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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/m^2/y. However, a significant percentage of apartments showed energy consumptions lower than 70 kWh/m^2/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.

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/m^2 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 CO_2 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 E_1 (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 CO_2 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 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 E_1 (2009) [27].

Table 1
Climatic data during 1996–2009.

Annual values	Maxim	Mean temperature (°C)	22.0
	Minimum		8.7
	Mean		15.5
	Global horizontal irradiance (MJ/m^2)[a]		16.3
	Relative humidity		72.7
July	Maximum	Mean temperature (°C)	14.3
	Minimum		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 °C)			1374
Annual heating degree-days (T_b = 20 °C)			1845
July heating degree-days (T_b = 20 °C)			368

Source: Vergara and Casagrande [33].
[a] Righini, Grossi Gallegos, and Raichijk [34].

2. Climate and building description

Fig. 1 shows the geographical location and a panoramic view of the city of Santa Rosa (36°27′ S, 64°27′ 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 m^3/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