According to the 2005 Energy Statistics, residential consumption increased 2.5% between 1996 and 2004, with a growth of the CO₂ rate of around 2.18% [28].

In recent years, the high consumption levels and the low available volumes of gas during winter forced the national government to strongly restrict the gas supplied to the industrial sector (with reductions as high as 50%). This decision was taken in order to supply gas to the residential sector, considered as the top priority sector. Thus, industries suffered a serious crisis due to the energy lacking. Given the high gas dependence of the energy consumption matrix, the lack of policy and investment on energy generation, and the fast growth of energy consumption in the last decades, the energy situation in Argentina became a cause of deep concern and the possibility to revise Norms, Regulations and Building Codes regulating buildings' energy efficiency turned into a reality.

In this context, it is clear that energy rating techniques have to be applied to better understand the variables influencing the energy consumption of buildings in order to identify best practices related to the energy efficiency. According to Olofsson et al. [29], when analysing variables affecting energy consumption of buildings, researchers face numerous problems with large data sets, including how to handle dimensionality, the existence of many variables and few observations – or vice versa–, the correlation between variables, the interruption of data, the detection of random factors extraneous to the process, and the need to extract information from all the data simultaneously. The authors agree that multivariate analysis can deal with such problems. Clustering techniques were proposed as a suitable methodology and some enlightening studies on this subject were carried out by different authors around the world. Santamouris et al. [30] proposed clustering techniques to carry out energy rating in school buildings. Data on the total and specific energy consumption of about 340 Greek school buildings were collected by the authors, and they applied fuzzy clustering techniques in order to create energy classes for school buildings. The methodology would allow for better planning of interventions to improve its energy performance. Yu et al. [2] used cluster analysis to examine the influence of users on the energy performance of a building. Their results showed that this method facilitates the evaluation of building energy-saving potential by improving the behaviour of the users. The method can be used to improve the modelling of user behaviour in numerical simulations. Gaitani et al. [31] applied clustering techniques to create an energy classification tool, using collected data regarding the heating energy consumption of school buildings and as a result five energy classes have been defined. The authors performed an analysis in order to assess the most appropriate intervention to save energy in schools. Olofsson et al. [32] modelled the use of energy for heating for 112 multifamily buildings in Sweden by using a multivariate PLS method (Partial Least Squares to Latent Structures).

In this context the aim of the present study is to evaluate the historical heating natural gas consumption between 1996 and 2009 in 72 apartments belonging to three different multifamily buildings in the city of Santa Rosa (La Pampa), through multivariate statistical analysis. The results will make it possible to study the potential energy-saving in the residential sector in a city in permanent

Table 1
Climatic data during 1996–2009.

Annual values	Maxim	Mean temperature	22.0
	Minimum	(°C)	8.7
	Mean		15.5
	Global horizontal irradiance (MJ/m ²) ^a		16.3
July	Relative humidity		72.7
	Maximum	Mean temperature	14.3
	Minimum	(°C)	1.9
	Mean		8.1
	Thermal amplitude (°C)		12.4
	Mean wind velocity (m/s)		2.8
	Global horizontal irradiance (MJ/m ²) ^a		8.1
Mean ground temperature (-1.00 m) (°C)			10.0
Annual heating degree-days ($T_b = 18^{\circ}\text{C}$)			1374
Annual heating degree-days ($T_b = 20^{\circ}\text{C}$)			1845
July heating degree-days ($T_b = 20^{\circ}\text{C}$)			368

Source: Vergara and Casagrande [33].

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expansion, located in a temperate cold climate, and to elaborate proposals towards a certification of buildings. The specific objectives are as follows: (i) to define the variables that explain the changes of winter and annual energy consumption, (ii) to cluster the apartments according to the explanatory variables of consumption, (iii) to identify in each cluster the apartments monitored in previous works, (iv) to define annual energy classes and their ranking, and (v) to assess the agreement between the of heating natural gas consumption level and the corresponding label, according to Argentina IRAM Norm 11900 E₁ (2009) [27].

2. Climate and building description

Fig. 1 shows the geographical location and a panoramic view of the city of Santa Rosa ($36^{\circ}27' \text{S}, 64^{\circ}27' \text{W}$, 182 m o.s.l.), capital of the province of La Pampa. It belongs to the III bio-environmental region under IRAM Norm 11603, 1996 [26], where the climate is temperate cold. **Table 1** shows some average climatic variables for the period 1996–2009.

The city has more than 100,000 inhabitants and, in recent years, there was an evident growth in the construction of new buildings, especially towers of multifamily housing with large glazed areas without sunscreens. Between 2005 and 2007, new construction developments increased around 24% (85% are apartment towers). Building refurbishment and enlargement grew about 42.8% (INDEC [35]). As stated above, this rate is similar to the values found in other urban centres in the country. From the energy point of view, an increase in power consumption of natural gas in the city has been recorded in the residential sector. According to the Gas Distribution Company, around 67% of the natural gas consumed annually, and around 75% of the gas consumed during winter, is used to heat buildings. The average annual natural gas consumption per-dwelling is 1420 m³/y (13,845 kWh/y) (Camuzzi Gas Pampeana [36]). Energy for air heating for buildings connected to the gas network is provided almost exclusively by this source. In Argentina, nation-wide fuel prices are low in relation to international ones, with natural gas being the cheapest per energy unit. Natural gas price for the residential and part of the business sector is between 5 and 15 times lower than international prices [24].

Three buildings were selected to carry out the present study: the *multifamily block buildings*, the *Avellaneda Tower*, and the *Gemelius Towers*. **Fig. 2** shows the location and orientation of the buildings, while **Fig. 3** shows some plan views and photographs.

- *Multifamily block buildings* (MB): They were built in the 1960s. There are 192 apartments distributed in 8 blocks of three stories

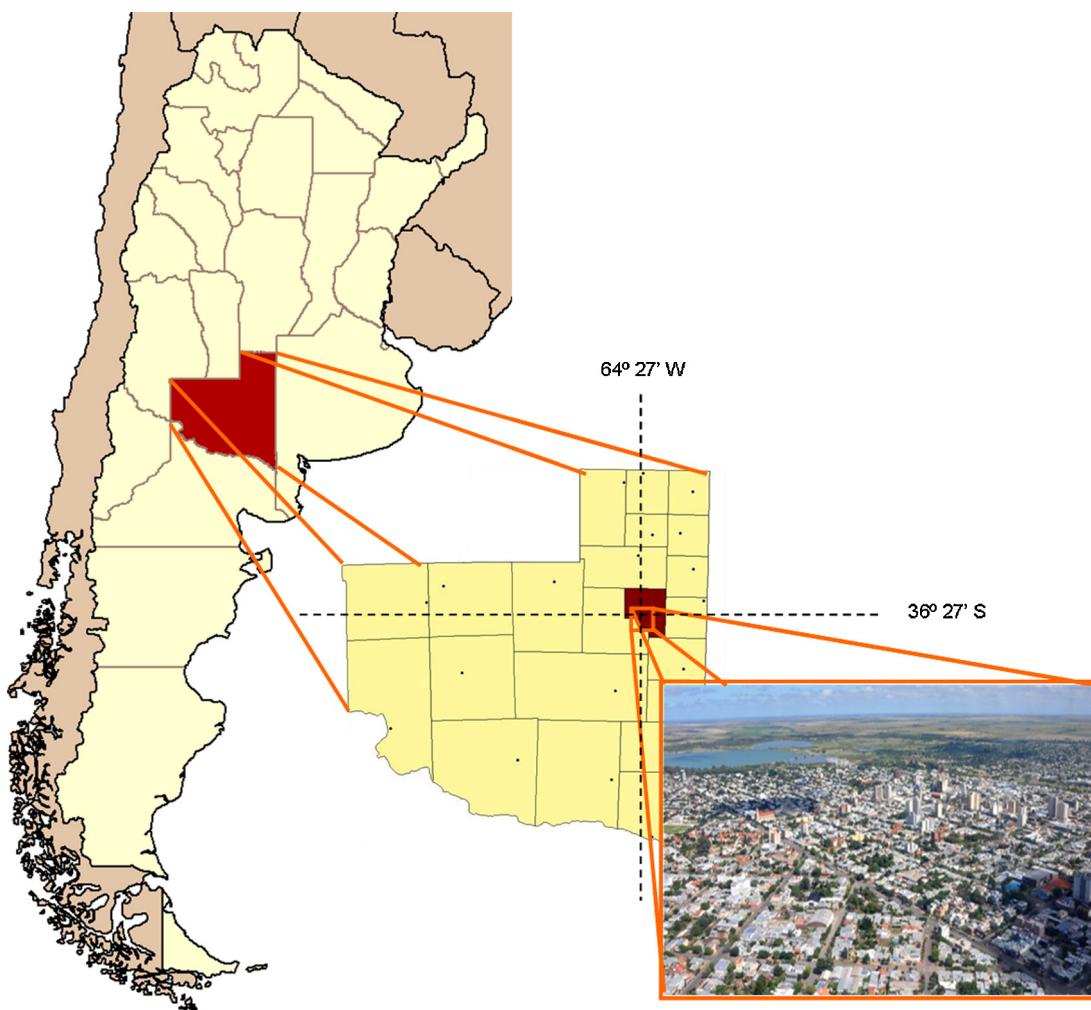


Fig. 1. Location and a panoramic view of Santa Rosa city.

along a SE–NW axis (Fig. 3a). There are 8 apartments on each floor (ground floor, first and second floor). The apartments have 1, 2 and 3 bedrooms: around 25% of flats have 1 bedroom, 25% 3 bedrooms and 50% 2 bedrooms. 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/m²/K) without thermal insulation. Windows are single-glazed with metal frames and external roller shutters (U -value = 5.82 W/m²/K). The roof does not have thermal insulation (U -value = 1.80 W/m²/K). Heating system consists of natural gas air heaters connected to the gas network. Additional information about geometry and building materials was presented in [16]. During 2009, three apartments of block 126 were monitored [16,17], named MB 126-15, MB 126-18, and MB 126-23.

- *Avellaneda Tower (Av)*: It is a high rise building of the early 1970s (Fig. 3b). It has 10 floors (one commercial floor and 9 floors of apartments). Apartments are 133 m² with 3 bedrooms. All units have the same orientation. Windows facing east (main façade) have rigid PVC external roller shutters. The technology used is independent reinforced concrete with a vertical and horizontal envelope without thermal insulation. The walls are of hollow ceramic bricks, plastered on both sides (thermal transmittance K = 1.84 W/m² °C). The roof consists of a concrete flat slab with its corresponding waterproof insulation (K = 3.82 W/m² °C). The building has a central natural gas boiler for water heating and each apartment has mini-boilers and radiators of hot water for heating the spaces. More details can be consulted in [37]. During

2008 and 2009, four apartments were carefully evaluated (Av4, Av5, Av7 and Av8). The results of this monitoring were presented in [37].

- *Gemelius Towers (GG)*: They are two blocks of 11 floors each (2–12); with 5 apartments on the ground floor: A, B, C, D and E (Fig. 3c). Apartments A and B in the block have their 20.0 m façade facing north. Apartments C, D and E in the back block have their 20 m façade facing south and looking towards the block's centre. All the building's façades are free from obstructions. Hermetic aluminium windows with external rigid PVC roller shutters, most of them with simple glass, complete the design. Each apartment has a water heating system with a natural gas boiler and radiators in each area of use. The technology of the studied buildings is conventional, that is, independent reinforced concrete with a vertical and horizontal envelope without thermal insulation. This is the usual technology in the country. The walls are of hollow ceramic bricks, plastered on both sides (thermal transmittance K = 1.84 W/m² °C). The roof consists of a concrete flat slab with its corresponding waterproof insulation (K = 3.82 W/m² °C). The Argentinean IRAM Norm 11900 E₁ (2009) [27] classifies the energy efficiency of buildings with labels ranging from A (most efficient, with $\tau_m \leq 1$ °C, see Glossary) to H (less efficient, with $\tau_m > 4$ °C). When applied to the apartments, the label category for each apartment is beyond H, that is, worse than the less efficient category, thus the building does not qualify from an energy-saving perspective. Additional information about geometry and building materials was presented in [38]. The historical

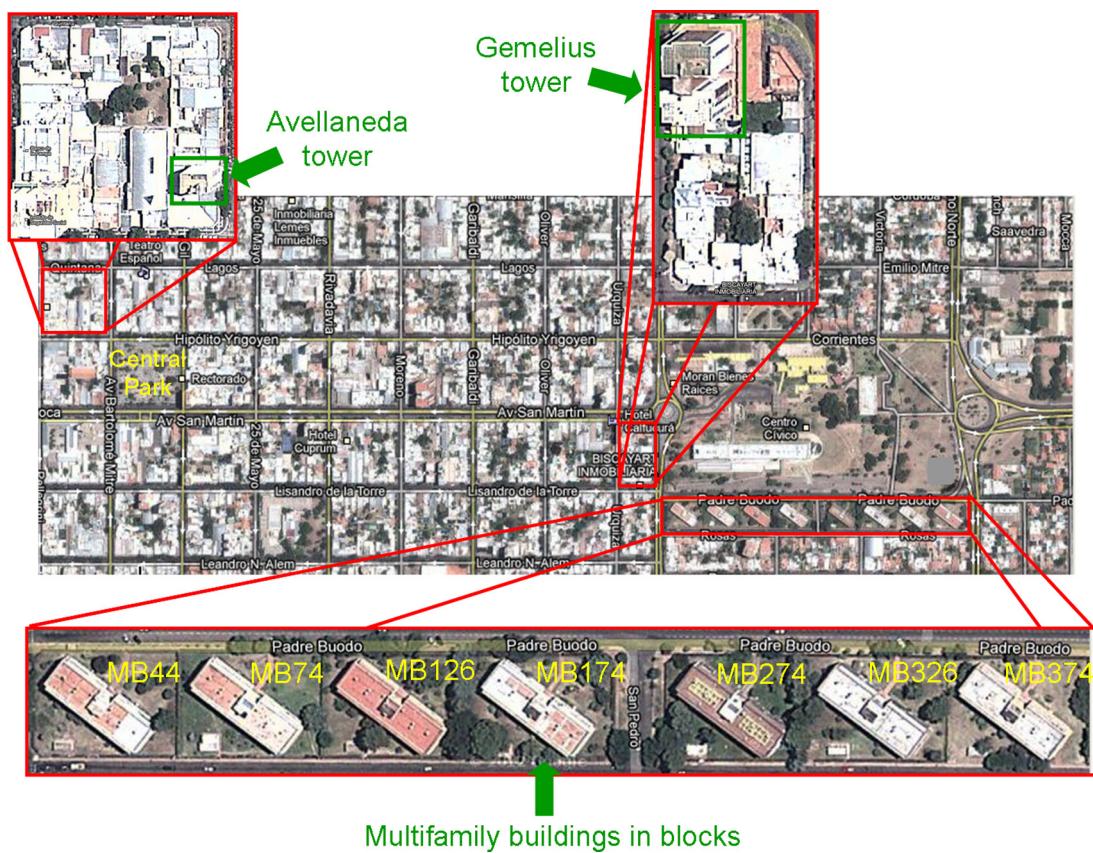


Fig. 2. Localization of studying buildings.

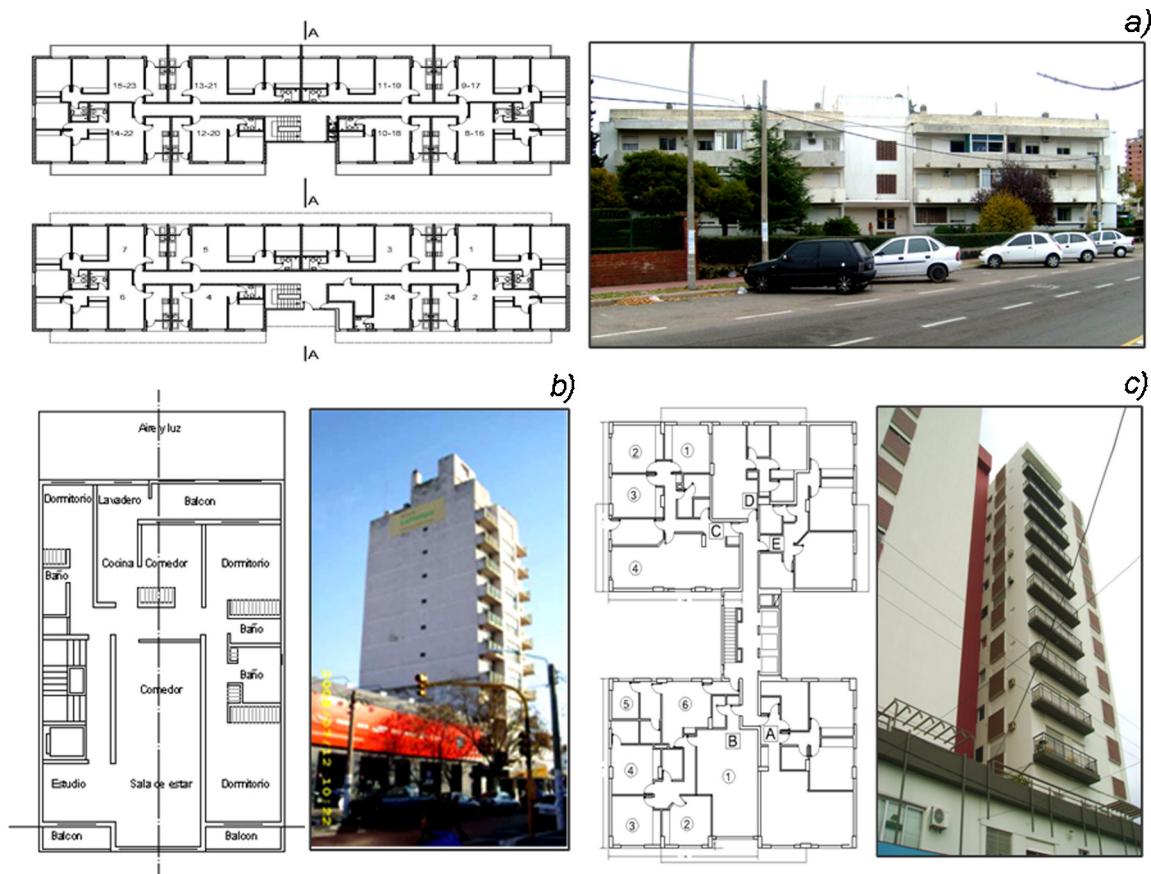


Fig. 3. Plan and views of studying buildings. References: (a) multifamily building; (b) Avellaneda Tower; and (c) Gemelius Towers.

consumption of natural gas of this building and the thermal behaviour of four apartments monitored during winter 2009 are described in [38]. The monitored apartments were located on the floor 11 and they are referred throughout the text as: GG 11B, GG 11C, GG11D, and GG 11E.

All the studied buildings use natural gas for air heating, thus electricity consumption is not included in the analysis. Conversions of gas consumption in m^3 to kWh were made (1 m^3 of natural gas = 9.75 kWh). The historical winter energy consumption and annual energy consumption for heating of 72 apartments, between 1996 and 2009, were obtained from previous studies and from the gas bills. 67% of the natural gas annually consumed in the study area is used to heat rooms [36]. This value rises up to 75% in winter months. Considering these percentages, each apartment's heating consumption was calculated on the basis of their gas bills. Geometrical data of the apartments (i.e., useful area, volume, envelope area, etc.) were obtained from the building plans, while other energy coefficients were calculated from the Argentinean IRAM Norms (i.e., volumetric heat loss coefficient G and weighted mean temperature variation τ_m , see [Glossary](#)). The resulting data was stored in a database.

3. Methodology

3.1. Cluster analysis

In order to group the apartments, a classification by cluster analysis was used [39]. This technique of exploratory data analysis consists in classifying objects in homogeneous groups named *clusters*, so the degree of association/similarity among members of the same cluster is stronger than between members of different clusters. To classify the objects, selection criteria must be previously defined. The selection of variables in which the clusters are based, is a crucial step in the methodology, because the selected group of variables should describe the *similarity* between objects. Thus, each cluster is homogeneous or compact with respect to these pre-defined variables, that are selected based on previous research, theory or hypothesis that must be proved. To evaluate the *similarity* between objects, there are three approaches commonly used: correlation measure, distance measure (for metric variables) and association measure (for categoric variables). The interested reader can find a deeper insight in [40]. In this case, the Euclidean distance was used. This approach defines a relative distance between objects to measure the *similarity* between them. Because the variables involved have different units, it is necessary to standardize the data. This standardization consists of transforming the variables by using "Z punctuation" and it is obtained by subtracting to each datum the mean value and then to divide the result by the standard deviation. Thus, the differences due to the different units of the variables are eliminated.

Once variables are selected and standardized, the clustering process starts. This process involves the selection of a clustering algorithm and the determination of the number of clusters that will arise. The clustering algorithms are divided into *hierarchical* and *non-hierarchical*, being the first approach the one used in this research. The *hierarchical cluster analysis* is characterized by the development of a tree structure named *dendrogram*. One of the most used hierarchical clustering methods is the *centroid method*. Thus, for each cluster a characteristic point named *centroid* is defined which is the point with coordinates equal to the average values of the variables considered in that cluster. In our particular case, the apartments are the items or members of the cluster, with a set of variables defining the position of each one in the cluster. Thus, if the positions of the

Table 2
Dimensional and energy variables.

Variables		Units
Useful area	UA	m^2
Volume (V)	V	m^3
Envelope	E	m^2
Envelope/useful area	E/UA	-
Envelope/volume	E/V	m^2/m^3
Availability of solar resource estimated on the envelope	ASR	MJ
Passive zone area	PZA	m^2
Availability of solar resource on envelope of passive area	ASREPA	MJ/m^2
Weighted mean temperature variation	τ_m	$^\circ\text{C}$
Volumetric heat loss coefficient	G-value	$\text{W}/(\text{m}^3 \text{ } ^\circ\text{C})$

points representing the apartments are close to the *centroid*, they could be considered representative of that cluster.

Finally, the results are presented in dendograms where the apartments are represented as nodes and the branches indicate the energy consumption.

3.2. Cluster analysis applied to the apartment' sample

The study sample consists of 72 apartments (27.6% sample universe), belonging to different buildings, with different orientations and levels from floor. Winter energy consumption and annual energy consumption for heating were considered.

Because the studied period is long (1996–2009), it could occur that different dwellers rented or occupied the same apartment and this could cause different energy consumptions patterns that affect the analysis. In order to ensure that the same dwellers were living in the studied apartments during the whole period, the following criteria were adopted: the gas meter's owner must remain the same, the gas consumption data must be continuous, and the coefficient of variability in the natural gas consumption during the historical period must be low. Also the good state of conservation and maintenance of the building was considered.

There are many variables that could influence the winter energy consumption of the apartments, and a selection should be made in order to detect the most influencing ones before the cluster analysis. Based on the characteristics of buildings in Argentina and on previous research on the subject [3,32], ten representative parameters were selected that could influence the winter energy consumption of the apartments. [Table 2](#) shows these variables, with their corresponding nomenclature and units. Then, those variables of greater explanatory power were selected, without losing useful information and eliminating those that were irrelevant, and that could increase the possibility of error in the final conclusion. In this way, we discarded any degree of multicollinearity that occurs when there are many variables. We used the criterion of stepwise selection, which related the energy consumption in winter (dependent variable) to the various variables affecting it (independent variables). This method, which consists in a progressive introduction of variables, allowed us to determine which variables should be retained in the regression model, with a significance level of less than 0.15, and which variables should be excluded with a significance level higher than 0.15.

The analysis was carried out for heating energy consumption (natural gas) considering two periods, winter and annual:

a. Cluster analysis for winter gas consumption: prior to the cluster analysis, a selection method was used to reduce the number of variables being investigated. Once the most useful variables were selected, we considered the *standardization of the data* to homogenize them, and avoid misleading results due to the use of different scales. The transformation of variables, using "Z

Table 3

Winter selected variables according to the stepwise selection method.

Step	Variable			P-value
	Introduced	Removed	Number	
1	Volume	–	1	0.0121
2	Availability of solar resource estimated on the envelope	–	2	0.0467
3	Volumetric heat losses, G-value	–	3	0.2310
4	Weighted mean temperature variation	–	4	0.3591

punctuation", was then undertaken, with a mean=0 and a standard deviation=1, eliminating the apartments between these values. Finally, a *hierarchical cluster analysis* was performed, based on the use of a metric distance (Euclidean distance) that defined the similarities and differences between the variables that identify the households' consumption. This analysis was carried out using the Ward method (or method of minimum variance or method of the sum of squares), that is the most efficient one when the intention is that the groups be homogeneous. This method calculates the distance between two clusters as the sum of squares between groups in ANOVA (Analysis of Variance), for all variables. ANOVA is a collection of statistical models and their associated procedures which compare means by splitting the overall observed variance into different parts [32]. Each step minimizes the sum of squares into clusters of all the possible partitions obtained, by merging two clusters from the previous step.

b. Cluster analysis for annual gas consumption: the same criteria described for case (a) was used (standardization, grouping method and distance metric). Twelve Energy-Classes were obtained from the analysis, which reveals the relationship between the annual consumption of the different housing analyzed. These results are shown by means of a dendrogram. There, the houses are represented as nodes and the tree branches indicate the consumption that has merged in a cluster; the length of the branches indicates the distance from the merger.

The Statgraphics Plus 5.0 software was used to carry out statistical analyses. Two statistical concepts are used: *confidence level* and *significance level*. *Confidence* measures the probability that a population parameter will fall between two set values. The confidence interval can take any number of probabilities, with the most common being 95% or 99%. In the following analysis, we selected a confidence level of 95%. *Significance* is a statistical assessment of whether observations reflect a pattern rather than just chance. In statistical testing, a result is deemed statistically significant if it is so extreme that such a result would be expected to arise simply by chance only in rare circumstances. Some popular levels of significance are 15% (0.15), 10% (0.1), 1% (0.01). If a test of significance gives a value lower than or equal to the significance level, the null hypothesis is rejected at that level. In our study we selected a significance level of 0.15.

4. Analysis of the results

4.1. Cluster analysis for winter energy consumption

Table 3 shows the four variables arising from the stepwise selection method with their corresponding P-value. These variables are: volume (V), availability of the solar resource estimated on the envelope's surface (ASR), volumetric heat loss coefficient (G) and weighted mean internal surface temperature (τ_m). Since the P-value of the model resulting from the ANOVA is less than 0.05 (P-value = 0.0267), there is a significant statistical relationship between the variables to assure a confidence level of 95%. That is, the association really exists and it is not due to chance because of

the presence of biased or confusing variables, thus avoiding any risk of error or inaccuracy.

The winter clustering was performed with the selected variables and taking into account the number of the thermally monitored apartments described in previous paragraphs. The results are shown in Fig. 4 and Table 4. Fig. 4 shows the 14 homogeneous groups (G1–G14) that resulted from the clustering. The monitored apartments are marked with a blue rectangle on the horizontal axis: GG 11E (for Group 1); GG 11C (for Group 2); GG 11B (for Group 3); GG 11D (for Group 5); Av2 (for Group 8); Av8 (for Group 9); MB126-15 (for Group 12); MB126-23 (for Group 13) and MB126-18 (for Group 14). Table 4 shows the statistical summary of the cluster analysis, the coordinates of the centroids, the energy consumption for heating (in July) of each cluster, and a ranking where the most energy consuming cluster is on the top of the list.

The average heating energy consumption of all the groups during July is 26.5 kWh/m²/month, with a CV (coefficient of variation) of 37.5%. Groups 2 and 10 show the lowest heating energy consumption (16.5 and 16.7 kWh/m²/month, respectively). Four apartments of the *Gemelius Towers* belong to Group 2, heated by water radiators. One of them (GG 11C) was monitored during July 2009. The weighted average indoor temperature was 20.6 °C, 14.4 °C higher than the outdoor average temperature (6.3 °C) and the heating energy consumption during July was 14.6 kWh/m²/month. Since the measured energy consumption of the apartment is less than the value for the centroid of the group, we assume that, with similar heating energy consumption, thermal conditions were similar in the other apartments. Group 10 comprises apartments of *multifamily block buildings* with individual heaters. In both groups, apartments oriented to the north, with good solar resource availability, prevail.

The highest consumption rates correspond to Groups 4 and 7 (with a heating energy consumption of 46.6 and 45.1 kWh/m²/month, respectively). The first group includes two apartments that are oriented to the north, with availability of solar resource, considered as special cases to be evaluated in a future work. In Group 7 there are 4 apartments which belong to the *multifamily block buildings* and one apartment in the *Gemelius Towers*. All of them are located on the top floor, so they have greater exposure to the external environment. Only one is facing north, the other faces south.

Groups 6 and 13 also show high consumption rates. Both include apartments facing south. The difference between these groups lies in the fact that the apartments in Group 6 are located in an intermediate level-first floor – having their envelope less outdoor exposure. Group 13 corresponds to apartments facing south and located on the top level of the *multifamily block buildings*, with greater outdoor exposure. This group includes an evaluated apartment, MB 126-23, monitored in June 2009. The indoor average temperature was of approximately 23.7 °C, 14.4 °C higher than the outdoor average temperature (9.3 °C). The heating energy consumption for June 2009 was 33.9 kWh/m²/month, a similar value to that of the group centroid (33.3 kWh/m²/month), which allows us to infer that the other apartments of the same group also reached the thermal comfort.

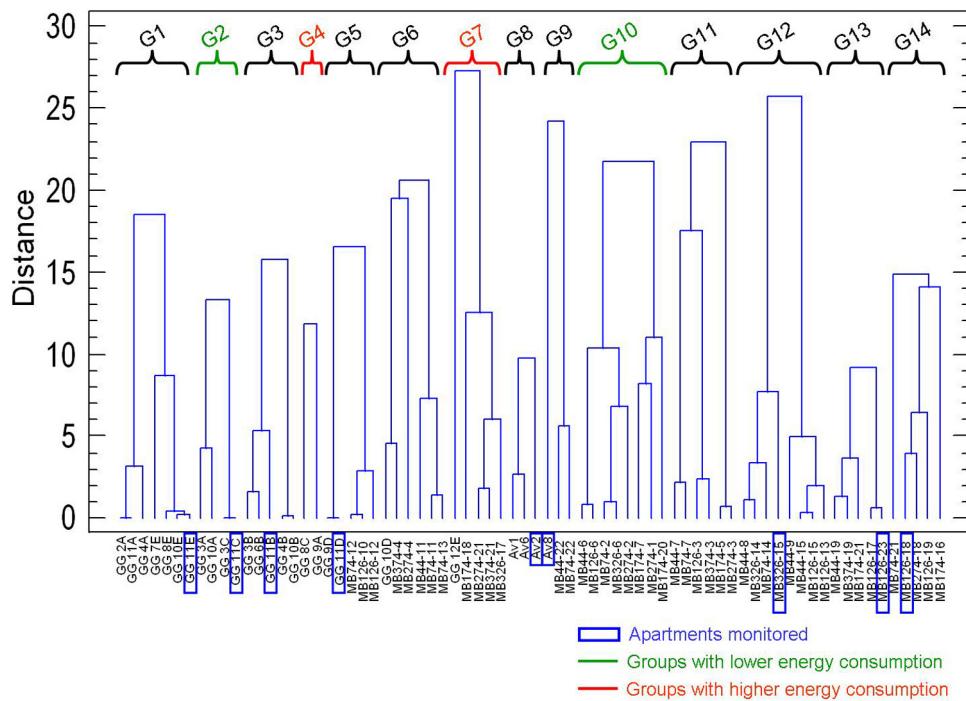


Fig. 4. Winter cluster analysis.

Group 11, fifth in the heating energy consumption ranking, shows a value of 28.2 kWh/m²/month, and it includes apartments from the *multifamily block buildings* oriented to the south and located on the ground floor. This group does not include any evaluated apartment which could be used as reference.

Group 1, ranked sixth (27.3 kWh/m²/month), comprises apartments from the *Gemelius Towers* located on the NW end, with solar resource availability in the sitting/dining-room but not in the bedrooms.

Groups 14 and 12, with similar centroids, are constituted by apartments from the *multifamily block buildings*. Three out of the four apartments in Group 14 face north and are located on the top floor. The group has one apartment monitored in 2009 (MB 126-18) facing north and located on the top floor of the building which had an average indoor temperature in June of 22.0 °C, 14.3 °C above the outdoor mean, with a heating energy consumption of 22.0 kWh/m²/month, a value which is close to the centroid. Group 12 is constituted by apartments facing north and south; all in the

multifamily block buildings and located in the intermediate level. The group has one monitored apartment as reference (MB 126-15) that showed in June 2009, an average indoor temperature of 22.0 °C, and a heating energy consumption of 17.6 kWh/m²/month. This value of energy consumption is lower than the value of the group centroid, and even lower than that of MB 126-18, which is an apartment that faces north but with greater part of its envelope in contact with the outside.

In Groups 8 and 9, the *Avellaneda Tower* apartments prevail. In the first we have the Av2, monitored during July 2009. Indoor temperature was 20.6 °C, 13.3 °C above the outdoor average temperature (7.3 °C). The heating energy consumption was 27.1 kWh/m²/month, a bit higher than that of the centroid for historical average values. To Group 9 belongs the apartment Av8 monitored between July 11 and 17, 2008, which were days with atypically warm outdoor temperatures (outdoor temperature average = 16.6 °C). That is why it is not considered as reference for this study.

Table 4
Winter statistical summary of the cluster analysis and special features of each group.

Cluster	Members		Centroids					July energy heating (kWh/m ²)		
	Number	Percent	V	ASR	G	τ_m	Energy	Ranking		Energy
								Cluster	Energy	
1	7	9.72	203.2	308.8	2.70	6.4	27.3	4	46.6	
2	4	5.56	250.9	352.4	2.60	6.4	16.5	7	45.1	
3	5	6.94	335.4	438.6	2.60	6.6	18.7	6	34.5	
4	2	2.78	250.9	352.5	2.60	6.4	46.6	13	33.3	
5	5	6.94	107.6	122.8	2.32	6.8	18.5	11	28.2	
6	6	8.33	119.3	119.0	2.34	6.8	34.5	1	27.3	
7	5	6.94	139.8	556.34	2.95	14.6	45.1	14	22.8	
8	3	4.17	302.0	677.8	1.12	6.4	21.2	12	22.3	
9	3	4.17	222.7	744.6	2.84	13.6	19.9	8	21.2	
10	8	11.11	152.6	245.0	2.48	15.3	16.7	9	19.9	
11	6	8.33	131.6	123.0	2.34	17.3	28.2	3	18.7	
12	8	11.11	154.2	200.5	2.54	6.5	22.3	5	18.5	
13	5	6.94	143.2	508.4	2.88	14.7	33.3	10	16.7	
14	5	6.94	130.1	427.7	2.84	14.9	22.8	2	16.5	

Table 5

Annual statistical summary of the cluster analysis and special features of each group.

Cluster	Number of Members	Percent (%)	Apartment name	Centroids								
				UA	V	E	E/UA	E/V	PZA	τ_m	G	Heating energy (kWh/m ² /y)
1	1	1.39	GG 2A	218.00	231.40	147.00	0.67	0.64	161.60	6.40	2.70	114.00
2	5	6.94	GG 3A GG 10A GG 3C GG 11C Av8	100.40	261.12	77.12	0.77	0.30	72.84	7.6	2.61	66.30
3	5	6.94	GG 3B GG 11B GG 6B GG 4B GG 10B	129.00	35.40	83.00	0.64	0.25	95.20	6.59	2.60	86.64
4	6	8.33	GG 4A GG 11A GG 7E GG 8E GG 10E GG 11E	76.33	198.47	56.67	0.75	0.29	55.20	0.65	2.70	124.52
5	3	4.17	GG 8C GG 9A GG 12E	87.67	227.93	63.10	0.73	0.28	65.07	8.87	2.87	203.53
6	7	9.72	GG 9D GG 11D GG 10D MB374-4 MB74-12 MB126-12 MB126-10	41.50	107.90	19.07	0.46	0.18	30.06	6.85	2.27	104.49
7	3	4.17	Av1 Av6 Av2	116.00	302.00	107.67	0.93	0.33	67.47	6.38	2.44	95.00
8	9	12.50	MB44-6 MB44-7 MB74-7 MB174-7 MB274-1 MB274-2 MB126-6 MB326-6 MB274-2	58.87	153.06	38.62	0.64	0.24	50.13	15.13	2.44	92.23
9	8	11.11	MB44-8 MB74-14 MB326-14 MB326-15 MB44-9 MB44-15 MB126-15 MB126-13	59.30	154.19	37.68	0.63	0.24	48.40	6.52	2.54	100.34
10	4	5.56	MB44-11 MB74-11 MB74-13 MB274-4	47.98	124.75	23.48	0.50	0.20	41.20	6.72	2.43	165.33
11	2	2.78	MB44-19 MB44-22	59.80	155.50	92.5	1.55	0.60	109.40	14.73	2.91	120.80
12	7	9.72	MB74-21 MB126-19 MB74-22 MB174-16 MB126-18 MB274-18 MB174-20	51.73	134.50	77.57	1.47	0.60	41.37	14.87	2.85	92.37
13	4	5.56	MB126-3 MB374-3 MB174-5 MB274-3	50.80	132.10	24.20	0.50	0.20	44.8	18.69	2.31	128.73
14	8	11.11	MB126-17 MB126-23 MB326-17 MB174-21 MB274-21 MB374-19 MB174-18 MB374-21	52.94	137.64	80.92	1.51	0.60	43.0	14.69	2.86	163.44

Group 3 includes apartments from the *Gemelius Towers* located on the NE end. It has an apartment which was monitored during July 2009, showing an average temperature of 20.5 °C, 14.2 °C above the outdoor average temperature (6.3 °C), with a heating gas consumption of 11.4 kWh/m²/month, below that of the centroid value.

Group 5 is constituted by three apartments facing north, located on the intermediate level of the *multifamily block buildings* and other two in the *Gemelius Towers*, facing south, without available solar resource and exposed to predominantly cold winds which may affect their thermal behaviour; however, these flats have less of their envelope in contact with the outside due to the fact that they are protected by two functional units. This group also includes an apartment monitored in July 2009, which showed an indoor average temperature of 23.9 °C, 17.6 °C above the outdoor mean (6.3 °C), with a heating energy consumption of 25.0 kWh/m²/month, a value above that of the group centroid.

In Argentina and according to IRAM Norm 11900 [27] the weighted mean temperature variation defines the category of the envelope's label. The members of the sample have a label category below H ($\tau_m > 4^\circ\text{C}$), indicating that the building's envelope energy does not qualify. To assess the agreement between heating energy consumption and the label category, a low-energy building in the study region, which was previously evaluated with label category C ($\tau_m = 2^\circ\text{C}$), is taken as reference. Heating energy consumption in the winter of 2008 was 13.6 kWh/m² to reach an average temperature of 21.4 °C. Group 2 and Group 10 show that heating energy consumption was only 18% higher than the reference building for a labelling category that does not qualify energetically with a τ_m value of 6.4 and 15.3 °C, respectively. For these groups of conventional buildings there might be a disagreement between the label category and the real energy consumption, a variable not considered by the mentioned Norm, as well as the solar heat gain.

4.2. Cluster analysis for annual energy consumption

The stepwise method applied to annual energy consumption allowed to select nine representative variables: useful area (UA), volume (V), envelope area (E), envelope area/useful area (E/UA),

Table 6
Heating energy consumption: annual ranking.

Energy class	Annual heating energy consumption (kWh/m ²)
5	203.53
10	165.33
14	163.44
13	128.73
4	124.52
11	120.8
1	114
6	104.49
9	100.34
7	95
12	92.37
8	92.23
3	86.64
2	66.3

envelope area/volume (E/V), passive zone area (PZA), volumetric heat loss coefficient (G) and weighted mean internal surface temperature (τ_m). Annual clustering was performed to define energy classes using the nine mentioned variables and the results are shown in Fig. 5 as a dendrogram with 14 groups, and in Table 5, which summarizes the clusters (with a list of the apartments belonging to each cluster), and the centroids coordinates for each cluster. In the fourth column, apartments that were monitored are marked with bold letters. Table 6 shows the ranking for annual energy consumption for heating, where the most energy consuming cluster is on the top of the list. The annual heating energy consumption average for the sample is 118.2 kWh/m²/y. According to Sartori and Hestnes [41], a low-energy building has operating energy consumption lower than 121 kWh/m²/y when expressed in end-use energy, and lower than 70 kWh/m²/y when heating only is considered. According to this value, 12.5% of the apartments of the sample are low-energy. Of the 87.5% of the other apartments, the highest percentage is constituted by units of the *multifamily block buildings*, oriented to the south and located on the ground floor, intermediate and upper floor. In the previous paragraphs we commented the fact that none of the apartments that comprise the sample under study has a label category which qualifies

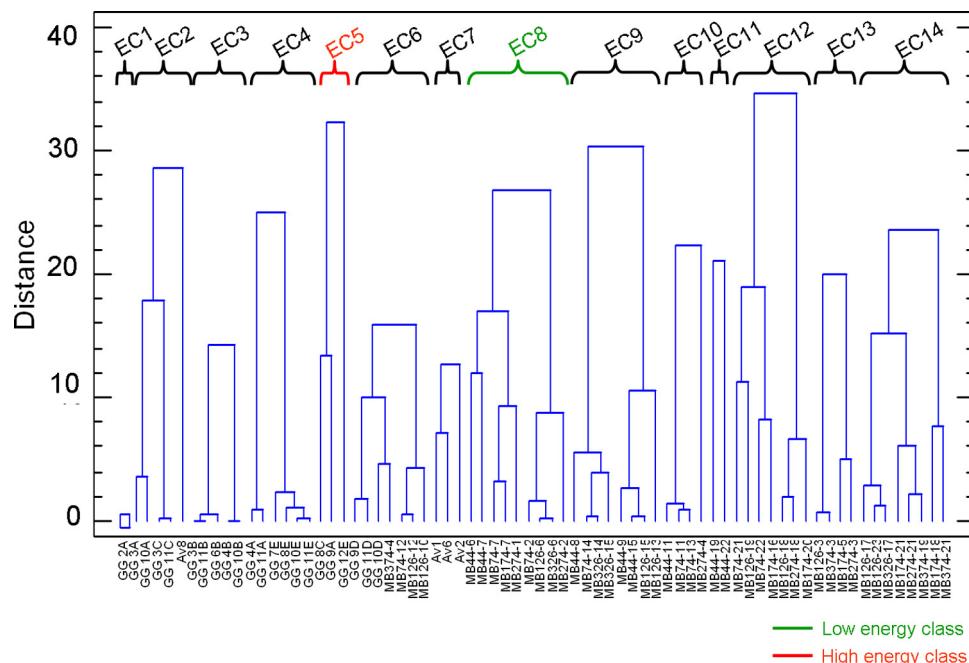


Fig. 5. Clustering according to annual energy classes.

energetically for the Argentinean IRAM Norm, thus a disagreement is observed again, between the label values according to IRAM Norm 11900 E₁ [27] and the real energy consumption for heating.

Furthermore, Energy Class 2 shows the lowest annual heating energy consumption of the whole sample with values of 66.3 kWh/m²/y (Table 6), that is, Energy Class 2 buildings consumed less heating energy than the expected in a low-energy building [41]. Two of the monitored apartments – GG 11C and Av8 – belong to this group, and both correspond to tower buildings (*Avellaneda* and *Gemelius Towers*) with water heating systems with individual boilers in each apartment. In previous paragraphs we stated that we would not consider Av8 for this study since it was monitored in July under atypical warm outdoor conditions. Assuming that the dwellers in apartment GG 11C, whose results were shown above, live in comfortable conditions, the centroid value for annual heating energy consumption is only 20.5% higher than the value of 55 kWh/m²/y set by the German Norm for low-energy multifamily buildings consumption.

Energy Class 5, which shows the highest annual heating energy consumption (centroid = 203.53 kWh/m²/y) includes 3 apartments of *Gemelius Towers*, one of them located on the top floor with greater exposure of its envelope to the outside. Apartments GG 8C and GG 9A showed the highest winter consumption within the cluster. Thus, they will be considered for future monitoring during the course of the next winter.

Energy Class 8 includes apartments from the *Gemelius Towers* with good winter solar resource availability. The centroid shows an annual heating energy consumption of 86.6 kWh/m²/y, 24% higher than the valued established by Sartori and Hestnes [41] for low-energy consumption buildings. In that class, apartment GG 11B, described above, was monitored and showed very good results regarding its thermal comfort. It can be considered as reference for the rest of the Energy Class. The low-consumption building mentioned above (Label C) consumed during 2001, 73 kWh/m² in heating for an average temperature of 22 °C. Energy Class 2, in which apartments with windows facing north prevail and with a label category that does not qualify energetically, consumed for the historical period, an average of 66.3 kWh/m², a value 10% lower than that of the solar building apartment. Within this energy class we find previously monitored apartment GG 11C. Results were satisfactory regarding the thermal behaviour. The relationship between energy consumption in solar versus conventional buildings in the region under study, confirms the potential of the solar resource to heat different spaces and to reach levels of thermal comfort while saving conventional energy.

5. Conclusions

The analysis of real records of existing buildings, as well as of surveys of specific designs, can deliver vital information to help researchers understand factors needed to achieve energy efficiency in the building sector.

The present work allowed us to define some explanatory variables that account for the variations of winter heating energy consumption in apartments located in the central region of Argentina with a temperate cold climate. These variables are: volume, availability of the solar resource estimated on the envelope's surface, weighted mean internal surface temperature and volumetric heat losses coefficient. They defined the first grouping of apartments (winter clustering), which clearly shows the relevance of the orientation of each apartment in the defined groups, considering also its location in the building, such as apartments on intermediate levels, on extreme levels or on the top level, most exposed to the severity of the climate. The thermally monitored apartments have also been identified. It is possible to infer that

indoor temperatures in the apartments' sample are comfortable in the winter season.

Energy-classes were defined according to the consumption of natural gas/m² of usable area/year. It is clear that the orientation, the degree of exposure, the thermodynamic characteristic of each apartment, and the environmental conditions determine the energy-classes, without forgetting that anthropic factors are also involved, though not quantified here. In one of the classes, the members are specific cases characterized by the user's individual thermal requirements (GG 8C); or by excessive shading (MB274-4); and there are also others located on the top floor with heat transfer to the adjacent apartments (MB174-18 and MB274-21). Finally, a class with one of the highest levels of energy heating consumption concentrates south-facing apartments.

In any case, the labelling category, according to IRAM Norm 11900 E₁ is not energy efficient. Even below this level there are classes with low-energy buildings, and especially some of them show values close to the German Norms for multifamily buildings. This confirms the need, when labelling, to consider other variables beyond the thermal transmittance of the envelope, as for example, the direct solar heat gain through the glazed areas.

Although in Argentina there are not many studies regarding heating energy consumption that could serve as reference and evidence their agreement/disagreement with the label category, the methodology described in the present study might be generalized with respect to other climates in our country in order to reach a more suitable certification of real energy consumption and not so much of the envelope thermal-physical characteristics. This could lead to a study of the potential of intervention to reduce energy consumption on the basis of sustainable criteria. This, in turn, would provide substantial help at the time of reformulating building codes and orienting policy-makers towards environmentally aware design practices.

According to Theodoridou et al. [42], the policies concerning energy conservation measures should be designed according to the buildings' real use, and to the status of occupation. Furthermore, clear definitions for building energy standards should be made, referring to specific categories of buildings, and providing the respective tools. Otherwise, the risk of prescribing standardized interventions for whole typologies, without taking into account important variables of differentiation, and resulting in less than optimum outcomes will still prevail.

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Glossary

Conventional building or simply Conventional: Refers to a building built according to the common practice of a specific country in a specific period (Sartori and Hestnes [41]).

Envelope: The exterior surface of a building including all external additions, e.g., chimneys, bay windows, etc.

G-value, Volumetric Heat Loss Coefficient: The total heat loss of a dwelling through the envelope and ventilation, divided by the heated volume and the temperature at which the loss occurs, IRAM Norm 11604 [43].

Low-energy building or simply Low-energy: Refers to a building built according to special design criteria aimed at minimizing the building's operating energy (Sartori and Hestnes [41]).

Passive zone area: Area that can be daylight and naturally ventilated and make use of solar gains for heating

τ_m : Weighted mean temperature variation between the internal surface of the envelope and the indoor design temperature (in °C) which defines the envelope's energy efficiency label according to IRAM Norm 11900 E₁ [27].