Economic Analysis of a Nearly Zero Energy Building in Social Housing: A Case Study in Southern Brazil

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Sponsoring Information: The authors receive research grants from Fundação IMED.
Acknowledgment: The authors would like to thank the Postgraduation Program of Architecture and Urbanism, School of Engineering and Applied Sciences of Faculdade Meridional (IMED) and the Fundação IMED, which provided the means to carry out this research.

Abstract

In Brazil, the possibility to produce electricity in buildings to supply its energy consumption is a reality. This article aims to investigate the energy consumption of a housing of social interest in the climatic context of southern Brazil, as well as to evaluate the feasibility of producing photovoltaic electricity to supply the building's energy demand, contributing to the dissemination of Nearly Zero Energy Buildings (NZEB). The object of this research is a social interest house in the *Canaã* housing in the city of *Passo Fundo/RS*. As a method it was estimated the energy consumption through computational simulation and the potential for local renewable energy generation. An economic analysis was also developed with the tools Net Present Value (NPV), Internal Rate of Return (IRR) and Payback. The work shows that it is possible to achieve NZEBs from an economic point of view to generate energy in a social interest typology in southern Brazil.

Keywords: Energy efficiency; Social housing; NZEB;

1. Introduction

When dealing with electricity, the building sector has a fundamental role in the question of energy use and maintenance, as it represents 50.5% of the final consumption of electricity in the base year of 2018, according to the National Energy Balance (BEN, 2019), where residential consumption was 25.4%, ahead of commercial and public consumption and only behind industrial consumption (BEN, 2019). In residential buildings in southern Brazil, HVAC systems are the biggest consumers of electricity, followed by water heating and cooling equipment (LAMBERTS, DUTRA and PEREIRA, 2014). A recent survey conducted by Eletrobrás (2019) based on the months of July 2018 to April 2019 points out that 25% of households in the state of Rio Grande do Sul (Brazil) have air conditioning equipment, with 95% of the air conditioning use being for heating. Rio Grande do Sul is the state that has the largest number of equipment with heating and cooling function in the country, where users assume that they use climate control intensively, that is, 6 to 7 times a week. The same survey of possessions and habits conducted by Eletrobras (2019) showed that the average of air conditioners in the state per housing unit (HU) is higher than the national average, with 0.32 units per HU in RS and 0.22 devices per HU in Brazil.

In this context of buildings energy use, the issue of Zero Energy Buildings has been receiving increasing attention. In 2010, the European Commission - Energy Performance of Buildings Directive approved the recast of the directive on the energy performance of buildings, which requires that by the end of 2020 all new buildings should present an energy balance close to zero, that is, that produce most part of its energy consumption (SUDBRACK, 2017). The European Buildings Directive, Energy Performance of Buildings Directive (DIRECTIVE 2010/31, p.6) mentions Zero Energy Buildings (ZEB) as a building "with a very high energy performance in which almost zero or very small energy needs should be replaced by energies produced locally or nearby".

Based on the European concept, the United Arab Emirates Council for Sustainable Buildings (EGBC, 2017) conceptualized the ZEBs buildings according to their demand and production of renewable energy for each building. The difference between energy consumption and power generation reflects the goal of ZEBs, resulting in Nearly Zero Energy Buildings (NZEB) with low energy consumption and renewable generation covering most of the annual demand and Net Zero Energy Buildings (nZEB) also with low energy consumption, but with renewable generation that fully cover their annual demand, being considered an annual zero energy balance building.

According to Voss and Musall (2013), the most important question about residential buildings with zero energy is consumption reduction. The majority of zero energy balance houses are currently located in countries with temperate climates where the greatest energy consumption comes from heating systems. Passive architecture strategies such as the use of natural ventilation, natural lighting, shading of openings in summer and taking advantage of the sun's radiation in winter are present in almost all projects. The energy supply equipment is mostly solar thermal collectors for heating water and photovoltaic systems to supply the demand for electrical energy in buildings.

Regarding the Brazilian lack of housing problem, the country has a housing deficit of more than six million homes, of these, more than seven hundred and thirty thousand in the South region alone, where the state of *Rio Grande do Sul* has a deficit of two hundred and forty thousand housing for the year 2015 (FUNDAÇÃO JOÃO PINHEIRO, 2018). In the scope of housing production to make up for the deficit, from 2009 onwards, the production of social housing through the *Programa Minha Casa, Minha Vida* – PMCMV (My House, My Life Program – our translation) stands out. In the case of projects developed at the PMCMV, according to Berleze and Silvoso (2018), the projects have shown little concern with cultural and environmental contexts of a society and climate as diverse as Brazilians, resulting in low satisfaction of residents with temperature aspects and humidity of some environments and little concern of the designers with the environmental quality of the houses.

In this sense, according to a study developed by WRI Brasil (DALL'AGNOL; CACCIA; MACKRES; 2018) analyzing the benefits and costs of adopting energy efficiency measures for social housing projects, the PMCMV government program is crucial, either by the bias of the expressive number of consolidated houses and the urban quality of the developments, or by the impact that urban occupation causes on the population, cities and the environment.

Thus, the objective of this study is to investigate whether the energy consumption of a social housing complex consolidated in the city of *Passo Fundo/RS/Brazil* and to analyze the economic feasibility of producing photovoltaic electricity to meet the building's annual demand. The object of the research is a consolidated building in the Canaã housing complex, from the PMCMV government program, in the *Leonardo Ilha* neighborhood.

2. Methodology

The method used to quantify the electricity demand adopted was based on the Technical Quality Regulation for the Level of Energy Efficiency of Residential Buildings (RTQ-R), addressing the simulation method where, through modeling in the SketchUp software and configuration in the software EnergyPlus v8.7, the standard of use, lighting and the internal load of electrical equipment for artificially heated buildings was used (INMETRO, 2012). For the computational modeling, a building with southeastern solar orientation was selected because 40% of the buildings in this complex have this orientation. The existence of solar water heating in buildings was considered, that is, excluding the energy demand for water heating from this study.

After simulating energy demand, the potential for generating photovoltaic energy integrated into the distribution network was dimensioned. For dimensioning the energy generation potential of the solar panels, daily data of solar radiation incident on the roof of the building are necessary. Values of monthly averages of the total daily solar radiation (kWh/m^2/day) for the annual period were obtained using EnergyPlus v8.7 software according to the solar orientation and building’s roof. The simulation climate data were calculated using the climate file of the city of *Passo Fundo* (RORIZ, 2012).

For the dimensioning phase of photovoltaic system connected to the electric grid (SFCR), according to the calculation methodology used to evaluate the potential of generating photovoltaic solar energy by Marinoski, Salamoni and Rüther (2004). Calculations of nominal power (generated from solar radiation) necessary to meet the average daily consumption of the building to estimate the area of modules to be installed were carried out. This calculation, according to Equation 1, shows the building's ability to achieve the null energy balance through solar energy.

$$P_{cc} = \frac{\left(E / G_{poa} \right)}{R}$$

Equation 1

Where:
Pcc = Average power required (kWpcc);
E = Average daily consumption during the year (kWh/day);
Gpoa = Gain by solar radiation: monthly average of the daily total (kWh/m^2/day);
R = Yield of the system (%).

From Equation 1, it is possible to verify the demand for the coverage area to install the photovoltaic modules. In this stage it was defined that the modules adopted will be of the Canadian Solar brand, model CS6U-335M, with 17.2% efficiency and energy classification "A" according to INMETRO. An On-Grid Reno 500 Slave inverter and an On-Grid Reno 201 Master monitor with web monitoring, as well as fixing structures on the roof, protection devices, cabling and installation and approval service with the local concessionaire. Thus, through Equation 2, the necessary area of photovoltaic modules for each of the four buildings is shown.

$$A_{total} = \frac{P_{cc}}{E_{ff}}$$

Equation 2

Where:
Atotal = Area of panels (m^2);

Pcc = Average power required (kWpcc);
Eff = Panel efficiency (%).

From the area of panels installed on the roof, it is possible to obtain the monthly average of energy generated by the system according to the incident radiation. After dimensioning the SFCR, the economic feasibility study was carried out based on the month of May 2020 with the following considerations.

• SFV with an average useful life of 25 years;
• Average electricity consumption of 266,61 kWh/month;
• Single-phase consumer units with a monthly availability cost of 30 kWh;
• Residential consumer belonging to subgroup B1, with a conventional and additional green flag tariff of R$ 0,88 / kWh (CPFL, 2020);
• Standard value of 8.63% p.a. for the correction of the electricity tariff, based on the 2019 annual adjustment (CPFL, 2020);
• Initial investment of R$ 16,976,38 according to research in the photovoltaic installers market in *Passo Fundo*;
• Operating and maintenance costs of 1% of year on the total initial investment of SFV (EPE, 2012);
• Loss of efficiency of the photovoltaic generator of 0.65% of year (EPE, 2012);
• Replacement of an inverter every 10 years, representing R$ 2,700,00;
• SELIC interest rate of 3.75% for the month of May 2020 (BCB, 2020).

The financial viability analysis uses the method of calculating the payback period, calculating the Net Present Value (NPV) and the Internal Rate of Return (IRR) referring to the cost of implementing the photovoltaic system dimensioned for supply the demand for the housing unit and the cost of electricity at the time of this research.

3. Object of study

The object of study consists of a single-family residence designed and executed following the national guidelines of the PMCMV program with a typology composed of a living and dining room, two bedrooms, kitchen, service area, circulation and a bathroom, distributed in 45,63m².

Properties of the materials and openings are decisive in the thermal and energetic performance of a building. In this stage of the study, components used were the same as those identified in the building construction. The simulated envelope transmittance data used were 3,98 W/m^2K for the floor, 2,22 W/m^2K for the 6-hole ceramic block for walls (14x19x29) and 2,45 W/m^2K for concrete tile coverage and PVC lining.

In the case of glass, it was considered a simple clear colorless glass of 6mm thickness, thermal transmittance of 5,7 W/m^2K, visible transmittance of 0,89 and solar factor of 0,87. For the floor, a single composition was modeled, consisting of a 0,01cm ceramic floor layer and a 7cm subfloor slab.

4. Results and Discussion

Energy consumption for heating was simulated at 2,229.13 kWh/year, as shown in Figure 1, an average of 185.76 kWh per month. When the building area is analyzed, the heating consumption per square meter is 48.85 kWh/m²/year. For cooling, energy consumption is 42.77 kWh/year, representing the lowest percentage of consumption. The average global energy consumption was simulated at 3,199.39 kWh/year, that is, 70.12 kWh/m²/year.

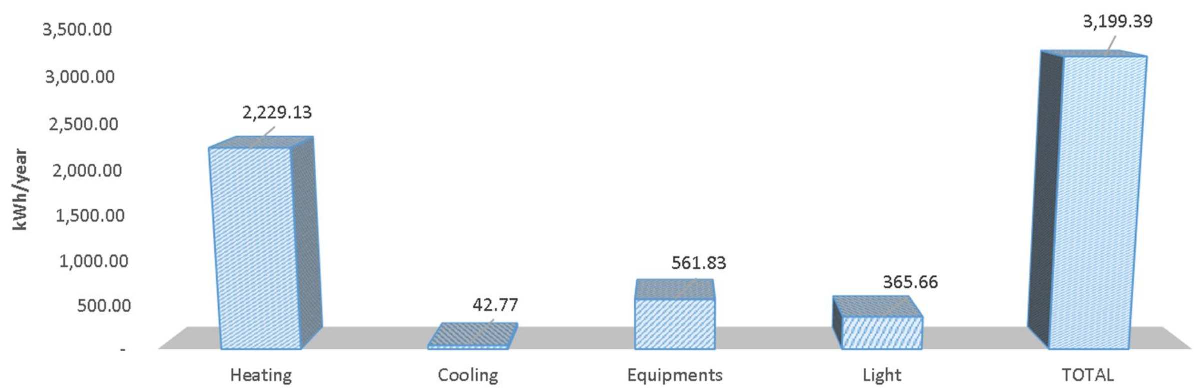

Figure 1: Simulated energy consumption for the analyzed building.
Source: Authors.

Based on the simulation, the average demand for air conditioning for heating represents 70% of consumption. The demand for equipment represents the second highest energy consumption with 18% of representativeness.

As for energy generation and economic viability, the current Brazilian economic scenario with an interest rate of 3.75% (05/2020) makes photovoltaic generation economically viable for simulated average energy consumption for the case study, taking into account the lowest electricity tariff (green flag).

Taking into account that the analyzed building has an average electrical consumption of 266,61 kWh/month, with an investment of R$ 16,976.38 in 8 photovoltaic modules, the investment becomes viable in all payment scenarios. However, due to the actual low *Selic* allied at high energy consumption, in this scenario the NPV is higher considering the payment in advance, as shown in Table 1. The Internal Rate of Return (IRR) shows what percentage of interest would make the investment unfeasible, being an indicator of the level of risk. In the most pessimistic scenario, the IRR stands at 15.97%, that is, high compared to the current *Selic* rate, characterizing this investment as low risk.

Higher consumption together with the high tariff price and low *Selic* percentage makes NPV more attractive, with a minimum IRR of 19.26% for payment in advance. The payback stayed in 6 years for the first scenario. For the installment payment scenario, the payback happens in 7 and 9 years for payment in 12 or 24 installments, respectively.

Table 1: Economic viability of photovoltaic solar panels base scenario.

Scenario	Investment	NPV	IRR	Payback
In cash	R$ 16,976.38	R$ 53,809.64	19.26%	6 Years
12x	R$ 20,371.66	R$ 50,569.83	18.78%	7 Years
24x	R$ 24,445.66	R$ 45,451.45	15.97%	9 Years

Legend: Consumption: 266.61 Kwh/Month, Selic 3.75% and Tariff: R$ 0,88.

Source: Authors.

The second scenario was made considering a monthly variation in the average energy consumption, maintaining the current electricity tariff and the *Selic* interest rate. In this scenario, the minimum consumption to make the investment viable is 96 kWh/month, as shown in Table 2, where the NPV becomes positive for cash investment and negative for installment investments. In this scenario, IRR is reduced to 3.79%, that is, close to the current *Selic* rate, considering that any positive variation in the discount rate would make the investment unfeasible, this consumption becomes risky from the point of view of financial investment. In this simulation the payback happened in 18 years.

Table 2: Economic viability of photovoltaic solar panels in minimum consumption scenario.

Scenario	Investment	NPV	IRR	Payback
In cash	R$ 16,976.38	R$ 83,64	3.79%	18 Years
12x	R$ 20,371.66	R$ - 3,156.17	2.4%	-
24x	R$ 24,445.66	R$ - 8,274.55	0.57%	-

Legend: Consumption: 96 Kwh/Month, Selic: 3.75% and Tariff: R$ 0.88.

Source: Authors.

In the third scenario, it was considered lowering the electricity tariff to assess the economic viability. It is clear that the investment only becomes viable when the tariff is at the minimum limit of R$ 0.27 in the cash payment scenario, that is, without considering installment payment, as shown in Table 3. Note that the IRR stood at 4.04% in cash, that is, close to the February 2020 interest rate, 4.25%, which indicates that a positive variation in monthly interest can make the investment unfeasible even if the electricity rate is maintained at R$ 0.27. Considering that energy tariffs are unlikely to fluctuate downwards, the higher the tariff the more viable the investment will be. Considering this scenario, the payback happens in 18 years.

Table 3: Economic viability of photovoltaic solar panels in minimum energy tariff scenario.

Scenario	Investment	NPV	IRR	Payback
In cash	R$ 16,976.38	R$ 662.67	4.04%	18 Years
12x	R$ 20,371.66	R$ - 2,577.14	2.67%	-
24x	R$ 24,445.66	R$ - 7,695.52	0.84%	-

Legend: Consumption: 266,61 Kwh/Month, Selic: 3.75% and Tariff: R$ 0.27.

Source: Authors.

It is shown in these simulations that the higher the energy consumption, the more economically viable an investment in photovoltaic solar panels will be. Likewise, the higher the energy tariffs, the more viable the investment will be. *Selic* with low percentages stimulates investments, as it makes scenarios viable even with low IRR compared to other conservative investments.

5. Conclusion

In this work, an analysis of an architectural project of a single-family building in bioclimatic zone two was carried out, using the climatic data of the city of *Passo Fundo*, obtaining the energy consumption through the simulation method recommended by RTQ-R.

Regarding financial viability, for the different investment scenarios in an SFCR, it can be concluded that cash payment is the best option for return on investment with better protection against risk, as it reaches a higher level of NPV with faster payback, maintaining the lower exposure of capital to changes in the financial market for the low energy consumption of an NZEB.

Considering the current economic scenario of rising energy tariffs, low interest rates for financing and the constant drop in the cost of installing and maintaining an SFCR, it is possible to conclude that it is financially viable for the simulated demand for a Social Housing Complex to install a photovoltaic energy generators aiming at zero energy balance, and it can even be profitable to divide the investment amount in 24 monthly installments. However, uncertainty regarding the 25 years of useful life of the system, where interest rates may change according to the market movement and the maintenance of the system due to bad weather, could decrease the projected profitability.

In the economic analysis, payback in the three scenarios was less than 25 years and occurs more quickly when the investment is made without payment in installments, combined with higher electricity rates and low monthly interest rates. NPV showed positive values at and the IRR was higher than the interest rate considered in the analysis. Therefore, the feasibility of the projected scenarios was proven through the investment analysis tools used, making it possible to consolidate the annual zero energy balance in the building under analysis for the Brazilian Bioclimatic Zone 2.

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