Energy footprint and the quality of life of users of multifamily buildings in the Santiago de Surco district of Lima – Peru

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Abstract.
The present research aims to determine the relationship of the energy footprint with the quality of life of users of multifamily buildings in the district of Santiago de Surco in Lima, the biggest cause of global warming is carbon dioxide with a large percentage that is due to the burning of fossil fuels, so when building real estate units, whether a new one or choose one that already exists is important to pay attention to its energy efficiency, The results of a questionnaire to collect data on topics such as energy consumption of appliances and lighting, indoor air quality, thermal and acoustic comfort, which are intended to serve as insights when determining the relationship of the energy footprint with the quality of life). As a result, it is deduced that there is a very high significant correlation between the variables Kg of CO2 and Kw for the use of air conditioning equipment. The correlation coefficient is equal to 0.094, which is a value very close to zero, so its correlation is Null. On the other hand, having a p-value of 0.181 greater than 0.05, there is no significant correlation between the variables Kg of CO2 and Kw for the use of artificial light. Finally concluding that there is a relationship between the energy footprint and the quality of life of the users of multifamily buildings in the district of Santiago de Surco in Lima.

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1. Introduction

While advances in science and technology have improved our quality of life, they have also revealed that within the construction sector, efforts are still not sufficient to counteract the fragile balance of the environment. The construction industry contributes significantly to various environmental impacts, including global warming and the depletion of natural resources. Global warming is no longer a distant concept, but a real threat to the future of humanity, which is why construction processes must preserve ecosystems, biodiversity and local landscapes, as well as ensure a better quality of life, guarantee the health and safety of the users of multifamily buildings [1][2].

Real estate developments generate environmental impacts throughout all stages of their life cycle, from the extraction of raw materials, transportation, the production process of materials, use, maintenance and demolition, hence the importance of designing and constructing sustainable buildings, which is why this research work will focus on determining the relationship of the energy footprint with the quality of life of the users of multifamily buildings in the district of Santiago de Surco in Lima.

The growth of the world economy implies a significant increase in energy consumption, forecasts point to an increase in energy consumption of 30% by 2040, this new scenario requires the development of energy efficiency practices, to protect the environment by reducing energy intensity and reducing carbon dioxide emissions, however, is society really aware of the importance of reducing energy consumption.

It is known that the major cause of global warming is carbon dioxide with a large percentage due to the burning of fossil fuels, so when building real estate units, whether a new one or choose one that already exists is important to pay attention to their energy efficiency, know what they consume and CO2 emissions emitted into the atmosphere, since the increase of CO2 and other greenhouse gases can cause unprecedented and irreversible changes in climate systems [3].

On the other hand, we must not lose sight of the fact that the renovation of real estate units or buildings has a negative impact on the environment, and their maintenance and use produce almost constant energy costs that increase greenhouse gas (GHG) emissions such as ozone (7%), carbon dioxide (56%), methane (18%), nitrous oxides (6%) and chlorofluorocarbons (13%). These gases trap an increasing portion of terrestrial infrared radiation, and several climate models predict that planetary temperature would increase by 2 to 7◦C in one hundred years[4][5].

The construction sector has a multiplying and multisectoral effect in relation to the large critical mass that moves in order to execute works in both the public and private sectors, however, multifamily building projects generate great impact on their environment, since they transform the site and turn it into areas that consume natural and energy resources, as well as generate waste and emissions, being responsible for: consuming 50% of water resources, 25% of forest destruction and the generation of 23% of solid waste.

Similarly, the historical use of hazardous materials in construction, specifically asbestos, mercury and lead, has had serious and negative impacts on human health. Diseases caused by exposure to these chemicals, including asbestosis, developmental problems in children and various forms of cancer still affect millions of people. While these compounds have been restricted or banned in buildings in many countries, they still pose a threat in countries that have not yet enacted the necessary limitations [6].

The role that buildings can play in human health and well-being is remarkable, so there is a need to understand the relationship between indoor air quality and human health, as well as the importance of creating spaces that enhance, rather than hinder, health and well-being for users of multifamily buildings especially considering that people spend approximately 80% of their time in these real estate units. During this time, inhalation exposure to indoor air pollutants can result in a variety of short- and long-term negative health and wellness outcomes that can vary in severity. Less severe symptoms of exposure may include headaches, dry throat, eye irritation or runny nose, while more serious health outcomes may include asthma attacks, infection by Legionella bacteria, among others. In the U.S. alone, indoor pollution contributes to thousands of cancer deaths and hundreds of thousands of respiratory health problems annually.

The most common indoor air pollutants are combustion sources, such as candles, tobacco products, stoves, furnaces and fireplaces, which release pollutants, such as carbon monoxide, nitrogen dioxide and small particles into the air (Cooperative Extension Service, University of Kentucky, generating health impacts, so the objective of this research work is to determine the relationship of the energy footprint with the quality of life of users of multifamily buildings in the district of Santiago de Surco in Lima. [7]

The impacts, especially the negative ones, on the environment and human beings such as: the inefficiency of energy consumption generated by the users of multifamily buildings and by the whole process of construction activity as a whole, entail anthropogenic effects, among which are the depletion of resources, loss of biological diversity due to the extraction of raw materials, elimination of waste, harmful effects on the environment and human health, due to poor indoor air quality, global warming, acid rain and smog caused by emissions generated by the manufacture of construction products and energy-consuming transportation, since any construction process requires various machinery and natural resources that generate many pollutants.

Several researchers, among them, summarize these pollutants as: noise pollution, air pollution, solid and liquid waste, water pollution, harmful gases and dust.

Most "construction activities such as excavation, backfilling, earth moving, whitewashing, painting, tiling, concrete mixing and finishing works cause an unfavorable effect on the environment, as they generate a large amount of particulate matter, increasing the risk of respiratory and cardiovascular diseases, as well as causing thousands of cancer deaths per year".

1.1 Frequent indicators of environmental impact

Global Warming Potential or carbon footprint or greenhouse gas emissions (Global Warming Potential GWP). It is an indicator that quantifies the amount of direct and indirect Greenhouse Gas (GHG) emissions that are released due to an activity or process.

This impact is directly related to climate change and serves as a tool for managing emissions in order to make more efficient use of resources and reduce the impacts of the activity in question. GHG emissions are quantified at all stages of production in terms of CO_2 equivalent (CO2eq) and their result and analysis can be used for the optimization of processes and raw materials as can be seen in Figure 1 on the analysis of a commercial project where different materials are compared for modelling [8].

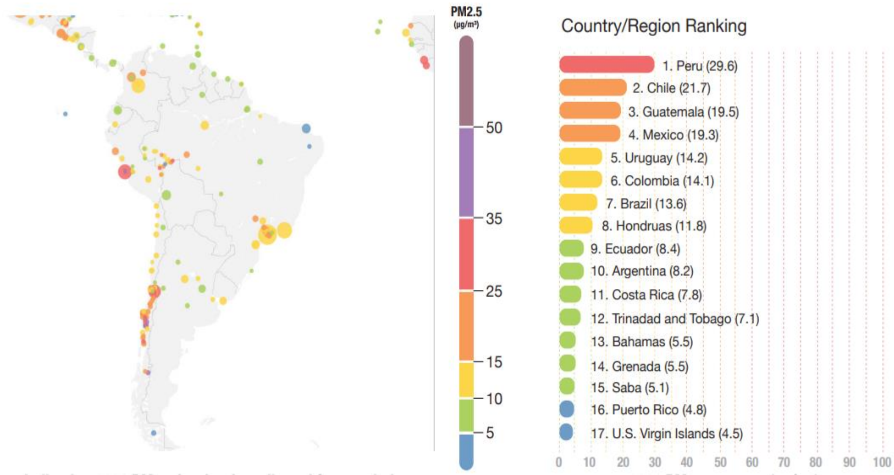

Figure 1. City markers indicating 2021 PM2.5 PM2.5 average PM2.5 levels (μg/m³). 2021, size adjusted for population

2. Method

2.1Population

The population for this research will consist of the multifamily buildings (EM) of projects A and B located in sectors 34 and 41, respectively, of the district of Santiago de Surco. For the selection of the MS, the following criteria were considered: i) height, ≥ 8 stories, ii) area of real estate units within the range of 60 to 140 m2, iii) apartment distribution: living room, kitchen, master bedroom, 3 and/or 2 secondary bedrooms, master bathroom, two bathrooms, a guest bathroom and laundry room, iv) type of building, porticoed and/or limited ductility, v) building type: aporticada and/or limited ductility [9].

2.2Procedures

For the development of this research work, environmental statements were reviewed in order to know how the sector is working globally to feed back and reduce the environmental impact of construction materials of multifamily buildings in order to determine the relationship of the energy footprint with the quality of life of users of multifamily buildings in the district of Santiago de Surco in Lima, to improve the standards of quality of life and welfare, considering as indicators the aspects related to health, housing, recreation and safety [10].

2.3Geographical identification

The geographic information process began by identifying the most important information for the purposes of the project, which included variables to determine the local climatic conditions near the evaluation projects, using the information provided by SENAMHI and the RNE standard E020, as well as the land use zoning to which the buildings of projects A and B considered in the research correspond according to ordinance N°620 of the Metropolitan Municipality of Lima (MML).

The beginning of the geographic information processing started by using the satellite views georeferenced with the UTM Datum WGS84 zone 18 coordinate system, obtained from the photogrammetry performed in the area, from which representative polygons of the buildings were generated to obtain the centroid of the polygon as shown in Figure 2, whose coordinates are representative for both cases of the buildings.

Subsequently, the area of the district where the structures were located (Santiago de Surco) was delimited and considered as the area of interest to obtain the geographic information from different databases [11].

Finally, once the interpolation method to be used was selected, the information was presented in two ways, the first one being a view with intervals classified as a histogram, to which a single coloration was associated, and the extended rendering way, in which the colorations are progressive and respond to a color bar that uses shades that increase according to the value. Both views can each be seen in a dataframe for the PM10, PM2.5 and SO2 variables. It can also be seen in Figure 2, which shows the histogram method on the left side and the gradual coloring method on the right side [12].

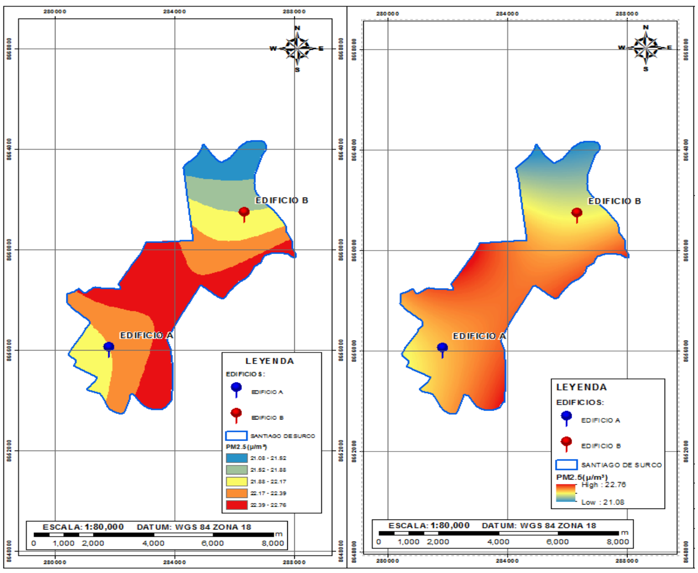

Figure 2. Dataframe for the variables PM10, PM2.5 and SO2

2.4

2.5Data analysis

The analysis of the results were presented based on the information obtained from the energy data matrix, for which a survey of the users of the buildings was also structured, covering the concepts of: i) energy, ii) comfort and iii) lifestyles.

2.5.1 Study site

Aerial data acquisition was performed using a Remotely Piloted Aircraft System (RPAS). First, flight plans were developed to cover the entire study area, which are the trajectories along which the aircraft will travel. Once the aircraft has taken off, since it has a satellite navigation system, it will move to the various positions where it has been calculated that it will capture aerial images, depending on the flight lines, flight height and photo overlap (characteristics that have been configured in the flight plan). These images are then processed, generating a digital terrain model and an updated orthophoto of the study area correctly georeferenced thanks to the ground photocontrol points determined. The elaboration of the flight plans has been carried out with a mobile application used in iOS operating system. Figure 3 shows the flight plan programmed for the RPAS to cover part of the study area [13].

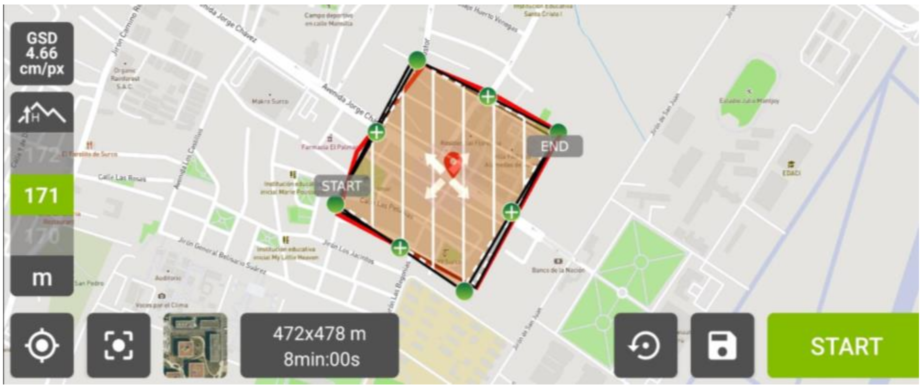

Figure 3. Scheduled flight plan within the study area

The longitudinal overlaps as well as the transverse overlaps in the aerial shots were adjusted to 80% in both cases, as shown in Figure 3. In this way, better detail is obtained in the processing and overflying is avoided in case of missing images in any section of the flight plan [14].

3. Results

Table 1. Most representative characteristic of the sample

Type of house	Real Estate Projects	
Characteristics	Project A	Project B
	8-story buildings	8-story buildings
	32 apartments	32 apartments
	area of 60 and 74 m2	area of 60 and 74 m2
Área	Type A	Type B
60 m2	34,74%	10,53%
74 m2	33,68%	21,05%
	68,64%	31,55%

According to the characteristics of the sample summarized in Table 1, it can be defined as a sample of 95 real estate units surveyed in 2 multifamily developments, where 68.64% corresponds to project A and 31.55% corresponds to project B[15].

Table 2. Frequency of surveys by building type

	Frequency	Percentage	Valid	Cumulative Percentage

			Percentage	
Type A	65	68,4	68,4	68,4
Type B	30	31,6	31,6	100
Total	95	100	100	

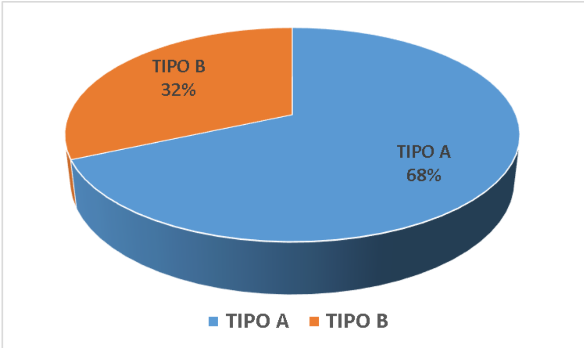

Figure 4. Survey frequencies by building type

According to the results of the 95 surveys between the two projects, which we have called A and B respectively, 65 surveys were conducted for project A, representing 68.4%, and 30 surveys were conducted for project B, representing 31.6% [16].

3.1Comparative Analysis of Means

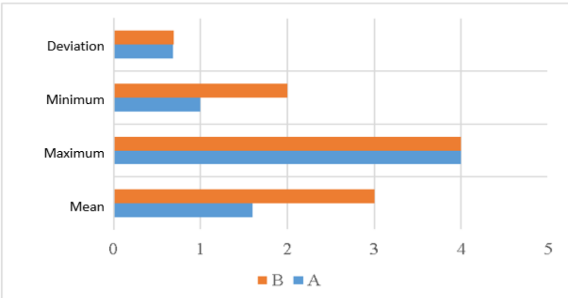

Figure 5. Comparative analysis of household wage income by type of project

The variable Family income is a categorical variable, which was divided into 4 ranges:

- 1: income less than 8000 soles
- 2: income between 8001 and 15.000 soles
- 3: income between 15001 and 30,000 soles
- 4: Income over 30,001 soles

With respect to project A, the average income is 1.6, equivalent to salaries between 5001 and 15,000 soles.

On the other hand, for project B, the mean has an income of 3 equivalent to salaries greater than 15. 001 and less than 30,000 soles [17].

In both cases their deviation is positive and close to zero, so the values are close to the mean.

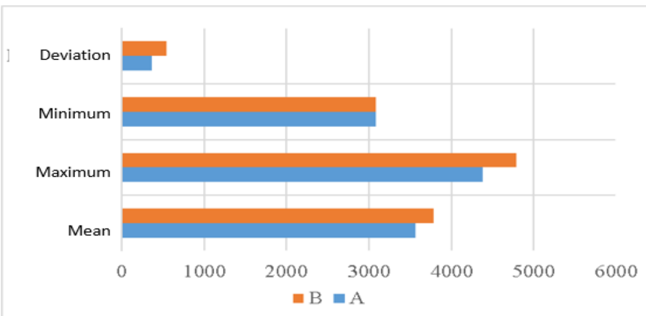

Figure 6. Proyect A

As can be seen in the graph, with respect to project A, the average Kw consumption for the use of household appliances is 3,567.45 Kw, with a maximum consumption of 4,381.20 and a minimum consumption of 3,080.70. The deviation indicates that most of the values are close with a maximum difference of 362.93 to the mean.[18] The deviation indicates that most of the values are close to the mean.

Regarding project B, the average Kw consumption for the use of household appliances is 3,785.04 Kw, with a maximum consumption of 4,786.20 and a minimum consumption of 3,080.70. The deviation indicates that most of the values are close to the mean with a maximum difference of 362.93 to the mean.

According to the total result, the average daily appliance consumption between the two projects is 3,636.16 kW per year.

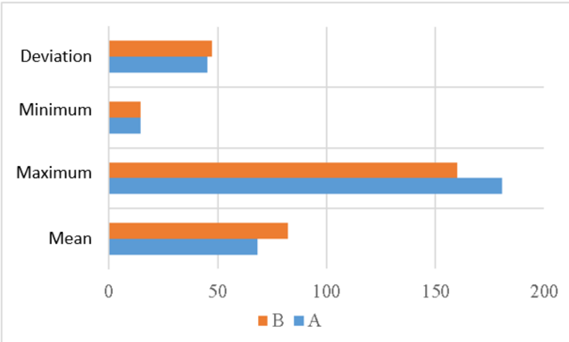

Figure 7. Comparative analysis of Kw consumption by household appliances for weekly use per year

As can be seen in the graph, in relation to project A, the average consumption of kW for the use of weekly appliances is 68.10 kW, with a maximum consumption of 180.48 and a minimum consumption of 14.40 kW. The deviation indicates that most of the values are close with a maximum difference of 45.20 to the average.

With respect to project B, the average Kw consumption for the use of appliances for weekly use is 82.03 Kw, with a maximum consumption of 160.08 and a minimum consumption of 14.40. The deviation indicates that most of the values are close to the mean at a maximum difference of 47.31 to the mean, which indicates values far from the mean[19].

According to the total result, the average consumption in appliances for weekly use between the two projects is 72.46 KW per year.

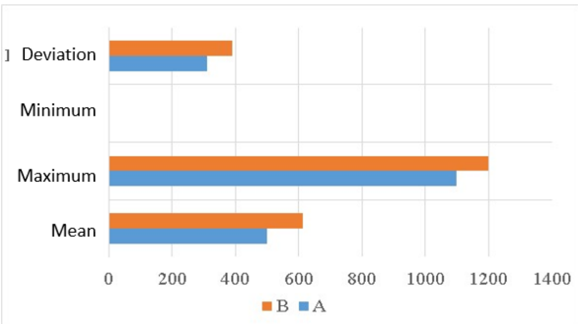

Figure 8. Comparative analysis of Kw consumption averages for weekly electrical equipment consumption per year

As can be seen in the graph, in relation to project A, the average consumption of Kw for the use of electrical equipment used weekly is 498.43 Kw, with a maximum consumption of

1099.20 and a minimum consumption of 0.0. The deviation indicates that most of the values are close with a maximum difference of 312.03 to the mean.
Regarding project B, the average Kw consumption for the use of electrical equipment for weekly use is 611.70 Kw, with a maximum consumption of 1199.04 and a minimum consumption of 0.0. The deviation indicates that most of the values are close to the mean at a maximum difference of 390.68 to the mean, which indicates values far from the mean [20].
According to the total result, the average consumption in electrical equipment for weekly use between the two projects is 534.20 KW per year.

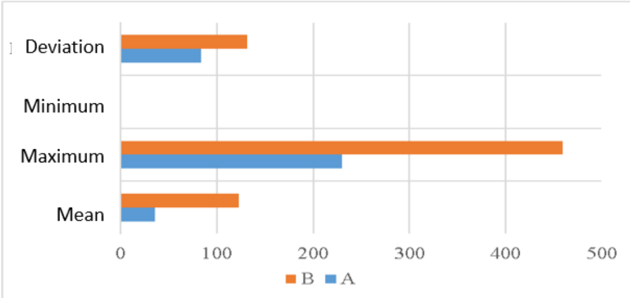

Figure 9. Comparative analysis of average Kw consumption in ventilation equipment for quarterly use per year.

The graph shows that the average Kw consumption of ventilation equipment per year in project A was 35.31 Kw, with a maximum consumption of 229.50 and a minimum consumption of 0.0. The deviation indicates that most of the values are close with a maximum difference of 83.45 from the mean.
Regarding project B, the average Kw consumption for the use of ventilation equipment per year is 122.40 Kw, with a maximum consumption of 459.00 and a minimum consumption of 0.0. The deviation indicates that most of the values are close to the mean with a maximum difference of 131.12 to the mean, which indicates values far from the mean [21].
According to the total result, the average consumption of ventilation equipment between the two projects is 62.81 KW per year.

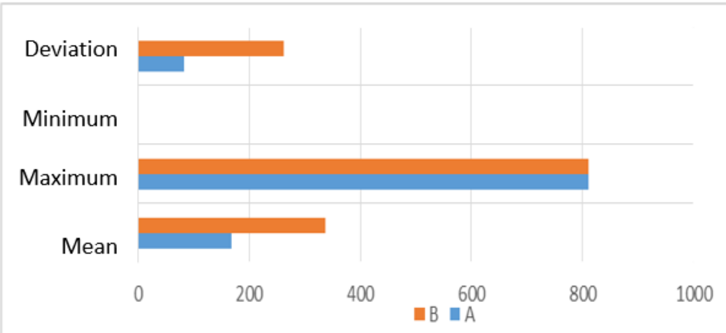

Figure 10. Comparative analysis of averages by Kw consumption in heating equipment for quarterly use per year.

As can be seen in the graph, in relation to project A, the average Kw consumption for the use of heating equipment used in three months of the year is 168.23 Kw, with a maximum consumption of 810.00 and a minimum consumption of 0.0. The deviation indicates that most of the values are close with a maximum difference of 83.45 to the mean.
Regarding project B, the average Kw consumption for the use of heating equipment used in three months a year is

337.50 Kw, with a maximum consumption of 168.23 and a minimum consumption of 0.0. The deviation indicates that most of the values are close to the mean at a maximum difference of 262.33 to the mean, indicating values far from the mean [22].

According to the total result, the average consumption of heating equipment used in three months of the year is 221.69 kW per year.

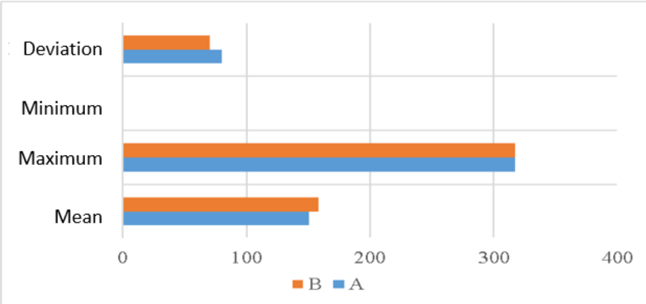

Figure 11. Comparative analysis of averages by Kw consumption in computer equipment per year

As can be seen in the graph, in relation to project A, the average consumption of Kw for the use of computer equipment per year is 150.42 Kw, with a maximum consumption of 316.80 and a minimum consumption of 0.0. The deviation indicates that most of the values are close with a maximum difference of 79.98 to the mean [23].

Regarding project B, the average Kw consumption for the use of computer equipment per year is 157.92 Kw, with a maximum consumption of 316.80 and a minimum consumption of 0.0. The deviation indicates that most of the values are close to the mean with a maximum difference of 70.19 to the mean, which indicates values far from the mean.

According to the total result, the average consumption of computer equipment per year is 152.79 Kw per year.

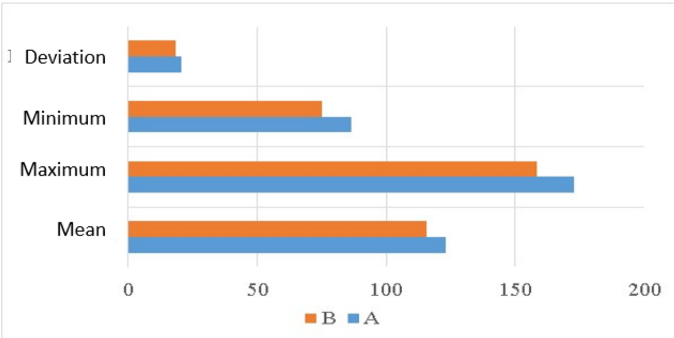

Figure 12. Comparative analysis of averages by kw consumption in artificial light use per year.

As can be seen in the graph, in relation to project A, the average Kw consumption for the use of artificial light per year is 123.18 Kw, with a maximum consumption of 172.80 and a minimum consumption of 86.40. The deviation indicates that most of the values are close with a maximum difference of 20.68 to the average.

Regarding project B, the average Kw consumption for the use of computer equipment per year is 115.58 Kw, with a maximum consumption of 158.40 and a minimum consumption of 74.88. The deviation indicates that most of the values are close to the average with a maximum difference of 18.35 to the average, which indicates values far from the average [24].

According to the total result, the average consumption of computer equipment per year is 120.79 Kw per year.

- The average analysis will be compared between the total carbon footprint produced by each real estate unit and its consumption of: appliances, air conditioning equipment, computer equipment and consumption of artificial light. If the sig value > 0.05, it is concluded that:

- The energy footprint is not significantly related to the quality of life of the users of multifamily buildings in the district of Santiago de Surco of Lima-Peru. If the sig < 0.05 then the proposed hypothesis is accepted. The energy footprint is significantly related to the quality of life of the users of multifamily buildings in the Santiago de Surco district of Lima-Peru. To establish the correlation value, Pearson's R scale is used.

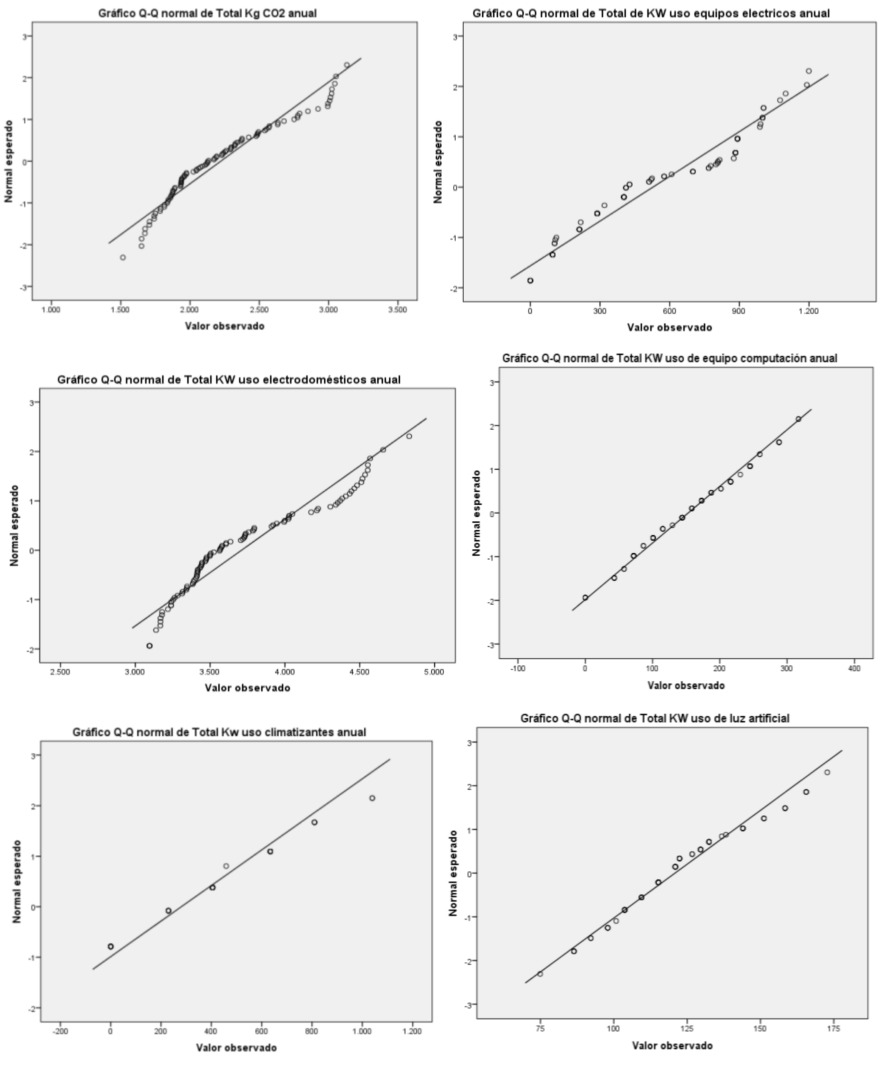

Figure 13. Normality between expected and observed

The energy footprint is significantly related to the quality of life of the users of multifamily buildings in the district of Santiago de Surco in Lima-Peru. In other words, it is observed that the greater the use of household appliances and electronic equipment, the greater the CO_2 production.

4. Discussions

According to the research developed, the results obtained affirm that there is a high correlation between the variables of energy footprint and quality of life, specifying that the correlation coefficient is equal to 0.839, therefore, the variables are directly related. Observing the p-value (0.000), thus rejecting the null hypothesis, there is a Very High significant correlation between the variables Kg of CO2 and Kw for the use of electrical equipment, but being low in the LEDs. [25] Entitled "Energy Life Cycle and Carbon Footprint in Two Types of Family Residences in the City of Lima" where their results show that the highest carbon footprint performance in the single-family residence occurs in the construction phase and in the multifamily residence occurs in the operation phase, The carbon footprint of the single-family residence is affected by the type and quantity of construction material, the energy sources used for its production as well as the electrical energy used in the appliances. [1] which is significantly impacted by the energy consumption per capita and the energy mix of the country. [7] As can be seen, the inefficient use of electrical energy has repercussions at the economic, social, environmental, educational and health levels, that is, in general, on the quality of life of the people [26].

5. Conclusions

The relationship of the energy footprint with the quality of life of the users of multifamily buildings in the district of Santiago de Surco in Lima, is direct between these two variables, rejecting the null hypothesis, evidenced by the fact that they do not consider some type of mitigation in terms of GHG emissions, and in the construction with environmental or geo-climatic considerations from its design, and in the failure to comply with voluntary or mandatory regulations on energy efficiency, which leads to a low quality of life of the residents.

The relationship of the energy footprint with the inefficient use of energy resources of the users of multifamily buildings is direct, i.e. there is a direct relationship, rejecting the null hypothesis of the research, therefore there is a very high significant correlation between the variables Kg of CO2 and Kw for the use of electrical equipment, in other words, it is observed that the more use is made of household appliances and electronic equipment, the greater the production of CO2.

The relationship of the quality of life with the lifestyles of the users of multifamily buildings, there is a direct relationship between these variables directly, rejecting the null hypothesis of the research, since the inefficient use of electrical appliances leads to the production of CO2 which is a pollutant to the environment and affects the health of people and the lifestyle of each resident.

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