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ANALYSIS OF TECHNICAL AND ECONOMIC VIABILITY OF COGENERATION AND PHOTOVOLTAIC SYSTEMS APPLIED TO A UNIVERSITY BUILDING

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Abstract. Distributed generation of electric energy is considered an alternative to supplying self-consumption and decrease the demand of the Brazilian grid, thus contributing to the reduction of losses of the central power generation systems. Cogeneration and photovoltaic systems are considered a way of generating energy that causes less impact on the environment and emits relatively low or no amounts of CO_2 during its operation. This work is based on the rules of National Electric Energy Agency – ANEEL NR687 and NR482 which regulates the distributed generation of energy, where an economic feasibility analysis was carried out through a study of cogeneration systems, photovoltaics and a combined system applied to the publishing house of the Federal University of Pernambuco. The combined system presented better results due to the intermediate costs between the systems, with a smaller area of photovoltaic modules and lower payback concerning the cogeneration system.

Keywords: Renewable energy, Cogeneration, Photovoltaic, Aneel.

1. INTRODUCTION

The rapid growth of world energy use has raised major concerns about energy supply difficulties, depletion of resources and environmental impacts (greenhouse effect, depletion of the ozone layer, global warming, and climate change). The use of fossil fuels on a large scale has substantially changed the composition of the atmosphere and the planet's thermal balance, causing climate change. The use of renewable energy sources is the best and most advantageous way of replacing the use of fossil fuels since they are practically inexhaustible and have very low or near zero environmental impact, without affecting the planet's thermal balance or atmospheric composition.

A method that can be used in this substitution is the use of cogeneration systems, which according to Balestiere (2002), corresponds to the simultaneous production of different forms of useful energy, such as electromechanical and thermal energies, to supply the needs of a industrial, agricultural, tertiary or an isolated system, from the same primary energy source. Cogeneration allows a fuel economy of between 10 % and 40 % and is therefore considered a powerful carbon reduction technology that can be used in different applications (ALCAN et al., 2013). That is, cogeneration allows the use of part of the energy that would previously be eliminated by the process, in the process itself or a secondary process.

Due to the benefits, cogeneration began to gain importance in several applications such as pulp and paper, food manufacturing, petrochemical, brewing, textiles in the industrial sector as well as hotels, hospitals, schools, and universities. Among its advantages, it generates less emission of greenhouse gases to the environment (TSAI and HSIEN, 2007), generating lower capital expenditures in the transmission grid capacity and avoiding transmission losses, while ensuring a high-quality energy supply (PANNO et al., 2007).

Silva et al. (2019) analyzed a case study using a cogeneration system in the university campus rectory building to meet all the demand for modeled and simulated electricity and refrigeration. The results showed that energetically this system would attend to the electricity and also to comfort needs of the building of the rectory of the UFPB. From the financial point of view, the proposed cogeneration system with a combustion engine to meet the electrical and cooling demands of the rectory was not attractive, since the return values would be reached after about 40-50 years. Only cogeneration systems using the 65 kW gas microturbine proved to be financially viable since the return time was around six years.

Another method that can contribute to the generation of energy and presents minimal impact to the environment is the Photovoltaic System, where the energy obtained through the direct conversion of sunlight into electricity, this occurs through an effect called photovoltaic which is the appearance of a potential difference in the ends of semiconductor material, produced by the absorption of light in the used Plates. According to ANEEL, photovoltaic systems are divided into three categories depending on the power installed, the power plants, the mini generation, and the micro-generation of energy. The photovoltaic system consists of Solar panels, solar inverter, fixation system of solar panels, wiring, connectors, and other standard electrical materials.

Wang et al. (2019) investigated through simulations, a combined system of cogeneration and solar system (photovoltaic) to be applied in buildings, where the combined system suited the electric and cooling demand. The results showed that although the combined system has a higher cost, it has advantages of better scheduling flexibility and lower equivalent annual cost. The potentiality of cost reduction will significantly decrease the payback period and will highlight real application value.

Liang et al. (2018) evaluated the performance of the cogeneration system under external climatic conditions, including useful heat gain, heating performance coefficient, photovoltaic efficiency in combined photovoltaic and cogeneration systems for a building. The results showed that the maximum water temperature and the heating of the COP during the test period were 43.9° C and 3.1, respectively. The average photovoltaic efficiency was about 9 %. From the point of view of the application, it is possible to mount the cogeneration system with the photovoltaic on the facade of a building.

2. COMPUTER TOOLS

The recent evolution of computing and associated potentialities allowed the development of a new area of evaluation of the thermal behavior of buildings, where the realizations of computational simulations in specific tools allow a critical analysis of the elaborated solutions and respective energy performance of buildings (COSTA, 2012). Due to the simultaneous processing capacity, the computational tools allow the dynamic analysis of the processes, in which a continuous interaction is carried out between the interior of the dwelling and the environmental surroundings during the analysis period.

According to CRAWLEY et al. (2000) Energy Plus is a free software tool for computational simulation of energy analysis and simulation of thermal load in buildings that uses a dynamic type approach in the phenomenon of energy transfer between building and exterior environment in which the interior of the dwelling is in constant interaction with the exterior environment throughout the simulation period. The software applies climatic files with the detailed definition of parameters related to the behavior of the local environment, outdoor temperature, humidity, radiation, and solar orientation.

The thermal performance of the elements of a building is directly associated with its external climatic variables. Knowledge of the climatic conditions is very important since they represent the basic requirements for the design of air conditioning systems, simplified calculations of energy consumption and the thermal energy simulations of buildings.

Currently, there are different types of sources for climate data that can be used in computer simulation programs. However, many of these types present data only for one country. In Brazil, among the different types of climatic archives available for use in computer simulation are Test Reference Year (TRY), Typical Meteorological Year (TMY), Solar and Wind Energy Resource Assessment (SWERA), International Weather for Energy Calculations (IWEC) and INMET.

3. UNIVERSITY PUBLISHING HOUSE

The University Publishing house, whose first name was University Press, was created in 1955 and was installed definitively in the next year as part of the structure of the Rectory of the University of Recife, former UFPE denomination. The publishing house, Figure 1, is one of the most important supplementary organs of UFPE. It is responsible for supporting the intellectual production of university professors and researchers and for printing various publications, such as books, periodicals, maps, folders, posters, among other materials. In addition to serving the academic community with regard to teaching, research, and extension. On-site, there is state-of-the-art equipment such as the Heidelberg CTP printer, computers, and duplicating machine. Currently, the publishing house contains an area of 813.14 m², presenting a high energy consumption.

Figure 1: University Publisher. Available from: https://www.ufpe.br/edufpe

The present work analyzed the technical and economic feasibility of using three types of system: Cogeneration, Photovoltaic, and a Combined System (Cogeneration and Photovoltaic) from data provided on the energy demand of University Publishing house, in which one of the systems had the ability to meet all energy consumption demand, contributing to a reduction in cost.

4. METHODOLOGY

The work was developed in the Cogeneration Laboratory - Congencasa of the Federal University of Pernambuco, wherefrom the operational and construction data of the building provided by the publishing house, it was possible to define the type of surfaces (doors, windows, walls) types of spaces and thermal zones of the installations. In the computational analysis of the system were considered parameters such as time and region of simulation, schedules of activities of equipment operation and entrance/exit of people, specific thermal loads for each site and HVAC (heating, ventilation and air conditioning systems) for ventilation and cooling.

4.1 Case Study 1

In order for the cogeneration to be economically feasible, the new system must override the old one in terms of fuel and energy expenditures, based on this information, a financial analysis was performed considering the payback based on the cash flow graph and discovering the internal rate of return, taking into account the current energy expenditure purchased by the grid and the expected gas consumption for the system. Table 1 shows the market values for natural gas, taking into account its calorific value, according to distributor Copergás (2019). For the cogeneration system, the equipment described in Tab. 2, data concerning the manufacturer, was used.

Table 1. Natural Gas Rates.

RATES	
(m³/day)	Price (R$/m³)
0 - 1000	1.2899
1001 - 5000	1.2657
Low Heat Value	
9.88	kWh/m³
Higher Heating Value	
10.92	kWh/m³

Table 2. Cogeneration System Equipment

TURBINE CAPSTONE C30		
DATA	**UNIT**	**VALUE**
Generated Electrical Power	kW	30
Generated Thermal Power	kW	65
Annual Electricity Generated	kWh/year	129,600.00
Annual Generated Thermal Energy	kWh/year	280,800.00
BROAD BE100 ABSORBING CHILLER		
Generated Electrical Power	TR	0
Generated Thermal Power	TR	50
Annual Electricity Generated	TRh/year	0
Annual Generated Thermal Energy	TRh/year	1,350,480.00

4.2 Case Study 2

For the Photovoltaic System, it is necessary to know the demand for the building (kWh). As a location of the publishing house that is in the city of Recife, the hour of sun peak (HSP) of the region required for the best sizing of the photovoltaic system was verified. For this information, the data provided by the Solar and Wind Reference Center Sergio de Slavo Brito - CRESESB, which presents data of solar radiation in Recife / PE, with latitude – 35.008676, longitude – 8.0421584, were used.

Some percentages of losses were considered as 12.65 % of losses per temperature, 1 % for DC-AC talk, 8 % for shading or dirt, and 2.35 % for cabling totaling 24 %. With all the data defined, Eq. (1) was used to size the power of the system needed to supply the demand of the enterprise. A financial analysis was performed considering the payback based on the cash flow graph, discovering the internal rate of return, taking into account the current cost of energy purchased by the network.

$$kW_p = \frac{kW_h}{HSP \times 30 \times (1 - Losses)} \tag{1}$$

In order to obtain the number of modules of the photovoltaic system, it is necessary to know the type of module to be used, the equipment configuration shown in Tab. 3 was used as a reference and the power obtained in Eq. (1) was used Eq. (2) to know the most significant integer of modules to be used to meet demand.

$$Number\ of\ modules = \frac{kWp}{power\ of\ the\ module\ (kWp)} \tag{2}$$

In order to choose the frequency inverter, it must be obeyed that the maximum limit of the sum of the power of the modules to be used must not exceed 30 % of the nominal power of the inverter.

Table 3. Configuration of the equipment that makes up the Photovoltaic System

CANADIAN SOLAR MODULE CS3U 325MS		
DATA	**UNIT**	**VALUE**
Power	Wp	325
Max voltage	Vpm	90.2
Maximum Current	Ipm	8.94
Length	m	2
Width	m	0.99
Module Area	m²	1.98
Weight	kg	22.6
Temperature Coefficient	W/ºC	-0.29
STRING INVERTER SUNGROW SG60KTL		
DATA	**UNIT**	**VALUE**
Max. efficiency	%	99
Nominal AC output power	kW	60
Nominal grid frequency	Hz	55 - 65
Max. DC/AC ratio		1.4
No. of MPPTs		1
Weight	kg	60

4.3 Case Study 3

A Combined System (Cogeneration and Photovoltaic) was elaborated to analyze the economic viability of the system and the need for infrastructure for its implementation, with these two systems together could supply the energy demand of Editora. In this case study, we used all parameters, the equipment listed in Tab. 4, equations, and simulations of case study 1 and 2. Figure 2 presents the configuration of the combined system.
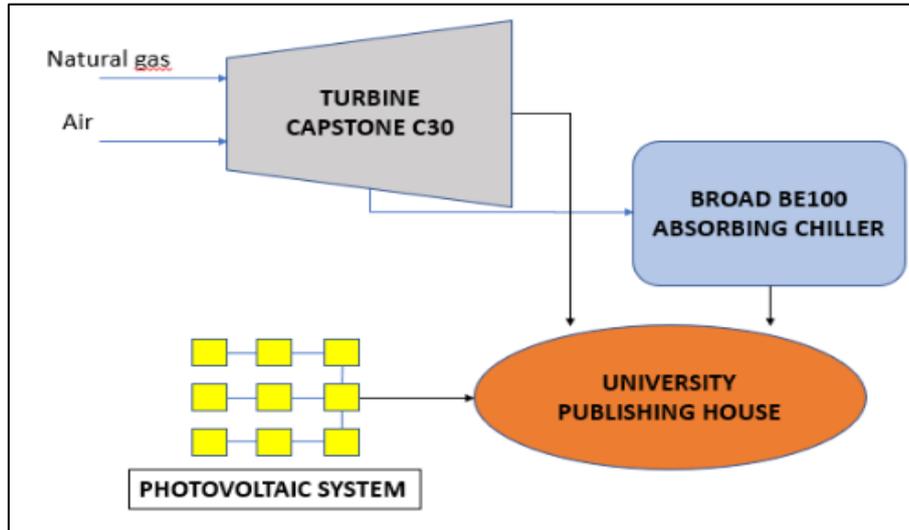

Figure 2. Configuration of the combined system (cogeneration and photovoltaic)

Table 4. Photovoltaic System Equipment

CANADIAN SOLAR MODULE CS3U 325MS		
DATA	UNIT	VALUE
Power	Wp	325
Max voltage	Vpm	90.2
Maximum Current	Ipm	8.94
Length	m	2
Width	m	0.99
Module Area	m²	1.98
Weight	kg	22.6
Temperature Coefficient	W/ºC	-0.29
STRING INVERTER SUNGROW SG36KTL-M		
DATA	UNITY	VALUE
Max. efficiency	%	99
Nominal AC output power	kW	36
Nominal grid frequency	Hz	55 - 65
Max. DC/AC ratio		1.3
No. of MPPTs		3
Weight	kg	48

5. RESULTS

5.1 Simulation

The results of the simulation are presented in Fig. 3, which shows the monthly specific consumption of electricity (lights and equipment) and refrigeration in a typical year with 8760 h, total and thermal electricity demand were 20137.23 kWh/month and 10119.05 kWth/month respectively. The month of March presented the highest annual thermal demand in comparison with the other months, due to the climatic variations in the region of Recife. For cooling, the month of March showed an increase of 88 % compared to the lower consumption during July.
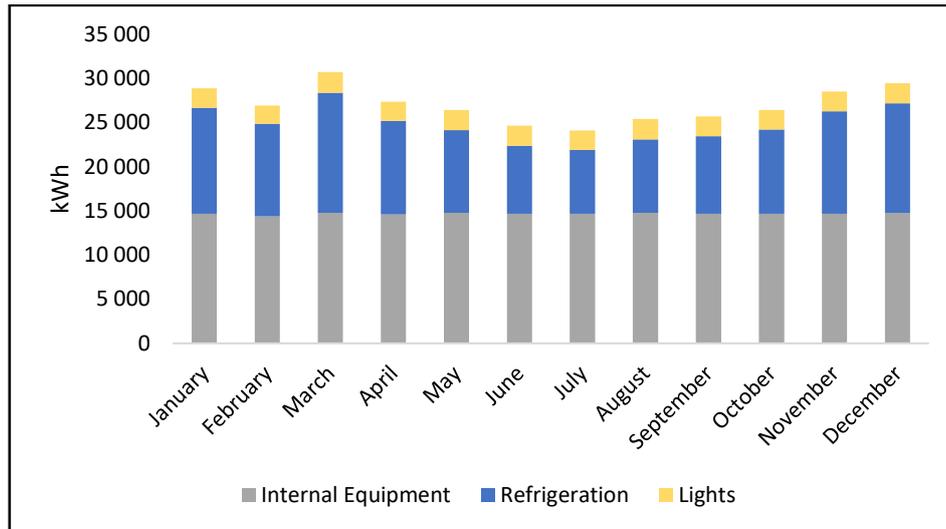
Figure 3. Results of simulation by Energy Plus software.

5.2 Results of Case 1

The energy scheme for the cogeneration unit for case study 1 is presented in Fig. 4, the electric and thermal power values indicate the average capacity of use 42 % for turbine and 56 % for the chiller. The demand for total electric consumption is 21968.88 kWh/month. The results showed that all of publishing house thermal demand was met by the system and a part of the electric demand, but it is necessary to complement the rest, the 7818.73 kWh/month through the energy concessionaire.
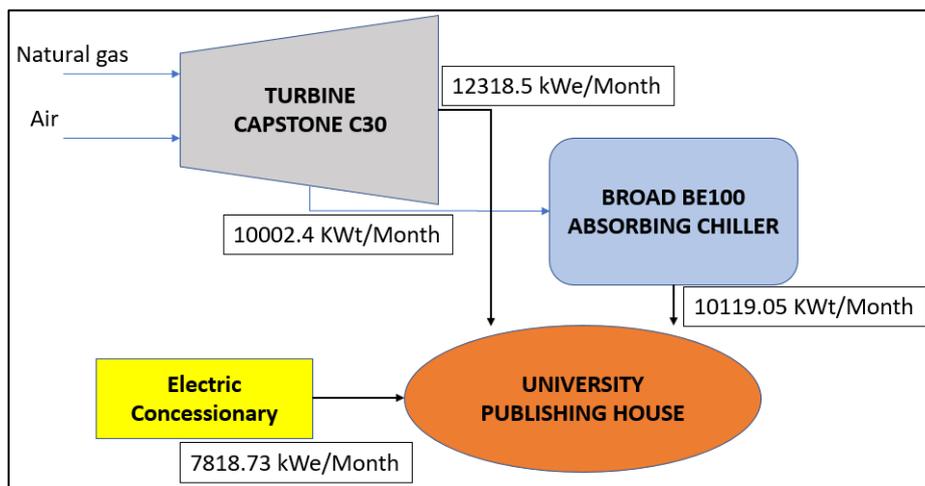
Figure 4. Configuration of the cogeneration unit.

5.3 Results of Case 2

According to the total electric power demand, as shown in case 1, a photovoltaic system with a power of 166.8 kWp was measured through Eq. (1). For this system to be connected to the electricity utility according to normative resolution NR 482 and 687 of ANEEL will require two string inverters of power 60 kW, 512 units of solar modules, according to the configuration shown in Table 3 and a total area of 1218.97 m².

5.4 Results of Case 3

The combined system (cogeneration and photovoltaic) was implemented to reduce the 7818.73 kWh/month of electrical demand, which case 1 could not supply. Using Eq. (1), the results showed that the system would need 93.6 kWp power, based on the configurations of Table 4, and would require 288 solar modules and two string inverters to be connected to the grid, occupying an area of 685.6 m².

5.5 Financial analysis

The photovoltaic system presented a better result as an investment, in Fig. 5 we can see a Net Present Value (NPV) of R$ 468.458,28 compared to an investment that yields 10 % per annum and if we consider a cash flow over 25 years, based on the life of the photovoltaic modules. For the Internal Rate of Return (IRR), the system presented a return of 17 % per year, with a return of 6.1 years. Figure 6 shows the IRR results for all case studies.

The combined system resulted in a decrease in its area used for 685.6 m², had an NPV of R$ 310.090,89 and a TIR of 15.68 %, this decrease is due to the costs of the cogeneration system, but in this case its implementation becomes more feasible due to the area required to fit the area provided by the project, with a return of 6.1 years. Figure 7 shows the return results for all case studies.
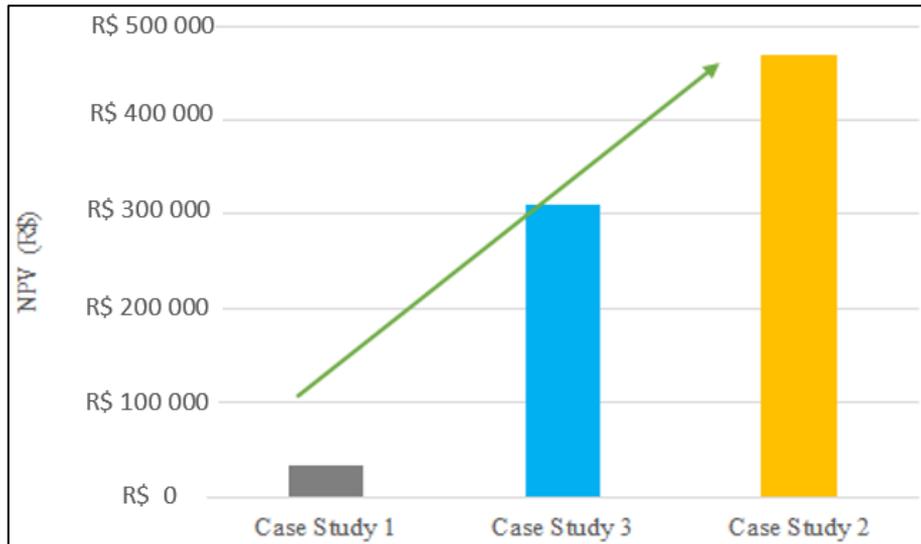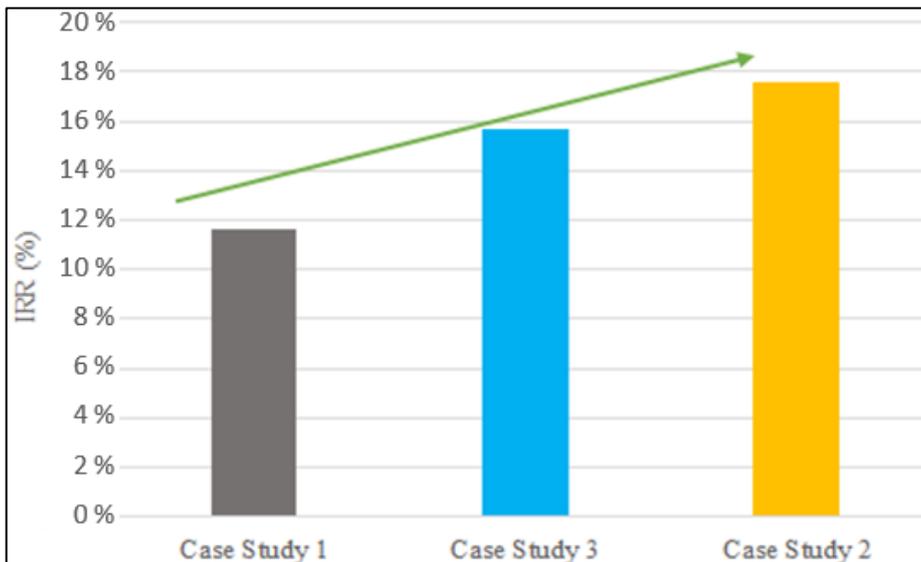

Figure 5. Net Present Value.
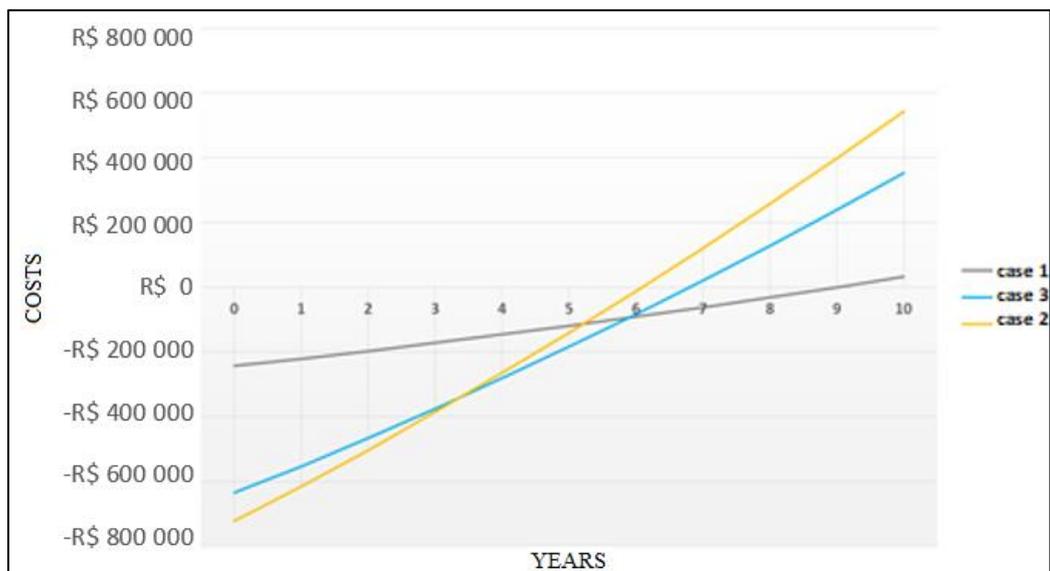

Figure 6. Internal Rate Return.

Figure 7. Payback.

6. CONCLUSION

Case 1 proved feasible to meet all the thermal demand generated, but its investment is paid in a very long period, with payback in 9 years. However, it is unable to supply a portion of the building's electrical demand.

Case 2, however, meets the entire electrical demand of publishing house, but it would require an area of 1218.97 m² for a system power of 166 kwp that represents 512 modules. However, the publishing house has a smaller area than necessary, making even with a lower payback in 6.1 years.

Case 3 presented the best result since it only needs an area of 685.6 m² and a system power of 93.6 kWp that represents 288 modules, with a payback of 6.8 years, taking into account the total thermal consumption and building. This case also proved to be the most appropriate in terms of operational safety because it has two distinct sources of energy, which enables the system to adapt to variations in solar and natural gas demand.

7. ACKNOWLEDGEMENTS

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