Design of a solar power system in San Agustín building Ocaña, Colombia

J Arévalo¹, M I Cabellos¹, and R T Marquez¹
¹ Grupo de investigación en Tecnología y Desarrollo en Ingeniería, Universidad Francisco de Paula Santander seccional Ocaña, Colombia

Email: micabellosm@ufpso.edu.co

Abstract. The purpose of this study is to design an autonomous solar system as an alternative to the electrical energy use of San Agustín building in the municipality of Ocaña, Colombia. The building has 8 floors of which the commercial and administrative zones consume 2447.2 Wh per month. Considering that electricity costs are high, the project focuses on lowering energy consumption in the billing. The research is carried out with the development of the phases of analysis, diagnosis, and design, in order to encourage the use of renewable energy in the building. The academic study is limited to providing the design of the autonomous system to the owners of the building to continue with the investment phase. The results are based on establishing the structural and energy parameters and validating the implementation of the solar power system taking into account electricity prices, which results in the use of 15 panels of 275 Watt and 7 panels of 325 Watt with a saving of approximately 1.500,000 Colombian pesos.

1. Introduction
At present, the use of naturally available renewable systems, such as solar, wind, tidal or geothermal energy, has emerged as an alternative to reduce electricity costs by developing projects with minimal environmental impacts compared to other generation systems [1]. Taking into account an economic perspective, it should be noted that electricity costs are the highest in households compared to other types of services [2]. The project is developed in San Agustín building taking into account the needs of the owners due to the considerable increase in electricity costs, reported to the users in the payment of the energy service, month by month. The energy source used for the development of this project is solar energy since the use of solar panels implies a great advance for society because it is obtained from a free, clean, inexhaustible source, which reduces dependence on oil or other polluting sources. Also, energy consumption is increasing, so finding alternative energy sources is essential for reducing polluting emissions [3]. For this reason, this work focuses on the design and economic feasibility analysis of a photovoltaic installation for the social and administrative zones of San Agustín building. Colombia has been developing projects that benefit communities to increase the use of renewable energy resources that generate clean energy using solar irradiation [4]. Also, Industries should focus on projects that focus on implementing alternative energy sources, thus seeking to reduce environmental pollution and greenhouse gas emissions [1].

2. Materials and methods
The development of this project will take into account quantitative and qualitative types of scientific research. The first stage will be based on a technological or design study that consists of looking for
concrete solutions to problems based on experimental sciences and mathematics. This research is based on a diagnostic phase that involves analyzing the importance of photovoltaic power systems and renewable energies when producing electricity. In a second stage, it is necessary to identify the required elements when choosing the solar power system. In addition, the structural and energy parameters of the autonomous solar system will be established. In this second stage, the relevant calculations are made for the structure and the different elements that make up the solar system. The above implies knowing the electrical consumption of the social zone of the building. Subsequently, the respective calculations of each of the elements of the photovoltaic system are carried out: solar panels, regulator, batteries, and inverter. Finally, the static analysis for the structure of the solar panels is made, and the design of the structure supporting the solar panels is carried out using Solidworks.

The second model based on observation allows knowing the condition of the building and the feasibility of using this renewable energy source.

3. Results and discussion
This research was carried out in a building in the municipality of Ocaña in Norte de Santander department, Colombia. The first step was a visit to the site where San Agustín building is located to know the needs of the place in order to establish the structural and energy parameters of the autonomous solar system.

Figure 1. Building energy consumption by section.

Figure 1 shows, from the data obtained, that the basements are the areas of the building with the highest electricity consumption. The magnitudes studied were electric energy consumption, power, hours of operation per day, and total energy needed (Wh) distributed in each of the sections of the building, thus showing the energy consumption (Wh) for each floor of the building under study. The building has eight floors and two basements, where the first three floors are divided into the commercial and residential zones. From the fourth to the seventh floor, there are only apartments, so their consumption will not be taken into account. The eighth floor, characterized by being the place where the main events take place, was also included in this study. In addition, the cost of the staircases along with the entrance of the site was taken into account, which allowed calculating the energy consumption per floor [5].

Ocaña is located in the northwestern region of the department of Norte de Santander, Colombia, which borders to the north with the municipality of Teorama; to the south with the municipality of Abrego and the department of Cesar, and to the east with the municipalities of San Calixto and La Playa. In addition, Ocaña, Colombia, has latitude of 8.2377 °N and altitude of 73.356 °W. As the solar photovoltaic system is independent of the roof structure of the building, it is necessary to establish through Equation (1) the optimal tilt angle of the solar module [6].
\[ \beta_{\text{OPTIMAL}} = 3.7 - 0.69|\phi| \] (1)

Where \( \beta_{\text{OPTIMAL}} \) is the optimal tilt for solar panels and \( \phi \) is the latitude of the place. In this case, we will work with 10° facing south because this value is recommended for the maintenance of the solar system.

### 3.1 Calculation of each element of the photovoltaic solar system: Solar panels, voltage regulator, batteries and solar inverter

The values of solar radiation taken for the calculation of the elements of the photovoltaic solar system are from the atlas of solar radiation of Colombia given by the institute of hydrology, meteorology and environmental studies [7]. These values have been carried out with a multiannual average of more than 20 years.

The value for the municipality of Ocaña is 3.5 KWh/m² or 3500 W/m² in its peak month [7]. Now, we will continue with the respective calculations for each of the elements of the system, which will be performed in a particular way for each building section [8]. Table 1 shows the calculation made for each building section, which shows the value of the photovoltaic modules, the batteries, and the solar inverter [9]. It is observed that each floor has an independent connection which considers for the previous calculation 15 solar panels of 275 W and 7 solar panels of 325 W [4].

**Table 1.** Respective calculation value for each building sector.

| Floor                        | EE (Wh/m²) | ADC (Ldm)(Wh) | NP | PPP (W) | Power (W) | SIP (W) | 24V battery (Ah/day) |
|------------------------------|------------|---------------|----|---------|------------|---------|----------------------|
| 1st floor commercial area    | 1086.72    | 1271.02       | 2  | 226.96  | 226.40     | 283.00  | 52.96                |
| 1st floor residential area   | 859.20     | 1004.91       | 2  | 179.40  | 179.00     | 223.75  | 41.87                |
| 2nd floor                    | 1112.64    | 1301.33       | 2  | 232.10  | 231.80     | 289.75  | 54.22                |
| 3rd floor                    | 1516.80    | 1774.03       | 2  | 316.80  | 316.00     | 395.00  | 73.91                |
| 8th floor                    | 2064.00    | 2414.03       | 3  | 287.38  | 430.00     | 537.50  | 100.58               |
| Basement 1 and 2             | 5616.00    | 6568.42       | 9  | 260.65  | 780.00     | 975.00  | 273.68               |
| Staircases                   | 1363.20    | 1594.38       | 2  | 284.71  | 284.00     | 355.00  | 66.43                |
| Total                        | 13618.56   | 15928.12      | 22 | 1788.00 | 2447.20    | 3059.00 | 663.65               |

EE: Electrical energy; ADC: Average daily consumption; NP: Number of panels; PPP: Peak panel power; SIP: Solar inverter power.

### 3.2 Static calculations for the structure that supports the solar panels

Table 2. describes the weight of each panel, which allows calculating the strength of the structure. To design the structure where the panels of the photovoltaic solar system will be supported, it is necessary to take into account the area of the site as well as the dimensions and weight of each module. Subsequently, the applied loads are defined, for which the weight of the components of the structure is needed.

**Table 2.** Number of panels with the mass that will support the structure.

| Amount | Description          | Mass (kg) | Total mass (kg) |
|--------|----------------------|-----------|-----------------|
| 15     | Solar panels of 275 W| 18.6      | 279.0           |
| 7      | Solar panels of 325 W| 22.5      | 157.5           |

After having the information required by the panels, it is proceed to enter all the information into SolidWorks software to determine the maximum and minimum stresses supported by the structure, and verify if it is adequate to withstand the number of panels or otherwise must be reinforced. Figure 2 shows the design in the software, which shows minimal values and, therefore, the structure should not be reinforced to make the assembly of the panels [10].
3.3 Analysis of the electrical consumption of the building

After having the calculations of the elements of the photovoltaic power system and their respective structure, it will be observed the electricity consumption according to the bills issued by the company “Centrales Eléctricas de Norte de Santander”, EPM Group, which is responsible for providing electrical energy in Norte de Santander department. It is important to emphasize that in this building there is one electricity meter, so the value that this provides shows both the obtained in the social and residential zones.

Figure 3 shows the energy consumption at the study site during the twelve months of 2017. It can be observed that energy consumption has been increasing month by month, especially in the last four months of 2017, with a significant increase in energy demand from September. As a result, economic expenditure is also increasing.

When charging for the energy consumption, the company takes into account the consumption by the unit cost that varies monthly according to the voltage level and other variables such as frequency and time in which it is used. With the implementation of the panels, there will be an economic saving in the billing of approximately 1.500.000 Colombian pesos, which allows saying that this implementation is feasible [11]. Also, those companies working with this type of energy will receive an economic incentive...
It should be noted that when investing in a solar power system, the laws and regulations implemented in the country for installing this system, especially law [5], have to be taken into account.

4. Conclusions
According to the objectives established for the development of the project in the phases of diagnosis, analysis, and design, the importance of the use of renewable energies is emphasized from the study carried out since they contribute to reduce pollution levels and to create a culture of environmental awareness in people who use this type of technology. In the diagnosis of the autonomous solar system, the structural and energy parameters were defined through the calculations performed on the elements of the photovoltaic system taking into account the location variables such as the value of latitude, altitude, irradiance, and energy consumption. Moreover, the exact data available allows making a proportional analysis, which in turn will make the investment no more expensive than necessary.

The design of the photovoltaic solar system was made in solidworks taking as criteria the structure where the panels are supported, the dimensions and weight of each module, and the assembly of the structure. The design of a solar system is a profitable energy generator since the sun, which is a renewable energy source, is not difficult to access. It should be noted that when investing in a solar photovoltaic system, it is necessary to know about the laws and regulations implemented in the country for installing such systems. According to the feasibility study, it was possible to know the internal rate of return (IRR), the cost recovery rate (CRR), and the investment period.

References
[1] Congreso Nacional de Colombia 2014 Ley 1715 por medio de la cual se regula la integración de las energías renovables no convencionales al Sistema Energético Nacional (Bogotá: Congreso Nacional de Colombia)
[2] J R Ramos Sánchez and R Chávez Rivera 2019 Consumo energético y económico de las celdas fotovoltaicas en viviendas de estrato social de clase media-alta de Victoria, Tamaulipas México Revista Cimexus 14(1) 13
[3] Ministerio de Minas and Unidad de Planeación Minero Energética 2016 Proyección regional de demanda de energía eléctrica y potencia máxima en Colombia (Colombia: Ministerio de Minas Unidad de Planeación Minero Energética)
[4] J S Gálvis-Garzón and R Gutiérrez-Gallego 2013 Proyecto para la implementación de un sistema de generación solar fotovoltaica para la población wayuu en Nazareth corregimiento del municipio de Uribia, departamento de la Guajira – Colombia Universidad Nacional Abierta y a Distancia (Colombia: Universidad Nacional Abierta y a Distancia)
[5] Florez Rojas Johann 2015 Energias alternativas en colombia bajo la ley 1715 (Colombia: Universidad Militar Nueva Granada)
[6] A M Vega Escobar 2017 Gestión de la energía eléctrica domiciliaria con base en la gestión activa de la demanda (Colombia: Universidad Distrital Francisco José de Caldas Bogotá)
[7] Ministerio de Minas and Unidad de Planeación Minero Energética 2005 Atlas de radiación solar Colombia (Colombia: Ministerio de Minas Unidad de Planeación Minero Energética)
[8] E Velasquez and J Solano 2012 Banco de pruebas de energía solar fotovoltaica con el fin de generar energía eléctrica para las luminarias de la plaza para vivacias a la vida de la Universidad Francisco de Paula Santander Ocaña (Colombia: Universidad Distrital de Paula Santander Seccional Ocaña)
[9] M A Celémin-Cuellar 2016 Estudio para la implementación de un sistema fotovoltaico como alternativa rural sostenible de la vereda san roque en el municipio de Ortega-Tolima (Manizales:Universidad de Manizales)
[10] R G Dydnas and J K Nisbett 2008 Diseño en ingeniería mecanica de shigley (México: McGraw-Hill)
[11] J A Montañez, J L Vargas, E M Trujillo and S S Palacios 2018 Análisis de factibilidad del diseño de un sistema solar fotovoltaico en la escuela campo 45 del corregimiento centro de la ciudad de Barrancabermeja Revista de investigación formativa Agrícolas Habitat 1(2) 1
[12] D Montaño-Quintero and Y A León-Forero 2016 Análisis de conveniencia para la implementación de paneles fotovoltaicos en el condominio campestre "El Cabrero" ubicado en el municipio de Ocaña departamento Norte de Santander (Colombia: Universidad Distrital Francisco José de Caldas)