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Application of the "NET ZERO ENERGY BUILDING (NZEB)" Methodology, through Photovoltaic Solar Technology Integrated into Urban Environments

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Abstract:- In this research work, a sustainable alternative to the consumption of electrical energy generated by a traditional way is proposed, which is highly polluting worldwide, however, part of a deeper problem, since the buildings in which it has been implemented the use of technological systems for the autonomous generation of clean energy "are hidden" from the eyes of man, generally located on the terraces of buildings wasting the great potential of their facades, since they are not designed from the ground up. functional-aesthetic point of view. The application of the NET ZERO ENERGY BUILDING (NZEB) methodology is proposed, through the use of photovoltaic systems that can be integrated in urban environments, designed under architectural conditions that allow them to be used as finishing or facade material in buildings, at the same time that they generate enough electrical energy to cover the demand of the building, obtaining a zero energy balance "0", in this way An overview of this concept is provided for future interventions in similar buildings in the city. This research, for analysis, data collection, and application purposes is focused on a case study in a collective housing building in Azogues, Ecuador.

Keywords:- *Renewable Energies; Photovoltaic Solar Technology; Sustainability; Functional Facades.*

I. INTRODUCTION

At present worldwide, we are facing an environmental crisis due to the greenhouse effect caused by the emanation of different gases, especially carbon dioxide (CO2), this fact is directly associated with the energy sector due to the use of fossil fuels in generation of energy in a traditional way. This energy is consumed mainly in urban areas where buildings play a leading role, since more than 50% of the world's population lives in urban areas, which occupy less than 3% of the earth's surface [1], and this is where more than two thirds of the energy is consumed. Cities cause between 70 and 80% of greenhouse gas emissions and by 2050 66% of the world's population is expected to live in urban areas; Thus, with the current energy model, more and more resources will be required with the consequent environmental impacts that this implies [2]. Given this situation, governments and international institutions have established objectives for cities to be less aggressive towards the environment, in this sense, the UN General Assembly adopted the 2030 Agenda for Sustainable Development in September 2015. The objective of which is that cities are more resilient to climate change, while boosting the economy and reducing poverty [2]. Previous research has identified eleven technologies that use resources that are available in cities, of which eight can produce electricity: biomass, bio digester biogas, landfill biogas, waste incineration, tidal technologies, small wind, small hydro and photovoltaic [2]. The latter is the technology with the greatest potential for use in the building sector, since solar energy is an infinite resource and its application is rich in meeting the needs of the population [3]. However, in buildings in which the use of these technological systems has begun, they have been considered as a set of components that must be "hidden", since they are not designed from the aesthetic point of view to form part of the facade of a building; This fact generates a dissociation between architecture and technological element, the usual thing is the arrangement of these elements on the roofs or terraces, thus wasting the existing area on the facade of the collective buildings as a potential for the generation of clean energy given its size and proportion . As a society and as professionals involved directly or indirectly in housing construction projects on a different scale, we must be aware that our actions are not just about building bigger and more ostentatious homes, but about building better homes. For this reason, this research is focused on achieving "ZERO" consumption of energy produced in a traditional way, by through the use of photovoltaic systems, conceived under conditions of direct integration into the architecture, incorporating functionalities that provide added value with bio-inspired materials. This research, although part of a worldwide problem, for the purposes of analysis, data collection, and especially for the application in a real case, will focus on a case study in a collective housing building in the city of Azogues, Ecuador.

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➢ *Photovoltaic solar energy, brief historical context and new technologies*

Since ancient times, the human being has resorted to the sun in his desire to plan the first settlements, a determining fact in the organization, location, orientation and development of the first cities. The Toltec culture can be cited, who built their pyramids of worship of the gods and human sacrifices considering the solstice and the inclination of the solar rays, the location of the buildings of the urban complex, the openings and public spaces were arranged in a cosmic logic ruled mainly by the sun [4]. In the Greco-Roman settlements, the Roman architect Vitruvius recommended principles of location, composition, orientation and arrangement of buildings in his classic work *Ten Books of Architecture* [5] these fundamentals came from a study of harmonization and logic to project cities and buildings considering the resources of nature such as the sun and the wind, etc. [4] In the cities of the 18th century, the buildings were practically conditioned by the exploitation of coal as their only source of energy, a practice completely far from passive strategies, however, at the end of the 20th century the principles of passive capture were retaken from the collapse of the energy system. Photovoltaic energy was introduced to the public after having been developed by the aerospace industry for the operation of its remote facilities, and at the end of the dean of the seventies the Department of Energy of the United States of America began to promote its applications domestic [6].

Solar energy is one of the renewable energy sources with the greatest potential in the residential sector [7]. The basic photovoltaic unit is the solar cell, and with it the photovoltaic modules that transform light into electricity are composed. There are a variety of types with different efficiencies and powers. Photovoltaic modules are made up of several solar cells connected in series or parallel. This technology allows us to produce clean energy, taking advantage of the solar radiation that reaches our planet, it does not produce noise, nor does it emit harmful gases, so it is friendly to our environment. Photovoltaic systems integrated to buildings are often configured as small power generators dispersed in urban areas and have several advantages, among which are not needing additional space for their installation, not requiring additional investments for infrastructure, it has low cost of assembly and maintenance, and they do not produce environmental pollution. It can be specified as a generation system for the exclusive use of the building (decentralized generation) with storage elements -batteries- for periods without electricity, or it can also contribute the surplus that it does not use to the electricity grid of its community. Among the technologies that were reviewed for this research, the following stand out:
Smit's grow: solar and wind photovoltaic "leaves" [8]

This system was developed by Teresita Cochran's sustainable design group, SMIT (Sustainable Mind Interactive Technology), it is called GROW, it is a device for generating energy from a series of flexible solar cells in the form of leaves. ivy. Among the advantages of using this system we have the following:

- It can be easily mounted on a vertical wall due to its light weight.
- Their leaves are not static, which allows them to move and catch sunlight from many directions.
- Due to the organic shape of each panel, they look and act like real leaves, providing an image of a creeper plant.
- The power declared by the manufacturer is 33 watts for each m2 of “Solar leaves”.
- *Solar tiles* [9]
- Photovoltaic tiles are similar to conventional tile models, which are provided with mini solar panels inside, usually 4 photovoltaic cells. Its advantages are as follows:
- Its aesthetic adaptation to roofs.
- In general, the available area on the roofs is enough to cover 100% of the electrical demand of your house when installing the solar tiles.
- By installing bidirectional meters, the possibility of selling excess electricity generated is opened up, which can help to recoup part of the investment.
- If for any circumstance, a solar tile breaks or breaks down, it can be changed individually without affecting the entire installation.
- They can be installed both on sloping roofs (recommended), and also on roofs where the orientation is not ideal.

Recent studies data declare that its estimated power is 66 watts for each m2 of "Solar Tiles".

Fig.1. Solar Tile System

Similarly, Tesla Solar Roof [10] they have launched their first roof with integrated solar cells together with their Powerwall backup battery, and they have also committed to developing more economical models.

➢ *ONYXSOLAR* [11]

It is a leading Spanish company at a global level in photovoltaic glass for buildings. The main objective of this company is to replace the conventional glass used in the building envelope with glass capable of generating electricity, thus reducing its CO2 emissions. Among the most innovative solutions is the world's first transparent photovoltaic glass with Low-E properties and the first walkable photovoltaic floor with non-slip properties.

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➢ *Leaf-shaped photovoltaic panel_ GREENDIX* [12]

Silicon photovoltaic panel that has a leaf shape, fully integrable to homes at different scales and urban equipment, its general specifications are:

TABLE I. General specifications of Leaf-shaped photovoltaic panel

General Product Specifications	
Product name	GDXPMLEF-1250SAt
Efficiency [%]	> 13%
Power [w]	1.25 w
Voltage [V]	5.37 V
Isc [mA]	280 mA
Vmax [V]	5.0 V
Imax [mA]	250 mA
Shape	Sheet
Colour	Green
Module size [mm3]	170.52 (H) x 83.5 (V) x 3 (D)
Module surface	0.001428 m2
Weight [g]	45g.

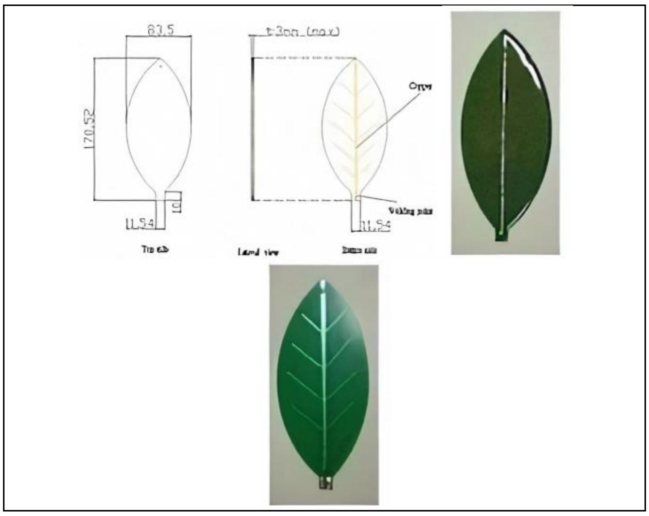

Fig.2. Leaf-shaped photovoltaic panel

➢ *Collective housing, importance.*

Collective housing according to French [13], has been a fertile field of experimentation in the 20th century and indicates the importance in the 21st century, mainly due to the ways of life, technological evolution and above all the need to increase the density of cities makes this typology have a considerable relevance. Collective housing as an urban space is probably the most determining factor in the image of the city, it is the architectural typology that makes up most of the urban structure of cities and is the protagonist of most real estate operations [14]. Collective housing as a typological manifestation has become a device for the urban, architectural and social transformation of the Latin American city, and it is a sample of cultural manifestation and a construction factor of the urban landscape, therefore, it constitutes a resource with enormous possibilities of enhancement, rehabilitation and reintegration of the urban fabric, landscape and functions, which opens a solution door, both to housing deficits and the need to repopulate urban areas [3]. The building analyzed in this research is the typical and most common one in the city, since the vast majority have 4 floors of construction with commercial uses on the ground floor and residential uses on the upper floors, which is why the data obtained from the This research can be considered and applied in other buildings in the region.

➢ *Case study in Azogues, Ecuador*

The territorial organization of the Republic of Ecuador is divided into provinces, and these in turn into cantons (cities), the case study building is located in the city of Azogues, capital of the province of Cañar, in the Andean region of Ecuador. According to the Ecuadorian Construction Standard, it is located in a Hot Humid Climatic Zone [15]. General data of the Building:

- Denomination: Castro Building. Year of construction: 2016.
- Typology: Collective housing, 4-storey high, attached to three sides and a single front facing west.
- Latitude: -2.746º. Longitude: 78.8486º. Altitude: 2,470 meters above sea level.
- Constructed area: Commercial premises on the ground floor of 80 m2; and three apartments of 120 m2 each.

Fig.3. Location of the building.

Fig.4. Current state of the building.

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II. METHOD

The research level of the present work is Applicative, its study universe is the buildings located in the Andean region of the southern Ecuadorian of a height between 3 to 5 floors and built in the last 10 years, due to similarity in features. The sample, as a research proposal, focuses on a case study in a collective house in the city of Azogues, Ecuador, in which it seeks to adapt the concept of "NET ZERO ENERGY BUILDING (NZEB)".

➢ *NET ZERO ENERGY BUILDING (NZEB).*

NZEB [16] refers to a building with a "zero" consumption of electrical energy; For this, bioclimatic design is used (in the design and construction phase of the building, it does not apply to the present investigation since it is a building already built), the implementation of electrical appliances with high energy efficiencies and finally to compensate the energy consumption required from renewable generation on site. The prefix NET indicates that the building will be connected to the general electricity supply network.

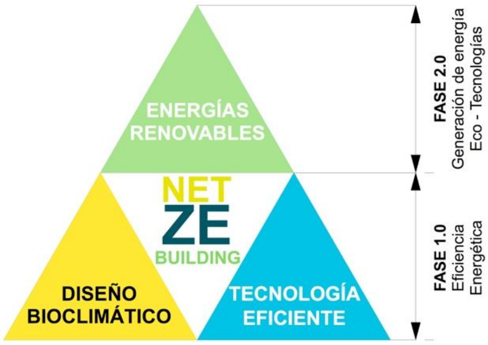

Fig.5. NET ZERO ENERGY BUILDING (NZEB).

We proceed to the following methodology:

1. Carry out the analysis of the energy matrix of Ecuador which is necessary to contextualize and characterize the problematic situation in the country, by reviewing the data declared in the MASTER PLAN OF ELECTRIFICATION, MINISTRY OF ELECTRICITY AND RENEWABLE RESOURCES 2018, they will be processed in specialized software.
2. We will proceed to determine the Baseline of the energy consumption of the collective housing case study, through the analysis of the electrical equipment, lights and their frequency of use. This activity will be carried out through the use of the "information sheet for electrical equipment and luminaires", developed by the author. These data should be contrasted with other secondary sources of information taken for the present investigation, these correspond to the consumption detailed in the electricity service payment sheets of the last 12 months (data correspond to the year 2019 which was the one with the highest electricity consumption, they were delivered to the author in digital form by the department of connections and meters of the Empresa Eléctrica Azogues).
3. Application of the methodology "NET ZERO ENERGY BUILDING (NZEB)", for which, the first requirement that a building must meet is to reduce its energy consumption through the implementation of highly efficient technology and applications, in the development of this research has been identified that the departments analyzed already have this type of technology, the same ones that are complying with the constant mandatory standard in the Standardization and Labeling Plan of the Ministry of Electricity and Renewable Energy [17] to promote the use of efficient equipment.

TABLE II. Types of technologies installed in the building

Type of artifact	Performance range	Reference norm
LED lamps and luminaires	Labeled with energy performance range A and B (lowest consumption)	RTE INEN 036.
Refrigerators	Labeled with energy performance range A (lowest consumption)	RTE INEN 035.
Televisions	Labeled with energy performance range A (lowest consumption)	RTE INEN 117

Promoting the production of renewable electric energy, without first reducing energy consumption, will demand more generation on site to compensate for the inefficient use of energy, generating a greater initial investment [16]. Next, the production of renewable electrical energy on site should be promoted, using integration and efficiency parameters.

4. Finally, the energy balance in the building must be evaluated.

Fig.6. Research scope, NET ZERO ENERGY BUILDING (NZEB) methodology.

III. ANALYSIS

➢ *Ecuador energy matrix*

According to data obtained from the "MASTER PLAN OF ELECTRIFICATION" of Ecuador, published on the page of the "AGENCY OF REGULATION AND CONTROL OF ELECTRICITY", in 2018 Ecuador had a production of electricity of 72.31% of the renewable type and 27.69% of the non-renewable type. This is the result of the implementation at the country level of the National Development Plan 2017-2021, in which it is established *"To guarantee energy supply with quality, opportunity, continuity and security, with a diversified, efficient, sustainable and sovereign energy as the axis of productive and social transformation"*; and to the fulfillment of its Goal: "Increase electricity generation from 68.8% to 90% through renewable energy sources by 2021".

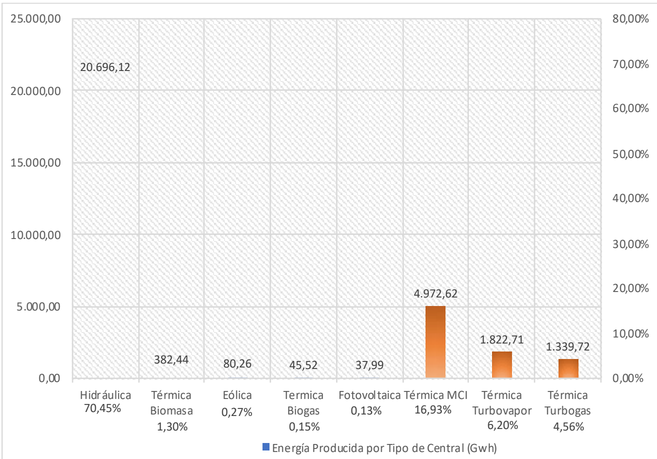

Fig.7. Energy produced by type of central plant in Ecuador

The analysis of the energy matrix of Ecuador indicates that 72.31% of the energy production in 2018 was produced in plants from renewable sources, which indicates that Ecuador is on the right track in terms of sustainability, however as professionals committed not only to sustainability but also to innovation and technological changes, we must increasingly aim higher, proposing better and more reliable power generation systems. As can be seen in graphs 3 and 4, photovoltaic energy represents only 0.13% in the energy matrix, which indicates that there is still much to do, since it is understood that it is a potential that is not yet exploited in our country despite being one of the most important renewable energy technologies worldwide.

➢ *Baseline of electricity consumption in collective housing*

The analysis of the architectural plans and technical specifications of the project was carried out, to characterize and determine the construction system of the case study, the information was collected about the electrical equipment, lights and their frequency of use. The rate for the cost of electricity was obtained after analyzing the electricity consumption sheets, it is $ 0.09 USD, which corresponds to the residential rate. This data was corroborated on the website of the Electricity Regulation and Control Agency ARCONEL. The total monthly consumption of the entire building is 428.50 Kwh, as shown in the following table:

TABLE III. Baseline of electricity consumption in collective housing.

Activities		Floor 0 (Kwh)	1st Floor (Kwh)	2nd Floor (Kwh)	3rd Floor (Kwh)	Total
Food storage and preparation		44.43	41.47	62.58	50.57	199.05
Washing, drying and ironing of clothes		0.00	15.10	11.90	11.90	38.90
Study, Home Office		13.74	19.74	26.34	20.94	80.76
Entertainment and Communication		21.36	25.44	29.52	24.00	100.32
Illumination		0.81	3.15	2.76	2.76	9.47
Total, monthly		80.34	104.90	133.10	110.16	428.50
Total, annual		964.08	1258.78	1597.16	1321.97	5141.98
Total, daily		2.68	3.50	4.44	3.67	14.28
Residential Rate: $ 0.09 USD	Daily Rate Cost	$ 0.24 USD	$ 0.31 USD	$ 0.40 USD	$ 0.33 USD	$ 1.29 USD
	Monthly Rate Cost	$ 7.23 USD	$ 9.44 USD	$ 11.98 USD	$ 9.91 USD	$ 38.56 USD
	Annual Fee Cost	$ 86.77 USD	$113.29 USD	$143.74 USD	$118.98 USD	$462.78 USD
Estimate per m2:	Floor area	80.00 m2	120.00 m2	120.00 m2	120.00 m2	440.00 m2
	Ratio: Consumption / m2	12.05 kwh/m2 per year	10.49 kwh/m2 per year	13.31 kwh/m2 per year	11.02 kwh/m2 per year	11.69 kwh/m2 per year

On the other hand, once these data had been processed, the final use of electric energy was determined in each of the departments of a collective house in Azogues:

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TABLE IV. Baseline of electricity consumption in collective housing.

Description	Average monthly consumption	Percentage
Food storage and preparation	49.76 Kwh	45%
Washing, drying and ironing of clothes	12.97 Kwh	12%
Study and Home Office	20.19 Kwh	18%
Entertainment and Communication	25.08 Kwh	23%
illumination	2.37 Kwh	2%
TOTAL	110.37 Kwh	100%

TABLE V. Monthly electricity consumption of the building, 2019.

Month	floor 0 (kwh)	floor 1 (kwh)	floor 2 (kwh)	floor 3 (kwh)	Daily consumption (kwh)	Monthly consumption (kwh)
JAN	47.00	83.00	91.00	178.00	12.87	399.00
FEB	45.00	78.00	87.00	22.00	8.29	232.00
MAR	42.00	72.00	81.00	2.00	6.35	197.00
APR	49.00	95.00	88.00	101.00	11.10	333.00
MAY	56.00	227.00	97.00	135.00	16.61	515.00
JUNE	53.00	187.00	95.00	40.00	12.50	375.00
JULY	42.00	204.00	92.00	87.00	13.71	425.00
AUG	37.00	173.00	99.00	113.00	13.61	422.00
SEPT	42.00	131.00	92.00	75.00	11.33	340.00
OCT	46.00	183.00	94.00	49.00	12.00	372.00
NOV	53.00	190.00	107.00	2.00	11.73	352.00
DEC	62.00	194.00	92.00	1.00	11.26	349.00

As seen in TABLE V. the consumption data of the electricity bill for 2019 was analyzed, since it was the year with the greatest habitability of the building, the processed data show that in the month of May 2019 there was a peak in electricity consumption of 515 Kwh, which indicates that the maximum daily demand is 16.61 Kwh, this data should be considered in the calculation of the photovoltaic system.

❖ *Implementation of renewable energies*

➢ *Technology selection and design strategy.*

The selection of technological systems for the generation of electrical energy was based on the architectural integration criteria suggested in the research work: *Criterios de integración de energía solar activa en arquitectura. Potencial tecnológico y consideraciones proyectuales* [6], the level of architectural integration should be "*4 (multiplicity) in which the equipment expressively contribute and contribute in a maximum way to the energy requirements"* [6].

To propose the design strategy, we proceeded to analyze the location and benefits of the building, the climate and the radiation potential of the place, these data are obtained with the Biosol program [18], from the following input data:

- Location, Latitude: -2.746º. Longitude: 78.8486º. Altitude: 2470 meters above sea level.
- Temperature. - The data was extracted from the National Institute of Meteorology in Hydrology "INAMHI" are entered, in this particular case we will work with the temperature data from 2011 to 2016.

The data is entered in the Biosol software [18], which shows the Irradiance data, for the present case is needed the data of: Horizontal Global Irradiance (w / m2) and the Global Irradiance data in vertical surface towards the only facade that the building has, which is westward. As a strategy for sizing the photovoltaic system, it is necessary to identify the least favorable month in terms of solar irradiation and size according to this criterion, in order to ensure that there is always enough irradiation to satisfy demand.

➢ *Design strategy*

Take advantage of the global horizontal irradiance of 3878.28 W/m2 daily, through the implementation of photovoltaic systems on the terrace of the building, which has a usable area of 120 m2. It is considered that the irradiation hours in the least favorable month (June) correspond from 7:00 to 17:00. After having analyzed the available technologies, it was decided to choose the Solar Roof tiles [9]. The global irradiance on the west façade of the building will be exploited through the implementation of photovoltaic panels in the form of a leaf from the company Greendix [12], the same ones that due to their benefits and great capacity for architectural integration will form part of the west (main) facade of the building, which has a usable area of 125 m2. Similarly, it is considered that the hours of irradiation in the least favorable month (June) correspond from 7:00 to 17:00. Given the greater irradiation potential of the horizontal surface of the building, the strategy is adopted that the greatest amount of energy is generated in this place.

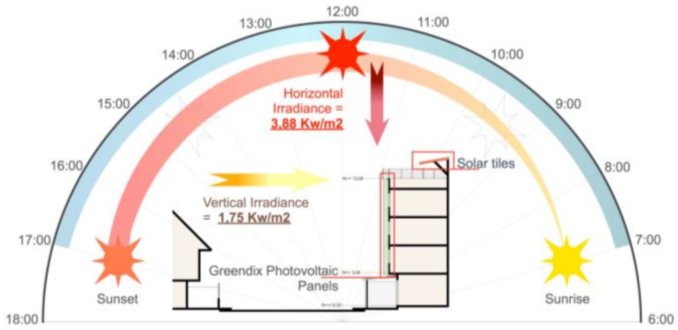

Fig.8. Proposed design strategy

➢ *Sizing of the photovoltaic solar system*

Photovoltaic solar systems are dimensioned based on the technical data of the equipment to be implemented, such as its power and the place where it will be implemented, since the data of the type of irradiation to be used depends on it, based on the following considerations:

TABLE VI. Variables considered for dimensioning.

Panel Type / Technology	Place to be implemented	Photovoltaic system power	Type of irradiation to use	Daily value of irradiation
Greendix Photovoltaic Panels [12].	West facade	1.25 w per sheet.	Global Irradiance on Vertical West Facade	1.75 Kw / m2
Solar tiles [9]	Terrace	66w per m2	Horizontal Global Irradiance	3.88 Kw / m2

IV. RESULTS

Sizing of the photovoltaic solar system

To calculate the dimensioning of the photovoltaic system to be installed, we proceeded to take as reference [19], the following formula applies (1):

$$\text{Number of modules} = \frac{\text{Maximum daily demand}}{\text{HSP x Power modules}} \quad (1)$$

Where:

- Maximum daily demand: 16.61 Kwh, data obtained from TABLE V.
- HSP represents Peak Solar Time (Daily Irradiance Value).
- Module power: 1.5 w per sheet for Greedex photovoltaic panels and 66 w per m2 for photovoltaic tiles.

TABLE VII. Results of the dimensioning of solar systems.

Panel Type / Technology	Place to implement	Power to install	Panels / m2	% contribution to total demand
Greendix Photovoltaic Panels	West facade	7.38 Kwh	3,373 sheets = 48 m2	44.43%
Solar tiles	Terrace	9.23 Kwh	36 m2 of solar tiles	55.57%

Similarly based on [19], the quantities of grid inverters, inverter chargers and batteries were determined, which is summarized in the TABLE VIII.

TABLE VIII. Results of solar systems.

Panel Type / Technology	No. of network inverters	Inverter charger no.	No. of batteries
Greendix Photovoltaic Panels	1 (Ingecon Brand, 5Kw)	1 (Quattro brand, 24V / 5kw)	2 (Life PO4 brand, 12v / 400Ah)
Solar tiles	1 (Ingecon Brand, 3.6Kw)	1 (Quattro brand, 24V / 3kw)	2 (Life PO4 brand, 12v / 400Ah)

To determine the inclination of the photovoltaic tiles, it was based on [20], from which it was obtained that the optimal inclination for this photovoltaic system is 12º. Next, the formal proposal of the photovoltaic systems integrated to the building is presented:

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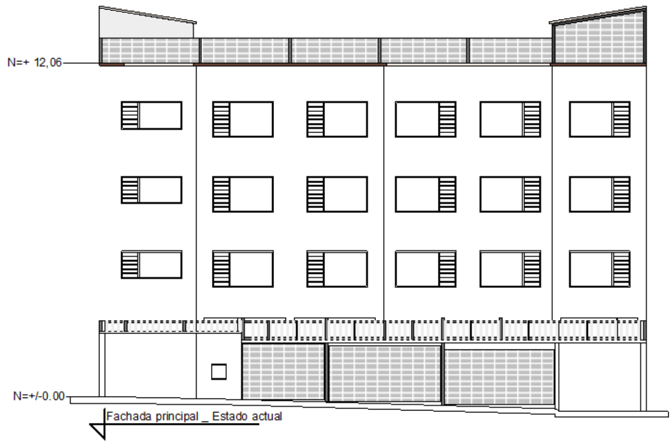

Fig.9. Main building facade case study, current state.

Fig.10. Main building facade case study, PROPOSAL.

V. CONCLUSIONS

With the implementation of 48 m2 of Leaf-shaped Photovoltaic Panels from the Greendix company on the west facade of the building, and with 36 m2 of the Solar Roof tiles system on the building's terrace, 100% of the energy demand is satisfied of the building, thus obtaining an energy balance zero "0" throughout the year. This invites us to reflect on the economic contribution that will result from the sale of energy to the local distributor in case of having a surplus, however, as a relevant result it is determined that the architectural integration of these technological elements to the building is total, obtaining from in this way, a building with good aesthetic quality, which reduces its electricity consumption to zero “0” and which contributes positively to the sustainability of its surroundings.

The area in which the case study building is located presents an average monthly hourly irradiation on horizontal surfaces of 3,878.28 W / m2 daily in the least unfavorable month. A fact derived from its equatorial latitude, which clearly indicates that the potential of use is this area for the generation of energy in a clean and sustainable way, on the other hand, more and more professionals who, committed to sustainability have already entered in the design and use of technological systems including photovoltaics, more than enough reasons to consider that within the academic field the implementation of different project areas is essential to train future professionals in the planning and design of photovoltaic systems from undergraduate already integrated in housing construction.

The line of research should continue to study and analyze the cost of implementing these technologies in urban environments, buildings and homes, with the goal of making them more and more economical and within everyone's reach, since all these technological elements should cease to be a "luxury" and become a quality parameter required at all levels.

A particular fact is that the technologies and systems analyzed in this research currently do not exist in the country and must be imported, which, instead of becoming a problem or weakness, should rather be understood as a potential niche. market for professionals, through which the implementation of these systems can be started in the region and in the country.

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