Energy Efficiency in Social Interest Housing: NZEB Building Analysis for Southern Brazil

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Abstract: This article aims to investigate the potential for energy savings and impact on greenhouse gas (GHG) generation of social housing in southern Brazil. Thermal and energy analysis of two architectural projects was carried out, one of them being a social interest housing unit and an optimized version of this unit characterized as Nearly Zero Energy Building (NZEB). At the end of the study, a cost analysis was carried out taking into account the building construction and local electricity generation through the installation of a photovoltaic (PV) system. Regarding the methods, software SketchUp Make and EnergyPlus was used for computer simulation, after which the PV power generation system for both buildings was dimensioned using the PvSol software. Subsequently, the percentage of adaptive comfort of ASHRAE 55 was calculated, as well as financial analysis for the building construction and PV modules installation. It is concluded that it is possible to reduce energy consumption of this social interest housing by 52% and the heating consumption by 72% with passive strategies and envelope insulation. Investing in an efficient building results in a 29% increase in building costs and promotes savings of 39.5 tCO₂ over the life of the building. The study demonstrates the importance of making NZEB buildings economically viable.

Key words: Energy efficiency, social interest housing, NZEBs, simulation.

1. Introduction

The actual energy scenario demands for buildings to be more energy efficient. In Brazil, buildings are responsible for 52% of final electricity consumption, according to the National Energy Balance [1]. In 2019, according to the NEB report, consumption in residential buildings was 21.9%, ahead of commercial and public consumption. The final consumption of electricity in the country in 2019 registered an increase of 3.46%. The sectors that contributed most to that, in absolute values, were residential which expanded its consumption by 626.3 TWh, 4.1% more compared to the previous year [1]. In the residential sector, air conditioning systems are the leading electricity consumers in the south of the country, followed by water heating and cooling equipment [2].

The National Energy Plan 2030 [3] which inserted energy conservation scenarios and goals to be pursued by the energy sector, set as one of the goals for 2030 a 10% reduction in energy demand, where the residential sector reaches a projection of 28% of national energy demand.

In this sense, the architectural design of residential buildings is intrinsically related to mainly two types of energy consumption: lighting and air conditioning. Natural lighting can be prioritized during the day, but artificial lighting systems are widely used at night. According to Romero and Reis [4], there is an estimated potential for a reduction in energy consumption of approximately 30% with energy efficiency actions in lighting, air conditioning, and intervention in the envelope of existing buildings. In the building’s design phase, the potential for reduction in consumption rises to 50% from the use of passive strategies and efficient active technologies in the building [4].
In this context, Nearly Zero Energy Buildings (NZEBs) are presented as an instrument for energy policies that aim at the transition from a fossil energy matrix to a renewable energy matrix [5]. According to Voss and Musall [6], reduction of consumption is the main question regarding nearly zero energy in residential buildings. Passive architecture strategies should be used to achieve this goal. As well as, energy generation strategies such as solar thermal collectors for water heating and photovoltaic (PV) systems to generate electricity.

Renewable energy sources become more competitive and financially viable as they increase their demand, with competitiveness resulting from reduced costs due to scale gains, technological advances, and competition in the market [7]. Public policies of financial incentives, credit lines, and tax exemptions also help in the consolidation of renewable energies [8]. In this context, buildings with nearly zero energy balance (NZEB) should be encouraged in Brazil [9].

Thus, to investigate the potential for electricity savings and impact on the greenhouse gas (GHG) generation of social interest housing NZEB in southern Brazil, a thermal and energetic analysis of two architectural projects was carried out, one of them being an existing building of a social interest housing complex built in the city of Passo Fundo, referred to in this study as “Base Building”, and a proposed building where guidelines were applied to reduce energy consumption to characterize it as NZEB, called in this study as “Proposed Building”. At the end of the study, a cost analysis was carried out for the construction of buildings and generation of PV electricity, seeking to verify the investment difference between a conventional building (Base) and a high-performance building (Proposed) and the impact on the generation of GHG due to the reduction of energy demand in the building use phase.

2. Method and Materials

The Base Building represents an architectural project of social interest that followed the Brazilian national guidelines of social interest housing. This project was built in the city of Passo Fundo/RS, in the form of a standard project, and comprises 210 houses. For the definition of the Proposed Building, an upgrade of the architectural design of the Base Building was carried out. To define the architectural design of a Proposed Building with nearly zero energy consumption (NZEB), the reduction of energy consumption in the use of the building in a passive way was prioritized.

Design strategies for a nearly zero energy balance house are addressed in this work in the form of a theoretical review of strategies for NZEB projects. A nearly zero energy balance means that the actual annual consumed energy is less than or equal to the on-site renewable generated energy [10].

For dimensioning the integrated PV power generation system, the network used the PvSol version 2020 software, opting to use modules from the BYD, model MIK-36-SÉRIE-5BB 400W, as it has high efficiency in comparison with other models (19.95%) and energy rating “A” by Inmetro; a Growatt 1.5 kW and 2 kW inverter for higher power systems. The available coverage area for the Base Building is oriented to the Southwest and for the Proposed Building is oriented to the North, with a 20 degrees inclination for both buildings.

A computer simulation was employed as a method to obtain the energy consumption of buildings, using the software SketchUpMake and Euclid for modeling and EnergyPlus v8.7 to obtain data. For the modeling stage of the Base Building and Proposed Building, each environment was modeled as a thermal zone and it was configured according to standard values presented in the RTQ-R simulation method for occupation, lighting, equipment, natural ventilation, and, later, a system of air conditioning [11]. In this work it was considered that the water heating is done by a solar thermal heater kit, that is, the use of the electric shower in energy consumption will not be considered;
neither will be the use of energy for cooking.

To measure carbon dioxide emissions for electrical generation offered by the Brazilian National Interconnected System (SIN), the average footprint of the twelve months of 2019 was used, equivalent to 0.518 t CO₂/MWh, according to the evolution report of CO₂ emission factors for electricity [12].

As a method to compare the level of thermal comfort of the two buildings, the calculation of degree-hours of thermal discomfort was used. The use of dynamic limits results from the assessment of thermal comfort through the adaptive model of ASHRAE 55 [13]. According to the method, the internal operating temperature must not exceed the maximum and minimum limits of external temperature. Limits are calculated using simulated operating temperatures for all days of the year in EnergyPlus v8.7.

Finally, both buildings were economically analyzed, measuring their execution costs based on direct costs. The budget breakdown presented in NBR 12.721 [14] was used to define services and later cost quotation in the National System of Research on Costs and Indices of Civil Construction (SINAPI) [15] considering the costs related to high-quality frames, performance, insulating material and installation of PV electricity integrated into the network of companies in Rio Grande do Sul.

In the next section, the Base Building will be presented, its urban insertion, and its constructive characteristics considered for the thermal, energetic, and budgeting diagnosis.

3. Base Building

The Base Building is part of the Canaã housing complex, which has a total area of 94,935.93 m² distributed in 210 lots. In this study, the building deployed with a larger roof in the southeastern solar orientation will be used, as it is the orientation of the largest number of buildings in the project, as shown in Fig. 1.

The Base Building (Fig. 2) has a living and dining room, two bedrooms, kitchen, service area, circulation, and a bathroom, distributed in 45.63 m². The building has a set of solar water heaters, so the demand for water heating is not counted in the electric bill or the energy calculation.

To graphically model the building, the components used were the same as those identified in the built edification. The building is made of 6-hole ceramic blocks (14 × 19 × 29) with plaster and paint on the seals, concrete tile, and polyvinyl chloride (PVC) lining on the roof. Thermal transmittance of the envelope for the floor, wall and roof are 3.98, 2.22 and 2.45 W/m²K, respectively.

Regarding windows, it was considered a simple clear colorless glass of 6 mm thickness with thermal transmittance of 5.7 W/m²K, visible transmittance of 0.89, and solar factor of 0.87. A single composition was modeled for the floor, consisting of a 0.01 cm ceramic floor layer and a 7 cm subfloor slab.

4. Proposed Building

To define a building with nearly zero energy
consumption (NZEB), first, it was necessary to identify the international concept of buildings with zero energy consumption. In the European scenario, from 2020, new buildings will have to be NZEBs. The European Directive for buildings, Energy Performance of Buildings Directive [16] talks about a building “with a very high energy performance in which the almost zero or very small energy needs should be replaced by renewable energy produced in the or nearby”.

Considering the objective of producing an energy-efficient architectural project, prioritizing the reduction of energy consumption in the use of the building in a passive way, different strategies must be considered for passive conditioning in the winter and summer periods. The Proposed Building used the same land lot with dimensions of 20 m × 10 m, also making use of the same built-up global area and the program needs, aiming to keep the characteristics of the project to the maximum and maintain the Brazilian social housing standard.

The Proposed Building is elongated on the east-west axis to reduce unwanted thermal gains, having the area with the largest facade to the north, as shown in Fig. 3. The kitchen and service area occupy the south sector of the building, with a decrease in openings.

The strategies for controlling natural lighting and solar radiation in summer were implemented through the 60 cm eave, having gable roof, as shown in Fig. 4.

In order to reduce the thermal flows and energy consumption of the building, a PVC frame and insulated glass model “Cebrace Cool Lite ST” was adopted, with a solar factor of 0.33 and a thermal transmittance of 1.9 W/m²K and 8 cm of thermal insulation in the opaque envelope (EPS) with thermal conductivity of 0.040 W/mK, density of 35 kg/m³ and specific heat of 1.42 kJ/kg·K. Thermal transmittance of the envelope for the floor, wall and roof are 0.453, 0.408 and 0.371 W/m²K, respectively.

The sequence of the study aims to verify the energy consumption of the Base Building and the Proposed Building by obtaining the percentage of reduction in the consumption of electricity obtained through the design strategies, as well as the reduction of GHG emissions related to the consumption of electricity.

5. Energy Consumption and Energy Generation

After modeling the two buildings, the numerical model was configured according to the standard values presented in the RTQ-R [11], obtaining an energy consumption of 3,196.80 kWh/year for the Base Building and 1,674.23 kWh/year for the Proposed Building.
The energy consumption of heating in the Base Building is 2,230.19 kWh/year, according to Fig. 5, an average of 185.85 kWh/month. When we analyze the building’s footage, we have a total consumption of 49.77 kWh/m²·year. The building’s global energy consumption was simulated at 71.34 kWh/m²·year. Heating represents 70% of the energy consumption of the Base Building. For cooling, energy consumption is 39.10 kWh/year, representing the building’s lowest percentage of annual energy consumption.

Based on the simulation, the Proposed Building has a heating demand of 614.26 kWh/year, that is, 13.70 kWh/m²·year, as shown in Fig. 5. Consumption for heating is still predominant, representing 37% of the edification. The energy consumption of the Proposed Building was simulated at 37.36 kWh/m²·year. When analyzing the demand, it is noted that the main energy expenditure in the city of Passo Fundo is concentrated on heating, which was reduced by 72% in the Proposed Building.

After quantifying the energy demand for each of the buildings, the potential for PV energy generation integrated with the distribution network was dimensioned using the PvSol software, version 2020. By adopting a 2.28 kWp system for the Building Base, seven PV modules with southeast orientation and inclination of 20 degrees were designed. In the case of the Proposed Building, 3 modules oriented to the north were dimensioned with an inclination of 20 degrees and power of 0.98 kWp.

From the environmental point of view concerning the electricity consumption of the national distribution network, the Base Building has a CO₂ emission of 1.65 tCO₂ per year. The Proposed Building, by using efficiency strategies and reducing consumption, has an equivalent CO₂ emission of 0.86 tCO₂ per year, that is, an emission saving of 39.5 tCO₂ when considering a lifetime of the building of 50 years.

6. Adaptive Comfort

For this analysis, the three extended-stay environments were selected: the living room/kitchen and the two bedrooms. The values of the average summer and winter external temperature of Passo Fundo were obtained through the average climatological day used in the climate file and the limits of acceptability calculated daily in the function of the internal operating temperatures for each extended-stay room.

When analyzing the double bedroom environment in the two buildings, as shown in Fig. 6, the environment is in discomfort due to cold during 56.93% of the hours of the year in the Base Building, representing a longer period in discomfort. The same environment for the Proposed Building does not
present discomfort due to heat and has 68.52% of the annual hours within the comfort limits.

For the single room environment, the Base Building presents 54.94% of the hours of the year in cold discomfort and 6.63% of the annual period in discomfort due to heat. The single room environment was the one with the best thermal comfort index in the Proposed Building, with 71.94% of the annual hours in comfort. The environment performed best in cold periods, with only 28.06% of annual hours in discomfort due to cold.

The living room/kitchen environment presented 60.54% of the hours in the year in cold discomfort, 5.97% of the annual period in discomfort due to heat and 33.49% of the hours within the comfort limits in the Base Building. In the Proposed Building it presented the lowest thermal comfort index of the three analyzed environments, with 51.15% of annual comfort hours. Cold discomfort reaches 48.50% of annual hours.

7. Budget

Based on the dimensions specified in the architectural design and descriptive memorial of the Base Building and the project presented for the Proposed Building, a quantitative survey of materials was carried out. The values referring to the composition of inputs, labor services and equipment were analyzed according to CAIXA [15] in June 2021.

In this study, the direct cost was considered. PVC frames with 6 mm monolithic glass and insulated glass were budgeted with Weiku, EPS thermal insulation was budgeted with Isolef and PV module systems were budgeted with DMF SOLAR. Table 1 presents the budget for services and the total investment of the two buildings, considering the investment of a PV system to fully supply the annual electricity demand of the Base Building, and a PV system for the energy balance of the Proposed Building.

Using the Base Building as an initial, its investment was compared with the Proposed Building, to verify the additional investment of the envelope optimization and the changes in the form of the project. According to Table 1, the initial investment for the execution of the Base Building with PV energy was R$113,656.19, where the generation of energy means a 10% share of
the total investment. The investment for the execution of the Proposed Building with PV energy was R$151,486.74, that is, R$7,800.00 of additional investment concerning the Base Building. The investment in PV power generation represents a 5% share of the total building cost. The investment in construction material and labor was 23% higher in the Proposed Building, whereas the investment in PV modules was 30% higher in the Base Building.

Taking into account the Basic Unit Cost (BUC) for the residential standard R1-B in June/2021, the cost of the Base Building represents 1.26 BUCs, while the Proposed Building represents 1.77 BUCs per square meter, without considering the PV module installations.

For the financial viability analysis of the PV power generation system, the method of calculating the payback period was used, the calculation of the net present value (NPV) and the rate of return on investment (ROI) referring to the cost of implementation of the PV system dimensioned to supply the demand of Base Building and Proposed Building, considering the following indicators: SFV useful life of 25 years; electricity consumption of 266.61 kWh/month (Base Building) and 139.52 kWh/month (Proposed Building); single consumer units with a monthly availability cost of 30 kWh; residential consumer to subgroup B1, with a conventional and additional green flag tariff of R$0.91/kWh [17]; standard value of 9.95% p.a. for the correction of the electricity tariff, based on the 2019 annual adjustment [17]; initial investment of R$11,100.00 (Base Building) and R$7,800.00 (Proposed Building) according to research in the PV installers market; operating and maintenance costs of 1% of the year on the total initial investment of SFV [18]; loss of efficiency of the PV generator of 0.65% of the year [18]; inverter replacement every 10 years, representing R$2,400.00 and R$2,660.00; Selic interest rate (the basic interest rate of the Brazilian economy) of 4.25% for June 2021 [19].

When assessing feasibility in the current Brazilian economic scenario, investment in PV generation is economically viable for the simulated average energy consumption for both buildings, taking into account the electricity tariff of R$0.91/kWh.

The Base Building has an average electrical consumption of 266.61 kWh/month, with an initial investment of R$11,100.00 in 6 PV modules, that is, the investment becomes viable in all payment scenarios, however, due to the low Selic allied at high consumption, its NPV is higher compared to the Proposed Building, where the highest NPV (in cash) is R$39,950.24, as shown in Table 2.

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<tr>
<th>Table 1</th>
<th>Total costs and percentages of buildings and electricity generation.</th>
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<tbody>
<tr>
<td></td>
<td>Base building</td>
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<td></td>
<td>Construction</td>
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<td></td>
<td>R$102,565.19</td>
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<td></td>
<td>90%</td>
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<td>Source:</td>
<td>the authors.</td>
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<th>Table 2</th>
<th>Financial viability for PV solar power generation.</th>
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<tr>
<td></td>
<td>Base building</td>
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<tr>
<td></td>
<td>Investment</td>
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<tr>
<td>In cash</td>
<td>R$11,100.00</td>
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<td>12×</td>
<td>R$13,320.00</td>
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<tr>
<td>24×</td>
<td>R$15,540.00</td>
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<td>Values corresponding to consumption 266.61 kWh/month (base), 139.51 kWh/month (proposal), Selic 4.25% and rate R$0.91. Source: the authors.</td>
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In the most pessimistic scenario for Base Building, the ROI stands at 30.58%, that is, quite higher compared to the current Selic rate, characterizing investment as low risk. Likewise, for the Proposed Building, the lowest rate was 17.28%, high compared to the current interest rate.

The lower energy consumption of the Proposed Building, together with the higher tariff price and low Selic percentage also makes the NPV attractive in all scenarios. The payback of the proposed building is 5 years and 7 months for payment in cash, and 3 years and 11 months for the base building. For the installment payment scenario, the payback takes place in 6 years and 6 months for payment in 12 installments in the proposed building and 4 years and 7 months for the base building. When making the payment in two years, the payback takes place in 7 years and 3 months for the proposed building and 5 years and 3 months for the base building.

8. Conclusions

When analyzing the energy demand of both projects, it is noted that the main energy expenditure for a building in the city of Passo Fundo, southern Brazil, characterized as ZB2, is concentrated in the demand for heating, which was reduced by 72% in the Proposed Building, that is, it went from 2,230.19 kWh/year to 614.26 kWh/year. Spending on cooling long-stay environments, in turn, increased in the Proposed Building, due to the greater thermal insulation of the envelope, with a jump from 39.1 kWh/year in the Base Building to 172.21 kWh/year in the Proposed Building.

Despite the increase in refrigeration consumption, the insulated building kept the overall energy consumption below the proposed building and a percentage of hours of superior comfort in all the long-stay environments evaluated, justifying the isolated passive project for residential buildings in ZB2 in the south of the country aiming at a nearly zero energy balance (NZEB).

When analyzing the data obtained from adaptive thermal comfort, the Proposed Building presents all environments of prolonged stay with a higher percentage of hours in annual comfort, in contrast to the Base Building, which has a greater annual period in discomfort due to cold in all extended-stay environments.

The comfort gains evidenced in the Proposed Building reflect lower energy consumption, greater satisfaction and quality of life for residents, revealing in the Base Building little concern with the thermal performance of social interest housing projects currently implemented in the southern region of Brazil.

The overall investment to construct a building that meets the Brazilian standard requirements for social interest housing with the installation of PV modules is still 21% lower than the investment on an optimized building without the installation of PV modules. In turn, the Proposed Building with PV modules presents an increase of 29% compared to the Base Building with PV modules, an increase that improves quality and comfort for users. This fact demonstrates the importance of relating the cost of the building to the operating cost over its useful life, inserting energy-saving requirements into housing programs and not just a spending limit for the execution of the building, where the initial investment is low, entailing greater annual energy demand per housing unit, consequently, greater energy supply by the national integrated system, in addition to low environmental quality for users.

In this work, it was demonstrated that the generation of PV electric energy in a building with high energy consumption, taking advantage of the current Selic and high energy tariffs, is more economically viable in comparison to a building with nearly zero energy consumption, through the highest NPV.

Despite the better feasibility of generating PV energy in a building with high energy consumption,
when considering the expressive energy-saving potential expressed in this work in the Proposed Building, in parallel with the United Nations’ objectives of ensuring clean energy for all, promoting sustainable growth and encouraging innovation, the creation of guidelines to encourage buildings with nearly zero energy consumption (NZEBs) in Brazil should be a priority on the part of National Housing Production Policies and National Policies for Conservation and Rational Use of Energy.

Given the results found, it is possible to point out the potential for energy savings that social interest housing can achieve, where the low-cost aspect should not limit the design strategies or give rise to the low thermal and energy performance of buildings intended for the low-income population. As a result, the current national policy of housing production of social interest should be related to the National Policy for Conservation and Rational Use of Energy, so that thousands of new buildings in addition to being more energy-efficient bring greater quality of life for the population.

References

