Chapter

Net Zero Energy Buildings and Low Carbon Emission, a Case of Study of Madagascar Island

Modeste Kameni Nematchoua and Sigrid Reiter

Abstract

The buildings respecting the concept "Net Zero energy" are becoming more and more flowering in the world these last years. The main goal of this research is to evaluate the different possibilities of implementation of buildings with Net zero energy and low environmental impacts in Sub-Saharan Africa. The proposed building is 80% made of local materials with low carbon emissions and especially at lower cost. The optimization and modeling of the building is carried out by the Design Builder software, which is a world-renowned software in the field of optimization of comfort, cost, carbon reduction, etc. By fixing the insulation thickness up to 11 cm, cooling and heating energy are found equal to zero during the different operating seasons in this residential building. The results show that the optimal solution to consider a net zero energy building in Antananarivo city requires an additional expense estimated at 40% of the cost of buildings more conventional encountered in the island. This will save $475 each year starting in 2030, with 99% reduction in the CO_2 release. The choice of local materials with low conductivity, low emissions, and low cost, has a significant impact on the implementation of a sustainable building, and more adapted to climate change concept.

Keywords: Net Zero energy, low carbon, building, island

1. Introduction

Nowadays, climate change has become one of the major concerns of all governments and politicians around the world [1, 2]. According to the IPCC, it is expected a temperature increase ranging from 2 to 3.5°C depending on the region [3, 4]. The results proved by some experts in this field showed that sub-Saharan Africa was one of the most vulnerable regions [5, 6]. The objectives of the European Union oriented towards the energy efficiency stipulate that the design of the ecological buildings and more adapted to the new current climate can be a solution to this plague [7]. The search for carbon neutrality by trying to live in the most ecological way is a good thing, but living, in addition, in "green" buildings is even better [8]. The notion of sustainable building varies according to the scientific and specialist fields. Overall, it is a healthy construction, using natural materials [7]. A building must first of all adapt to the man, the well-being of the occupants being capital [9]. Specialists in this field condemn the use of toxic substances in the industrial manufacture of building materials. The key role of energy conservation specialists is to limit the negative impacts of human habitat on the environment, using state-of-the-art technologies, and to reduce the energy consumption of buildings, houses and buildings [10]. Indeed, they advocate reinforced thermal insulation and sharp construction techniques. "Eco-Builders" consider the building throughout its life. In addition to saving energy, they are also concerned about the origin of the materials used and their management (disposal, recovery) at the end of their life. Sustainable construction is not a specific construction method, but it brings together a set of techniques, materials and technologies that, properly integrated into a building, contributes to enhancing its environmental performance [11]. In its ideal embodiment, green building optimizes energy efficiency, limits water consumption, makes maximum use of recycled, recyclable and non-toxic materials and generates the least amount of waste possible during construction as well as occupation [12]. Around 40% of total energy use and around 24% of CO_2 emissions come from worldwide energy use in buildings. Energy use and emissions include both direct, on-site use of fossil fuels as well as indirect use from electricity, district heating/cooling systems and embodied energy in construction materials [13]. The term ZEB is commonly used as propaganda without any mastery of the different realities and constraints specific to each country. There are several methods and strategies to reach net-zero energy, however, for NetZEBs to become mainstream in the international market, it requires several consensus on clear definitions, and also agreement on the building performance which could inform "zero energy" building policy, programs and industry building practices, as well as design tools, case studies and demonstration projects that would support industry adoption [14]. The different objectives of Net zero energy were considered to be a new proposal that was inaccessible because of its high cost, they were recommended only for large projects. Today, it is now possible for all types of construction [15]. Net Zero-Energy Building has become a popular catch phrase to describe the synergy between energy-efficient building and renewable energy utilization to achieve a balanced energy budget over an annual cycle. Several experts have proposed different methods for designing zero energy and carbon buildings in several types of climate [16–22]. But no study has yet been done in the specific case of a country in the Indian Ocean (Madagascar, Mayotte, Reunion, Comoros etc.). This study has for fundamental objective to propose a model of implementation of buildings to Net Zero energy in Madagascar. Section 2 gives the different stages of implementation of this district.

2. Methodology

2.1. Studied place

Antananarivo is a city overlooking a hill that rises 1248 meters above an area of rice paddies. It is the capital of Madagascar and it is also the economic and administrative lung of this country. Antananarivo has a tropical climate of altitude. Although it is located in the inter-tropical zone, the average temperature over the year is moderated by the effects of altitude. The climate is characterized by cool and very dry winters and mild and very wet summers. Cool season rarely drops below 10°C. In the hot season, it rarely exceeds 32°C. The choice of this city for the implementation of this type of building is not random, indeed, the climate of this city is very favorable to the implementation of eco buildings. The building materials used in the architecture of this building is cheap in this city. The deficits and power cuts are regularly observed in this city. The popularization of this building throughout the country can help the government to solve this problem.

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2.2. Climate parameters

The different outdoor weather data of the last 15 years of Antananarivo are downloaded with the Meteonorm software and applied to this study. The Meteonorm software is one of the world's best meteorological software that allows you to connect in a few minutes to a meteorological station of the city you are looking for or to the nearest city and to download the climatic data specific to this city. The output data can be recorded on several types of freely selected formats.

2.3. Comfort parameters

The different comfort parameters are evaluated in this study with the Design Builder software. It is possible to calculate the operating temperature of the building (uniform temperature). We evaluated the PMV (Predicted Mean Votes) of Fanger, Kansas and Pierce. Comfort hours are assessed based on ASHRAE recommendations with 90% occupant acceptability, CEN15251 Category I, II and III.

2.4. Description of building

The building evaluated is a family house spread over an area of 273 m2, and consists of: three bedrooms, shower, living room and kitchen, occupied by 5 people. The modeling of the building is shown in **Figure 1**.

Table 1 showed the different characteristics of materials applied in this building.

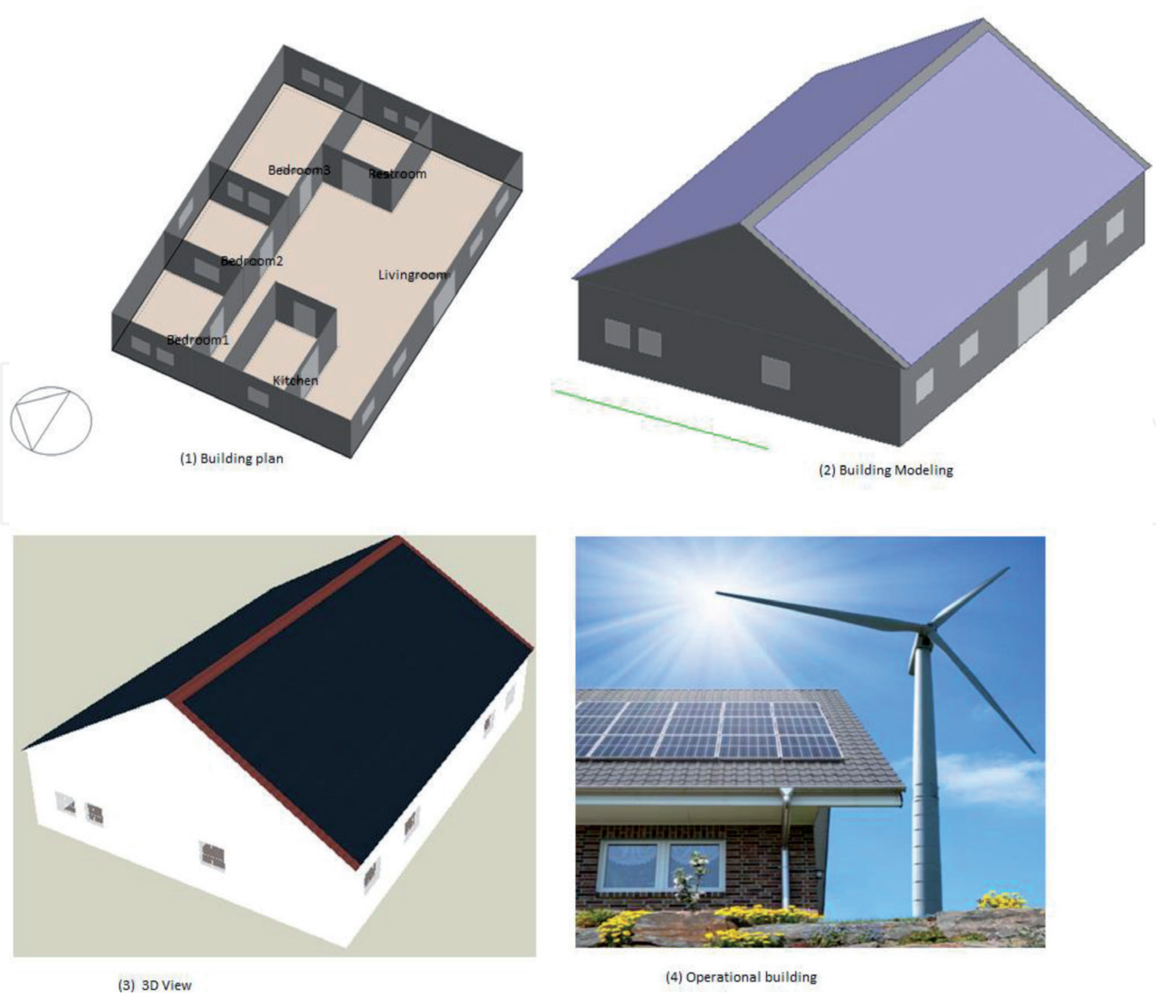

Figure 1.
Studied building.

	Layer	Component	Thickness (m)	Thermal conductivity (W/m-K)	Density (kg/m3)	Specific heat capacity (J/kg K)	Embodied Carbon (kgCO2)	Cost ($/m2)	U-value (W/m2-K)
Building element	Layer1	Ceiling	0.02	0.056	380.0	1000.0	1.2	6.6	0.20
	Layer2	Hemp	0.09	0.04	25.0	1000.0	0.0	27.5	
	Layer3	Limestone silicon	0.10	0.136	270.0	880.0	0.0	16.5	
	Layer4	wood	0.05	0.056	380.0	1000.0	1.2	6.6	
	Layer1	Roof tiles	0.030	0.08	530.0	1800.0	0.19	30	

Table 1.
Thermal properties of some materials.

It was seen in this table that the materials as Hemp and Limestone Silicon do not produce CO_2.

2.5. Description of software

The modeling of the building and all simulations were led thanks to Design Builder. The Design Builder software is one of the most famous existing software in modeling and optimization of the building. It also helps reduce the carbon content. The most recent version 6.3 is used in this study. The Design Builder tool also minimizes costs and hours of discomfort.

2.6. Calibration of model

To calibrate this model, we compared the different simulated and measured values of a building typically encountered in Madagascar [23], by calculating the linear correlation coefficient (R^2) to analyze the margin of error. The literature shows that the error is negligible if the correlation coefficient obtained is around of ±1.

2.7. Wind turbine and photovoltaic systems

Wind turbine with alternating current worked 24/7. This wind turbine was a rotor type horizontal with a diameter estimated to 41 m, a height of 31 m, number of blades 3, with a maximum power coefficient of 0.4.

The photovoltaic panels occupied almost three-quarters of the roof area, making an angle of 45°C, with maximum orientation from south to north. The different panels consisted of polycrystalline cells with a mixed association.

2.8. Scenarios

In the reference scenario, we decided to study this residential building without any physical constraint. In its state as naturally as possible, and there is no source of electrical production. In this case, we use the A2 scenario, designed by the IPCC, which is the most realistic in Madagascar [24] for assessing indoor air quality and temperature in the future.

In a scenario 1, we install photovoltaic panels on two-thirds of the roof, while increasing the thickness of insulation by 2 cm (from 9 to 11 cm). The main facade is oriented from south to north, with solar protection on each window. The inclination of the solar panels is set at 45°C. The network was not connected to a power storage system (e.g., the battery).

In Scenario 2, we apply all the details presented in Scenario 1, except that the entire power grid is connected to a storage system. In addition to this, we apply the wind turbine to the building, whose characteristics are detailed in the previous paragraph. We made simulation this building according to each scenario and we got found new results.

3. Results and discussions

3.1. Indoor air

Air temperature and relative humidity are both environmental parameters which their variation has a significant impact on the occupant's comfort. **Figure 2** shows the variation of indoor air temperature in the new building. We can see that currently, in the building, indoor air temperature varies from 19.83 to 22.57°C; in 2030, the indoor air temperature is expected to be between 19.96 and 22.82°C; in 2050, in the same condition, indoor air temperature will be between 20.41 and 23.10°C. Globally, indoor air will increase to 0.30°C in 2030, and 0.52°C in 2050; compare to current air temperature. In addition, it is seen in **Figure 3** that presently, relative humidity varies between 59.57 and 75.41%. In the future, it will vary between 58.77 and 76.03% in 2030, and, from 59.82 and 77.25% in 2050. The analysis showed that relative humidity will increase to 1.51% in 2030, and 2.73% in 2050; compare to 2017. The ASHRAE 55 ranges of comfort suggested indoor air temperature of 23–26°C; and relative humidity of 30–60% [25]. These different values are outside the ASHRAE ranges. Antananarivo is dominated by several mountains which affect the climate of this city. This interval is low compare to that found by Nematchoua et al. [26], in traditional buildings in Madagascar, which were between 24.6 and 28.4°C.

3.2. Electricity

Figure 4 analyzed the potential of total energy demand and produce by this building. Monthly electricity consumption varies between 123.8 and 137.1 kWh.

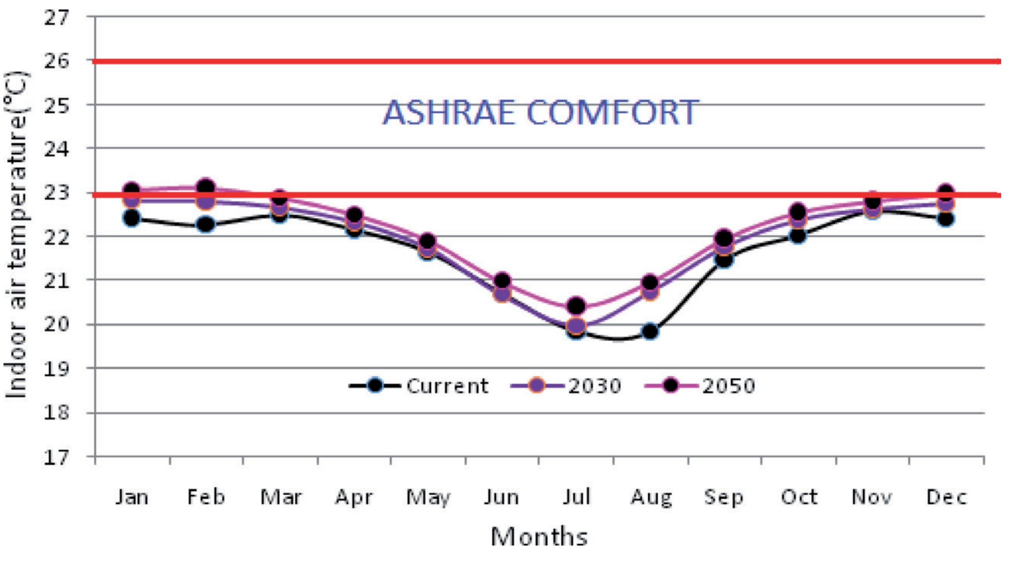

Figure 2.
Monthly indoor air temperature in the new building distributed on three periods (current, 2030 and 2050).

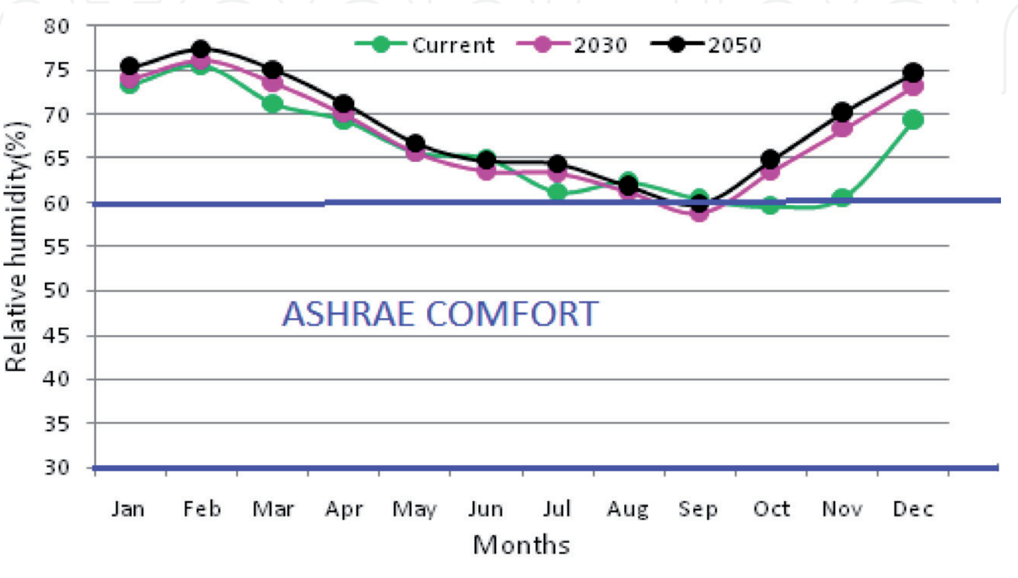

Figure 3.
Monthly relative humidity in the new building during three periods (present, 2030 and 2050).

We can see under basic of this scenario electricity generated by this building corresponds net to electricity consumption; with zero cooling energy building during the different seasons. In the specific case of this scenario, which simply recommends an application of solar panels covering a total area of 182 m^2, Net Zero Energy Building objectives are achieved for this building(energy produce = energy consumption). Electricity generated was estimated to be around of 0.49 kWh/m^2. In the second scenario which some results are showed on **Figure 5**, it was applied simultaneously wind turbine and photovoltaic panel on the building.

It is noticed that in this case, the electricity generated by the building is equal to 13 times the average electricity consumed by the building. At this precise moment of operation of the building, the new building can be considered as a building with positive energy, that is to say it produces more than it consumes (energy consumption < energy produced). The annual total electricity that can be sold to individual consumers is estimated to 18946.86 kWh per year; it allows to save 4550$. The frequency of comfort and total energy consumption is showed on **Figure 6**.

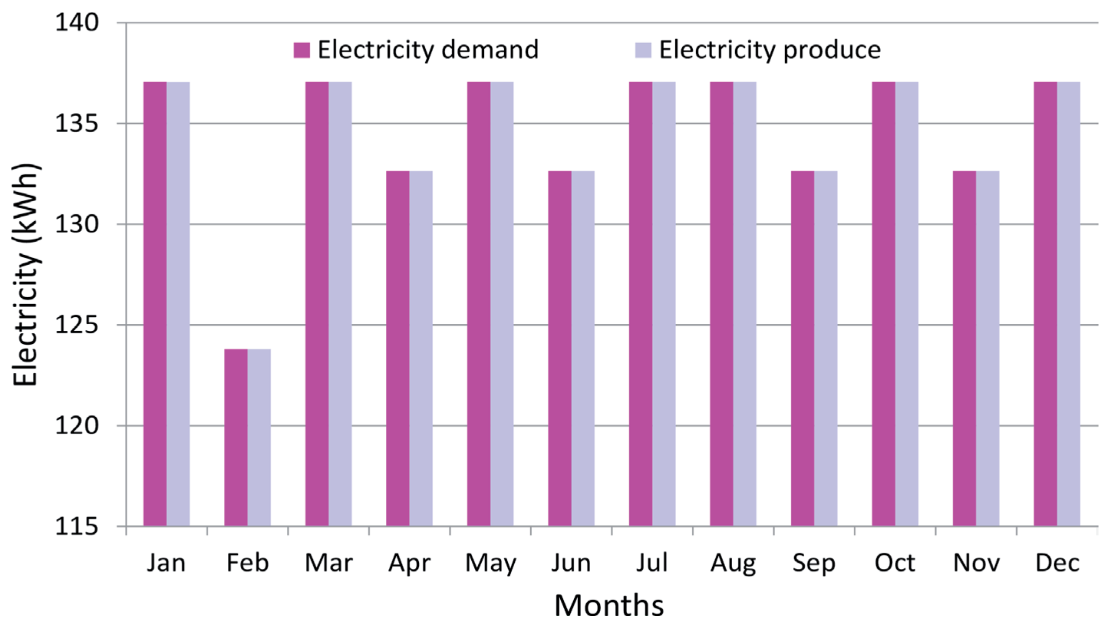

Figure 4.
Scenario of Net Zero Energy of building.

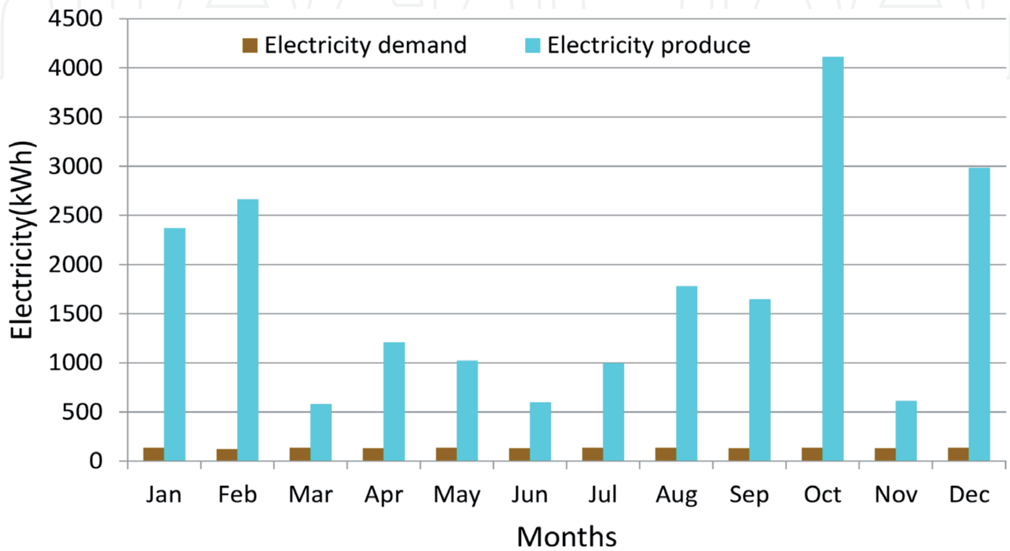

Figure 5.
Application of wind turbine and photovoltaic panel on the building.

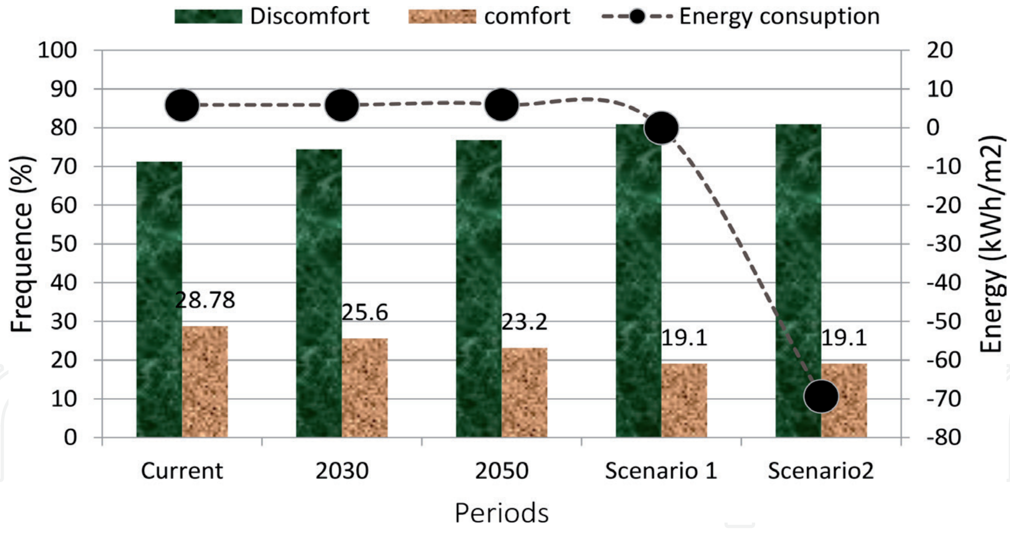

Figure 6.
Comfort potential and building energy consumption.

Discomfort potential was estimated to 71.2% (current); 74.4% (2030), and 76.8% (2050). These results show that in 2050, indoor air of the building will be 5.6% more uncomfortable than currently.

It is very important to notice that in specific case of scenario1, energy demand is found at zero. This does not mean that the building does not consume energy, it is just to explain that at this point the energy production is equal to the consumption of the building. The different energy values assigned a sign (−), explain that at this moment there is overproduction. These results are very interesting, and can be used by the building specialists. The electrification rate in Madagascar is one of the lowest in Africa: only 15% of the inhabitants are connected to an electricity grid. This figure rises to 58% in urban areas and drops to 4.7% in rural areas, which nevertheless accounts for 70% of the country's population. It would be recommended to the Malagasy government to create favorable conditions to encourage the population to design new buildings more ecological and comfortable. One of the limitations of this research is that the type of building proposed costs up to 40% more expensive than the more conventional buildings found in the big island. But today, it is revealed in the literature that only 2% of the Malagasy population would be able to build this kind of building. We are well aware of this, but we think that the ideal for a more sustainable solution is to build new buildings in the big island by respecting the criteria mentioned in this study.

4. Conclusion

In this research, we analyzed and suggested a model allowing to reach net zero energy building and in certain measure created a building with positive energy in Antananarivo. Operational carbon was estimated to be around 3.7 $kgCO_2/m^2$. The operative temperature was between 19 and 23°C, in this period, the comfort potential was from 30%. The results found in this study showed it is possible to reach objective "Net Zero energy building" in Madagascar island by respecting the way detailed in this research. The degree of vulnerability in climate change is very high in Madagascar. The Malagasy government should propose more reliable control and adaptation strategies, for example the case of the extension of ecological buildings is very interesting. In a future study, we will study the case of implementation of the concept Net zero energy neighborhood.

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