



Sustainable Practices Improving the University Campus: Feasibility of A Photovoltaic System

J.C.B. Menezes^{1*}, J.C. Cury^{1,3} and L.M. Souza²

¹Postgraduate Program in Technologies for Sustainable Development, CAP, Federal University of São João del-Rei, Brazil

²Department of Exact and Biological Sciences, CSL, Federal University of São João del-Rei, Brazil

³Faculty of Pharmaceutical, Food and Nutrition Sciences, Federal University of Mato Grosso do Sul, Brazil

*jcarlamenezes1@gmail.com (Corresponding Author)

ARTICLE INFORMATION

Received: February 23, 2021
Revised: April 13, 2021
Accepted: May 04, 2021
Published Online: June 26, 2021

Keywords:

Sustainability, Electricity, Photovoltaic, Conservation, University

ABSTRACT

This article aimed to discuss the principles of sustainability applied to the built environment, highlighting the importance of universities as replicators of these practices. To respond to a demand from the campus for more security in the energy supply, the work proposes the implementation of a solar photovoltaic energy system. For this, it carried out an economic viability analysis through bibliographic review activities, characterization of the study area, dimensioning of photovoltaic systems, budgets, cost analysis and payback calculation. The research evaluated the system's implementation considering two energy demands, for the entire campus and for a smaller building. It was found that the CSL-UFSJ consumes, on average, 27,300.38 kWh, at a cost of US\$ 2,736. Thus, an annual savings of US\$ 32,833 is calculated. The cost estimate analyzes showed a value of US\$ 139,784 for the implementation of the system. The return on investment time was calculated for 4.3 and 4.9 years considering simple and discounted Payback respectively. It is estimated that the consumption of the DECEB building is 13,187.1 kWh with a cost of US\$ 1,322 per month, which results in an annual savings of US\$ 15,860. The cost estimate analyzes showed a value of US\$ 40.601 for the implementation of the system and values of 4.3 and 4.9 years were obtained as return on investment time considering the calculations for simple and discounted Payback, respectively. The research demonstrates that the implementation of the photovoltaic solar energy generation system is feasible for both cases analyzed.

DOI: [10.15415/jce.2021.72006](https://doi.org/10.15415/jce.2021.72006)



1. Introduction

Since the 1950s, when the first perceptions about the environmental impacts caused by nuclear pollution, a product of the Second World War, began to emerge, much has been discussed about the environmental issue. These discussions have brought changes that can be observed, for example, in the theoretical-conceptual scope, where the understanding of sustainability is increasingly broadened beyond the economic, social and environmental dimensions, and also taking into account other important points like, political, cultural and technological aspects.

In the built environment context, this evolution is evident in the growing search for solutions aimed at increasing the efficiency and self-sufficiency of buildings. In addition, the search for better conditions for mobility, accessibility, sanitation and urban infrastructure also demonstrates a certain valuation from construction practices that establish more harmonious relationships with the environment in which they are inserted.

According to Chau (2003), as an extension of society, the university must be considered as a social institution capable of bringing rich contributions to society. In this perspective, the performance of universities is of great importance, mainly because they are able to promote projects and research with themes in these areas of knowledge and also to produce viable examples of these practices, being able to stimulate, encourage and incorporate sustainable practices within the community where it is located.

This work was motivated by the desire to make a practical proposal for a real demand from the campus, demonstrating that a research can be applied in solutions for limitations in the infrastructure of these institutions. In this perspective, the work issue is mainly due to a demand for greater security in the energy supply of the campus, considering the strong activity of the laboratories that depends on the full functioning of the electrical equipment to maintain the research activities and the samples.

Therefore, this work proposes an economic feasibility analysis for the implementation of a photovoltaic power

generation system at the SeteLagoas Campus of the Federal University of São João del-Rei (CSL-UFSJ), using the building of the Department of Exact and Biological Sciences (DECEB) as a model. For this, it was carried out: the bibliographic review, elaborated from three discursive topics on themes involving built environment, sustainability, energy and photovoltaic systems; and the case study, which, to assess the economic viability of the system, stimulated the activities of characterization of the study area, dimensioning and budgeting of photovoltaic systems, cost analysis and return on investment calculation.

The research, which evaluated the economic feasibility for implementing the system considering two energy demands, for the entire *campus* and specifically for the DECEB building, allows the viability of the photovoltaic solar generation system for both delimited cases. In addition, it is highlighted that the implementation of alternatives for electricity generation, as in this work, can contribute to the development of sustainable techniques applied to civil construction, reduce maintenance costs and promote the university's self-sufficiency.

2. Built Environment and Sustainability

The perception of a possible global environmental crisis started in the 1950s, with the first reflections on the global impacts associated with nuclear pollution caused by the Second World War. The commotion generated after war conflicts motivated the creation of international organizations in an effort to maintain peace between nations and conserve cultural and environmental heritage (Bandarin et al. 2011).

Currently, several areas of knowledge have discussed and dedicated to the environmental crisis and climate change. Factors such as population growth, associated with structural unemployment, generation of population surplus, increased production of consumer goods and, consequently, generation of waste, are directly related to the current capitalist economic model and contribute to the deepening of this crisis (Foladori, 2015).

The need to integrate the concepts discussed in the scope of sustainability and the proposals applied in the field of civil construction is also a topic that has been widely studied today. The growing awareness about the effects of the current economic model on the planet has contributed to an increase in movements that encourage the promotion of more efficient and self-sufficient buildings, showing a possibility of a change in the civil construction paradigm that, according to Castanheira & Bragança (2014), promises to change the ways in which buildings are designed, built, used and rehabilitated.

However, it is observed that, to a large extent, the efforts to implement sustainable practices in the built

environment still carry a strong influence of the concept of sustainable development, which is based on the social, economic and environmental tripod. It is important to note that this model, the result of the Rio 92 Conference, has been questioned for disregarding other important aspects such as cultural and political dimensions (Bizerril et al. 2018). Furthermore, technological aspects should also be considered, since they contribute to the sustainability of buildings, offering solutions that, once incorporated into the construction processes, can act in all phases of the building's life cycle.

3. Built Environment and the Energy Issue

The advances in the technological field, together with an advance in human development and economic growth in some countries, are responsible for an increase in the demand and consumption of electricity in the context of South America (Ferreira et al., 2018). This occurs both due to the greater possibility of access to electronic equipment by the population, as well as a growing search for assimilating these technologies in order to facilitate daily practices and improve the quality of the spaces produced.

It is possible to observe that these new technologies, largely powered by electricity, are highly incorporated in the daily life of contemporary man, whether in the scope of accessibility and environmental comfort, through the use of elevators, mats, electric gates, air conditioning, sound and lighting equipments, whether in the use of refrigerators to conserve food, medicines, laboratory samples, research or even in the frequent use we make of electronics and appliances in our daily lives.

The recent advances in the technological area and the consolidation of the digital era, in the face of the current world pandemic scenario, has given power to virtual events, meetings and other types of remote activities. Considering that these activities depend on the use of equipment that requires electricity for its operation, it is possible to assume the increase not only in the demand for electricity, but also the feeling of insecurity and dependence in relation to the services provided by the energy distribution concessionaires.

Recently in Amapá, in the northern region of Brazil, the population experienced three weeks of extreme chaos caused by an energy crisis that reached 13 municipalities in the state. After facing a 4-day blackout, which started on November 3, 2020, the population was subjected to a rationing regime that generated several conflicts in the state, affecting water supply, access to ATMs, communication, thermal comfort, and maintenance of refrigerated food, causing losses to traders and residents (G1, 2020 a).

In addition to the inconvenience caused to almost 90% of the population, which was forced to adapt the routine

due to the partial electricity supply, which began to rotate every 4 hours, many residents had electronic equipment and appliances burned due to oscillations in the power supply (G1, 2020 b). The losses generated and the delay in dealing with the problem underscore not only the seriousness of the energy issue, but also the vulnerability of the population, who are in a relationship of complete dependence on the companies that provide these services.

With regard to electricity produced in Brazil, it can be seen that 42.8% are consumed in public, residential and commercial buildings (Ben, 2017). Currently, the main form of electricity production in the country corresponds to hydroelectric power, which represents about 60% of production. Despite being considered clean and renewable, hydroelectric energy causes several environmental impacts due to the need to flood large areas, inducing the generation of a large amount of methane gas (CH_4), which is emitted from the organic matter degradation process submerged, in addition to causing changes in local vegetation (dos Santos et al., 2006; Ferreira et al., 2018).

According to resolutions of the Special Commission for People Affected by Dams, among the socio-environmental impacts caused by the construction of hydroelectric plants are: the flooding of fertile lands, destruction of forests and genetic heritage, flooding of cities and their infrastructure, compulsory displacement of people and degradation of the conditions of socio-cultural reproduction of traditional populations (CDDPH, 2011).

4. Solar Energy: Photovoltaic Systems

In the last years, there has been a significant increase in the number of research in the field of renewable energy, which, according to Dinçer (2011), can be defined as being sources of sustainable and clean energy from nature. It is also possible to point out the increase in studies on solar energy, considered one of the most promising sources, and on bioclimatic architecture, which proposes a better use of available climatic conditions, considering location, surroundings, incidence of winds and solar orientation during the shots of design decisions, and promoting the construction of spaces with higher quality and lower energy consumption (Frota & Schiffer, 1995).

Solar thermal energy represents an important renewable source that can significantly reduce energy consumption in buildings, since the highest levels of energy consumption are mainly due to heating, ventilation, air conditioning systems and also the demand for hot water in bathrooms (Panno et al., 2019). According to Buonomano et al., (2019), solar thermal energy is widely used due to the simplicity of the system and affordable prices, in addition, it can also be used in a complementary way to photovoltaic systems, which are

already found on the market and have been used for more than 30 years in some European countries. The countries that have made the most progress in the use of photovoltaic panels are the United States, China and Japan (Dinçer, 2011).

Photovoltaic solar energy is obtained through the photovoltaic effect, defined as a phenomenon that occurs in certain semiconductor materials through solar incidence. Solar radiation stimulates electrons to jump to the conduction layer, creating tension and, consequently, electric current (Panno et al., 2019). The photovoltaic effect was first observed in 1839 by French physicist Edmond Becquerel, who found that metal plates immersed in a liquid electrolyte were capable of producing a small potential difference when exposed to light (Machado & Miranda, 2015).

The first photovoltaic apparatus, however, was only developed in 1876, so that the effect could only be confirmed in 1887 by Heinrich Hertz. Industrial production started in 1956 due to the growth of studies and investments in the area of microelectronics. The space research sector also contributed to the development of technology, since solar cells were the most suitable technology, as they present less weight, cost and amount of energy required, for long periods in space (CRESESEB, 2014). Data obtained by Copel (2014), show that investments in research in the area of photovoltaic energy increased due to the need for diversification of energy sources, caused by the oil crisis that emerged from the 1970s.

Solar photovoltaic systems are considered extremely promising today because, in addition to not emitting pollutants in the electricity generation process, they can be used anywhere on the planet. Solar photovoltaic systems, especially those that are within the urban core and integrated with the distribution systems, provide several advantages to the electrical system. Among these advantages can be highlighted the cost reduction, since these systems allow: reduction of losses during the process of transmission and distribution of energy; reduction of investments to build the necessary infrastructure for transmission and distribution; construction of buildings with integrated photovoltaic technology, not requiring exclusive areas and offering greater volumes of electricity in times of excessive demands (FERREIRA et al., 2018).

5. Methodology

The water crisis experienced by Brazil in 2016 highlighted the need to reduce the consumption of water and electricity throughout the country. Encouraged by such instability, the Brazilian Ministry of Education guided its organizations and institutions to develop actions aimed at greater energy efficiency and rational use of water. With this, the UFSJ

launched a campaign aimed at the preservation of water and the conscious use of electricity on university *campus*. These facts, combined with the topics discussed above, stimulated the idealization of this research. Furthermore, the work was also motivated by the demand presented by the *campus* for greater security in the energy supply, which, considering the strong activity of laboratories, depends on the full functioning of electrical equipment for the maintenance of both samples and research activities.

Based on this, the research aimed to carry out an economic feasibility analysis for the implementation of a photovoltaic power generation system at the CSL-UFSJ, using the building of the DECEB'S department as a model. In order to evaluate which is the best option, the analysis was made considering both the possibility of applying the system to meet the specific demand of the DECEB building, and for the entire *campus*.

In addition to the bibliographic review, the following activities were carried out: characterization of the study area; identification of the main energy demands and uses of CSL-UFSJ and DECEB building; surveys and measurements *in locu*; dimensioning of the photovoltaic system considering the entire CSL-UFSJ and specifically demand of the DECEB building; budget for photovoltaic systems; cost analysis and return on investment calculation.

The dimensioning of the photovoltaic system was calculated considering the implementation of an on-grid system, that is, connected to the concessionaire. For this purpose, the minimum power required for the inverter, the number of panels to supply the demands and the proportional value related to the other equipment that make up the system were calculated in this work.

The inverter, an electronic device capable of transforming the electric load generated by the photovoltaic panels from direct current to alternating current at the same frequency and phase of the electrical network, promotes the energy compensation between the photovoltaic system and the electric power utility. An efficiency of 85% was adopted as a reference, considering the possibility of losses. To calculate the minimum power of the inverter, the following equation was used:

$$P_{\text{inverter}} = \frac{C_{\text{daily}}}{\text{HSP} \times \eta_{\text{shading}} \times \eta_{\text{panel}} \times \eta_{\text{inverter}} \times \eta_{\text{cable}}} \quad (1)$$

Where:

P_{inverter} is the minimum power of the inverter (kW);

C_{daily} is the daily energy consumption (kWh);

HSP is the full sun hours (h);

η_{shading} are the losses of solar irradiation by shading (%);

η_{panel} is the loss of energy in the panels (%);

η_{inverter} is the loss of energy in the inverter (%);

η_{cable} is the loss of energy in the cables (%).

The minimum power value of the inverter and the power of each panel are necessary to calculate the required number of panels. For this, the following equation was applied:

$$N_{\text{panel}} = \frac{P_{\text{inverter}}}{P_{\text{panel}}} \quad (2)$$

Where:

N_{panel} is the number of panels;

P_{inverter} is the minimum inverter power (kW);

P_{panel} is the panel power (W).

The cost of the other equipment in the system was calculated according to data from the Institute for the Development of Alternative Energy in Latin America, which establishes that the inverters and photovoltaic modules together represent 59% of the total system cost (IDEAL, 2019).

In order to obtain a more accurate analysis considering the monetary update, the calculation of the Net Present Value (NPV) was performed. The method was used adopting the value of 1.9% for the discounted value referring to the basic interest rate of Brazil, Selic (BANCO CENTRAL DO BRASIL, 2021).

Characterization of the Study Area: Sete Lagoas Campus (CSL-UFSJ)

The CSL-UFSJ, located on the edge of the MG-424 highway, is installed in an area provided by the National Research Center EmbrapaMilho e Sorgo (CNPMS/EMBRAPA). It is possible to observe the location of the *campus* in relation to the cities of Sete Lagoas and Prudente de Moraes, in Figure 1 and the CSL-UFSJ service program, in Figure 2.



Figure 1: CSL-UFSJ and surroundings.

Source: adapted from Google Earth (2019).

There are currently four undergraduate courses in the CSL-UFSJ, Agronomic Engineering, Forestry Engineering, Food Engineering, Interdisciplinary in biosystems and also a

Postgraduate course in Agricultural Sciences. In addition, they operate 4 departments: the Department of Agricultural Sciences (DCIAG); Department of Food Engineering (DEALI); Department of Forestry Engineering (DEFLO) and the Department of Exact and Biological Sciences (DECEB).

Around 57 outsourced professionals work in the *campus* who work in cleaning, reception, concierge, surveillance, maintenance of buildings, gardens and other external spaces, and drivers. In addition, CSL-UFSJ has about 65 teachers on its faculty, 28 technicians and a flow of 800 students distributed by undergraduate courses.



Figure 2: CSL-UFSJ service program.
 Source: Adapted from Google Earth (2019).

Characterization of the Study Area: DECEB Building

The model used to carry out this work, the DECEB building (Figure 3), was granted in a lending contract to the UFSJ by EMBRAPA and is a one-story building, built in the 1970s. It has a coverage area of about 4,300 m² covered with asbestos tiles. The building consists of masonry walls in 18 cm perforated brick with metal and glass frames. The main façade of the building is oriented to the Southeast.

For a better understanding of the activities carried out in the building, we opted for the elaboration of an analysis by sectoring the building through 6 blocks, as can be seen in Figure 4. The services performed in the building are varied, with spaces for laboratories, classrooms, administrative functions, faculty offices and an amphitheater. The building has a total of 6 bathrooms in areas for public use and 4 restricted access to administrative areas, in addition to 2 drinking fountains for public use. The blocks with the highest and lowest energy consumption are blocks 1 and 4 with the values of 4,149,9 and 1,735,5 kWh, respectively. Block 2 was not considered in the analysis due to the fact that it was unoccupied.



Figure 3: DECEB building.
 Source: personal archive (2019).

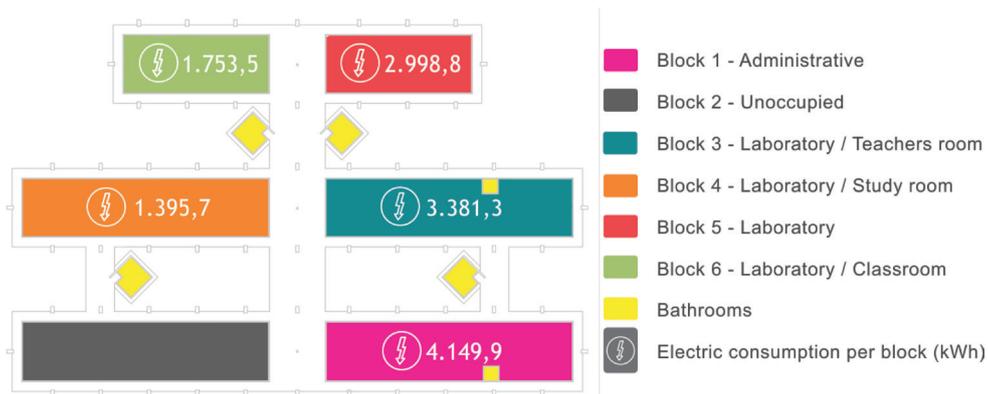


Figure 4: Sectorization of the DECEB building by blocks.
 Source: personal archive (2019).

Survey of Electricity Consumption

Data on the demand for electricity at CSL-UFSJ were provided by the CSL-UFSJ General Services Sector, based on measurements made by CEMIG, the concessionaire responsible for supply. Figure 5 shows the monthly

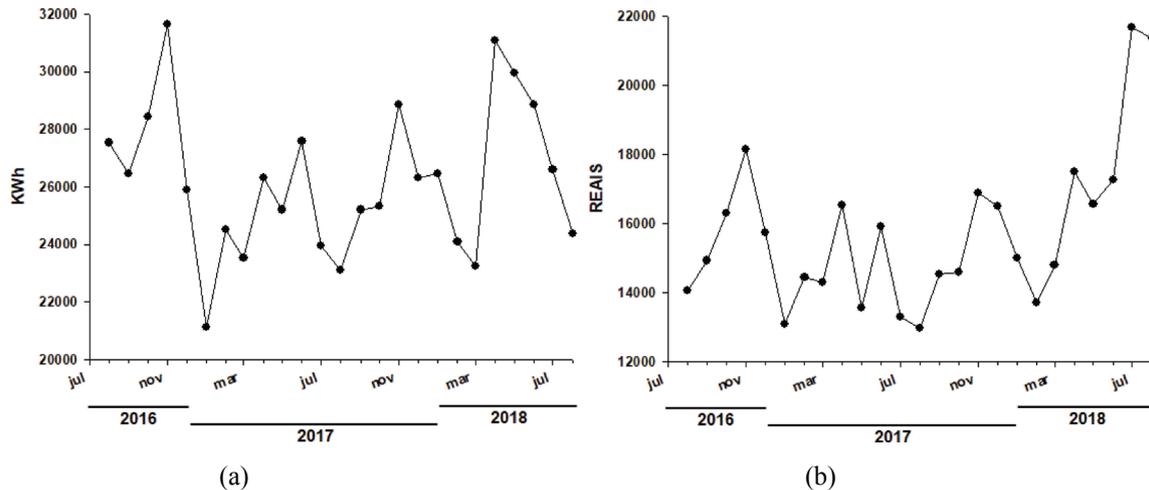


Figure 5: (a) CSL-UFSJ's monthly electricity consumption in kWh; (b) amount invested by the university in Reais.

Source: Personal collection (2018).

The specific energy consumption of the DECEB building was obtained by surveying the existing electrical equipment in the building. The data collected are detailed in Table 1. The power values were obtained using the equipment itself. For those that were not readable, the values provided in Distribution Standard 5.1 (Cemig, 2013) were considered. In this survey, the same power value was adopted for all equipment of the same type, except for the auditorium air conditioning, which showed a significant difference in relation to other devices.

The installed power was determined by the product between multiplying the quantity of equipment by its power

consumption of the entire *campus* in the period between August 2016 and August 2018. The average monthly consumption of CSL-UFSJ is 27,300.38 kWh, with the average monthly amount paid by the university being US\$ 2.710.

value. Final consumption is given by multiplying installed power, demand factor and equipment usage time. Energy consumption for pumping water was also considered for the possibility of implementing a rainwater recovery system.

Considering that not all equipment is connected simultaneously, and in order to have a more accurate analysis, the demand factor was used, which suggested the values of 0.4 for refrigerators and freezers, 0.7 for BODs and 1 for other equipment, according to Distribution Standard 5.1. Therefore, the value of 13,187.1 kWh was obtained for the final monthly consumption of the DECEB building.

Table 1: Estimation of electrical energy consumption of DECEB building equipment.

Equipments	Amount	Wattage (W)	Installed power (W)	Demand factor	Usage time (h / month)	Monthly consumption(kWh)
Air conditioning	4	1490	5960	1	240	1430,4
Auditorium airconditioning	1	5608	5608	1	240	1345,9
Refrigerators	14	190	2660	0,4	720	766,1
BOD	5	500	2500	0,7	720	1260
Fan	24	200	4800	1	240	1152
Computer	42	360	15120	1	240	3628,8
Microwave	6	1350	8100	1	2,52	20,4
Coffee machine						

Misteira	3	1280	3840	1	2,52	9,7
Boiler	1	760	760	1	2,52	1,9
Projector	2	1000	2000	1	7,5	15
Modem	2	200	400	1	240	96
Printer	4	12	48	1	240	11,5
Lamps	4	350	1400	1	240	336
Normal centrifuge	295	40	11800	1	240	2832
Balance	2	500	1000	1	0,51	0,5
Microscope	6	12	72	1	0,51	0,04
Knife mill	31	30	930	1	0,51	0,47
Magnetic shaker	1	200	200	1	0,51	0,10
Orbital shaking table	1	300	300	1	0,51	0,15
Magnifying glass	1	300	300	1	0,51	0,15
Hot plate	9	15	135	1	0,51	0,07
Waterbath	1	1400	1400	1	0,51	0,7
PH meter	3	1000	3000	1	0,51	1,5
Greenhouse	3	5	15	1	0,51	0,01
Exhaust fume hood	4	2070	8280	1	15	124,2
Autoclave	2	475	950	1	0,51	0,48
Electrophoresis source	3	4000	12000	1	1,8	21,6
Security cabin	2	180	360	1	0,51	0,18
Spectro photometer	3	400	1200	1	5,1	6,1
Water pump	1	150	150	1	0,51	0,08
Air conditioning	1	1041	1041	1	120	124,92
Total Consumption						13.187,1

Dimensioning the Photovoltaic System: Sete Lagoas Campus (CSL-UFSJ)

The minimum power of the frequency inverter that will be connected to the concessionaire was calculated using equation 1, demonstrated in the methodology. The solar irradiation data provided by the SunData v 3.0 software was used to perform the calculations, using the annual average

index for 5.51 kWh / m² / day shown in Table 2. Daily consumption was given by the ratio between consumption final monthly of the DECEB building (27,300.38 kWh) and 30 days, obtaining the value of 910 kWh / day. Considering the system's 85% efficiency, the 0.85 index for equipment losses was adopted. Thus, the value of 194.3 kW was obtained for the minimum power of the inverter to supply the entire *campus*.

Table 2: Daily solar radiation in the DECEB building, according to SunData software v 3.0 - (kWh / m² / day).

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
Annual average	5,44	5,87	5,45	5,53	5,23	5,21	5,55	6,1	5,99	5,57	5,04	5,18	5,51

Two possibilities were verified for the inverters to be implemented, the first using 10 inverters with a power of 20 kW and the second using 2 inverters with a power of 100 kW. The following market values for the inverters were

considered: US\$ 4,487,1, for each inverter with a power of 20 kW, and US\$ 7,280,5, for the inverter with a power of 100 kW. The difference in values is quite significant, so that, taking into account the need to purchase 10 inverters

with a power of 20 kW to reach the building's demand, the total cost would be US\$ 44,871, while the cost of 2 power inverters with a power of 100 kW would be US\$ 14,561. Thus, the acquisition of 100 kW inverters is more economically viable.

The number of panels was determined from equation 2. A panel with dimensions of $196 \times 99.2 \times 4$ cm was used for the calculation, with a maximum power of 330W and a cost of US\$ 115,3. Thus, the number of 589 photovoltaic plates was calculated. Considering the market value for this panel model, it is estimated a cost of US\$ 67,911, which added to the cost of US\$ 14,561 of the inverters results in a total of US\$ 82,472 for the acquisition of this equipment. According to data provided by the Institute for the Development of Alternative Energy in Latin America (IDEAL, 2019), the costs of inverters and photovoltaic modules represent 59% of the total price of the system. Thus, the value of US\$ 139,784 was obtained for the total estimated cost for the photovoltaic system in order to supply the entire *campus*.

Considering the average monthly amount of US\$ 2,736 invested by the university in electricity, it is estimated that the average annual investment by the institution is US\$ 32,833. Thus, a simple payback time for the installation of the photovoltaic system was calculated for 4.3 years. The NPV calculation was also positive, demonstrating the system's viability and the discounted Payback result was 4.9 years.

Dimensioning the Photovoltaic System: DECEB Building

In order to reduce the initial costs for the implementation of the photovoltaic system, a calculation was made for the dimensioning aiming specifically to supply the DECEB building. The adopted methodology was the same used in the dimensioning of the system for the entire CSL-UFSJ. Considering an average monthly consumption of 13,187.1 kWh, a daily consumption of 439.6 kWh / day was obtained. In this way, the value of 93.8 kW was calculated for the minimum power of the inverter to supply the DECEB building.

Considering the same panel model used in the design for CSL-UFSJ, with a power of 330 W, it was possible to determine the number of 284 photovoltaic plates, totaling a cost of US\$ 33,321, which added to the value of US\$ 7,280 regarding the inverter, results in a cost of US\$ 40,601. Adding the other costs of the system, it was obtained the amount of US\$ 68,816, referring to the total estimated value for the photovoltaic system aiming specifically to supply the DECEB building.

To calculate the savings generated by the implementation of the system, a simple rule of three was used, considering the average monthly cost of electricity

and the average monthly consumption presented by the entire *campus*. Thus, the estimated values of US\$ 1,322 for the monthly cost and US\$ 15,860 for the annual cost were obtained. Simple Payback is estimated for the 4.3-year photovoltaic system. The NPV calculation had a positive result demonstrating the feasibility of implementing the system, the estimated Payback discount was 4.9 years.

There is a significant reduction in the investment value for the system designed specifically for the DECEB building in relation to the values obtained for the entire *campus*. Thus, it is recommended initially to implement the system only for the demand of the DECEB building, being possible to expand the system in the future.

Considering the implementation of the photovoltaic system to meet the demand of the DECEB building, it is proposed to install panels grouped in modules of 14 plates distributed on the building's roof. It is recommended to install the panels on the roof of the blocks that have shown higher energy consumption, and also due to the proximity to the other equipment of the photovoltaic system, in order to reduce energy losses, considering that the shorter the distance between the panels and the system, greater the efficiency of it. For the storage of photovoltaic system equipment, it is proposed to build a specific space located next to CEMIG's bidirectional energy meter.

Cost Analysis of No-Breaks

Due to the need to ensure the preservation of samples, reagents and experiments that depend on the operation of refrigerators, freezers and BODs, in case of interruption of energy supply by the concessionaire at night, the costs for the acquisition of an Uninterruptible Power Supply (UPS) was raised. For this purpose, the electrical energy consumption of the equipment to be connected to the safety device was estimated, which can be found in Table 3.

Table 3: Estimated electricity consumption of DECEB equipment to be connected to the safety device.

Equipments	Total building	Wattage(W)	Installed power (W)
Refrigerator	9	250	2250
Freezer	3	300	900
BOD	4	500	2000
Total Consumption			5150

Considering the use of the no-breaks to supply the calculated demand, it would be necessary to acquire 6 pieces of equipment with 1500 W power and one with 1000 W power, where the installation would take place as follows: 3 arrangements composed of 3 refrigerators with power

250 W connected to 1500 W equipment; 3 arrangements composed of 1 BOD with 500 W power and 1300 W power freezer also connected to 1500 W equipment; and 1 BOD with 500 W connected to a 1000 W device, totaling a cost of US\$ 2,389.

In addition to the costs for the purchase of the UPS, it is necessary to consider the purchase of 3 stationary batteries in order to maintain the equipment loads for an estimated period of 5 hours in case of interruption of the power supply during the night. The current market value for each battery is US\$ 489, thus, the estimated total cost for the acquisition of the no-breaks and batteries required to maintain the equipment's functioning would be US\$ 3,856.

Budget for Photovoltaic Systems

In order to evaluate and compare the value of a photovoltaic system in the current market and the results obtained in the dimensions made in this work, budgets were made in authorized companies considering the cost of acquisition and installation of the system. The budgets were made using two demand values, one considering the investment amount necessary to supply the demand for the CSL-UFSJ (27,300.38 kWh) and one considering the demand only for the DECEB building (13,187.1 kWh). The results can be found in Tables 4 and 5.

Table 4: Budget for photovoltaic systems to supply the demand of 27,300.38 kWh, referring to the consumption of the entire CSL-UFSJ.

Budget	Number of panels (unit)	Minimum required area (m ²)	Investment amount (US\$)	Return on investment (years)
A	720	1440	163.848,00	5,5
B	969	2422	180.050,00	7,1
C	850	1700	175.689,00	6,4
Average	846,3	1854	173.196,00	6,3

Table 5: Budget for photovoltaic systems to supply the demand (13,187.1 kWh) of the DECEB building.

Budget	Number of panels (unit)	Minimum required area (m ²)	Investment amount (US\$)	Return on investment (years)
A	380	867	86.171,00	4
B	468	936	86.958,00	4
C	410	820	84.744,00	3,5
Average	419,3	874,3	85.958,00	3,8

The results obtained in the dimensioning carried out in this work were similar to those shown in the budgets. It is observed, however, that the values obtained in the design

were lower than the budgeted values. It is believed that this is due to the fact that the budgets provided by the companies include, in addition to the equipment required by the system, installation costs and percentage of sale relative to the professionals responsible for the dimensioning.

In addition to the costs analyzed for the photovoltaic system, costs must be taken into account for the construction of a cabin to house the equipment that makes up the system. Thus, considering the data from SINAPI (2019), the estimated cost would be US\$ 3,353 for a 3 m² cabin, considering 1 working day for laborers and masons.

Conclusions

The CSL-UFSJ consumes, on average, 27,300.38 kWh, at a cost of US\$ 2,736. Thus, an annual savings of US\$ 32,833 is calculated. The cost estimate analyzes showed a value of US\$ 139,784 for the implementation of the system. The return on investment time was calculated for 4.3 and 4.9 years considering simple and discounted Payback respectively.

It is estimated that the consumption of the DECEB building is 13,187.1 kWh with a cost of US\$ 1,322 per month, which results in an annual savings of US\$ 15,860. The cost estimate analyzes showed a value of US\$ 40.601 for the implementation of the system and values of 4.3 and 4.9 years were obtained as return on investment time considering the calculations for simple and discounted Payback, respectively.

Thus, the research demonstrates that the implementation of the photovoltaic solar energy generation system is feasible for both cases analyzed. However, considering that the initial cost for implementing the system is significantly lower for specific implementation in the DECEB building, it is possible to point greater economic viability for this case.

It is also noteworthy that the implementation of alternatives for the use of electric energy such as those presented in this work can contribute to the development of sustainable techniques applied to civil construction. When implemented in universities, such alternatives gain greater importance, as such institutions can function as replicators of the importance of sustainable practices. In addition, alternatives such as those presented in this work can also enable educational institutions to obtain development indexes since it promotes surveys and information related to the characterization of the *campus* environment and infrastructure, in addition to presenting practical proposals for action in the energy areas and climate change.

Acknowledgment

I would like to thank all the team members who contributed to the development of this work; to UFSJ; to PPGTDS

teachers and colleagues; CAP and CSL-UFSJ technicians, servers and friends; and the department of general services at UFSJ. This work was carried out with the support of the National Council for Scientific and Technological Development (CNPq) and the Minas Gerais Research Support Foundation (FAPEMIG).

References

- Agência Nacional de Energia Elétrica (2018). Matriz de Energia Elétrica. ANEEL, Brasília. Retrieved on December 05, 2018 from <https://www.aneel.gov.br>.
- Bandarin, F., Hosagrahar, J., & Aalbernaz, F. (2011). Why development needs culture. *Journal of Cultural Heritage Management and Sustainable Development*, 1(1), 15-25. <https://doi.org/10.1108/20441261111129906>
- Banco Central do Brasil. (2021) Oficial Page, Dados diários. Retrieved on February 14, 2021 from <https://www.bcb.gov.br/estabilidadefinanceira/selicdadosdiarios>
- Bizerril, M., Rosa, M., & Carvalho, T. (2018). Construindo uma universidade sustentável: uma discussão baseada no caso de uma universidade portuguesa. *Avaliação (Campinas)*, 23(2), 424-447. <https://doi.org/10.1590/s1414-40772018000200009>
- Buonomano, A., Forzano, C., Kalogirou, S., & Palombo, A. (2019). Building-façade integrated solar thermal collectors: Energy-economic performance and indoor comfort simulation model of a water-based prototype for heating, cooling, and DHW production. *Renewable Energy*, 137, 20-36. <https://doi.org/10.1016/j.renene.2018.01.059>
- Castanheira, G., & Bragança, L. (2014). The Evolution of the Sustainability Assessment Tool SB Tool PT: From Buildings to the Built Environment. 2014, 10. <https://doi.org/10.1155/2014/491791>
- Centro de Referência para as Energias Solar e Eólica. (2014). Manual de engenharia para sistemas fotovoltaicos. CRESESB, Rio de Janeiro, RJ.
- Centro de Referência para Energia Solar e Eólica Sérgio Brito, & Centro de Pesquisas de Energia Elétrica (2018). Potencial Solar - SunData v 3.0. CRESESB and CEPEL, Rio de Janeiro, RJ. 2018. Retrieved on July 11, 2019 from <http://www.cresesb.cepel.br/index.php?section=sundata&>
- Chauí, M. (2003). A universidade pública sob nova perspectiva. *Revista Brasileira de Educação*, 24, 5-15.
- Companhia Paranaense de Energia (2014). Energias renováveis: políticas públicas e planejamento energético. COPEL, Curitiba, PR. 2014.
- Conselho de Defesa dos Direitos da Pessoa Humana. (2011). Atingidos por Barragens: Relatório da Violação dos Direitos Humanos na construção de barragens [Comissão Especial] Resoluções nºs 26/06, 31/06, 01/07, 02/07, 05/07. CDDPH, Brasília, DF. Retrieved on March 30, 2019 from <http://www.direito.mppr.mp.br/arquivos/File/barragens/sumario.pdf>
- Dinçer, F. (2011). The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy. *Renewable and Sustainable Energy Reviews*, 15, 713-720. <https://doi.org/10.1016/j.rser.2010.09.026>
- Dos Santos, M., Rosa, L., Sikar, B., Sikar, E., & Dos Santos, E. (2016). Gross greenhouse gas fluxes from hydro-power reservoir compared to thermo-power plants. *Energy Policy*, 34(4), 481-488. <https://doi.org/10.1016/j.enpol.2004.06.015>
- Ferreira, A., Kunh, S., Fagnani, K., De Souza, T., Tonezer, C., Dos Santos, G., & Coimbra-Araújo, C. (2018). Economic overview of the use and production of photovoltaic solar energy in Brazil. *Renewable and Sustainable Energy Reviews*, 81, 181-191. <https://doi.org/10.1016/j.rser.2017.06.102>
- Foladori, G. (2015). O Capitalismo e a crise ambiental, Revista Outubro, ed. 15, No.8. UFPR, Curitiba.
- Frota, A., and Schiffer, S. (1995). Manual de conforto térmico. (2ª ed) São Paulo, SP: Nobel. pp. 243.
- G1. (2020 a). 'Após 22 dias de apagão no Amapá, distribuidora e governo dizem que rodízio terminou e que energia foi retomada em 100%' G1 Amapá. [online] 24 November. Retrieved on December 03, 2020 from <https://g1.globo.com/ap/amapa/noticia/2020/11/24/amapa-entra-no-22o-dia-de-apagao-com-novo-transformador-ligado-na-subestacao-que-pegou-fogo.ghtml>
- G1. (2020 b). Apagão no Amapá: comércio atende apenas sob "luz do sol", e famílias somam prejuízos com eletrodomésticos. G1 Amapá. [online] 19 November. Retrieved on <https://g1.globo.com/ap/amapa/noticia/2020/11/19/apagao-no-amapa-comercio-atende- apenas-sob-luz-do-sol-e-familias-somam-prejuizos-com-eletrrodomesticos.ghtml>.
- Instituto para o desenvolvimento de energias alternativas na América Latina. (2019) O Mercado Brasileiro de Geração Distribuída Fotovoltaica. IDEAL. Retrieved on December 17, 2020 from https://issuu.com/idealeco_logicas/docs/o_mercado_brasileiro_de_gera_o_distribu_da_fv_-_e
- Machado, C., & Miranda, F. (2015). Energia Solar Fotovoltaica: Uma Breve Revisão. *Revista Virtual de Química*, 7(1), 126-173. <https://doi.org/10.5935/1984-6835.20150008>
- Ministério de Minas e Energia (2017). Balanço Energético Nacional de 2016. Brasília, DF, 2017. Retrieved on August 20, 2018 from <http://www.mme.gov.br>

Panno, D., Buscemi, A., Beccali, M., Chiaruzzi, C., Cipriani, G., Ciulla, G., Di Dio, V., Lo Brano, V., & Bonomolo, M. (2019). A solar assisted seasonal borehole thermal energy system for a non-residential building in the Mediterranean area. *Solar Energy*, 192, 120-132.
<https://doi.org/10.1016/j.solener.2018.06.014>

Sistema Nacional de Pesquisa e Custos e Índice da Construção Civil. (2020). Cálculos e Parâmetros. SINAPI, Brasil, Governo Federal. Retrieved on December 17, 2020 from https://www.caixa.gov.br/Downloads/sinapi-manual-de-metodologias-e-conceitos/Livro2_SINAPI_Calculos_e_Parametros_2_Edicao_Digital.pdf



Journal of Chemistry, Environmental Sciences and its Applications

Chitkara University, Saraswati Kendra, SCO 160-161, Sector 9-C,
Chandigarh, 160009, India

Volume 7, Issue 2

March 2021

ISSN 2349-7769

Copyright: [© 2021 J.C.B. Menezes, J.C. Cury and L.M. Souza] This is an Open Access article published in Journal of Chemistry, Environmental Sciences and its Applications (J. Chem. En. Sci. A.) by Chitkara University Publications. It is published with a Creative Commons Attribution- CC-BY 4.0 International License. This license permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.