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Assessment of technical-financial analysis of a zero energy building for Brazilian hot and temperate tropical climate

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Abstract. The growing concern about energy consumption and environmental resources has led to research on sustainable approaches in construction. Efficient buildings have been built not only to attract new investments but also to take environmental considerations into account. Zero Energy Buildings; use a variety of passive strategies for energy efficiency and to decrease the use of heating, ventilation and air conditioning. These techniques impact directly on cost benefit and energy performance. The objective of this research is to identify efficient approaches for housing, considering the influence of climate, the energy generation, for two Brazilian cities. The cities climates area classified as Af (tropical climate) and Cfb (hot and temperate). The methodological procedures were divided into three stages: simulation to determine energy consumption in the efficient building; estimation of the balance between electric demand and generation by means of a building-integrated photovoltaics (BIPV); assessment of the life cycle cost of the net present value of BIPV. The results show that for the tropical climate the payback is 6.75 years and Internal Rate of Return (IRR) of 15.06% and for the temperate, payback is 10.25 years and IRR of 8.49%. These outcomes demonstrate that in hot climate payback happens in less time, due to the high incidence of solar radiation in the year.

1. Introduction

Secure and sustainable energy supply is one of the biggest challenges facing society since the beginning of the 21st century. Population growth and rising living standards put pressure on existing energy infrastructures and the concepts of provision. At the same time, fossil fuel reserves are depleting and carbon-intensive energy sources contribute to climate change with unpredictable consequences [1].

In addition to the need for environmentally sustainable buildings, with reductions in energy consumption and greenhouse gas emissions to limit harmful climatic impact, there is also the need to improve the building's interior comfort, thus increasing the welfare of users.

A problem frequently raised by construction professionals is about the limit of using energy efficiency measures in terms of cost-benefit [2]. In this context, the climate and the region of implantation will influence the cost to improve the building physical properties, for example, double walls may be more expensive, but they have the potential to reduce consumption of refrigeration and heating.

Efficient buildings are composed of passive design strategies, reducing the demand for refrigeration, lighting, heating and efficient equipment, also reducing energy consumption [3]. Therefore, efficient buildings must be adequately designed so that the expenditure with the implemented measures is not greater than the economy with the energy consumption. An example of this is the Zero Energy Buildings (ZEB), which, according to [4], are buildings that produce the same amount of energy that is consumed in a temporal space, using renewable energy. Achieving ZEB requires the adoption of two broad



strategies: minimizing energy consumption through effective passive measures and using local energy production to reduce the cost of energy delivery [5]

Deng et al. (2001) [6] highlight that climate and cultural characteristics influence the spread of projects. Weissenberger et al (2014) [7] e Sharma et al. (2011) [8], emphasize that most projects do not analyze the economic viability nor the Life Cycle Cost (LCC). About 25% of the authors evaluated the financial return [9-19], making the investigation of economic viability important, especially for investors and government plans.

Thus, the economic viability evaluation of buildings becomes essential for the performance analysis of such strategies, as well as if their application is financially compensatory. The objective of this study is to investigate the technical and economic viability of a project ZEB, in Bioclimatic Zones (BZ) 1 (city of Curitiba) and 8 (city of Salvador), cities of temperate and hot climates, respectively. [20]

2. Methodology

The methodology was divided into four stages. The first stage consists in determining the reference building and the constructive characteristics. In the second stage, the energy efficiency strategies were applied. In the third stage, the simulations of thermoenergy performance and the quantification of the results were performed. Finally, the LCC economic calculations of the reference building and the economic feasibility analysis were carried out.

2.1. Reference building

The calculations of the model were based on a typical Brazilian new house of low standard. According to PROCEL (2007) [21], more than 80% of Brazilian housing are single-family. The single-family house has approximately 60.00 m² (Figure 1). The constructive characteristics are hollow brick in the walls and solid concrete slab in the roof.

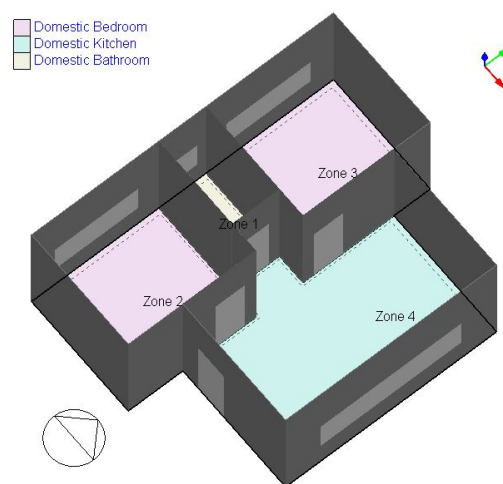


Figure 1. Reference building

2.2. Energy efficiency strategies

Aiming at energy efficiency at a low cost, strategies were implemented to reduce consumption. Such strategies are: appropriate opening orientation, to take advantage of natural light and entry of lower thermal load; ideal window area; natural ventilation and opening shading. The same thermal load of equipment was considered for all models. The constructive characteristics of the building were considered the same for both cases.

The reference building does not have any type of shading, the efficient building counts on two external shading devices that cover all openings. The openings are facing west and east in the reference building and south and north in the efficient building. The thermal absorption adopted for walls and cover in the reference model was 0.6 and in the efficient equals to 0.3. Three constructive systems for

walls were tested, the chosen systems are composed of hollow brick with 6 holes. The standard system has a thermal transmittance of $3.19 \text{ W/m}^2\cdot\text{K}$, with a thickness of 14 cm. The double brick system has a thermal transmittance of $2.37 \text{ W/m}^2\cdot\text{K}$ and a thickness of 24 cm. The third system, composed of expanded polystyrene, presents transmittance of $0.96 \text{ W/m}^2\cdot\text{K}$ and thickness of 15 cm. The roof system for all models was solid slab with transmittance of $3.74 \text{ W/m}^2\cdot\text{K}$. This cover was chosen for the subsequent installation of the photovoltaic system, since the best efficiency of the panel is in the north orientation with slope equal to the latitude of the place.

2.3. Simulation

For the energy simulations the software DesignBuilder was used. The software has tools that allow efficient maximization of parameters such as natural ventilation, natural lighting, and also has a database with different materials for construction and climatic files. According to Lopes (2012) [22], DesignBuilder uses mathematical models from the EnergyPlus software [23]. Thus, the strategies were applied in the simulations according to the previous step and the geographical location of each BZ was defined as Curitiba (BZ 1), located at latitude $25^\circ 25'42''\text{S}$, longitude $49^\circ 16'24''\text{O}$ and altitude 925m and the city of Salvador (BZ 8), latitude $12^\circ 58'16''\text{S}$, longitude $38^\circ 30'39''\text{W}$ and altitude of 8m. [20] According to Frota and Schiffer (2001) [24], the climatic variables change according to several factors such as altitude, relief and latitude.

Each BZ was evaluated independently and, according to the climatic variables the renewable energy generation system was designed with the purpose of supplying the energy demand of the building. The process of applying the ZEB strategy and its operation is shown in Figure 2.

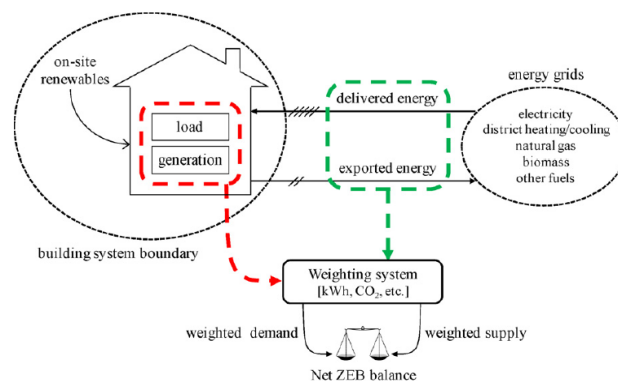


Figure 2. Sketch of the operation of a zero energy building.

Source: Sartori et al., 2012 [25].

Renewable energy was supplied through the installation of photovoltaic panels and the PVsyst software [26] was used, which considers the climatic data of the region of implantation. In addition to the electrical losses of the panel, it was considered the losses due to dirt that can accumulate over time. No shading was considered over the panels. In order to calculate the power generated by the panels, daily data of incident solar radiation were required. The values of the monthly averages of the daily total solar radiation ($\text{kWh/m}^2/\text{day}$), in all months of the year, were obtained through Meteonorm climate files. Finally, with the mentioned data, inclination and solar orientation of the building, the PVsyst software simulates the power required, after that, the data is crossed with the power calculated by the consumption of the building so that all the demand is supplied.

2.4. Life cycle costs and economic analysis

Costs are considered for the life cycle of the construction, and are calculated in two parts: the initial investment and the cost of energy. As the Brazilian territory is extensive, construction prices are different, so the values of the materials and services used were considered according to the BZ mentioned. For this purpose, the Basic Unit Cost of Construction (UCC/m^2) was used as a reference for the

calculations, these values vary according to the economy of each state. The Brazilian Construction Industry Unions is the responsible for calculating the UCC/m² [27]. Thus, the initial investment relies on the amount spent on the construction as a whole and on the energy generators in the case of ZEB. The cost of energy is a variable that only counts in the reference house, because in the ZEB the renewable energy generators must provide energy considering the annual balance sheet.

The financial viability of an investment is studied within a period stipulated by the investor, where it is estimated whether the applied effort is worth more than an application in the market with minimum attractive rate (MAR) [28]. The viability will be calculated by the Net Present Value (NPV), which determines the value considering the discounts at the initial moment of the investment. Another important factor in decision making is the repayment time of the amount invested, known as payback, and are presented in indicators of the term of return on investment and the rate of return on investment. Thus, the NPV calculation requires the value of the cash flow (c), the number of periods (n) involved and the minimum attractive rate as shown in the Equation 1 below.

$$NPV = \sum_0^n \frac{c}{(1+i)^n} \quad (1)$$

The cash flow value was adopted according to the energy consumption of the Reference building of each city for the period of one year. The rate of the Special Settlement and Custody System (Selic), calculated by the Central Bank of Brazil for September 2017, was adopted at 8.25%. The resulting value of the NPV is a corrected value used in the calculation of the discounted payback and it was chosen because it takes into account the discount rate on the future cash flow. Finally, another indicator of economic viability is the Internal Rate of Return (IRR), which shows how much an investment yields in a given period of time. For the ZEB, a 20-year time frame was adopted, based on the lifetime of the photovoltaic panels [29]. It should be noted that for an enterprise to be profitable, the IRR must be equal to or greater than the MAR.

3. Results

Applying the passive energy efficiency strategies, a reduction of 23% was achieved for Curitiba (BZ 1) and 42% for Salvador (BZ 8), when compared to the reference building. Such strategies were: adequate orientation of the openings, in the case to the south and north, being 20% for Curitiba and 30% for Cuiabá, according to the simulation for ideal window area of the site, with shading in all openings. For BZ 1, the most cost effective and chosen system was the third one with expanded polystyrene insulation and transmittance of 0.96 W/m².K. For BZ 8 the best system was the hollow brick with thermal transmittance of 3, 19 W/m².K, since this location presents a hot climate, the insulation is not the most ideal solution.

Through the calculation of the photovoltaic energy, panels of approximately 16m² were obtained for Salvador and of 17m² for Curitiba taking into account the balance of the annual consumption of the building, becoming a Zero Energy Building.

The changes made in the building envelope reduced the energy consumption in a minimal way, considering the cost of applying the material in the calculation the economic feasibility. Cash Flow is a Financial Management Instrument that projects for future periods all the inflows and outflows of financial resources applied, indicating how the balance will be for the projected period. The cash flow for the application of photovoltaic systems to the two cities is demonstrated in Figure 3. The indices used to evaluate economically were Payback and IRR. Salvador had a payback of 6.75 years and IRR of 15.06%, while Curitiba had a payback of 10.25 years and IRR of 8.49%. The MAR adopted was 8.25%, so in the two bioclimatic zones economic viability was obtained. However, the hotter climate region achieved faster viability, higher yield and return.

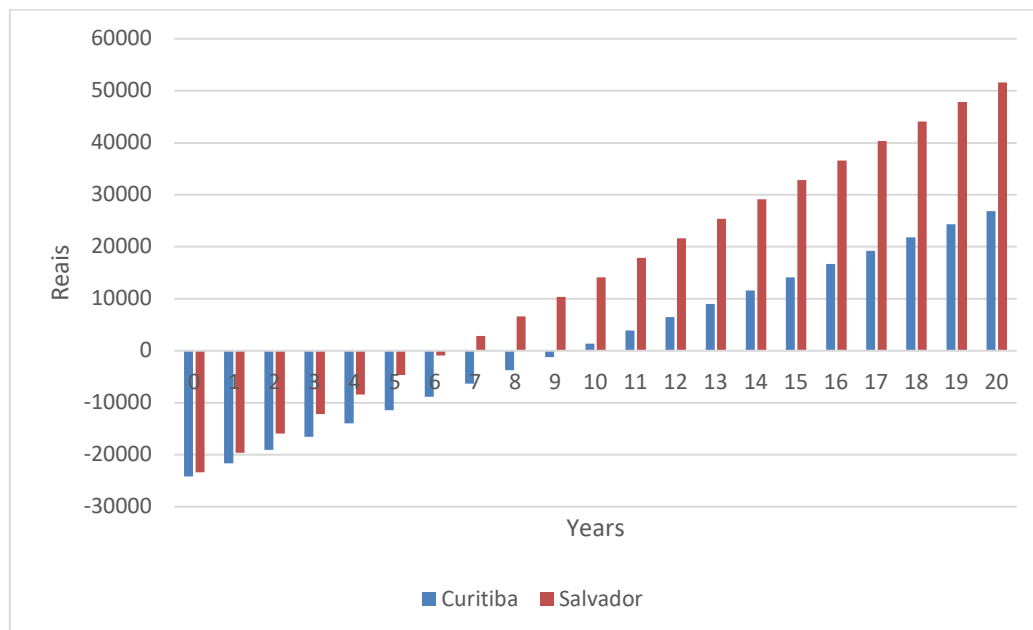


Figure 3. Photovoltaic cash flow from Salvador and Curitiba

4. Conclusion

This study presented the methodology of ZEB application with economically efficient solutions and can be used for any type of building and for other regions, considering the local climate, energy resources and local economic conditions that lead to a zero annual energy balance. The research also sought to encourage and demonstrate the contributions and gains that solar energy provides to enhance a more efficient and zero energy residence by taking advantage of natural lighting and solar radiation.

It is concluded that due to the higher incidence of solar radiation and the milder winters, which favors the use of cheaper and less insulating envelopes, investment in zero-energy houses is more viable for warmer climates, bringing a faster and greater return, favoring Brazil, which has an extensive territory of hot weather.

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