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CONSUMOS ENERGÉTICOS DE GAS NATURAL Y ELECTRICIDAD EN EDIFICIOS ESCOLARES DEL ÁREA METROPOLITANA DE SAN JUAN, ARGENTINA. ANÁLISIS ESTADÍSTICO EN FUNCIÓN DE VARIABLES ARQUITECTÓNICAS

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THE NATURAL GAS AND ELECTRIC ENERGY CONSUMPTION OF SCHOOL BUILDINGS IN THE METROPOLITAN AREA OF SAN JUAN, ARGENTINA: A STATISTICAL ANALYSIS BASED ON ARCHITECTURAL VARIABLES.

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RESUMEN

El presente trabajo tiene por objetivo indagar sobre los consumos energéticos de 17 escuelas localizadas en el Área Metropolitana de San Juan. Se analizan aquí los consumos por año y por unidad de superficie para obtener una lectura general de la situación actual. Además, se realizan análisis estadísticos con el fin de comprender las posibles relaciones entre los consumos energéticos y dos variables arquitectónicas que caracterizan el diseño y la tecnología constructiva: Área vidriada al Norte y K global. Los resultados indican que la energía con mayor participación anual relativa es la eléctrica (55%), mientras que el gas natural lo es durante la estación fría (72%), asociado al abastecimiento de energía en calefacción. Respecto al consumo por tipo de energía y por unidad de superficie cubierta, los valores son de 26,24 kWh/m2.año para la electricidad y de 21,80 kWh/m2.año para el gas natural. El desarrollo de la investigación permite concluir que existe una importante asociación entre la envolvente edilicia, tanto opaca como transparente, y el consumo de energía, con lo cual se reconoce la potencialidad de mejoramiento de la envolvente, en búsqueda de una optimización energética.

Palabras clave
arquitectura, energía, escuelas

ABSTRACT

The present work aims to investigate the energy consumption of 17 schools located in the Metropolitan Area of San Juan, Argentina. To obtain a general overview of the current situation, consumption per year and per unit area were analyzed. In addition, statistical analyses were carried out in order to understand possible relationships between energy consumption and two architectural variables that characterize design and construction technology: glazed area to the north and global U-value. The results indicate that electricity is the energy with the greatest relative annual use (55%), while natural gas predominates during the cold season (72%), as associated with heating energy supply. Regarding consumption by type of energy and per unit area covered, the values were 26.24 kWh/m2. year for electricity and 21.80 kWh/m2.year for natural gas. Through the research it was possible to conclude that there is an important association between the building envelope, both opaque and transparent, and energy consumption, thereby recognizing the potential to improve the envelope for energy optimization.

Keywords
architecture, energy, schools.

Consumos energéticos de gas natural y electricidad en edificios escolares del Área Metropolitana de San Juan, Argentina. Análisis estadístico en función de variables arquitectónicas
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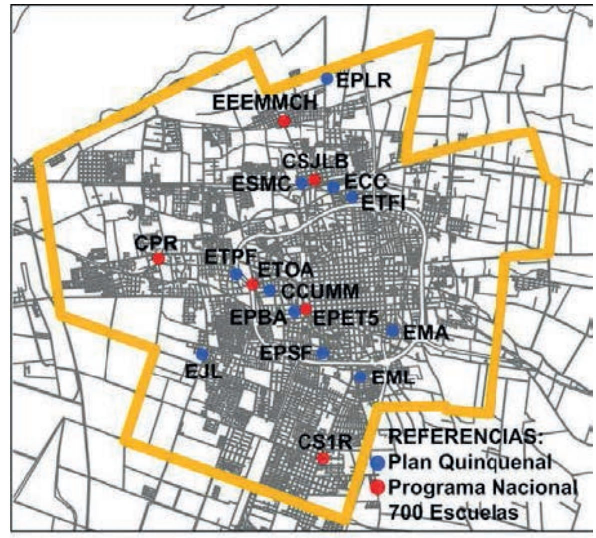
INTRODUCTION

The energy consumption of buildings is a topic to consider in times of scarcity of non-renewable resources, as currently it is the case worldwide. According to the data published by Secretaría de Energía de la Nación (2012), the participation of residential, commercial and public sector buildings in the total energy consumption is 31%; while, if only electricity consumption is considered, it is 55%, and gas per network is 50%. The high registered consumption requires the implementation of energy efficiency optimization plans, in order to reduce the demand.

The lack of knowledge about the factors that determine the use of energy in buildings represents a difficulty to achieve the energy efficiency of them (Yoshino, Hong y Nord, 2017). Schools are public buildings that have particularities in their design, construction and operation; that is why the analysis of consumption in school typologies from empirical data of energy audits is a topic that has interested many research groups in different places of the world (Rospi et al, 2015; Trebilcock *et al.*, 2016; Raatikainen *et al.*, 2016; Mohamed and Mohamed, 2017; Droutsaa *et al.*, 2017). In Daegu, South Korea, a study carried out on 10 elementary schools, analyzes historical consumption, per year and per unit area, getting the following conclusions: that electric power is the most used, followed by gas; the energy consumption per unit of class-room based area was 289 kWh/m^2 year of electricity and 90 kWh/m^2 year of gas, during the year 2010; and that, in terms of uses, more energy is consumed in heating, followed by cooling and lighting (Woo, Guk and Hwa, 2012).

In Argentina, important contributions have been made from the scientific field in the field of schools also (Filippín, 2005; Melchiori, San Juan y Díscoli, 2014; Boutet, Hernández and Jacobo, 2016; Ledesma *et al.*, 2016; Walter *et al.*, 2016; Giuliano and Garzón, 2017; Mazzocco, Filippín and Flores Larsen, 2017) and in the management of statistical studies as a tool used for thermal and energy characterization in buildings (Czajkowski, 2009; Muñoz, Marino and Thomas, 2016; Boutet, 2017).

In San Juan, several researches have allowed grouping the schools of the Metropolitan Area in building typologies, as well as knowing the energetic behavior, the hygrothermal comfort levels and the seismic vulnerability of different cases belonging to representative historical periods (Michaux, 2014; Ré, Blasco Lucas and Fillipín, 2016; 2017; Yacante *et al.*, 2017). The objective of this work is to provide empirical data regarding the consumption of gas and electricity registered in schools and, also, to identify existing relationships with architectural variables that define the building envelope.



TIPOLOGÍA	CODIGO	NOMBRE ESTABLECIMIENTO ESCOLAR
PLAN QUINQUENAL	EML	Escuela Manuel Lainez
	EPBA	Escuela Provincia de Buenos Aires
	ETPF	Escuela Teniente Pedro Nolasco Fonseca
	CCUMM	Colegio Central Universitario
	EPSF	Escuela Provincia de Santa Fe
	EMA	Escuela Miguel de Azcuénaga
	ECC	Escuela Comandante Cabot
	ETFI	Escuela Teniente 1º Francisco Ibáñez
	ESMC	Escuela Salvador María del Carril
	EPLR	Escuela Provincia de la Rioja
	EJL	Escuela Julia León
PROGRAMA NACIONAL 700 ESCUELAS	ETOA	Escuela Técnica Obrero Argentino
	EPET5	Escuela Provincial Educación Técnica N°5
	CPR	Colegio Provincial de Rivadavia
	EEMMCH	Escuela Especial Múltiple Martina Champanay
	CSJLB	Colegio Secundario Jorge Luis Borges
	CS1R	Colegio Superior N°1 Rawson

Figure 1. Metropolitan Area of San Juan. Location of school facilities. Source: Made by the author.

UNITS OF ANALYSIS

Schools of two architectural types of the Metropolitan Area of San Juan are considered as a study population (AMSJ, by its initials in Spanish), registering the highest rates of construction of school infrastructure of public management. One of them corresponds to the period of the reconstruction of the city, after the earthquake of 1944, with the prototype created in the framework of the Five-Year Plan (PQ, by its initials in Spanish); the other typology concerns the Programa Nacional 700 Escuelas (PN700) (National Program of 700 Schools) developed between 2004 and 2008. For this article a representative sample is taken (Sierra Bravo, 1991) formed by 17 Analysis Units (UA, by its initials in Spanish), which corresponds to 85% of the study population and it was defined when considering all those facilities that have electricity and natural gas network service. In Figure 1, you can see the location of school buildings along with a table of references that identifies them; a code is established with respect to the name and a color according to the building typology to which they belong: PQ in blue (11 UA) and PN700 (6 UA) in red.

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Figure 2. Cases of typology PQ. Photograph: Guillermina Ré.

Figure 3. Cases of typology PN700. Photograph EEMMCH: Programa Nacional 700 Escuelas (http://www.700escuelas.gov.ar) and Raúl Alfonzo. Photograph CPR: Guillermina Ré.

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The schools from PQ they are more than 50 years old and are fully operational, some with a better condition of preservation than others (Figure 2). Most have expansions made with different construction technology than the one used in the original typology (Ré, Blasco and Filippín, 2017). Infrastructures of PN700 (Figure 3) are characterized by their morphology and materialization of the envelope (Ré, Blasco and Filippín, 2016) and not by a similar functional organization, as happens with those of PQ. As for the equipment for air conditioning, all UA use stoves and/or gas screens to heat indoor environments, however, some schools have electric heaters or auxiliary heaters in the administrative sectors. For cooling, only ETPF and CCUMM schools have air conditioners (AA) in the classrooms.

METHODOLOGY

The energy consumptions were requested from companies supplying the natural gas and electricity service, and correspond to a variable period of ten years (2006 to 2015) for the oldest schools (PQ); and from the first year of operation, for those of recent construction (PN700). The gas consumption data, which were originally in m^3, were converted to kWh to enable the analysis together with those of electricity, using a factor of 8.33kWh/m^3 (Blasco Lucas, 2013).

Simultaneously, the different areas of use are computed. The covered areas are distinguished from the heated ones since, unlike what happens in homes or other public buildings, in the schools there are important covered areas without artificial air conditioning with heating and/or cooling equipment, for example: toilets, store houses, circulations and multipurpose room (SUM), in some cases.

In a first instance of the study, which, as indicated, aims to know the general situation regarding energy consumption in school buildings, we work with all the data obtained. In a second stage, the sample is reduced to the years 2014 and 2015, which are those with information on electricity and gas consumption for the 17 units of analysis.

To define the architectural variables to be studied, a correlation matrix is developed in advance of different design variables that characterize the morphology, technology, functionality and use of the school buildings, and the average annual consumption of the years 2014 and 2015, differentiated into: total, seasonal and by energy source. From it, two variables are selected that define the external building envelope and are closely linked to a design that aims at energy saving: Glazed surface to the North (m^2) and global K (W/m^2°C).

Regarding the statistical analysis, software Statgraphics is used. A simple linear regression analysis is carried out in order to estimate the values of the dependent variable (energy consumption), after obtaining of the linear function. The mathematical notation of the equation is: $y = a + b*x$. The good fit quality of the data to the simple linear regression model is then assessed through the statistical indicators:
Simple Linear Correlation Coefficient (r), that measures the degree of linear association between two variables oscillating between 1 (strong positive linear association: as they increase the values of one variable, the values of the other one will increase) and –1 (strong negative linear association: as they increase the values of one variable, the values of the other one will decrease); and II) Value - P: a value less than 0,05 indicates a statistically significant association with a level of confidence of 95%.

To calculate the thermal transmittance (K, in the Argentine denomination; U internationally) of the elements that make up the building envelope, the program developed by Gonzalo et al. is used (2000). The K global values are obtained with the programmed spreadsheets KG-MOD (Blasco Lucas, 2013), that apply the procedures suggested in Standards IRAM 11601, 11604 y 11605.

ELECTRICAL ENERGY AND NATURAL GAS CONSUMPTION

First, the average annual energy consumption of the schools is analyzed, which allows a general reading of the subject under study. Figure 4 shows that the values are between 32.378,93 kWh (ETPF) and190.461,83 kWh (CCUMM), for schools of PQ typology, and between 83.899,32 kWh (CPR) and 158.545,82 kWh (EEMMCH), for PN700 infrastructures.

In relation to the consumptions per unit of covered and heated surface (Figure 5), it is observed that the school with the lowest consumption is the ETPF, with annual values of 23,56 kWh/m2 regarding the cover and 39,22 kWh/m2 and the heated. The highest consumption is recorded by the EEMMCH of typology PN700, with values of 111,82 kWh/m2 and 149,44 kWh/m2, respectively, followed by CCUMM (PQ), with annual consumption of 80,33 kWh/m2, according to the covered area and 123,92 kWh/m2 of the heated area.

In addition, we study the temporal variation of annual energy consumption per unit of covered area, recorded in a period between 2006 and 2015. In Figure 6, it is noted that the EEMMCH school has presented high

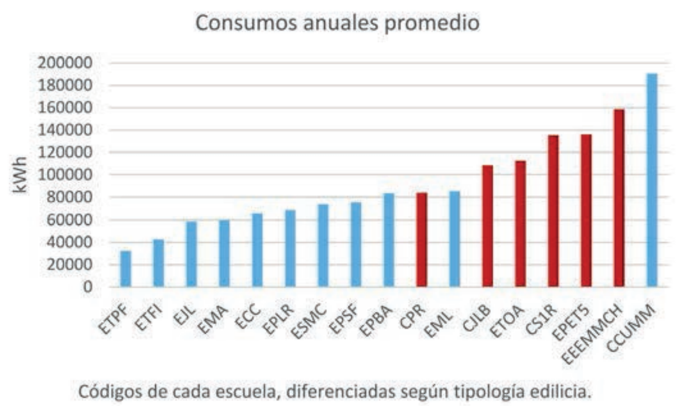

Figure 4: Average annual energy consumption. Source: Made by the author.

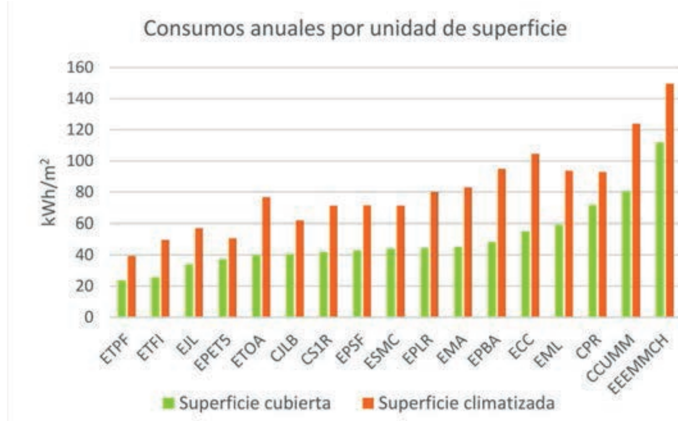

Figure 5: Annual energy consumption per m2 of covered and heated surface. Source: Made by the author.

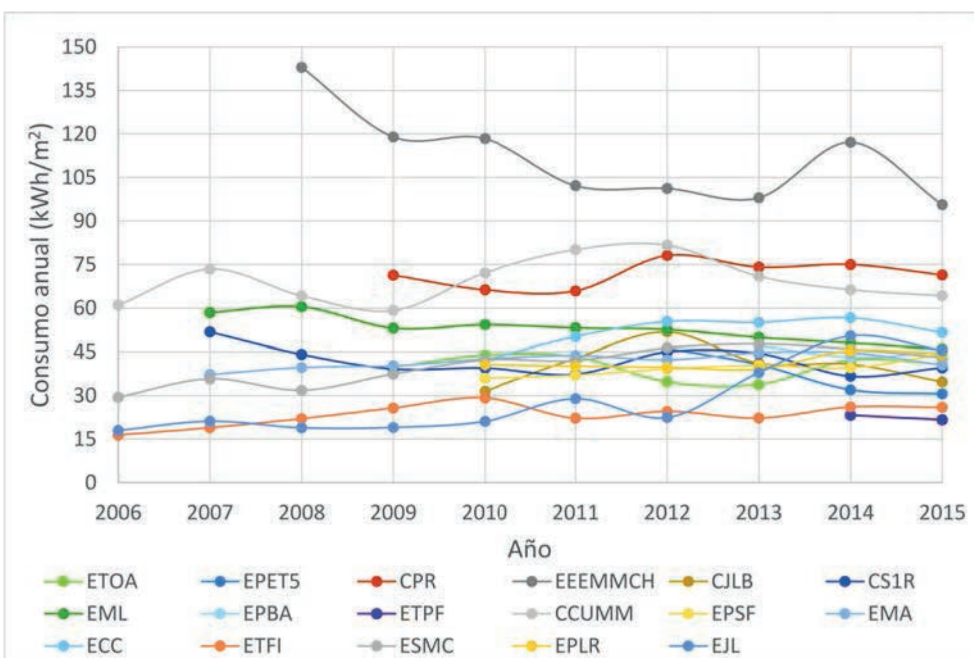

Figure 6: Temporal variation of annual energy consumption per unit of covered area. Source: Made by the author.

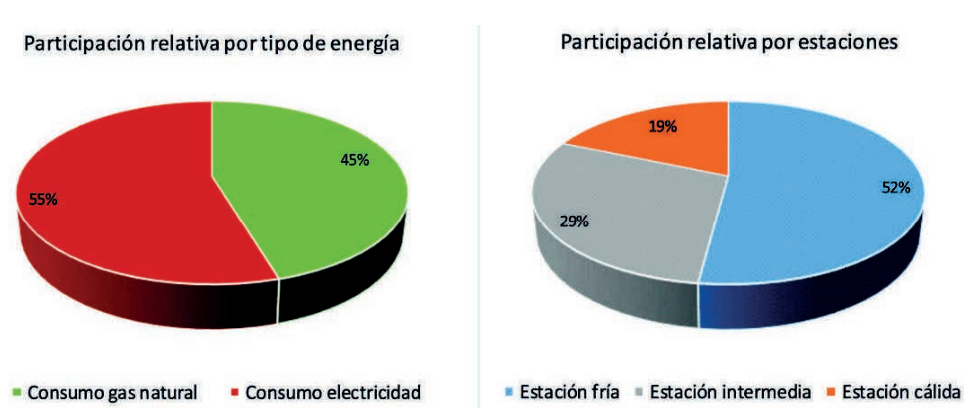

Figure 7: Relative participation of average annual energy consumption (2014 and 2015). Source: Made by the author.

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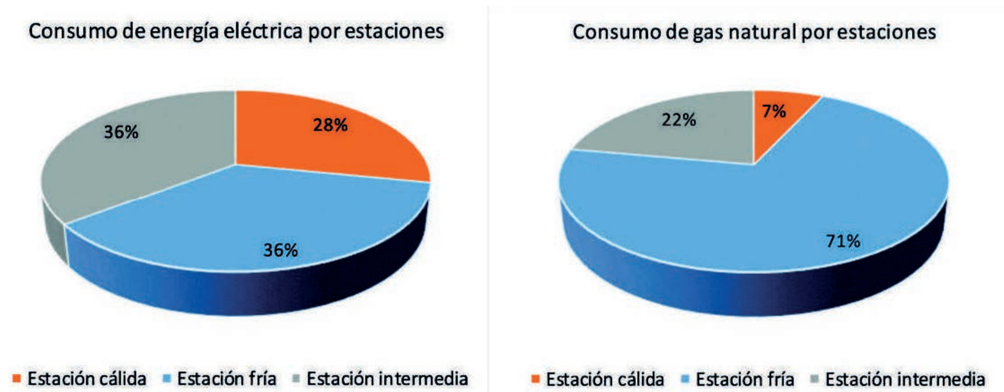

Figure 8: Consumption of electricity and natural gas according to season. Source: Made by the author.

consumption since the beginning of its activity in 2008; on the other hand, the CCUMM, belonging to the typology of the Five-Year Plan, fluctuates between values of 59,14 kWh/m2, in 2009, and 81,65 kWh/m², in 2012, disputing the second highest consumption position with the CPR (PN700), whose variations range from 65,91 kWh/m², in 2011, to 78,1 kWh/m², in 2012. The lowest consumptions during the entire instance of analysis are obtained by the schools ETPF and ETFI.

On the other hand, the relative participation of different types of energy in the total average consumed during 2014 and 2015 is investigated. The calendar year is divided into three seasonal periods, with the purpose of analyzing the incidence of electricity and gas in each one of them. The cold period is composed of the months of May, June, July and August; the warm one by November, December, January and February, and the intermediate stations formed by March, April, September and October.

Figure 7 (left) indicates that electricity consumption represents 55% of the average annual total. With respect to total energy consumption, the energy consumed in winter has the highest coefficient of variability1 among the study cases (63.9%) and also the highest seasonal relative participation (52%). The total energy consumed during the school year (cold and intermediate periods) represents 81% and far exceeds the energy consumed in summer (19%), a situation that is associated to the school break (Figure 7 right).

In terms of electricity consumption (Figure 8 left), its relative share in the cold months is equal to that of the intermediate period (36%). The fact that there is more electricity consumption in the intermediate seasons than in summer (28%), is associated with a greater demand for equipment, lighting and cooling of spaces, during the class period. With regard to natural gas (Figure 8 right), consumption in the cold period it gets to 71% and shows the highest coefficient of variation among the case studies (87%), which may be associated to architectural variables, climatic conditions and/or behavior of users.

CONSUMPTION AND ARCHITECTURAL VARIABLES

In Figure 9, the relations between the Glazed Area to the North (m2) and the total annual, seasonal, and energy source are observed in different scatter plots. Table 1 shows the statistical indicators of the analysis.

Energy Consumption		R2	Value-P	Correlation coefficient
Annual	Total	0.386	0.0001	0.62
	Electricity	0.504	0.0000	0.71
	Natural Gas	0.093	0.0779	0.31
Cold season	Electricity	0.542	0.0000	0.74
	Natural Gas	0.162	0.0181	0.40
Warm season	Electricity	0.311	0.0006	0.56
	Natural Gas	0.395	0.0001	-0.63
Intermediate season	Electricity	0.526	0.0000	0.725
	Natural Gas	0.018	0.4421	-0.136

Table 1: Statistical indicators of the analysis of the glazed area to the North vs. Energy consumption. Source: Made by the author.

[1] The coefficient of variation is the ratio between the standard deviation and the average * 100; where the typical deviation or standard deviation is the measure of parametric dispersion equal to the square root of the variance or the mean of the square of the deviations of the values of a distribution with respect to its average (Sierra Bravo, 1991:174).

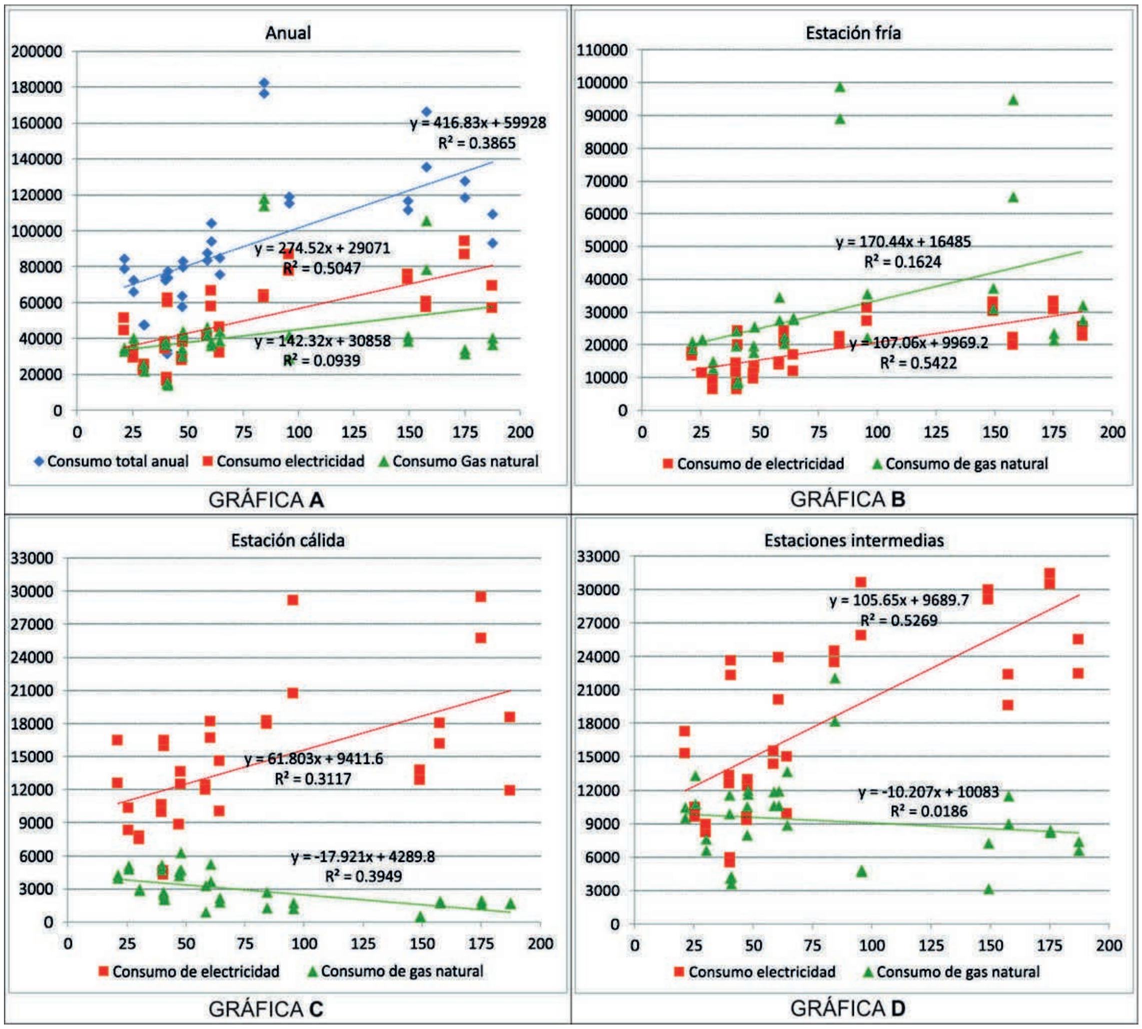

Figure 9: Simple regression analysis; Glazed area to the north (m2) on the X axis and Energy consumption (kWh) on the Y axis. Graph A: Annual consumption. Graph B: Cold season. Graph C: Warm season. Graph D: Intermediate season. Source: Author's elaboration.

Graph A shows the regression lines and the value of R2 for annual consumption. For total consumption and electricity consumption (which absorbs 55% of total consumption according to Figure 7 left), the correlation coefficients would indicate a moderately strong relationship between variables with values of 0.62 and 0.71, respectively, both with a P-Value less than 0.05. In the case of natural gas, with a P-Value of 0.0779, there would be no statistically significant relationship and the correlation coefficient (0.31) would indicate a weak association between variables.

For the cold period and in divergence with what is expected considering a design variable that would allow direct solar gain, the regression lines are rising (Figure 9, Graph B). From the statistical point of view, the correlation coefficient for electricity consumption in winter is 0.74 and the P-value is less than 0.05, there is a moderately strong and statistically significant relationship between variables. In the case of natural gas, the correlation coefficient is 0.40 and it would indicate a relatively weak relationship (Table 1). The glazed areas to the North in the studied buildings are not always free from obstructions, a situation that would reduce the effectiveness of the collection area. The implantation of perennial tree species, the incorporation of carpentry with distributed glass and the presence of partially closed mobile sunshades, hinder the possibility of using solar energy to heat indoor spaces in winter. In addition, the increase in electricity consumption for lighting, due to the reduction of hours of natural light; it is also possible that the rising trend is due to the use of auxiliary air conditioning equipment powered by electricity, in the administrative sectors.

In Figure 9 (Graph C), the regression lines of the behavior between the variables in summer are illustrated. Electricity consumption shows a rising trend, with statistical indicators showing a P-value of less than 0.05 and a correlation coefficient of 0.56, which suggests a moderate relationship between variables (Table 1). It is possible that an inadequate design of shade elements for the summer period generates the heating of the glazed areas in certain hours and conditions the requirement of greater cooling load.

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The behavior of energy consumption in the intermediate seasons is shown in Figure 9 (Graph D). Regarding electricity, a statistically significant relationship is distinguished (P-value less than 0.05) and moderately strong between variables, with a correlation coefficient of 0.725. For natural gas, the relationship is negative, showing that the larger area decreases consumption, however, this relationship is weak (correlation coefficient -0.136) and it is not statistically significant (Value - P = 0.4421). The intermediate seasons are characterized by the presence of thermal anomalies, very marked in the case of San Juan, which has cold or temperate days and others with high temperatures. In this way, it is possible to infer that the building requires a greater auxiliary load of cooling regarding the increase in temperature of the glazed area, product of an adequate design of the respective shadow elements.

Finally, the energy consumption is related to the K global (W/m^2. °C), it refers to the constructive technology of the building envelope (Figure 10). Table 2 shows the statistical indicators of the simple regression analysis.

Energy consumption		R2	Value-P	Correlation coefficient
Annual	Total	0.277	0.0014	0.53
	Electricity	0.438	0.0000	0.66
	Natural Gas	0.043	0.2332	0.21
Cold season	Electricity	0.438	0.0000	0.66
	Natural Gas	0.094	0.0766	0.31
Warm season	Electricity	0.341	0.0003	0.58
	Natural Gas	0.365	0.0002	-0.60
Intermediate season	Electricity	0.434	0.0000	0.66
	Natural Gas	0.042	0.2426	-0.21

Table 2. Statistical indicators of the analysis of K global vs. energy consumption. Source: Self made.

In Graph A of Figure 10, the regression lines and the R2 value of the relationship with the annual energy consumption are observed. Results show that, for the total energy and electricity consumption, the correlation coefficients would indicate a moderate relationship between variables, with values of 0.53 and 0.662, respectively. In both cases, the P-value is less than 0.05, giving a statistically significant relationship with a confidence level of 95%. In the case of natural gas, there would be no relationship between variables (correlation coefficient of 0.21).

The regression lines of the analysis during the winter period are shown in Figure B (Figure 10). According to the statistical indicators obtained (Table 2), the correlation coefficient for electricity consumption is 0.66, which suggests a moderately strong and statistically significant relationship (P-value less than 0.05) between variables. The correlation coefficient in the case of natural gas is 0.094 and it would indicate a relatively weak relationship, with a P-value greater than 0.05. Results show that the consumption of electricity increases considerably with the decrease of thermal resistance of the envelope, which could indicate, for some cases, the need to use auxiliary electrical equipment for heating in administrative spaces.

Figure 10 (Graph C) shows the relationship between the variables in summer, with rising lines of regression in electricity consumption, whose statistical indicators (Table 2) reveal a P-Value less than 0.05 and a correlation coefficient of 0.58, which suggests a moderate relationship. The increase in electricity consumption is noticeable as the global K values increase, which could connote that, the greater the heat exchange with the exterior, through a building envelope with values of low thermal resistance and high absorption coefficients in the roof tiles of colonial tiles (PQ) or with tile coverings (PN700), an increase in the energy requirement for cooling occurs.

The behavior of the electric power consumption in intermediate seasons (Figure 10, Graph D) denotes a statistically significant (P-value less than 0.05) and moderately strong relationship among the variables, with a correlation coefficient of 0.66, which could indicate the use of cooling equipment, at certain times of the day of classes, for a period characterized by large daily and stationary thermal amplitudes. Regarding natural gas, the trend is negative with a weak relation (correlation coefficient -0.206, value - P = 0.4421).

CONCLUSIONS

The work carried out allowed reach the proposed objective. The results obtained generate a significant contribution to the state of knowledge, providing data referring to the energy consumption of school buildings in the Metropolitan Area of San Juan, of two representative typologies. Based on the study, a range of annual energy consumption is recognized between 23.56 kWh/m^2 and 80.33 kWh/m2 of covered area, for the schools of the Five-Year Plan, and between 37.34 kWh/m^2 and 111, 82 kWh/m^2, for those that integrate the Programa Nacional 700 Escuelas. The amplitude of the energy consumption margins in the different UA

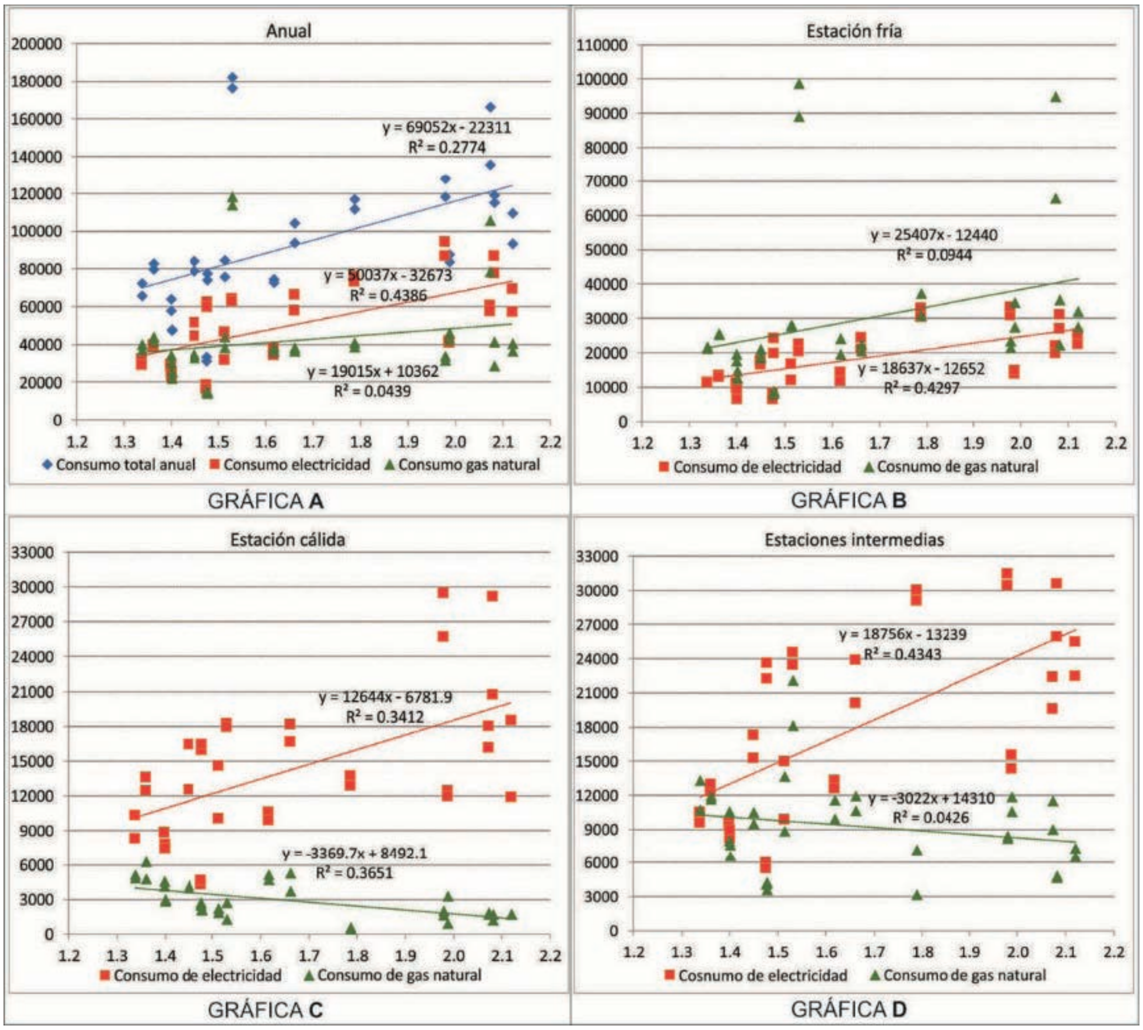

Figure 10: Simple regression analysis; Global K (W / m2.K) on the X axis and Energy consumption (kWh) on the Y axis. Graph A: Annual reports. Graph B: Cold season. Graph C: Warm season. Graph D: Intermediate seasons. Source: Self made.

could be conditioned by the state of conservation of the building infrastructures, the hours and days of use, and/or the behavior of the users and those responsible for the operation of the buildings.

The availability of consumed energy information conditioned the sample of those schools with uninterrupted data during 2014 and 2015. The results revealed that electricity is the most used annually, with a participation of 55%, since it serves to supply lighting at day and at night, the operation of equipment (refrigerators, freezer, computers, printers), the cooling of environments and, in some cases, auxiliary heating in teaching and administrative sectors. As for seasonal energy consumption, the highest records occur in winter with 52%, with a demand for natural gas that gets to 71%. The energy consumption, per unit area average for study cases, is 21.80 kWh/m^2 (covered surface) and 35.50 kWh/m^2 (heated surface), for natural gas, and 26.24 kWh/m^2 and 42.73 kWh/m^2 for electricity, respectively.

The statistical study allowed conclude that, for the sample analyzed, the Glazed Area to the North is an influential variable in the total energy and electricity consumption, but not in the natural gas consumption (main energy source used for heating). The direct solar gains in winter would not be enough to contribute to the air conditioning of the interior spaces due to possible obstructions, but they would negatively affect the environments in summer due to overheating. It was possible to detect, in the cases that present the highest consumption per unit of heated surface (EEMMCH, CCUMM, ECC, EPBA), that a large part of classrooms and administrative spaces are facing South or East, and the glazed areas to the North correspond to closed circulation areas or enclosed patios.

Regarding the global K variable, a strong relation of the increase of the electrical consumption in summer months and intermediate seasons regarding less efficient envelopes is recognized; this factor could indicate the greater use of auxiliary equipment for space cooling, as the cause of a building envelope that presents heat exchanges during class time.

The analyzes performed with the architectural variables allowed to confirm the importance of the design of the envelope and its association with the energy consumption. These variables exhibit a strong potential for improvement: a change that aims to increase the energy efficiency of school buildings, preserving and/or optimizing thermal and lighting comfort conditions.

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