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# Innovative Solar-House Aiming at Zero Annual Electricity Consumption with Energy Conservation and GHG Reduction

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***Abstract*— The aim of this study is to determine the contribution of a residence for sustainable development in the mitigation of global warming through an energy efficient and environmentally sustainable home model by reducing emissions of greenhouse gases (GHG) from country power system. In terms of methodology, a model of solar house is taken (Ekó House prototype), which uses the sun as the only energy source and is designed to operate efficiently and able to generate annually all the energy consumed through photovoltaic own-system. The study goes through the characterization of the sustainable housing unit model and estimates per unit of energy savings related to its operation over time and in the geographical space of interconnected electric system; quantitative and qualitative understanding of energy generation in the National Interconnected System (SIN) related to GHG sources and emissions, and an inter-related assessment of energy use and GHG emissions for the residential sector. The study adopts strategies and systems which ensure the efficiency and rationality in its procedure, including the photovoltaic peak-generation. The replacement of conventional single-family homes by unities modeled on the reference prototype is considered for the results. The reference prototype meets the developed countries comfort standards and is more efficient when comparing its monthly consumption (around 735 kWh per month) to average consumption of an American (958 kWh per month) or Spanish (876 kWh / month) household; In comparison to Brazilian households solutions adopted in prototype provide improved comfort conditions without increasing energy demand. The generation of solar photovoltaic energy allows a reduction of GHG emissions of about 320 g of $CO_2$/kWh for emissions from electricity generation by the Network; each solar-house avoid emissions up to 7.1 ton per year of $CO_2$, which means 355 ton in its lifetime and the full potential of avoiding $CO_2$ emissions reaches up to 3550 million of tons, considering an specific Brazilian region. From the results, it may be concluded that the model of the solar house in the Ekó House prototype patterns consolidates actions for the sustainable development, ensuring the use of energy efficiently and rationally over time, without restricting users from their activities and meeting their needs. It contributes to the mitigation of global warming by reducing greenhouse gas emissions since it uses photovoltaic generation and relies on design solutions that increase efficiency when compared to a conventional residence. Thus, it is evident that systems and sustainable housing strategies with the sun as a source key can be applied taking advantage of the facilities from CDM, enabling economically its replication on a large scale by the addition of carbon credits and allowing the development of the country in a more responsible way in from the social and environmental point of view.***

***Index Terms*—Building Integration, CDM, Energy Efficiency, GHG reduction, Solar Architecture, Solar Home System, Zero Energy.**

## I. INTRODUCTION

The traditional model of economic development considers the environment an endless source of natural resources and final destination, with unlimited capacity to receive waste generated by human activity. Added to this the inefficiency and wasteful use of natural resources, especially energy which is one of the essential inputs for the provision of the basic conditions of human life. From this model and the unbalanced form of exploitation and use of these resources derive the current environmental problems. Among the environmental problems associated with the energy sector we highlight the increasing emission of gases associated with greenhouse with significant impact on global warming and climate change. Studies show the human influence on global warming and climate change. The IPCC (Intergovernmental Panel on Climate Changes), shows, through models of climate study, that the annual average temperature of the planet may increase from 2 °C to 6 °C for a reference scenario (business-as-usual), considering an horizon of 100 years. Compared to industrialized countries the Brazilian energy matrix contributes little to the emission of greenhouse gases. The Energy Matrix of Brazil has always been distinguished internationally for the high participation of renewable energy, initially only result of hydroelectric projects in electricity production and later by the introduction of alcohol from sugar cane as fuel in cars. This provided the country a cleaner matrix in terms of environmental pollution and for benefit of the entire Brazilian society [2]. The National Interconnected System (SIN) is the Brazilian system of production and transmission of electricity with a strong predominance of hydroelectric plants. The SIN, which holds approximately 96% the production capacity of the country's electricity, is composed mainly by hydroelectric plants that produce 73% electricity, followed by conventional power plants that participate in 15.4% of the electricity generated.

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The small hydropower plants (PCHs), cogeneration (biomass) and wind farms account for 9.5% electricity generation. Only 3.4% capacity of electricity production in the country is located out of SIN, in small isolated systems mainly sited in the Amazon region [16].

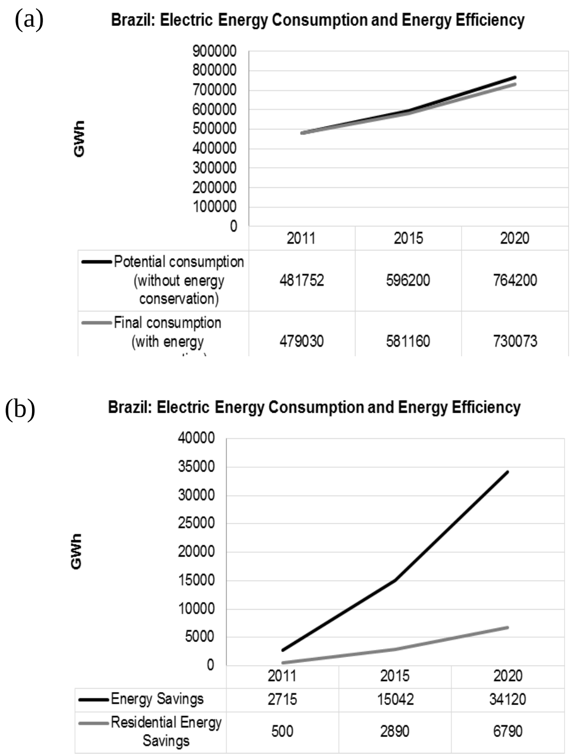


**Fig. 1: Estimates of consumption and energy efficiency in Brazil Source: Own elaboration from [3].**

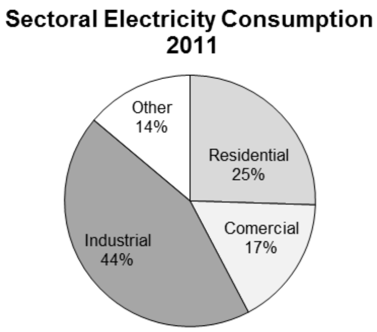


**Fig. 2: Distribution of Electricity Consumption in Brazil Source: [9]**

To meet the growing demand for electricity, as predicted in the Decennial Plan for Energy Expansion (PDE) for 2020 [3], SIN expansion will be required. The hydroelectric plants will continue to be the main source for electricity generation in Brazil. However, since most - or all - the water resources of southern and southeastern are already being explored and most remaining reserves are located in the Amazon, far from centers of population and industry of the country [15], the trend indicates the construction of new power plants, plus one more nuclear power plant (Angra III). This should entail an increase of GHG emissions with their corresponding environmental impacts. Considering the logic of sustainable development, future energy demand will be met based on strategies focused on energy efficiency measures and the use of renewable sources. The implementation of energy efficiency measures in Brazil, according to forecast in PDE 2020 [3], may help to reduce total consumption by 2020 equivalent to approximately 34.127 TWh, the industrial sector being the main contributor to the preserved electricity, followed by residential and commercial sectors (see Fig. 1).

The energy efficiency measures in the residential sector have a significant impact, given the sector is currently responsible for over 25% electricity consumption in the country (see Fig. 2). Furthermore, the increased purchasing power of the population associated with the reduction of interest rates and reduced tax on industrialized products (IPI) have contributed to the increase in sales of home appliances, increasing electricity consumption in households across the country in the coming years. In residential buildings, energy efficiency can also be achieved through design solutions and construction, and through actions that reduce energy consumption in thermal conditioning, water heating and artificial lighting. Projects that provide an adequate thermal insulation, natural ventilation strategies for a proper solar orientation and optimal use of natural lighting, can contribute to the energy efficiency of residential buildings. Local systems of water heating and electricity generation, for example, with the use of solar collectors and photovoltaic panels installed on the building itself, are forms of direct use of the sun as clean and renewable source of energy and also contribute to the energy efficiency of the system. The use of solar collectors and photovoltaic system reduces dependence on electricity production centralized in power plants, reducing system losses during processing, transmission and distribution. Accordingly, this article aims to determine the contribution a housing unit, oriented to sustainable development, help mitigate global warming. Therefore, having solar energy as directional source, the sustainable model of a solar house that operates energy efficiently and is able to generate the energy it consumes by using photovoltaic panels is assumed as a reference of residential system verification. Ensuring availability of future energy always requires the accounting of GHG emission reduction and other benefits in terms of energy and environment. This research starts from the premise that the large-scale replacement, of common single-family housing units and served by the system (SIN in Brazil) by housing units based on the model of the solar house, will allow an improvement in the standard of comfort of the residential buildings and will also contribute to the sustainable development of the country, as for energy efficiency and generation of electricity through a clean and renewable source.

## II. FUNDAMENTALS OF THE SUSTAINABLE HOUSING UNIT

The sustainable housing unit is represented by a type of solar house, named Ekó House prototype (Fig. 3) whose design has the premise to optimize the use of the sun to generate the energy needed for its operation and maintenance, as well as to provide its residents welfare. The

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welfare conditions are associated with luminal comfort with the best use of natural lighting and thermal comfort and the indoor environment health with the least expenditure of energy. By generating its own electricity using photovoltaic systems, this unit avoids the use of energy provided by SIN, which in addition to GHG emissions originating from generation plants, presents losses during transformation process, transmission and distribution of energy.

**Fig. 3: Outside view from a sustainable solar house Source: [19].**

The fact that the model adopted locally generates the energy required for its operation, using a renewable source, and the concern to meet the requirements of comfort through passive strategies, which tend to reduce energy consumption, makes this type of solar house to be sustainable when compared to conventional houses produced on large scale in Brazil. Importantly, the model of the solar house, considered in this study as a model of sustainable housing, incorporates the concept of Zero Energy Buildings (ZEB). ZEB is defined as a building that produces, through local sources – and preferably renewable ones – the energy it consumes, considering an annual review [21]. It is also the premise of the solar house model to be capable of connecting to the commercial distribution network and integrate a system of local photovoltaic electricity generation. The photovoltaic panels are integrated into the building as well as the solar collectors (evacuated tubes) to heat sanitary water. The Ekó House prototype was developed aiming at the participation of a Brazilian team in the international competition Solar Decathlon Europe 2012 (SDE – http://www.sdeurope.org/), held in Madrid in September 2012. In this event the prototype was assembled, operated and evaluated according to the competition specific requirements such as energy efficiency, sustainability, comfort conditions, architecture, engineering and construction, among others. The isolated core of the prototype, with 54 $m^2$ floor area, has basic program as a conventional housing unit: kitchen, bathroom, bedroom, living and dining rooms. Internal facilities are integrated, being the bathroom the only compartmented area of the house (see Fig. 4). Outside, the prototype is surrounded by balconies that act as extension of the social area and shelter the technical control of the building systems (electrical and hydraulic installations). Adding the coverage areas of the isolated core and balconies, 120m² projection area are totaled (see Fig. 4). On the roof of the prototype 48 photovoltaic panels are installed for electricity generation and four solar collectors for water heating. The photovoltaic peak-generation added is capable of supplying up to three times the demand of the house considering the annual energy balance.

### *A. Solutions applied to the solar house model*

The solar house model incorporates vernacular solutions whose efficiency is known for its practice such as the use of balconies and materials with low energy added (bamboo and wood). The project also employs technological solutions still little used residences, such as the photovoltaic peak-generation incorporated to the covering of the house and the home automation system. The integration of these solutions is intended to ensure the operation and housing maintenance as effectively as possible.

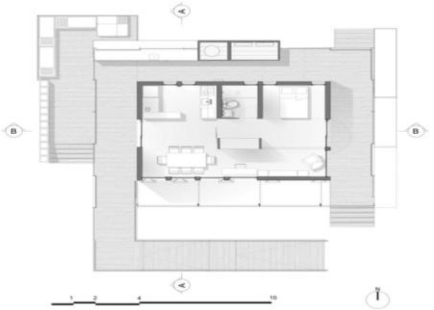

**Fig. 4: Prototype of sustainable solar house: general layout. Source: [19].**

The implementation, occupation and maintenance of the solar house should consider typical situations, but geographically different, not necessarily southern, such as: days of hot, dry weather and cold nights. The solutions adopted must allow good performance in different bioclimatic conditions. The Ekó House prototype (see Fig. 5) presents the following characteristics:

- Orientation of the longitudinal axis of the house according to the east / west direction, so that the largest facades had north and south orientation;
- On the north facade (with the implementation in the southern hemisphere) there are large openings, contributing to illumination uniformly distributed mostly the prototype and greater heat gain during the winter;
- The use of external blinds and internal curtains on the north facade enables control of lighting levels inside the prototype;
- The projection of the coverage on the north facade works as an element that shadows the openings during the summer, and allows the entrance of the sun during the winter, also helping with thermal conditioning of the prototype;
- The openings located on the east and west facades face balconies areas, which act as buffer zones and have thermal shading elements, which also help control the entrance of light and heat exchange through the frames;
- On the south facade the openings are smaller to avoid thermal losses and complement the lighting of the internal space of the prototype;
- According to computer simulations performed, the range of daylight is about 60%; even with the shading device closed

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it is possible to achieve adequate levels of illumination for user activities using only natural light during most of the year

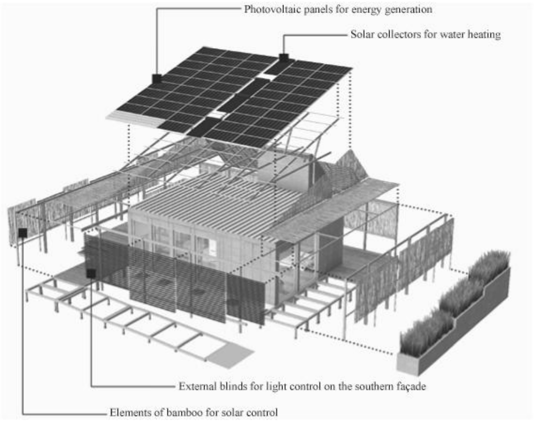


**Fig. 5: Global view of the Ekó House prototype**

Source: [19].

• Construction techniques that allow control infiltration and exfiltration;

• Home automation control and integration between different systems to reduce energy consumption.

The Ekó House prototype features high levels of thermal insulation to ensure adequate levels of comfort with low energy consumption. As insulation materials glass wool, present in the wall panels, floor and roof are used. The insulation of the facades is complemented by the high insulating performance based on synthetic amorphous silica, continuous filament fiberglass and magnesium hydroxide, a product whose use is not conventional in residential buildings and predominantly used in industrial plants. In addition to isolation, the provision of openings on all facades provide good natural ventilation conditions within the prototype, providing better comfort and environmental conditions besides indoor air quality without additional expenditure of energy. The frames (doors and windows) have good insulation due to the use of glass with properties of low emissivity (low E), to double glazing system with inert gas chamber and the finishes and construction details to guarantee the tightness of the assembly. Such characteristics contribute to the better performance from the thermal and acoustic point of view.

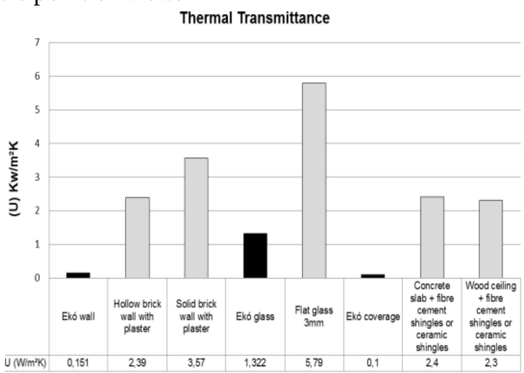


**Fig. 6: Thermal transmittance of materials in the Brazilian construction industry**

Source: Own elaboration based on data from [14] and [19].

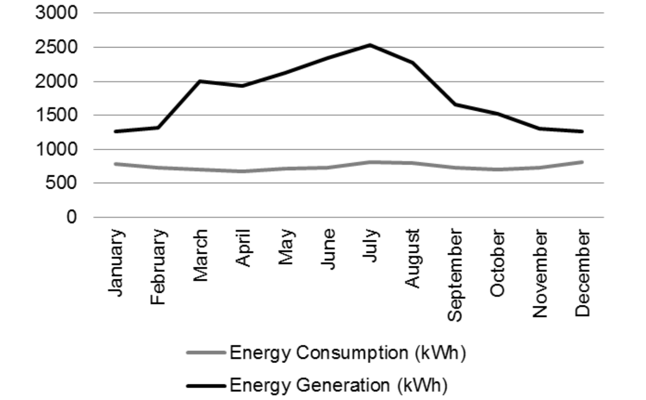


**Fig. 7: Simulation of Annual Energy Balance for the Ekó House Prototype**
**Source: [19].**

By comparing the levels of thermal transmittance of the materials used in the Ekó House prototype to materials conventionally used in the Brazilian construction industry, the distinction between the performance of materials and components used in large scale in the country can be seen in Fig. 6, which usually leads to high operating costs in most buildings in the country. As a passive system for cooling, an evaporative system combining mechanical ventilation and water spray was adopted in the Ekó House prototype. Through a specific pipe for this system, an action of taking air from the exterior is performed, below the prototype, where the air is cooler and shaded. This air is directed into the prototype with the aid of a low power consumption fan, and a water sprinkler, that air is humidified before being blown inside the house. To allow passive heating, radiators using water heated by solar collectors were installed, assisting in internal heating of the house with low energy consumption. Through the openings, the prototype can still benefit from passive solar gain for heating without electricity consumption. The use of energy efficient appliances available on the market was prioritized. The equipments have PROCEL seal (National Program for Energy Conservation) "A" level. Artificial illumination was designed to complement natural lighting inside the prototype. The system uses LED lamps (light-emitting diode or LED), which ensures greater energy savings, less maintenance and longer life. According to computer simulations performed, the energy balance of the annual Ekó House prototype (see Fig. 7) shows that photovoltaic energy generated is satisfactory to meet demand over the year, considering the connection between the prototype and the public distribution network. The most important innovation in the prototype, in the Brazilian context, is the adoption of the design process that includes virtual prototyping, digital production of standardized components, prefabrication and assembly of elements, rather than the design practice of traditional building techniques widely used in the country. This enables greater control of materials use, in a more rational and less waste and residual generation. Due to the system to assembly and disassembly designed for the prototype, the operation and maintenance required over time of use are facilitated, and the end of life expectancy those different materials can be

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separated, making it easy to reuse, recycle or proper disposal. The Ekó House project breaks paradigms when proposing a more efficient and rational model of construction and new solutions for maintenance, contributing to prolong life expectancy and management of waste in the production of the building. The choice of materials for the Ekó House prototype was held to meet technical and environmental requirements. The prototype uses approximately 5.4 m³ Brazilian teak (Cumaru). This wood was chosen for its high structural strength as well as resistance to attacks by biological agents, which makes it durable enough without having to be impregnated with toxic chemicals against attacks by fungi and termites. In addition, wood is a renewable resource, since extracted from the environment in a responsible manner. A ton of dry wood consumes over 1.7 ton of $CO_2$, incorporates 0.48 ton carbon and returns 1.22 ton oxygen to the atmosphere [4]. It is also important to highlight that the wood used in the structure of the Ekó House prototype has Forestry Source Document - DOF, which ensures the legal origin of the wood. The wood used for the outside deck is thermally treated Teca (Thermoteak ™). Approximately 2.2 m³ from this wood are used, which undergoes a heat treatment increasing its resistance to attack by fungi and, since it is free of chemicals as well as the structure of the timber, it can be easily reused or discarded as organic waste free from toxic substances. Ekó House also uses tiles on the roof structure, and balconies structure of aluminum profiles, totaling about 2000 kg. This material is lighter and, if compared to steel it is more resistant to atmospheric corrosion and weathering. Aluminum is a material that can be recycled, enabling the reincorporation of that material to the supply chain by the end of the building useful life. In Brazil the aluminum recycling industry is well organized and pungent. In 2010 the share of recycled aluminum accounted for 36% of metal domestic matrix supply in Brazil, while the world average is 28% [1].

## III. RESIDENTIAL CONSUMPTION

Besides electricity, firewood and liquefied petroleum gas are important energy sources used in Brazilian households. In the residential sector energy use is intended primarily to food cooking, water heating, lighting, environmental conditioning, food preservation, and leisure and general services. The graph in Fig. 8 illustrates the contribution of each source in the Brazilian residential sector, with data for the years 2005 and 2010 and projections for 2020 and 2030, with electricity presenting a growing interest share in this sector. In Brazil, the residential sector is responsible for approximately 25% of the total consumption of electricity in the country. While maintaining the proportion of relative consumption virtually unchanged from 2011 to 2020, there are estimates of the increase in electricity consumption in the residential sector by around 4.5% per year, from 112.690 GWh in 2011 to 166.888 GWh in 2020 [3]. Yet by 2020 PDE, energy efficiency measures adopted by the residential sector may contribute to an economy in which the consumption of 500 GWh for the year 2011 reaches 6,790 GWh in 2020. However, the share of electricity in the energy consumption of the residential sector on the national energy matrix nearly doubles between 2005 and 2030 [2], as shown in Fig. 11. With respect to specific consumption by appliances and equipment in Brazilian households, results of research conducted by PROCEL [18], with base year 2005 show that the shower, the fridge, air-conditioning and artificial lighting are responsible for the largest amounts of electricity consumption in the residential sector (see Fig. 13). According to the graph in Fig.13, the electric shower is responsible for most of the electricity consumption in Brazilian homes. The use of solar collectors for water heating is an alternative that can dramatically reduce this energy consumption in a country like Brazil, which has favorable conditions and levels of solar radiation throughout the year. With regard to the air conditioning consumption, strategies - already described - applied to the Ekó House prototype such as proper solar orientation, thermal insulation, optimization of the use of natural ventilation and control systems of solar radiation can help reduce electricity consumption without thermal comfort loss. Likewise, energy employed for artificial lighting can be reduced if the architectural design predicts appropriate sizing and guidance of the openings to optimize the use of natural light, and if energy saving lamps (LED) are used in artificial lighting systems. Fig. 9 shows the distribution of households sample per range of consumption.

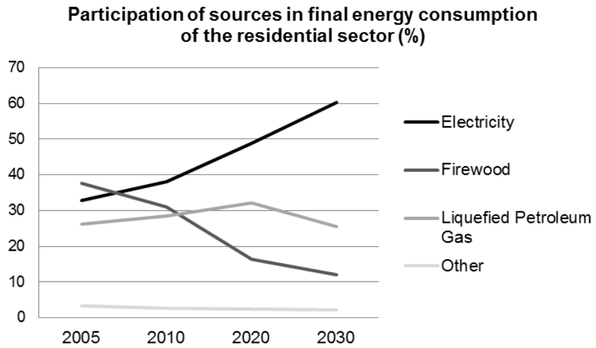


**Fig. 8: Residential energy consumption per source**
**Source: Own elaboration based on data from [2].**

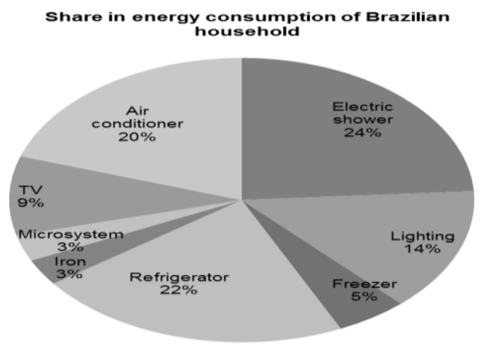


**Fig. 13: Consumption per household appliances in Brazilian homes**
**Source: [18].**

The PROCEL [18] survey also indicates that most households, about two-thirds of the total, consume up to 200kWh/moth. This characteristic indicates, according to the document, the existence of room for an increase in electricity

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consumption, which should be driven by the incorporation of appliances and electronics in everyday life of the Brazilian citizen. It is also important to be aware to the unmet demand which contributes to most households surveyed to be in the range of lower consumption. With a majority of the population having access to electricity, through government programs such as "Luz Para Todos" [Light for All], in addition to the increase in purchasing power, this situation will change and the average consumption of this population is expected to increase.

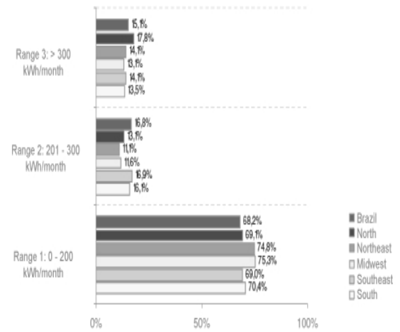
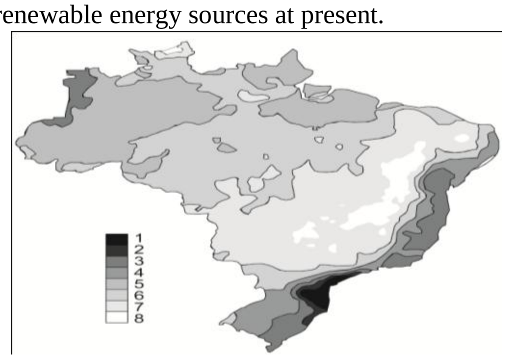



**Fig. 9: Distribution of consumption of households per range**
**Source: [18].**

## IV. RELEVANCE AND SINGULAR EVIDENCE OF AUSTRAL SOLAR SOURCE

With regard to generating solar energy, Brazil has already shown some progress. EPE has developed a technical memorandum intended for analysis of the insertion of solar generation in the Brazilian energy matrix. In that document the EPE shows huge potential for the exploitation of solar energy in the country (see Fig. 10). The average annual irradiation varies between 1,200 and 2,400 kWh/m²/year, values that are significantly higher than most European countries. As the scale of the Solar energy potential it can be estimated that the consumption of the national interconnected system - SIN observed in 2011 would be fully satisfied with covering an area of 2,400 km ², slightly more than half the area of the city of Salvador, BA, with photovoltaic panels in a region with average insolation of approximately 1,400 kWh/m²/year [8]. With regard to distributed generation, from rates of power distribution to the final consumer, the comparison of values with photovoltaic generation indicates the condition of economic viability for some points of the power grid. The same does not occur with centralized generation, larger, whose prices are not competitive with other renewable energy sources at present.




Specific average productivity of photovoltaic generation in selected areas of the Brazilian territory

| Area | Average productivity (Wh/Wp/year) | Average capacity factor (1) |
|---|---|---|
| # 5 | 1.260 | 14,4% |
| # 6 | 1.320 | 15,1% |
| # 7 | 1.370 | 15,6% |
| # 8 | 1.420 | 16,2% |

(1) Taking as reference 8760 hours per year

**Fig. 10: Irradiance and Solar Generation in Brazil**
**Source: [8].**

To enable the reduction of photovoltaic production costs it is necessary to stimulate further development of the solar energy market, including the direct involvement of photovoltaic's industry worldwide [8]. Accordingly, in 2012, ANEEL approved a resolution establishing rules for solar micro-generation and mini-generation of energy in the country. The concept is to enable the installation of photovoltaic systems by consumers in residences, businesses and industries, and that the production derived generates credits, which will be discounted from the electricity bill. These studies and measurements show that although solar generation is still not significantly considered by PDE 2020 or the National Energy Matrix, the country already shows efforts to encourage the participation of solar generation in the energy matrix. Considering the potential for exploitation of solar power generation, the present study starts from this identified potential and progress in this direction to study whether, from the economic point of view, the use of photovoltaic panels for energy production distributed on a large scale could be viable, also as a Clean Development Mechanism (CDM) project in the country, intended for contributing to meet the growing demand for electricity through a renewable source, reducing or preventing the installation of new thermal power plants using fossils fuels. The use of the sun as a resource in architecture is also an important aspect that is observed in this study, because as shown in the reference prototype, proper solar orientation and design that allows control of solar radiation inside the building can substantially improve the energy efficiency by appropriate use of natural lighting and also for passive use of the sun in the thermal conditioning of the building.

## V. EMISSION OF GREENHOUSE GASES (GHG)

Brazil is a signatory of the UNFCCC (United Nation Framework Convention on Climate Change), but as a developing country, had no goals to reduce GHG emissions for the first commitment period established by the Kyoto Protocol, which ended in late 2012. Even without reduction targets, the country has been making efforts to contribute to the mitigation of global warming by reducing greenhouse emissions, announcing the 15th Conference of the Parties (COP-15) held in December 2009, a voluntary target to reduce, by 2020, between 36.1 and 38.9% of its total

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emissions projected for that year. In this context, the importance of ten-year energy plans is highlighted as an important tool for scenario projection mitigation of anthropogenic greenhouse gases emissions. These plans are developed having among their objectives to achieve a reduction target set in advance. In those plans policies and initiatives to mitigate or control emissions in the generation of electricity are considered, also expanding hydroelectric and other renewable sources of energy and encouraging efficiency in electricity consumption.

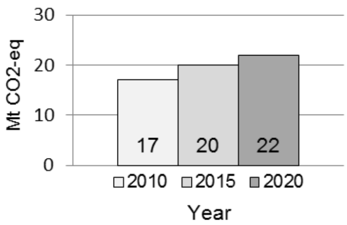


**Fig. 11: Annual GHG emissions in Residential Sector until 2020 Source: Own elaboration based on data from [3].**

As already pointed out in the PDE study, energy consumption by the Residential Sector will remain, as expected, with a significant portion of the total consumption of the country, and the predicted increase in energy consumption by sector indicates that energy efficiency measures and reducing GHG emissions from power generation to stimulate this sector can contribute significantly on the national scene. The graph in Fig. 11 illustrates the estimated increase in GHG emissions by residential sectors in the country. In Brazil, data on GHG emissions by different power generation plants are still limited or insufficient. However, considering emissions from power generation in SIN, there are data available in GHG emissions by the Ministry of Science, Technology and Innovation (MCTI), and also in CDM projects approved in the country. By MCTI data, published for SIN, in the past six years GHG emissions by power generation, show an increase in some moments, in part by the need to increase power generation by thermal power plants due to low levels in the reservoirs of Brazilian hydroelectric plants. This fact shows that the thermal generation will be greater than predicted, and the importance of alternative and renewable sources of energy to reduce emissions of greenhouse gases. This paper is based on GHG emission factors calculated for CDM projects approved by the UNFCCC to be deployed in Brazil, to be considered consolidated data and openly evaluated. Thus, in the project "Garganta da Jararaca" Small Hydroelectric Power Plant (SHP) [5], the value obtained from the monitoring system was 0.3273 t.$CO_2$/MWh for the SIN Emission factor, for the year 2008, and in the Malagone SHP CDM project [6] the value obtained for the GHG emissions factor of the national electricity grid is 0.3111 ton of $CO_2$/MWh. Both projects, Garganta da Jararaca and Malagone, are nearby each other. Accordingly, for this study, an average of the values calculated for these projects already approved by the UNFCCC will be adopted as a Factor of GHG emissions. This corresponds to 0.3192 ton of $CO_2$/MWh. For the amount of GHG emissions from the PV system, this study uses Special Report of the IPCC "Renewable Energy Sources and Climate Change Mitigation" [13] whereby average emissions of GHG generation by solar photovoltaic energy are of the order of 0.043 ton of $CO_2$-eq/MWh, and this value may fluctuate due to the rapid evolution of these systems and the different types of photovoltaic cells applied. These data were obtained from analysis of solar photovoltaic power generation life cycle. Combining data obtained from the project to the PCH approved as CDM in Brazil to the data available in the IPCC report, it is possible to estimate the contribution to mitigating global warming, that energy efficiency measures such as those adopted in the reference prototype and energy generation from clean and renewable source can represent when applied on a large scale, aiming at sustainable development.

## VI. CONTRIBUTION IN ENERGY EFFICIENCY AND GHG REDUCTION RELATED TO A SOLAR-HOME

This section presents the analysis of the contribution of the solar-house, whose reference is the Ekó House prototype, for energy efficiency, reducing greenhouse gas emissions and sustainable development. From data relating to the operation of the SIN on GHG emissions, emissions of PV systems and the overview of energy consumption by the residential sector of Brazil, it is possible to discuss and analyze the contribution of the solar house model presented. Data for the Ekó House prototype are fundamentally derived from computer simulations to estimate values of energy generation and consumption by this prototype over a year of operation. These simulations were performed by a team of researchers on the project. A timetable of occupation and residence operation was established, considering how many people would be in the prototype, the frequency of use of the appliances, the need for artificial thermal conditioning and the use of artificial lighting. Is worth remembering that this prototype was designed to meet the standards for the use and comfort at developed countries due to the participation of the Brazilian team in the international competition Solar Decathlon Europe 2012. The project has been conditioned by the rules and requirements of the tender and does not represent the standard of living of a large part of the Brazilian population. Therefore, for instance, the prototype uses an electric cooktop instead of the traditional gas cooker, electric oven, clothes dryer, air conditioner and dishwasher, equipment still uncommon in the households of the country which have meaningful participation in the energy consumption of Ekó House. However, it is applicable to consider these appliances in the analysis on account of the increase of energy consumption in the residential sector predicted by PDE 2020 [3] due to the factors already mentioned. Because these differences, checking the efficiency of the prototype is made not only by comparing its consumption to an ordinary housing unit in Brazil, but also with the consumption of housing units in developed countries and the very projection of increased consumption of energy predicted by the Brazilian residential sector in PDE 2020 [3].

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Another aspect to be considered is that the consumption data for monthly average are obtained from computer simulations; on-site measurements have not been carried out for all seasons to get real data from operation of the prototype. If on one hand the prototype is equipped with electric cooker, electric oven and dishwasher, which increase the energy consumption in its operation compared to average consumption in households, on the other hand electric shower is not used, only solar collectors for water heating, and artificial lighting is all LED. In addition, studies were conducted to ensure maximum use of natural light, and bioclimatic strategies associated with thermal insulation ensure comfort conditions with reduced power consumption by active thermal conditioning systems. The graphs in Fig. 12 demonstrate the household appliances contribution to energy consumption of the prototype.

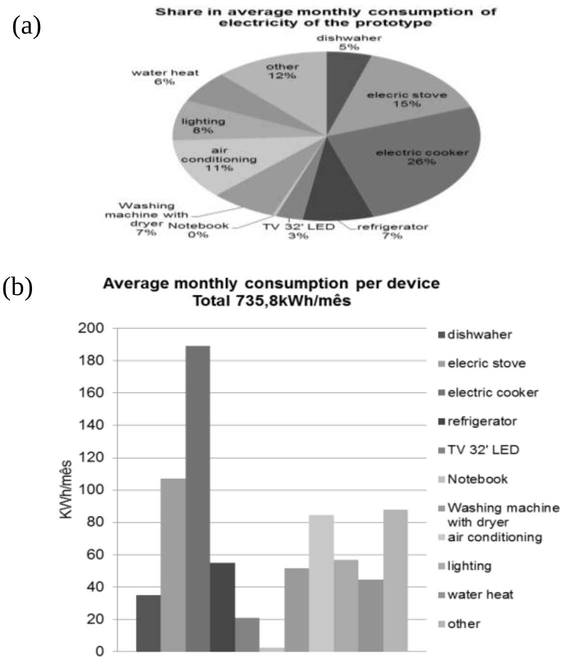


**Fig. 12: Participation of household appliances in the consumption of the prototype**
**Source: Own elaboration with [19].**

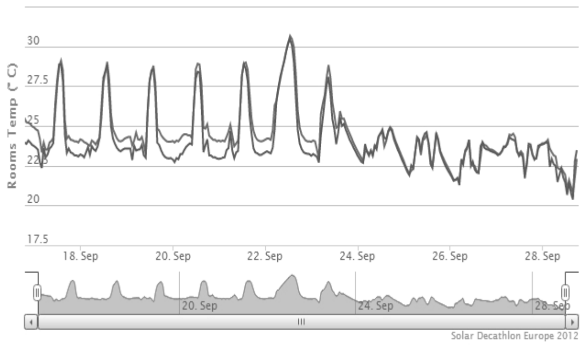


**Fig. 13: Temperatures recorded during solar house checking**
**Source: [20].**

Excluding the use of the cooker and electric oven, dishwasher and clothes dryer, the electrical power consumption of the prototype would present a monthly average of 350 kWh per month, which would approach the consumer prototype consumption of major part of Brazilian households that is defined between 0 and 200 kWh per month. Regarding the thermal conditioning of the prototype, simulation data are programmed so that the house remains in the range 23-25 °C throughout the year. However this in does not apply to an everyday situation, and tolerance should be more flexible, reducing the consumption of air conditioning. Furthermore, in the actual test, the operation of the prototype took two days using only passive systems and comfort conditions remained tolerable during this period. Suppressing also the use of air conditioner and other passive systems, the monthly consumption of the prototype would be 265 kWh. The graph in Fig. 13 shows the temperatures recorded during the entire checking period of operation and occupancy of the solar-house (held in September 2012). It is important to note that in periods when internal temperatures are close to 30 ºC the house was opened to the public with lots of people inside the prototype which caused internal temperature increases. Out of the period for visiting, temperatures were maintained most of the time between 22 and 25 °C, which is considered a comfortable range, including the period in which there was no use of conditioning active systems. It can be stated then that passive methods of conditioning are effective with reference to this evaluation period, highlighting that the need for artificial air conditioning is low, which ensures the comfort of residents with low power consumption. Considering the limitations and circumstances stated above regarding the energy consumption data of the prototype and the characteristics of the data relating to energy consumption in the Brazilian residential sector, taken as a reference for this study, it is possible to observe the potential of the prototype solar house Eko-House in contribution to an improved quality of life and standard of comfort of residents without necessarily increasing energy consumption.

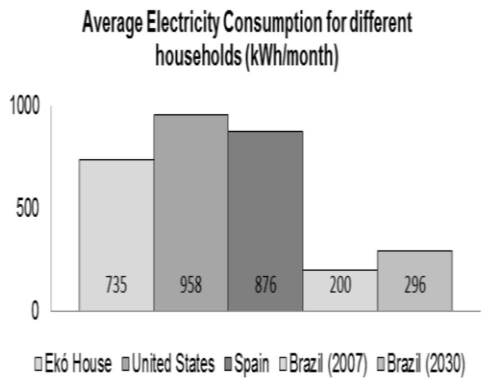


**Fig. 14: Residential consume worldwide vs. Ekó House.**
**Source: [19], [7]EIA, [12]IDEA and [3]PDE2020.**

When comparing the average monthly consumption of the prototype with simulated monthly average consumption data of households in developed countries like the United States and Spain, for example, it is clear that maintaining the same levels of comfort and convenience that meet the standards of

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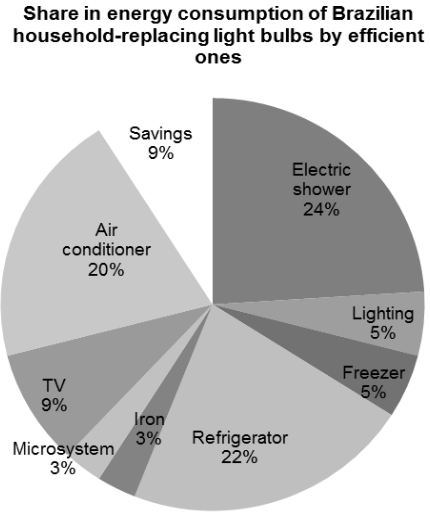
these countries, the prototype shown to be more efficient in energy consumption. As shown in Fig. 14, with the exception that the mean value in the case of Brazil (including projection) reflects relative energy consumption for the average home in a developing country where there is still unmet demand in terms of comfort and welfare in the 21st century. According to data from the United States Energy Information Administration - EIA, the U.S. homes built after 2000 are, on average, 20% bigger than the houses constructed prior to this period, however the level of energy consumption remained the same or less, even with higher household appliances, air-conditioning and greater area to be conditioned. This saving in energy consumption is attributed to a more efficient thermal insulation of new homes, including doors and windows with double glazing and better seal, new and more efficient equipment and lighting using fluorescent or LED [7]. In Brazil little is invested in heat insulation and some other passive systems to improve the thermal comfort of buildings, which increases the energy consumption needed for conditioning the environment in the home country. Moreover, the best use of natural lighting and the use of more efficient artificial lighting can also contribute to the reduction in energy consumption and better comfort conditions, as has happened in the United States in recent decades. Referring to data PROCEL and considering the replacement of the electric shower by solar heating, the reduction in energy consumption would reach 24% of the total. With respect to artificial lighting, the use of LED could considerably reduce energy expenditure. According to PROCEL research, in 2005, 62.3% of the municipalities had at least one fluorescent lamp in use [18]. Whereas all households possessed only fluorescent lamps, energy consumption for lighting could be reduced by five times if only LED was used. As shown in Fig. 15, the possibility of a house to generate electricity savings by using solar collector for water heating and artificial lighting efficiently achieves significant value for the residential sector.

(a)




(b)

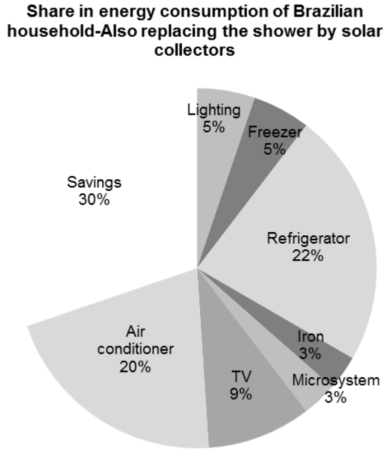



**Fig. 15: Consumption savings in water heating and lighting**
**Source: Own elaboration based on data from [18].**

Taking into account only the replacement of electric shower by solar heating and the use of artificial lighting to LED, the prototype shows a reduction of about 30% in electricity consumption, energy efficiency increases without detriment to the comfort of the users and no changes in habits. With respect to GHG emissions, Southeast region of the country is taken as an example of geographic space which according to the IBGE Census 2010 has around 25 million residences, of which approximately 80% are single houses [11]. At this point, it is important to highlight that the scenario study to analyze the benefits of a sustainable solar house model, refers to the replacement of existing houses for homes that add design solutions used in the Ekó House prototype. Whereas half of the households would generate their own energy using photovoltaic panels instead of using the energy distributed by SIN (National Interconnected System), the avoided emissions would be between 273g/kWh and 320g/kWh of electricity generated. If every household consumes about 200 kWh per month, the reduction of GHG emissions would be between 54,6 kg and 64 kg of $CO_2$ per month per household. Considering 10 million housing units, which equates to approximately half of single-family homes in the Brazilian Southeast, this per household value would be from 546 to 640 ton of $CO_2$ per month (see Fig. 18). Taking into account only the replacement of common bulbs by the economic ones and the replacement of electric shower by solar collectors for water heating, 60 kWh per month per household would be spared. As a result of the avoided emissions due to energy savings would be about 19,2 kg of $CO_2$ per month for each residence. If this measure was adopted by 50% of single-family housing units in the Brazilian Southeast, the avoided emissions each month would be from 163 to 192 ton of $CO_2$. Besides avoided emissions by energy efficiency measures and PV micro-generation, it is possible to estimate emissions avoided by the surplus energy generated which is injected into the grid. With approximately 1050 kWh per month generated surplus power, the avoided emissions per unit along the lines of solar-house would be between 218.7 and 256.4 kg of $CO_2$ per month. This surplus energy generated by 10 million housing units could avoid emissions between 2187 and 2564

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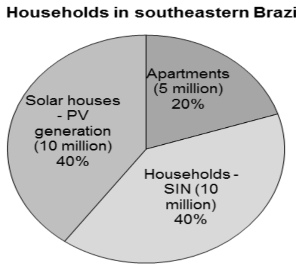
ton of $CO_2$ per month in the Southeast Brazilian region above mentioned (where will be ease to introduce solar-homes like Eko house prototype). For one single home this mean to avoid up to 7.1 ton of $CO_2$ per year, bringing benefits to the environment and the health and wellbeing to the population.

(a)




(b)

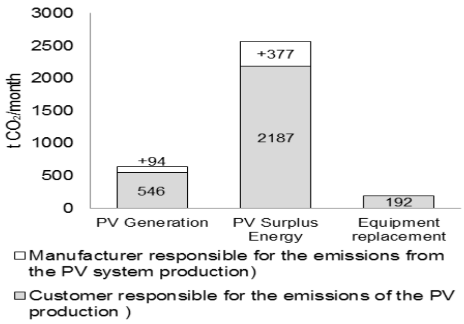



**Fig. 16: GHG reduction in home replacement by the solar house prototype**
**Source: Own elaboration based on data from [13], [19] and [18].**

## VII. CONCLUSIONS AND FINAL CONSIDERATIONS

The adaptive zero-energy solar-house, when responsibly designed, should be realized seeking efficiency in the consumption of energy and natural resources, with a concern to improve the use of these and minimize the generation of waste contributing decisively to the sustainable development. This is both by the rational and efficient use of natural resources in general and through the mitigation of global warming, in particular the reduction of greenhouse gases emissions. This statement is evident in many aspects of the solar-house model examined, whether for the strategies of energy efficiency and the use of clean and renewable source to generate its energy, or the full use of a renewable and free of charge source, which is the sun. Energy intensity saved expresses precisely the efficiency in final energy consumption, and this efficiency also contributes to the global climate changes mitigation with the reduction of GHG emissions in the atmosphere. The share of renewable energy sources is important because, in the long term, dependence on non-renewable sources can be considered economically or environmentally unsustainable. The use of solar energy does not imply social and environmental impacts, as opposed to the installation of hydroelectric or thermoelectric plants. This study showed that energy efficiency measures contribute in avoiding GHG emissions, and the fact of the residential sector consumption increase in the next couple of years allow us to realize the relevance of these measures. Avoided emissions by replacing electric shower by solar collectors and for savings in artificial lighting can reach up to 0.23 ton/year or 11.57 ton in a lifetime for each single house. However, the PV micro-generation has showed a contribution even higher to avoid emissions, especially when energy is over-generated and net-shared. Avoided emissions by PV generation can reach up to 3.84 ton each year for one single house, or 192 ton in a 50 years lifetime. From the results it is concluded that specifically considering the potential for reducing GHG emissions we can reach almost a potential of 3550 million of tons of $CO_2$ in the Brazilian Southern region. Particularly by the replacement of standard houses for solar ones (like Eko house prototype) and adopting measures of energy efficiency on a 50 years lifetime horizon, it can be stated that from the CDM point of view, the modeled Ekó House and their systems applied alone would present additional benefits, being used as CDM, which would help their large-scale deployment from the economic point of view through generated carbon credits generated. However, to prove additionally and check if this project would meet all the requirements for the CDM, further studies are needed on the topic. The large-scale deployment of houses as the zero-energy solar-house model, would consequently contribute to sustainable development through the reduction of GHG emissions, considering that the energy released by SIN could be replaced by photovoltaic generation, or its use could be reduced by the substitution of specific equipment or to take other measures to ensure the energy efficiency in the operation and maintenance of the housing units. Future studies could be developed to measure the contribution of passive strategies for conditioning and natural lighting in the energy efficiency of these buildings, which would also contribute to the reduction in GHG emissions. The application of other alternative and renewable sources such as wind generation distributed or even the use of biogas generated from the digestion of waste can also be an inherent part of a solar home that minimizes the use of resources (not just natural) and annually consumes a swing zero energy with respect to the commercial network. As a model of housing that meets the standards of comfort in developed countries, the cost of many solutions is relatively high for Brazilian standards. The photovoltaic system, in some sense, still has no commercial viability for homes in Brazil and in the country due to the lack of policies to encourage the use of these systems for distributed generation. Given these particularities, it is concluded that the possibility of this prototype (including systems present in it), to be applied as CDM (Clean Development Mechanism), would allow economically a deployment on a large scale through the carbon credits generated.

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