Zero Energy Solar-House Model for Isolated and Environmental Protection Areas in Brazil

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ABSTRACT
This study aims to analyze the benefits of applying a Zero Energy Building (ZEB) as an alternative to conventional buildings in isolated and environmental protected areas in Brazil as a hosting unit. A Zero Energy Solar-House (ZESH) is defined, considering its fabrication, assembly systems, use of natural resources and strategies for energy efficiency, leading to low environmental impact. A Brazilian scenery is described regarding energy feeding conditions in isolated areas, the occupation of protection areas, which are coveted by real estate market and touristic exploitation, and the consequent environmental impact. The ZESH harnesses sun's energy throughout a photovoltaic (PV) system for energy generation, solar collectors for water heating and passive environmental conditioning. Besides, it has local wastewater treatment and solid waste management systems, reducing the environmental impact arising from the occupants activities. To verify the ZESH model, this study takes the Ekó House Project, an efficient solar house prototype that meets the ZESH premises. This study results in accounting greenhouse gases (GHG) emissions reduction by the solar PV electricity generation instead of diesel generators. Results point out a potential to avoid up to 14.4 t of CO₂/year for one ZESH unit. It is observed that the ZESH contributes to enable the occupation of these areas by local communities or touristic exploitation with responsibility, low resources consumption and reducing the environmental impact when compared to conventional buildings, allowing these areas to develop on a sustainable way and benefiting local communities.

INTRODUCTION AND APPROACH
Brazil is a country known for its rich biodiversity, a coastline with almost 8000 km long and the world's largest tropical rainforest, the Amazon. Brazil is ranked fifth in the world in relation to territory and is the largest country in both South America and the southern hemisphere. Given the Brazilian territorial dimension, many communities are still living in isolated locations with restricted or no access to infrastructure such as electricity, sanitation, transport, health and education. To obtain minimum comfort conditions, these communities rely on isolated systems, when possible, mostly through diesel generators, which are very expensive, cause environmental impacts and affect population’s health (Di Lascio, 2009). Furthermore, the lack of infrastructure for sewage treatment and solid waste management
also cause environmental impacts such as contamination of soil and water courses (UNEP/UNWTO, 2005).

Besides the demand and impact of the native populations living in isolated areas, often these sites are targeted and exploited by tourism sector, which often causes similar impacts in environmentally sensitive areas. Some negative impacts can be associated with tourism, such as disordered development or inappropriate tourism scale to the area, causing degradation of the resource base and ecosystems; increasing pressure on the natural environment, with degradation or destruction of fragile ecosystems; impacts resulting from the implementation of roads, sanitation, airports, urbanization, and centers for final disposal of solid waste, that could cause negative environmental and social impacts (Brasil, 2009).

On the other hand, there are also positive impacts of tourism activities in isolated and environmental protection areas. Examples include the diversification of economic activities, employment generation and income for local communities; improvement in sanitation; proper handling and disposal of solid waste; improvement in water quality in water bodies and aquifers due to the installation of domestic wastewater treatment systems; possibility of expanding educational and environmental awareness programs (Brasil, 2009).

Many of mentioned impacts, positive and negative, have a direct correlation with the buildings for housing and lodging in remote locations and environmental protection areas. Thus, this study aims to analyze the contribution of a Zero Energy Solar-House (ZESH) model to reduce environmental impacts and improve the quality of life of local populations and in touristic areas, analyzing how architecture can respond to a demand for social and economic development with low environmental impact.

**OCCUPATION AND ENERGY ACCESS IN ISOLATED AREAS IN BRAZIL**

In Brazil the electric energy is provided almost entirely by the National Interconnected System - SIN a large hydrothermal system, with a strong predominance of hydroelectric plants. Only 3.4% of the country's electricity production capacity is out of SIN (ONS, 2013) mainly in small isolated systems located in the Amazon region. These isolated areas are almost entirely located in the Northern Region and are served by thermal generation (EPE 2013).

The regions without access to electricity are regions where enroll minors Human Development Index - HDI (Di Lascio, 2009). The lack of access to electricity limits the access of isolated populations to basic infrastructure. The power supply from the diesel is often unfeasible economically. With an intense demand for energy, the cost to universalize regions such as the Amazon under the current model, which is based in isolated fossil fuel thermal systems, supported by a strong allowance, can be very costly to the country. The cost of power generation from existing generation systems is made possible by the Fuel Consumption Account - CCC, which in 2006 reached R$ 4.5 billion, approximately 25% greater than the amount of R $ 3.6 billion approved for 2005 (Gonzalez, 2008). Is worth point out that in remote villages, away from the distribution grids, there is only power when the community itself manages a generator and a mini grid, with no public electricity service. Moreover, the diesel to power these engines is usually acquired at a very high price from traders (Di Lascio, 2009).

Besides the issue of economic viability, the diesel generators impact the health of communities supplied by this fuel. In many isolated communities lamps fueled by diesel oil or kerosene are used. This alternative, in addition to being inefficient (7.3 diesel lamps are needed to obtain the same luminance of a 9 watts compact fluorescent lamp) causes respiratory and ophthalmic diseases (Di Lascio, 2009).

The alternative of using overhead transmission and sub-transmission lines has a high rate of acceptance by planners. However, when observing the regional reality, is possible to realize that this type of infrastructure is too costly, or even ecologically unsustainable for many isolated areas (Di Lascio, 2009).

In Brazil, the Light for All (Luz para Todos) program was launched by the Federal Government in 2003 with the challenge of ending the electricity exclusion in the country and bring access to electricity to more than 10 million people (Programa Luz para Todos, 2009). In places where the electricity arrives, the population acquire consumer goods that they could not have when was relying on diesel generators.
Among those appliances, most families buy televisors, refrigerators, blenders and water pumps (Seo, L. M.; Esteves, J. R., 2010. This also encourages these communities to diversify its economy. Some residents are opening their own business, sometimes associated with tourist activities, such as small hotels or restaurants. The access to electricity also favors public facilities such as health centers and schools, improving the quality of life of these communities, allowing an improvement in healthcare services, education and digital inclusion (Seo, L. M.; Esteves, J. R., 2010).

Many are the benefits obtained through the access to electricity. Thus, it is important to notice the suppressed demand for electricity in isolated areas and the importance of adopting energy efficiency measures together with the electricity access.

TOURISM IN ISOLATED AREAS

Considering initially mentioned positive influences that tourism can have on isolated areas, this study assumes the possibility to integrate environmental tourism activities with the native communities of such areas, collaboratively, looking toward a benefit to both parties. Naturally, this can only happen through a sustainable tourism way, which is the “tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities” (UNEP/UNWTO, 2005).

UNEP points out that tourism has the potential to contribute to local communities, especially the poor, through the development of local economy. The extent of the direct benefits to communities depend in large part on the percentage of tourism needs that are offered onsite, as product, labor, tourism services, and, increasingly, the "green services" on energy efficiency and water and waste management. UNEP also shows that over a third of travelers are in favor of eco-tourism and are willing to pay between 2% and 40% more for this experience. Tourists are interested in relevant social, cultural and environmental issues for the destinations they visit, and are interested in supporting hotels committed to protecting the local environment (UNEP, 2011).

Programs of the Ministry of Tourism in Brazil define indicators of environmental sustainability for tourism in the country, this study assumes as relevant for a ZESH hosting unit the following indicators: water and energy consumption per guest, waste generation per guest and the percentage of solid waste recycled or sent to composting (Brasil, 2007). Furthermore, it is important to highlight the potential that such tourism development may represent with regard to education and environmental awareness, influencing its audience to adopt different habits to reduce consumption of natural resources and environmental impacts (Projeto Ekó House, 2012).

It is noticeable that the global tourism economy represents 5% of the Gross Domestic Product (GDP) and accounts for about 8% of total employment (UNEP, 2011). It is expected that the "greening" of tourism contribute to improvements in energy efficiency, water and waste systems, and enhance the potential for job creation in the sector with greater hiring and prospecting site and significant opportunities in tourism oriented to the local culture and the natural environment (UNEP, 2011). Thus, this study works with a scenario in which tourism projects focused on isolated and environmentally sensitive areas are developed along with local communities, promoting economic and social development, improving quality of life in an environmentally sustainable manner.

POTENTIAL OF SOLAR ENERGY IN BRAZIL

Brazil has favorable conditions for harnessing solar energy. Average annual irradiation varies between 1.200 e 2.400kWh/m²/year, values that are significantly higher than most European countries. As shown in Figure 1, the higher irradiation areas are the areas 5 to 8, in which the average productivity varies between 1.260 e 1.420Wh/Wp/year (EPE, 2012).
In addition to this, in locations without conventional electric service, photovoltaic (PV) systems constitute a viable alternative when compared with the extension of the power grid, diesel generation and other sources (Pinho, 2008). The problem lies in the economic conditions of people living in these isolated areas that cannot afford such systems. However, some kinds of subsidies may contribute on economic viability of PV systems in Brazil, such as reducing taxes on industrialized products, discount on income tax, specific lines of credit (EPE, 2012). Besides, the same way the government subsidizes diesel, subsidy for PV systems could increase, given the social and environmental benefits by the use of PV as an alternative to diesel. Subsidies could also be associated with sustainable tourism development.

ZERO ENERGY SOLAR-HOUSE BASED ON EKÓ HOUSE PROTOTYPE

A Zero Energy Building - ZEB is defined as a building that produces, through local sources – and preferably renewable ones – the energy it consumes, considering an annual balance (Torcellini et al, 2006). The ZESH modeled for this study integrates several systems to ensure its operation and functionality, comfort for the occupants, and low environmental impact. To verify this ZESH model it is adopted the Ekó House prototype. This prototype was developed by Team Brasil, a partnership between University of São Paulo and Federal University of Santa Catarina, and represented Brazil in Solar Decathlon Europe 2012 competition, held in Madrid.

Ekó House is taken as reference for this study because it meets the guidelines of a ZESH. In addition, the specific purpose for which the prototype was conceived is hosting in isolated environmentally sensitive areas in Brazil. The prototype can be connected to a local grid and could export the surplus energy to meet the demand of local facilities, like schools and healthy centers, or dwellings in these isolated locations. The ZESH strategies and systems are presented below.

Solar trajectory and orientation

The ZESH adopts a geometry that results in elongated facades facing north and south orientation, in order to obtain a better use of the sun throughout the year. In summer, when the sun is more directly overhead, radiation is less intense on north oriented facades than is east and west oriented facades (Southern Hemisphere). In winter the sun is lower, and radiation is more intense in north oriented facades than in east and west oriented facades, as shown in Figure 2. North oriented facades receive more direct solar gains in winter and less in summer than other facades.
Building envelope

Many strategies are possible to achieve environmental conditioning. The envelope elements of a ZESH have appropriate thermal performance, based on climate conditions of the location, through strategies such as insulation, the use of thermal mass and/or natural ventilation, among others. The Ekó House prototype has high thermal insulation levels and windows properly dimensioned and positioned, ensuring natural lighting and ventilation. This results in good comfort conditions with low energy consumption by integrating passive and active strategies. Simulation models indicate a Daylight Autonomy of 60% for the Ekó House prototype (Projeto Ekó House, 2012).

However, the climatic conditions vary widely, as well as the solutions to adapt the buildings to each climate. Considering this, a pre-fabricated structure made of modular panels is proposed to enables the use of different materials and, therefore, different strategies to the envelope, allowing an adaptation of the ZESH to different needs and conditions. Besides, the use of wooden pre-fabricated structural panels allows faster and cleaner assembly when compared to conventional constructions. Figure 3 shows this modular construction system.

Management and treatment of waste and sewage

Domestic waste, when correctly managed, can reduce significantly the volume of rejects to be discarded. Specific compartments for waste disposal can be integrated in the house design, both inside (for dry waste) and outside (composter). Adequate space for waste storage and organic material composting are essential and help the occupants to dispose wastes correctly.

In a ZESH there is a concern with the proper treatment and disposal of wastewater. Ekó House sewer system is decentralized. A composting toilet, which requires no water, is adopted. This technology accelerates the composting process to avoid odors and contribute to reduce fresh-water consumption (Projeto Ekó House, 2012). Through this system, it is possible to obtain an organic compound free of contaminants, avoiding the need for larger scale systems for treating such waste. The wastewater from shower, sink and washing machine, kitchen sink and dishwasher is treated by a natural system planted.
with hybrid filters macrophytes (wetlands). After this process the water can return to the environment without harming nature (Projeto Ekó House, 2012). Through such systems consumption of potable water is reduced. Furthermore, there is a system for collecting rainwater, which can be used as non-potable water or even be treated and consumed. Figure 4 illustrates such systems.

![Figure 4](image)

**Figure 4**  (a) Systems for waste treatment and (b) composting toilet. (Projeto Ekó House, 2012)

Such systems for solid waste and wastewater management may waive the installation of large infrastructure for such purposes, and contribute to avoid contamination of soil and water bodies in areas where such infrastructure is often unfeasible.

**Structure for solar systems**

Architectural integration of solar system into ZESH is supposed to enable the profitable and advantageous use of solar energy into good quality architectural design. The architectural design can influence the performance of solar systems, allowing its integration into the envelope faces with higher levels of solar radiation and the proper arrangement of the system.

In Ekó House prototype, the roof surface is the suitable area for installing PV array due to its advantageous irradiation, is the face that gets higher incidence of radiation throughout the year, so it was used for the installation of solar systems. An aluminum frame, fastened to zipped metallic tiles supports PV systems and solar collectors. This structure is oriented to the North (considering the location in Brazil) and can be adjusted at different angles (10°, 15°, 20°, 25° and 30°). This ensures the efficiency of solar systems throughout the year and in different regions of the country, as shown in Figure 5.

![Figure 5](image)

**Figure 5**  Structure for solar systems in the Ekó House prototype and adaptability to different Brazilian latitudes. (DIAS, 2014)

**Water heating system**

Heat water demand is associated to bathing, home appliances and in the thermal conditioning. Solar radiation can be harnessed to meet this demand in a ZESH. Solar collectors can be applied associated with electric shower, gas heating, electric boiler, among others. Flat plate solar collectors and evacuated tubes systems are examples of widely used collectors. The Ekó House prototype has four u-pipe solar collector (evacuated tubes) ensuring a high efficiency system.

The fastening system shall also be suitable to the envelope and it is important to provide appropriate space for reservoirs, passing pipes, and integration with other heating systems. Access for maintenance is also essential to ensure system performance.
**PV Solar System**

The solar PV generation on single houses can happen in two ways: with a system interconnected to the grid; or through a standalone system, and a storage system and/or additional generation is needed to ensure system’s energy security. For the ZESH hosting unit is considered the adoption of a photovoltaic system associated to a battery bank and diesel generator set. It is important to notice that, in Brazil, the use of alternative fuels for electricity generation in autonomous systems has increased, as the use of biodiesel (Gonzalez, 2008) and even experimental processes such as gasification from the seed of the acai berry, which has a cost three times less than the cost of diesel per kWh generated (Freitas, 2006). Thus, it is possible to have a system that complements photovoltaic generation with a lower environmental impact.

The Ekó House prototype comprises 48 monocrystalline PV panels, with an 18.5% efficiency and 11 kWp of total installed capacity. Considering the location in Madrid, the PV system generates, on average, 1.790kWh/month, enough to meet the prototype energy demand, which is around 735 kWh/month, and still provide around 1.055kWh/month of clean energy to the grid (Projeto Ekó House, 2012).

In a ZESH the architectural design must contribute to a higher efficiency of the system, ensuring that PV modules are arranged on the sides of the envelope with better solar radiation, or even through the use of devices which adjust the tilt or track the sun, adapting the PV system for the orientation throughout the day and the year. Moreover, the architectural design should also provide suitable and safe conditions to place other equipment forming part of the solar PV system, as inverters spaces, in addition to providing space and appropriate protections for electrical wiring, terminals, fuses and circuit breakers. Cleaning and maintenance of the modules shall also be considered in the architectural design to ensure the best system performance throughout its lifetime. (Projeto Ekó House, 2012). ZESH solar systems are exemplified in Figure 6.

**Figure 6**

Solar systems for a ZESH. (Projeto Ekó House, 2012)

The strategies adopted in ZESH confer a degree of adaptability, allowing the model to meet different demands. The full model, including all of its systems, responds to comfort standards of developed countries. However, the modular system allows beginning with the most basic systems to lower cost, and then install systems and expand square footage by attaching new modules. This modularity also provides flexibility in the final occupation, and this model can meet the demand for housing by local communities or units for hosting tourists.

**ENERGY CONSUMPTION IN A ZESH**

The data presented here are from the Ekó House prototype, which are fundamentally derived from computer simulations to estimate values of energy generation and consumption by this prototype over a year of operation. The energy consumption considers the prototype in Madrid. Is worth remembering that this prototype was designed to meet the standards for the use and comfort at developed countries due to the participation in the international competition Solar Decathlon Europe 2012. The project has been conditioned by the rules and requirements and does not represent the standard of living of the
largest part of Brazilian population, especially those living in isolated areas. Thus, it is possible to assume that the Ekó House average consumption, of 735 kWh/month, represents a situation of highest level of electricity consumption, even for hosting units in Brazil.

The energy generation was simulated on RETScreen® 4 software and consider both the prototype in Madrid and in some places in Brazil with potential to apply the prototype as a hosting unit in isolated areas. The PV system is the same of the prototype in all places, with 11 kWp. The slope and orientation of the system are changed in order to achieve better efficiency of the system for each location. These places are Manaus, in the Amazon region; Parati, touristic place located near Rio de Janeiro with some isolated communities; and Florianopolis, which is an island with some few isolated spots and less favorable solar radiation levels along Brazilian territory. Figure 7 brings energy balance data for the Ekó House prototype.

![Figure 7](image.png)

**Figure 7**  Ekó House energy balance considering different locations for energy generation. (Projeto Ekó House, 2012; RETScreen® 4)

It is possible to observe that even with a consumption that reflects standards of developed countries, the prototype proves more efficiency than homes in countries like the U.S., where the average consumption is 903 kWh/month for each residence (EIA, 2012). Besides, the PV system has a positive balance throughout the year. In addition, the modular structure favors the adoption of different materials for the envelope. This enables an adaptation to the climate of each region, providing appropriate comfort with lower energy consumption.

Regarding GHG emissions associated to energy generation, the emission factor for diesel oil generator set is 808 g CO₂/kWh (IPCC, 2007). When properly maintained, the generators have normal efficiency of 350 g/kWh, but most groups used in isolated areas in Brazil receives no adequate maintenance, increasing fuel consumption for about 500 g/kWh (Di Lascio, 2009). For the PV systems it is applied an average emission factor of 46 g CO₂/kWh (IPCC, 2012). Thus, avoided emissions by generating energy through PV system instead of diesel would be 762 g CO₂/kWh.

The table and graph in Figure 8 demonstrate energy generation and avoided emissions for one year of operation of a ZESH. It is worth noting that even a high energy consumption situation is compensated by the use of a clean source. Besides, the more efficient is the electricity consumption in ZESH units, more clean energy can be shared with local communities.

![Figure 8](image.png)

Figure 8  (a) Energy generation and (b) avoided emissions for one year of operation of a ZESH.

**CONCLUSION**

This study concludes that ZESH demonstrated and verified by the Ekó House prototype represents
an alternative to enable the occupation in remote and environmentally sensitive areas with low environmental impact, promoting access of local communities to a basic and autonomous infrastructure that can contribute to its socioeconomic development. This ZESH can be adopted both by local people and by tourist developments. It is a model that responds positively to environmental indicators set by the Brazilian government and to the concept of sustainable tourism defined by UNWTO.

The solutions proposed for this ZESH model, demonstrate the important role of architecture with regard to the use of the sun, both associated with passive strategies for greater energy efficiency, and for obtaining energy through active systems such as PV and water heating systems. In this way, it is possible to maintain comfortable levels for occupants without necessarily increasing energy consumption. The prototype also demonstrates that it is possible to associate to a housing unit some systems that ensure access to basic infrastructure for sewage treatment and solid waste, avoiding contamination of soil and water, and providing healthy and hygienic conditions for local and tourist populations.

Finally, the ZESH model presented in this study can be adopted and contribute to the mitigation of global warming by reducing GHG emissions, to an improvement in the quality of life of local populations in remote areas, to develop tourism in a sustainable way in environmentally sensitive areas, to promote socioeconomic development in remote communities, and also to educate different audiences (local and visitors) about how some appropriate systems and habits can reduce the impact of human activities on the environment.

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