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Green Energy supply and efficiency measures for the renovation of the Grande Hotel building in Beira

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Abstract

On March 14 2019, the cyclone Idai strucks the central region of Mozambique with tremendous force, causing widespread human loss and economic damages. The city of Beira received the full force of the cyclone and large areas within the municipal boundaries were flooded; as a consequence, most buildings in Beira were damaged and many were destroyed. In the weeks after the cyclone, an outbreak of cholera added to the disaster, and several dozens of people lost their lives.

In the current situation, it is necessary to reconstruct the city center of Beira from its foundation and it has to be done in suitable and sustainable way. This thesis aims to contribute to the energy efficient and sustainable reconstruction of part of the city, in particular of the historical building of the Grande Hotel of Beira. Nowadays the Grande Hotel is in part destroyed and in part occupied by the refugees of the cyclone in really harsh hygiene and health condition without water and electricity.

The idea is to built in this structure apartments, markets and community spaces where people can live in a better condition to improve life quality. This thesis, thanks to the collaboration of Lab Beira's architects layout design (this is a joint initiative from Politecnico di Torino and Comunità di Sant'Egidio) , is focused on the apartments which will be part of the block B of the structure. The aim is to simulate their energetic consumption and make them as efficient as possible through the energy management by using the software EnergyPlus.

EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for cooling, ventilation, lighting and plug and process loads. As far as energy supply is considered, the thesis aims to investigate the renewable power production from PV system which is sized through the software HOMER Pro and analysed by its affordability through economical parameters and costs and sensitivity analysis. Indeed, the sizing is based on the minimization of electricity supply cost also considering environmental effects such as greenhouse gas emissions.

In conclusion, this thesis is a part of a bigger project which wants to give back to a large number of persons who have lost almost everything a place where they can have ensured better lifestyle condition, electricity and space to reconstruct social, educational and economical improvement in the most efficient and sustainable way as possible.

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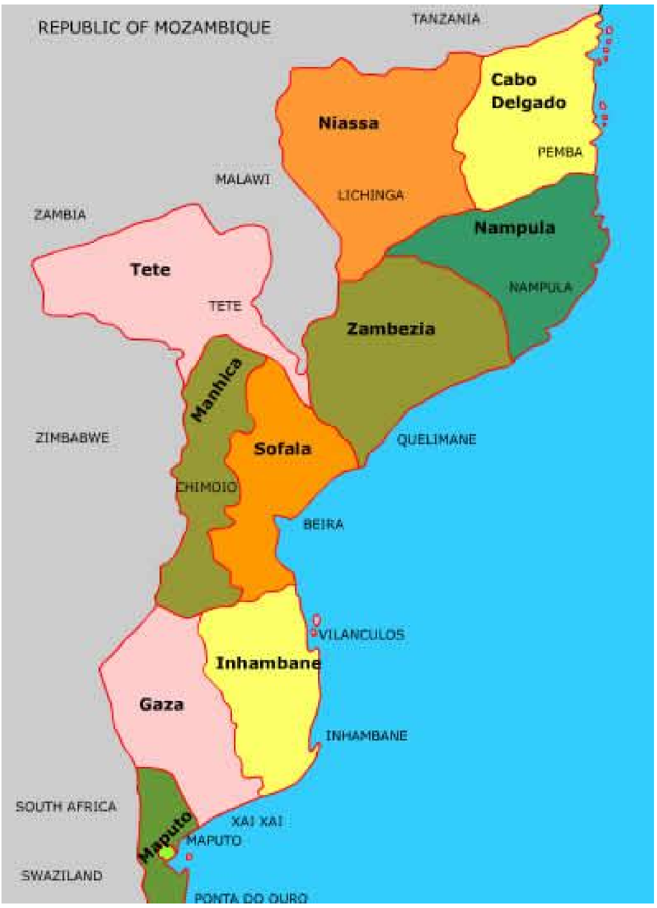
1.BACKGROUND

1.1 DAMAGES FROM THE CYCLONE

The climate change have a really big impact in Mozambique and its correlated events are more frequent and tangible each year. They must be taken into account now and in the next years.The country is often devastated by cyclones, floods or droughts, and the 2019 cyclones and floods were the most devastating in recent history in terms of human and physical impact and geographic extent. A total of 64 districts and 19 counties were directly affected, but nearly the entire country suffered from its negative socioeconomic effects. The disaster has disrupted the provision of basic services such as water and electricity, damaged roads and bridges essential for commercial activity, and destroyed homes, stores, and other buildings. [1]

Here's a map of Mozambique and its regions:



- Figure 1 – Mozambique's regions maps: *http://www.ritualkillinginafrica.org/category/angonia-district/*

Beira is the capital of the province of Mozambique called Sofala, as well as the second most important city of Mozambique. Thursday, March 14, 2019 occurred Cyclone Idai which caused rains and winds up to 177 km / h affected and partially damaged and destroyed several regions including Mozambique, Malawi and Zimbabwe. As if that was not enough on April 25, after only six weeks, Cyclone Kenneth strucks northern Mozambique 600 miles north of the Idai impact zone. This was the most violent cyclone had ever occured in Africa with a wind speed of 220 km / h. [2]

In the span of just six weeks, two of the most violent and destructive cyclones ever recorded in the southern hemisphere. They struck and devast some of the world's poorest countries, leaving 3.3 million people in desperate need of humanitarian assistance.

After one year in Mozambique 1.5 million people have suffered damage in their quatidianity, not to mention that 600 people have lost their lives and another 1,600 have been injured. In terms of city structure and buildings 240,000 homes have been damaged or destroyed and 400,000 people have been displaced, no longer having a home. Also on the fishing and fishery sector the cyclone has caused serious damages, in fact 2044 fishing boats have been destroyed. together with the agricultural sector 4309 hectares of remote land are counted, aggravating the current food insecurity and making 1.359.159 people remain without food support. Infrastructure damage was also substantial, with 3490 km of national roads damaged (29% of the total) and schooling disrupted as 382,717 children's schools were destroyed. Cyclone Kenneth hit northern Mozambique causing damage to 74,000 people, 37,930 homes and leaving 18,029 people without a home. [3]

The main effects of cyclone IDAI were reported in the following table specifically damaged or destroyed houses, schools, health facilities, cultural centers, livestock, irrigation systems, businesses, water and sanitation facilities, power and transportation infrastructure. [4]

AGRICULTURE	FISHERIES	LIVELIHOODS
433,056 affected households need seed assistance	116,476 M2 of fish tanks affected	Over USD$ 39 milion in income was lost due to unemployment
9,710 animal deaths	1,728,800 avelinos lost	
4.9 million animals need vaccines	2,044 fishing vessels destroyed	
4,309 ha of irrigated land needs rehabilitation		

WATER & SANITATION	ENERGY	TRANSPORT
71,450 damaged latrines affected in rural areas	Destruction or damage to:	Damaged 3,490 km of national roads, 29% of total
118,600 damaged latrines in urban areas	2 generation plants 90 MW	20 bridges affected
	1345 Km of transmission lines	39% of the national rodoviária network damaged
	10216 Km of distribution lines and 30 substations	Significant damage to railroads, with effects on internal trade
	4000 transformers	

HOUSING	EDUCATION	HEALTH	CULTURE
240,000 houses were partially or totally destroyed	1372 schools affected	89 health facilities partially destroyed	10 cultural centers severely damaged
	4,219 classrooms Affected	3 health facilities completely destroyed	15 historic buildings severely damaged
		2 health training facilities were partially destroyed	

Table 1 – Damages caused by cyclone Idai divided by context [4]

The next table presents a summary of damage and losses estimated by the PDNA for the four provinces affected by IDAI: Sofala, Manica, Tete, and Zambezia. Damage caused by IDAI is estimated to total over $1.4 billion, reflecting the cost of replacing infrastructure and physical assets. Most of the damages fell heavily on the transportation sector followed closely by the real estate sector and the third sector to suffer severe damages is Industry & Commerce , followed by the energy sector where damages are estimated at $133.5 million. Damages were relatively lower but still significant in the Environmental sector at $80 million and for the Agricultural sector at $48 million. [5]

Sectors	Damage			Loss		
	Public	Private	Total	Public	Private	Total
TOTAL	**748,9**	**660,9**	**1409,8**	**180,0**	**1205,8**	**1385,8**
Produtive	14,2	190,4	204,6	0,0	986,6	986,6
Agriculture	14,2	33,6	47,8	0,0	512,6	512,6
Fishery	0,0	16,7	16,7	0,0	4,0	4,0
Ind. And Comm.	0,0	140,1	140,1	0,0	470,1	470,1
Social	97,8	411,9	509,7	121,9	61,8	183,7
Housing	0,0	410,5	410,5	7,6	61,7	69,3
Education	14,7	0,3	15,0	5,5	0,1	5,5
Health	80,4	1,1	81,5	108,9	0,0	108,9
Food Security	0,0	0,0	0,0	0,0	0,0	0,0
Culture and Sports	2,8	0,0	2,8	0,0	0,0	0,0
Infraestruture	534,2	56,0	590,2	56,0	150,2	206,3
Transport	391,7	50,0	441,8	5,3	147,5	152,8
Energy	133,5	0,0	133,5	47,9	0,0	47,9
Telecomunications	0,0	0,0	0,0	0,0	0,0	0,0
Agua/San	8,9	6,0	14,9	2,9	2,7	5,6
Cross-cutting	102,7	2,6	105,3	2,1	7,2	9,3
Gender	3,0	0,0	3,0	0,0	1,2	1,2
Environment	77,7	2,1	79,8	2,1	1,3	3,4
Governance	11,9	0,0	11,9	0,0	4,7	4,7
DRR	10,0	0,5	10,5	0,0	0,0	0,0
Livelihoods	0,1	0,0	0,1	0,0	0,0	0,0
Social Protection	0,0	0,0	0,0	0,0	0,0	0,0

Table 2 – Damages caused by cyclone Idai in USD [4]

1.2 MOZAMBIQUE ENERGY SITUATION

Mozambique has the largest energy generation potential of all southern African countries; it could generate 187 gigawatts of energy from its coal, hydroelectric, gas and wind resources, excluding solar. The most of the energy currently generated comes from hydroelectric projects. However, coal, gas, and renewable energy sources are changing the energy sector and are expected to play a significant role in the future, with natural gas-fired power plants expected to provide 44% of total power generation over the next decade. [6]

Currently, about 28% of Mozambique's population is electrified. In 2016, about 25% of the population was electrified through the grid and 2% through off-grid systems (World Bank, 2017; Robinson et al., 2016). Although the grid connects all 128 district offices in Mozambique, access is largely limited to urban areas. Access in the rural population is less than 5%, and the priority has been to connect schools, health centers, and administrative posts first. Mozambique's population is about 29 million in 2017, 70% of whom live in rural areas, mainly along its 2700 km coastline. By 2030, the country will have more than 40 million people or 8 million households. Mozambique's draft National Electrification Strategy sets an official target of 100% electrification by 2030, in line with the goal of universal energy access under the UN's SE4ALL goal.[7]

Solar capacity in Mozambique has grown from 1 MW in 2011 to 15 MW in 2017 but its potential it's really higher. There are currently 1.3 MW of PV-based mini-grids installed in Niassa, funded by the government of South Korea, about 200 kW (50x 4 kW each) of PV-based solar mini-grids funded through the Portuguese Carbon Fund, and a handful of multi and bi-lateral programmers (e.g. World Bank, Belgian Development Agency (BTC), UNIDO, Energizing Development) have focused on installing Solar Home Systems (SHS) on rural institutions, micro-enterprises, and households. Most of these projects are off-grid, stand-alone systems and decentralized mini-grids scaled to meet the needs of highly dispersed rural communities.[8]

Here is shown the map of the solar potential through the Mozambique:[8]

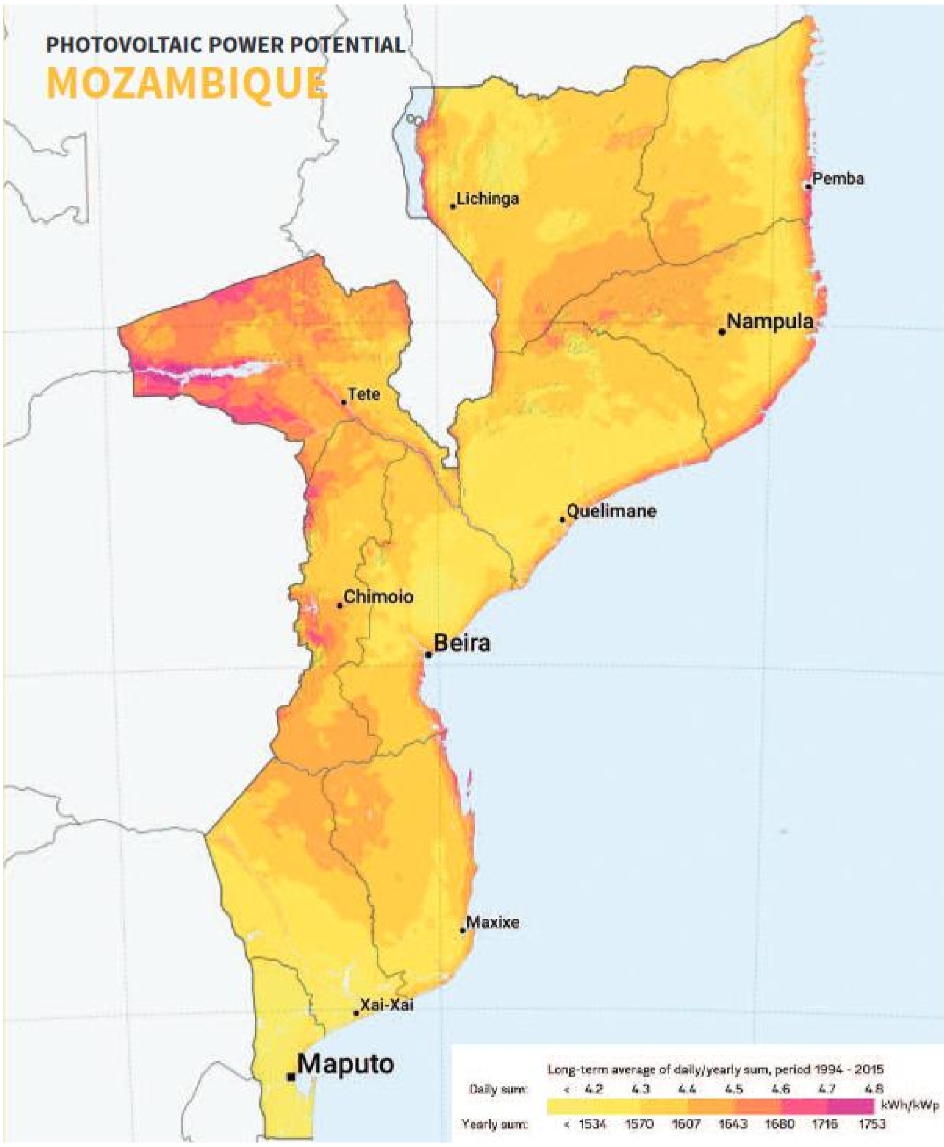


Figure 2 – Photovoltaic power potential Mozambique Map [8]

The importance of making investment in clean and renewable energy in this emeging situation is evident thanks also to the visible and tangible effects that the global warming and the climate changes which have caused and will cause severe damages in this country. The solar source is one of the most affordable for now, as the maps show, the potential solar energy is really considerable.

Here is a list of advantages and opportunities of off-grid solar in Mozambique:

Advantages	Opportunities
• High quality solar resources endowment across the country • Falling cost of solar power • Strong government interest in off-grid solar power • Role of off-grid solar power is recognized in major national strategies/ plans • Rural energy agency FUNAE has considerable experience with off-grid solar power installations • Success stories in Africa to learn from	• Rapidly falling costs of solar and battery technologies • Increasing retail prices of conventional fuels • Successful regional experiences to emulate from • High penetration of mobile phones and increasing availability of mobile money • Increasing interest from development donors and private sector • Potential many-fold increase in state revenues from expanding extractive industries that could support the sector's development

Table 3 – Advantages and opportunities of off-grid solar in Mozambique [9]

Mozambique can meet the need for off-grid electrification using its enormous renewable resources, as evidenced by the thousands of projects identified in areas with off-grid populations (MIREME, 2014). Both solar and hydropower have significant and considerable technical potential estimated at 23 TW and 19 GW, respectively. Currently, hydropower is the largest source of total electricity generation (at 86% in 2016). Mozambique is the largest producer of hydropower in Africa with a large percentage of production coming from 4 main hydropower plants, the largest of which is Cahora Bassa, which contributes to over 90% of total hydropower production in the country.[9]

With the risks of environmental impact and climate change effects surrounding hydropower generation, solar energy is an increasingly attractive electrification option for Mozambique. In fact, solar irradiation in Mozambique is comparable with the best in the world, averaging about 2000 kWh/m2/year.[9]

Driven by the rapid increase in investment and innovation globally, the cost of PV has dropped rapidly and considerably (IRENA, 2017). simultaneously, the cost of lithium-ion batteries is similarly undergoing dramatic cost reductions (BNEF, 2018).[9]

Given that Mozambique has vast landscapes and sparse population electrification with off-grid solar systems is a more cost-effective option than grid electrification. Of the 23 TW technical solar potential, it is estimated that more than 2.7 GW could be tapped relatively easily with such systems in peri-urban and rural areas. The cost of connecting per household for an off-grid solar system is estimated to be less than $200 in Mozambique - only 6% compared to the ~$3,500 required to connect to the grid.[9]

Even though Mozambique has this enormous production potential, only 34 percent of the population has access to electricity. this is because the energy distribution network is underdeveloped and the bureaucracy involved in developing new energy projects is severely slowed down. industries and businesses are the ones driving the demand for energy, as most of the population cannot afford the current rates, despite being heavily incentivized.

infrastructure resources in electricity production, transmission and distribution in Mozambique are, however, highly developed.

A significant portion of the electricity infrastructure in areas affected by the violent weathering caused by climate change has been damaged. In particular, several damages occurred to hydropower plants, transmission lines, primary/secondary substations, distribution lines, transformers and stand-alone solar PV systems. This damage has interrupted and disrupted the supply of electricity not only to households but also to institutions in the affected areas. estimates say that 570,000 customers were affected and that due to the need for resources to make the damaged grid infrastructure operational again the supply had to suspend service.133.5 million dollars is the estimated cost of physical damage to the electrical infrastructure. Beira, followed by Chimoio, Quelimane and Tete, was the city hit hardest by Idai, suffered the most damage.

The lack of electrical services involved and disrupted critical social lifelines such as hospitals and water treatment, as well as other public services in the provincial capitals and surrounding areas. Not to mention that in an emergency, the lack of these services severely affects effective response and recovery. The following universal damages have been assessed and considered:

- Employment and livelihoods: a negative impact was estimated on employment and livelihoods in the provincial capitals given the inability and inability of industries and businesses to manage their assets (such as production machinery, water pumps, hotels).

- Environment: Due to a loss in the supply and distribution of electricity and gas, health risks associated with the increased use of traditional fuels (e.g. firewood, coal, kerosene) will increase and consequently there will be accelerated deforestation for wood fuel.

- Governance: Administrative structures and functions have been compromised by the lack of electrical services and the availability of communication tools has also been negatively affected. [4]

1.3 BEIRA GRANDE HOTEL

1.3.1 Introduction

The Grande Hotel Beira was once a luxurious hotel built and inaugurated as such in 1954 in Beira, Mozambique. called the "Pride of Africa" until 1963, and then referred to as the "white elephant". In the English language, this is a way of saying to indicate a useless or troublesome asset that is expensive to maintain and difficult to dispose of. The hotel first became, during the civil war, a military base and later was considered a refugee camp such remains to this day, in fact, it is in use as a shantytown housing more than 1077 homeless people. these people are currently forced to live in poverty and poor hygiene. The building is often defaced of its internal construction materials and additives to generate income for the primary daily survival. For example, both the water, sewage, and electrical systems have been totally removed in order to recover food and water, and wood from the parquet floor is burned as fuel for cooking. [10]

The following images shown the Grande Hotel at its begin and after the cyclone:

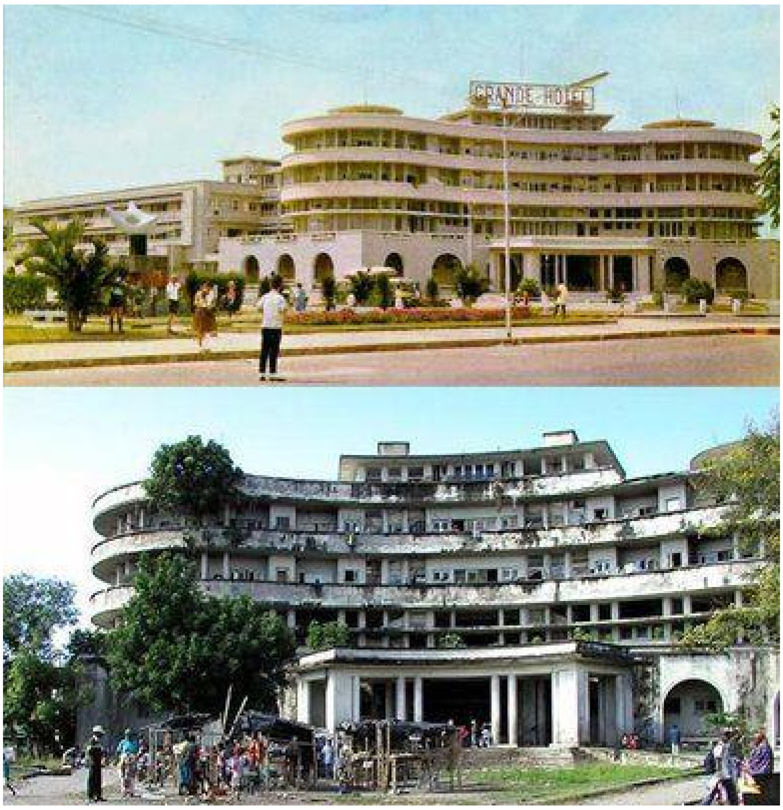


Figure 3 – Facade of the Grande Hotel before and after its closing : http://perolasfinas.blogspot.com/2017/05/grande-hotel-beira.html

1.3.2 History

The architect Francisco de Castro built the prestigious Grande Hotel between 1953 and 1955 while the architect José Portosi took care of the concept design. The purpose of this project was in fact to celebrate the success of the Portuguese fascist regime of the Estado Novo of the time in Beira.

The budget was exceeded three times by the actual cost of the materials so that they would be as refined luxurious and modern as possible.

Arthur Brandão, a person of high influence within the regime, was the client who requested the project and it was he who gave importance to these aspects.

The hotel had a floor plan of 21,000 m² and had only 116 rooms on this surface, huge and luxurious and far too lofty and expensive for the tourists who do not often come to the port and industrial area of Beira but prefer to visit the Krügerpark, the Victoria Falls and the Bazaruto archipelago. The Grande Hotel would never be profitable even by the most optimistic and prosperous estimates, in fact it was in full operation only from 1954 to 1963.

It was so that after only eight years of activity in 1963 the hotel was closed by the companhia de Mocambique. Clearly the expected amount of wealthy guests is never presented and the hotel has never made any profit, even given the large workforce employed compared to the amount of guests actually received and given the high maintenance costs to be able to maintain the same conditions of luxury.

Beginning in 1963, the Olympic-size swimming pool remained open only for the residents of the neighborhood while the hotel's indoor facility was used for important parties or as a conference center.

Given the impossibility of obtaining a casino license for the hotel, it was not even possible to fall back on that, which was considered by many the only way to earn money. This was because the regime argued that it was not morally acceptable to have gabling places in its African colonies. The pool was the only Olympic facility in the colony at the time and remained the main training facility for the Mozambican delegation at the Olympics.

The Grande Hotel's structure just built is shown in the following figure:

Figure 4 – Initial construction of the Grande Hotel : http://malomil.blogspot.com/2013/02/grande-hotel-da-beira.html

For large events and conferences the hotel was used only twice: in the first case it hosted members of the United States Congress who were taking a cruise along the East African coast and the second occasion was in 1971 the wedding of Petusha Jardim. She was the daughter of Jorge Jardim, Mozambique's Minister of State at the time. [10]

A photo of the Olympic-size swimming pool of the Grande Hotel at its beginning:

Figure 5 – Olympic pool of the Grande Hotel : http://malomil.blogspot.com/2013/02/grande-hotel-da-beira.html

Mozambique was declared an independent state on June 25, 1975. The only independence movement represented in Mozambique, Frelimo, took power and on that day, under the new Frelimo regime, the first marriage took place in the Grande Hotel in Beira.[10]

Symbolically, this marriage represented an optimistic, bright and joyful future, and the pool bar became the office of the Revolutionary Committee, the organization responsible for the creation of the communist state in Beira and Sofala province. [10]

The basement of the hotel was used as a prison for opponents against the new ruler and in fact in 1977 civil war broke out throughout the province of Sofala.

The civil war was an escalation of the global cold war pitting communism and capitalism against each other, Frelimo against Renamo and the hotel thus became a military base of the Frelino.

The third floor was used as housing for communist soldiers.

From 1981 Beira was annexed to a neutral zone under the ZImbawe defense forces that put under control and security surveillance both the port and the Corridor that had become a very important infrastructural line.[10]

While in the interior Frelimo and Renamo fought on a guerrilla basis, security also reigned in that area to control that both the import and export of the country did not do business with apartheid-ruled South Africa. For this reason, even from the interior were attracted refugees and the Grand Hotel became a refugee camp viato the supply of aid and security of the area.

Currently, the conditions of the Grand Hotel have definitely deteriorated. Also since 1992, the civil war has ended and a stable peace reigns in Mozambique, which has allowed for the complete rehabilitation of the seaport and the continued expansion of the economy thanks to the development of a new economy.

Since 1992, Mozambique has experienced a stable peace. The seaport of Beira is completely rehabilitated and is now experiencing a booming economy through the transit of minerals to Asia. [10]

Conditions at the Grande Hotel today are overcrowded with a population hovering around 4,000 at risk as the structure has been severely damaged and the risk of collapse is high. Serious social, health and environmental problems are faced daily by these people, most of whom work in the informal economic sector or have an insecure income to afford food on a daily basis. Poverty has made the living standards of the hotel lower and lower, such as the fact that water and sewage system has been practically completely removed by the inhabitants to get money for food and water. there is no organization in maintaining the communal space and garbage is laid everywhere in the structure there are also rainwater leaks and stairs and elevators are often inaccessible. Rainwater is collected in the swimming pool and by standing still it becomes stagnant and toxic but is often still used by the hotel residents which exacerbates the already unhealthy and hygienic conditions present.[10]

The conditions of the swimming pool nowadays are shown in the following figure:

Figure 6 – Olympic pool of the Grande Hotel nowadays : https://www.gettyimages.it/detail/fotografie-di-cronaca/young-residents-of-the-grand-hotel-beira-play-fotografie-di-cronaca/106631682

1.3.3 Architecture

The exterior of the Grande Hotel definitely has a style inspired by the Art Deco movement that was the main architectural style in Portugal between the 1930s and 1940s. Its sinuous geometric shapes and elegant repetition of lines were representative for the modern time and rapid development, this building wanted to represent the Estado Novo era of Portugal. This need arose in contrast to the previous dominant neo-baroque era.[11]

Representing a bright future, the use of cutting-edge materials and technology was essential, and a simple, linear exterior, devoid of ornamentation and decoration is a feature symbolizing this movement.

The interior, on the other hand, was very richly decorated in a decidedly eclectic style, and exclusive materials of a luxurious refinement were used on purpose so that the result was the best and most modern of its time.[11]

All this was in stark contrast to the poverty of Beira's time, even works previously designed by the same architect, De Castro, such as the famous CFM train station, a famous example of the Brazilian expressionist movement in Mozambique.

The grand hotel was therefore greatly influenced by the Cilentians who made it a mixture of three different movements, art deco, modern movement and eclecticism.[11]

The next figure shows the entrance staircase of the Grande Hotel just built:

Figure 7 – entrance staircase of the Grande Hotel : https://sometimes-interesting.com/2013/05/21/the-grande-hotel-of-beira-mozambique/

The constituent structure of the grand hotel is based on the five principles of les Corbusier's modern architecture. The materials of the foundations are all local materials such as the reinforced concrete of the columns and floors and the facade made partly of concrete and mostly non-load bearing.

To date, only the interior space division walls and the main supporting constructions remain, the rest of the additive materials have been removed for sale and for use as fuel.[11]

There are semi-temporary structures made with basic and very simple materials and techniques, similar to the informal vernacular construction techniques of the area, which see for example the use of wood bricks and cement and straw mats and sink roof slabs.

Internally the water system has been totally removed as well as the ventilation system, sewer and electricity are absent. A single water pump supplies water on a private charge, or alternatively the other water source is through the collection of rainwater, as is the case in the Olympic swimming pool, which however is highly polluted. To conclude with the absence of public toilets currently represented by the beach and the small park next to the hotel.[10]

In the next figure the conditions of the entrance staircase of the Grande Hotel nowadays are shown:

Figure 8 – Entrance staircase of the Grande Hotel nowadays : https://www.bbc.com/news/world-africa-36092920

1.4 GRANDE HOTEL LAB BEIRA PROJECT

This part of the project have been developed by architecture's students of Politecnico di Torino (Ang Li, Jingxuan Tang and Yao Zhang). [12] The masterplan of the whole structure reconstruction is thought to built both common spaces and private apartments. As shown in the next figure:

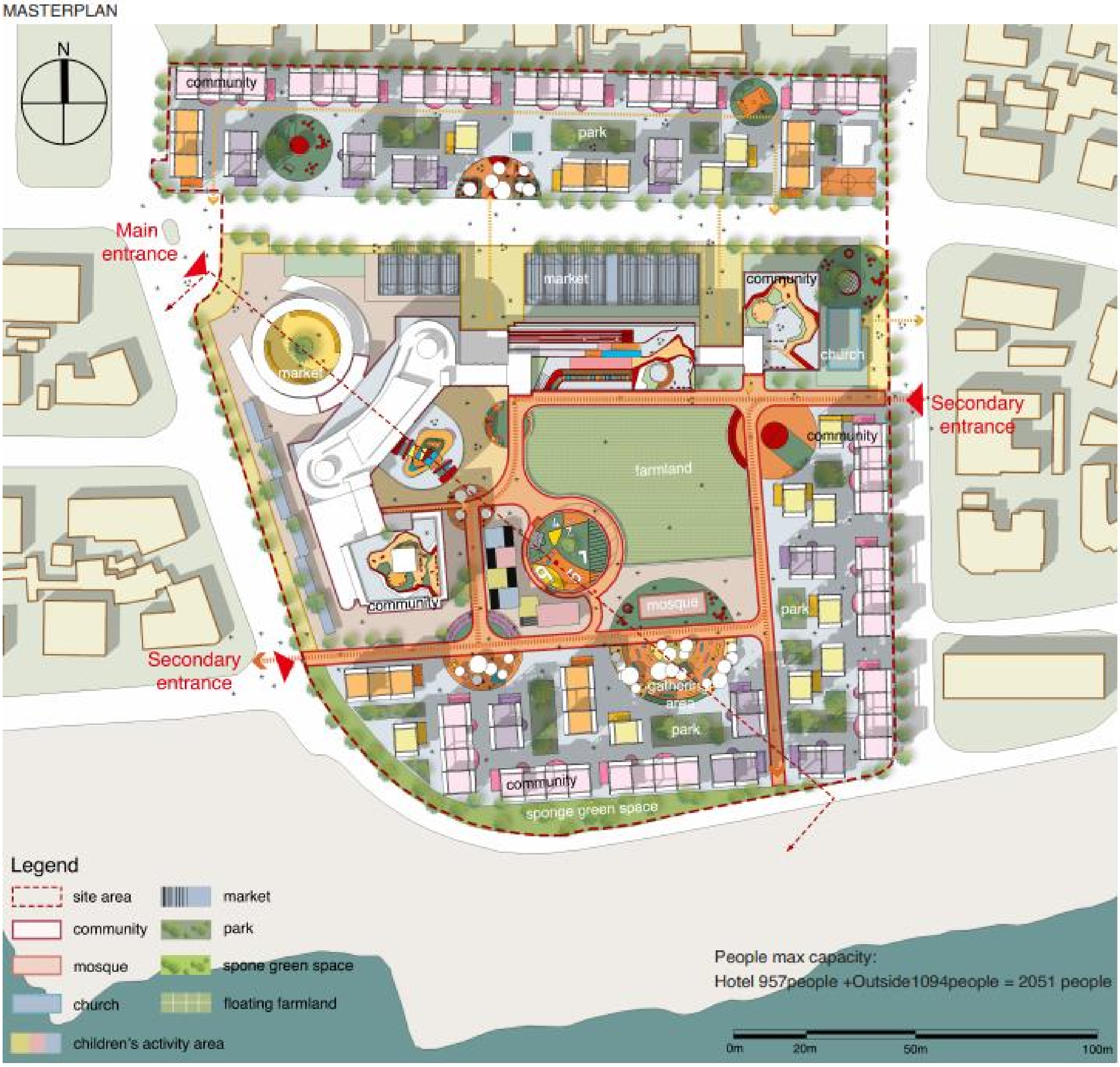


Figure 9 – Masterplan of the renovation of Grande Hotel building [12]

More specifically the details of the road network, the building function, the public and the green areas and the site sunshine duration are shown in the figures below:

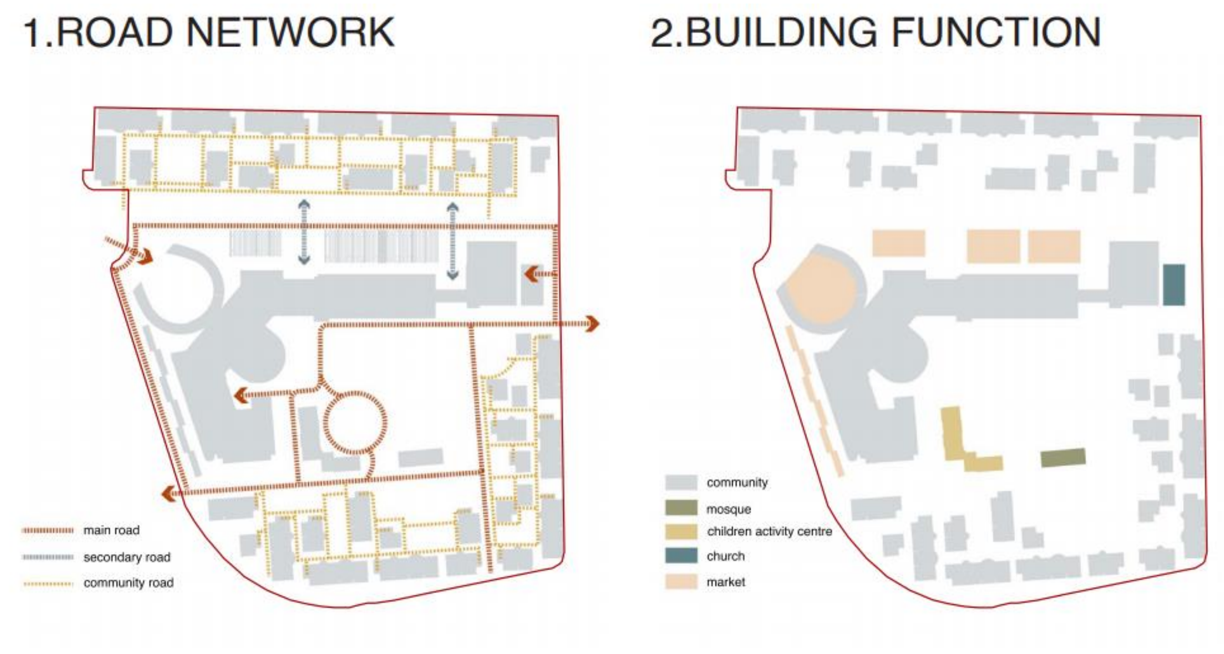


Figure 10 – Road network and building function of the project [12]

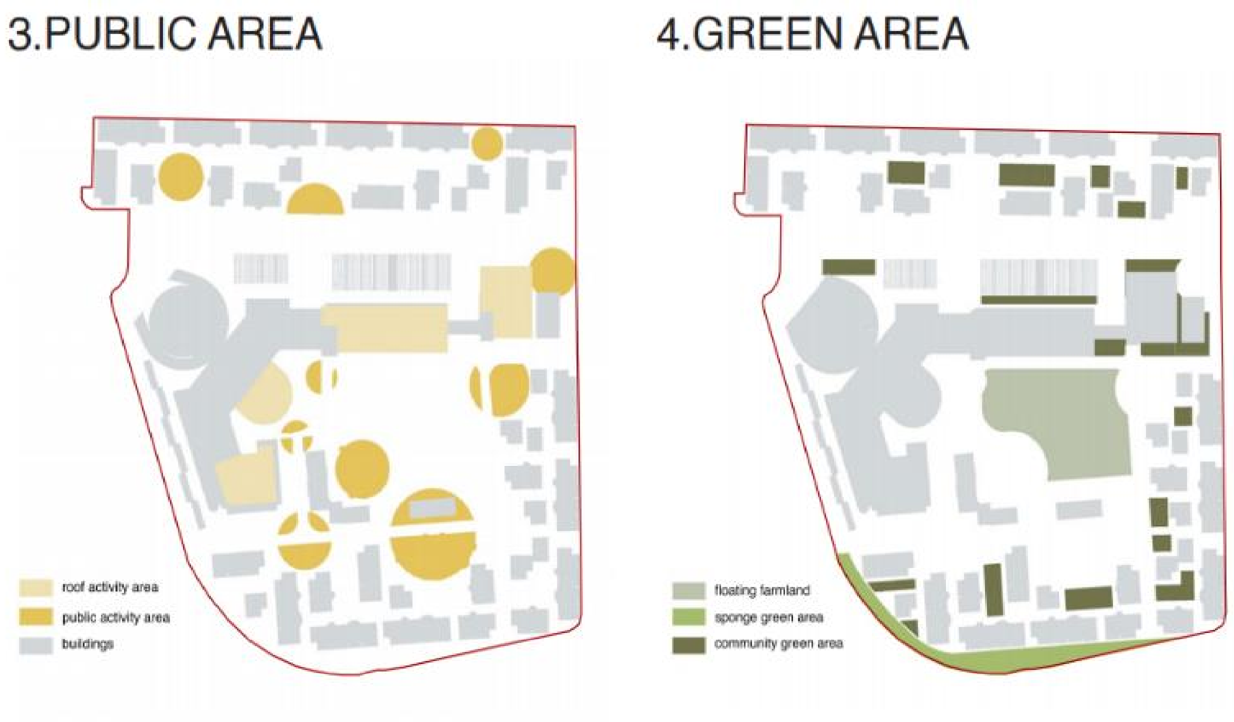


Figure 11 –Public area and green area and building function of the project [12]

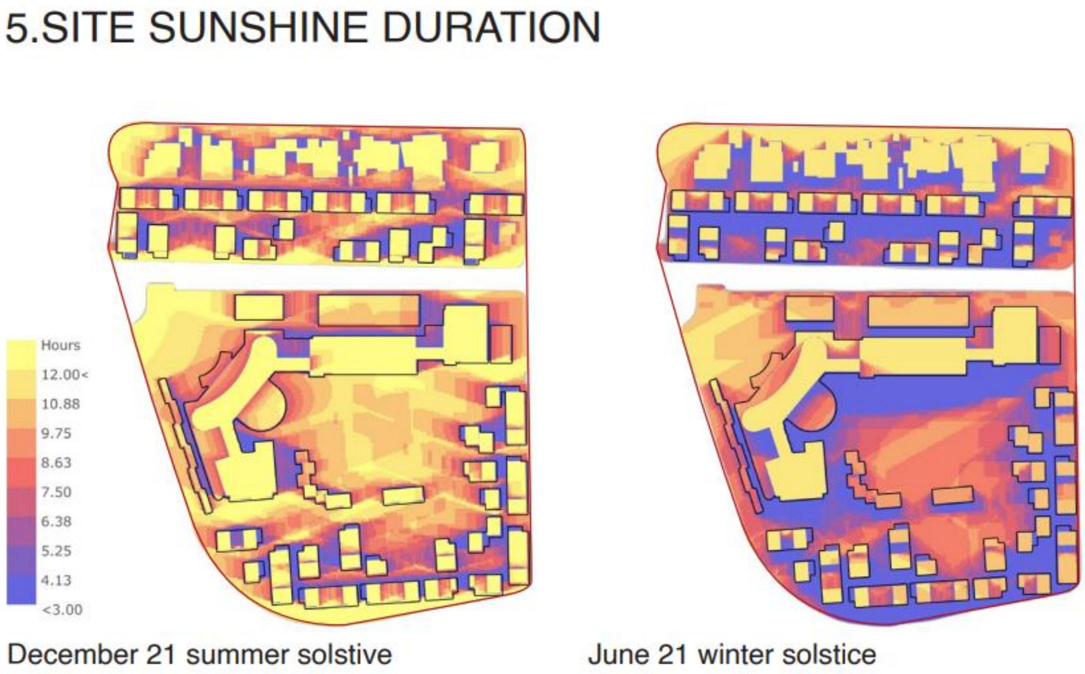


Figure 12 – Site sunshine duration of the project [12]

The team has also developed an axonometric drawing of the whole structure from which the zoom of the different spaces are here reported:

1. Circular market (user: Residents and steet vendors)
2. Market (user: Residents & Street vendors)
3. Mosque sqaure (User:Residents & Worshippers)
4. Community Playground (User: Residents)
5. Children Playground (User: Children)
6. Church Square (User:Worshippers)
7. Community Entrance Square (User:Residents)
8. Community Activity Square (User:Residents)

Figure 13 – Circular market [12]

Figure 14 – Market [12]

Figure 15 –Mosque square [12]

Figure 16 – Community playground [12]

Figure 17 – Children playground [12]

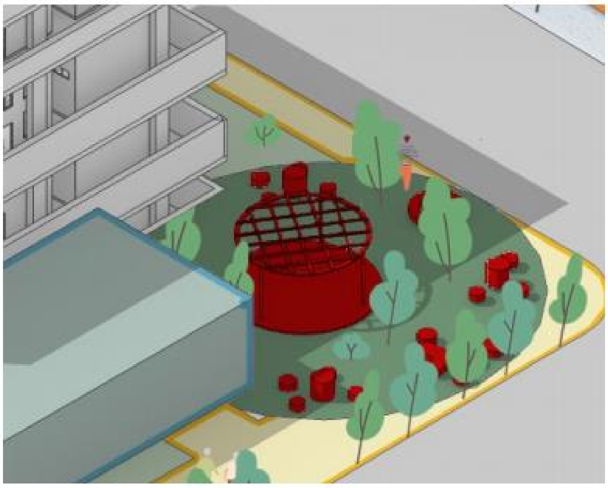


Figure 18 – Church square [12]

Figure 19 – Community entrance square [12]

Figure 20 – Community activity square [12]

Another interesting idea of the project is the one to build a floating farmland inside the structure which can deal the flood situation without compromise its function. The structure of the farmland is illustrated in the next figure.[12]

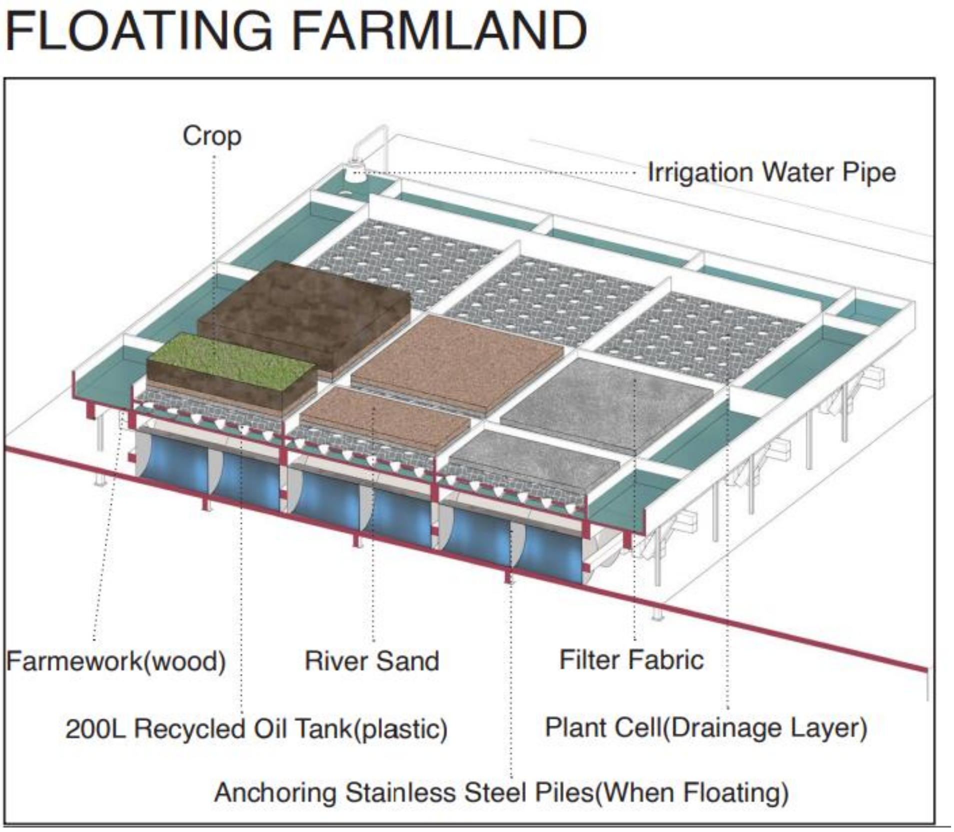


Figure 21 – Floating farmland [12]

2. METHODOLOGY

The whole project have been thought to be an ensemble of different technical knowledges. After the disaster caused by the cyclone Idai in fact the whole Politecnico had structured a project to reconstruct the whole city.

The first step was to collect data about the situation in Beira both before and after the hurricane. It has been created a worldpress page “beiraafterthestorm” on which all materials, articles and datas have been published to make them accessible to everyone. Videos of the city, climate data and damages report were posted and after this step a second part of the project begin.

The architects have structured another drive of data through which they have developed their projects by splitting out the city into different zones. Through the sharing of these data it has been chosen the setting of this project about the energetic analysis and efficiency management. The hystorical structure of the Grande Hotel has been chosen. In particular the set of residential apartments which have been planned to be built in the Block B of the Hotel’s structure.

By converting the layout of the apartments, which have to be built in the hotel, into coordinates it has been possible the use of the software EnergyPlus to make the calculation of the electric consumption, The energy consumed by apartments is given by the lights, the electric equipment and the cooling system. So the research about the data to make realistic assumption about these appliances in that particular zone and situation has been done.

Once the electric consumption has been obtained by the software, different scenarios have been simulated following the energy efficiency by changing the setpoint temperature of the cooling system for 26 and 28 degrees, changing the lights bulb from CFL to LED.

After the energy efficiency management the output file reporting the consumption’s data has been converted to be inserted as input in the software Homer Pro. This software makes the dimensioning of the PV system and economic parameters calculations. Different simulations have been done since an on-grid system is thought to be installed and two sensitivity analysis have been made, one on the sellback price of the energy and one on the CAPEX of the PV.

3. ENERGYPLUS SIMULATION OF ENREGY CONSUMPTION

EnergyPlus is a console-based program that reads input parameters and writes output variables requires into text files. It ships with a number of utilities including IDF-Editor for creating input files using a simple spreadsheet-like interface, EP-Launch for managing input and output files and performing batch simulations. In this case the only output which is needed is the consumption of the whole building. All the data collected have to be converted and insert in the IDF file as input file.

At first the EPW weather and climate data file of Beira have been collected [13] and the location have been defined in the IDF file as:

Name of site = Beira

Latitude [°] = -19.833, Longitude [°] = 34.850, Altitude [m] = 17

Climatic zone = V, 4

To make the energy consumption simulation the data of the new Grande Hotel building structure has been taken from the project of architecture of Politecnico di Torino who are working on the LAB BEIRA project with the prof. Francesca De Filippi. The data about the planimetry and the dimension of the building. In particular this project taken in consideration the apartments of the Block B of the Grande Hotel, following the definition given by the following figures [12].

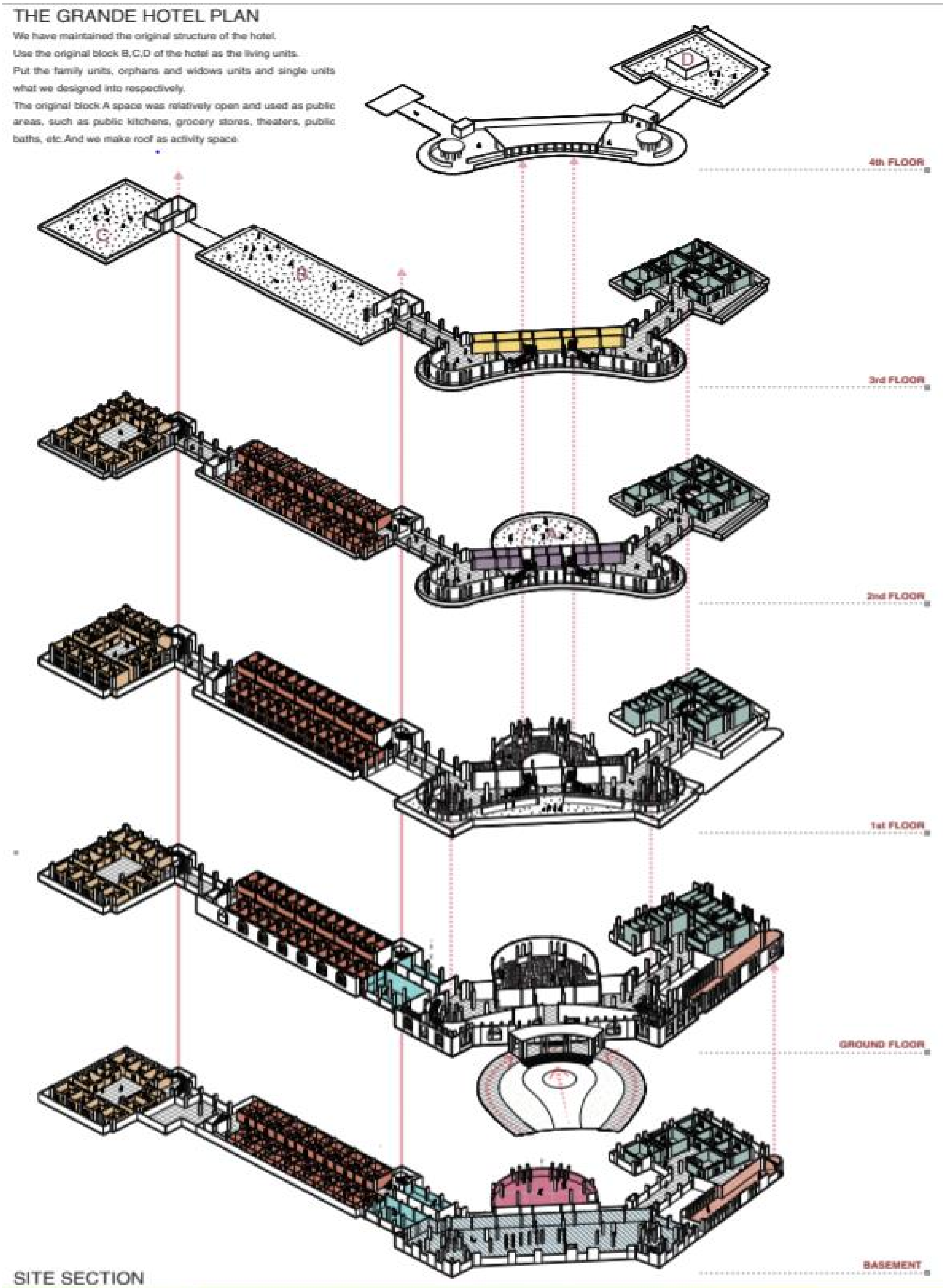


Figure 22 – The Grande Hotel plan divided by floors [12]

The Coordinates of all the facades of the apartments have to be defined in a three dimensional axis system with as starting vertex position the upperleft corner and counterclock wise vertex entry direction following the WORLD coordinate system, as well as the orientation respect to the north. The height and the dimension of the doors and of the windows have been selected as in the figure below to proceed with the simulation. [12]

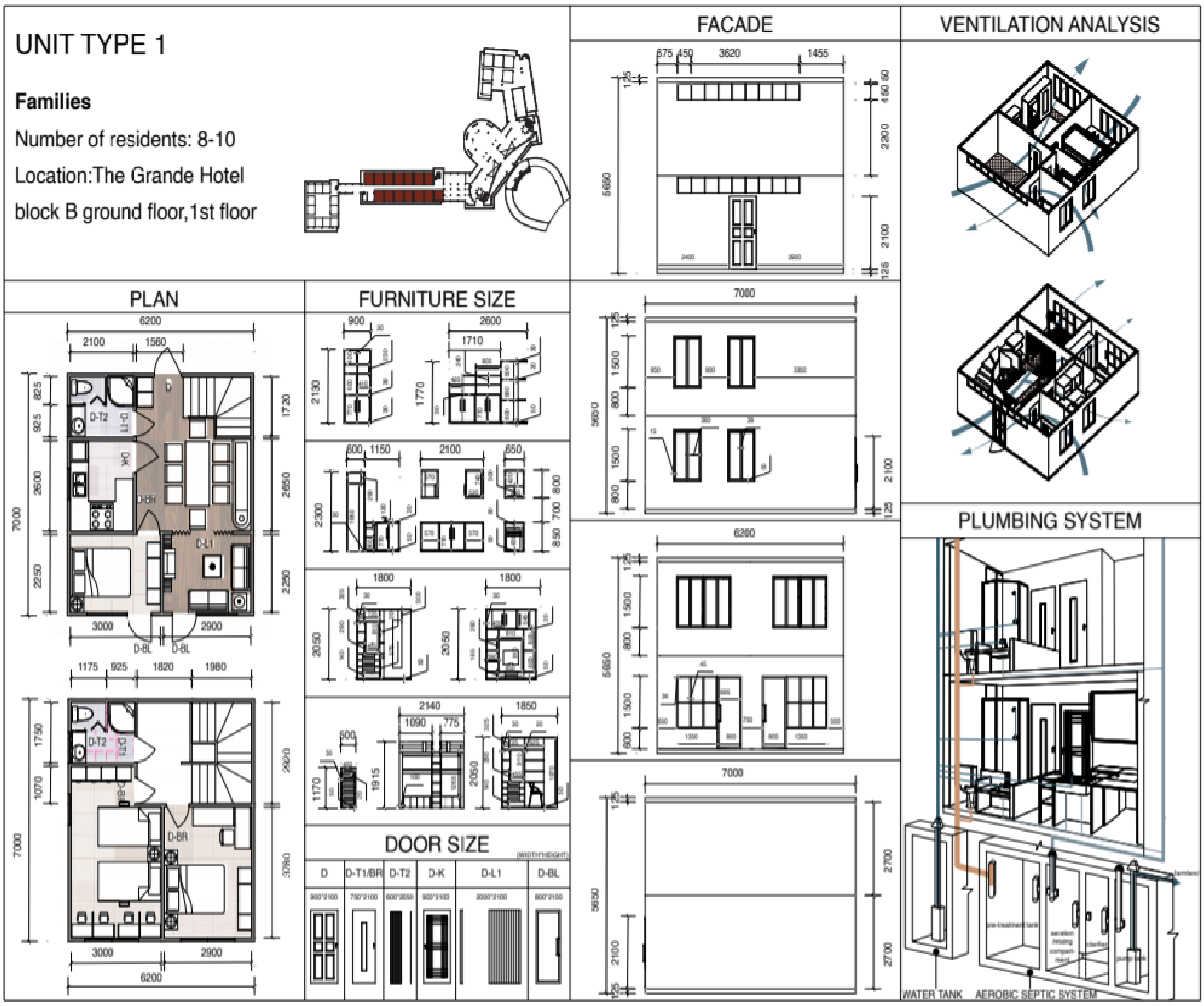


Figure 23 – Data about the dimension of the apartments [12]

The apartments are a two-storey structures with three bedrooms, a kitchen, a living room, a launch room, two bathrooms, and an entering room. They are thought for 8 – 10 residents. There are 14 apartments identical, for this reason only one has been considered for the simulation and the consumption will be the same for all. In the IDF file for the shading calculation method the Polygon Clipping method have been chosen with Sutherland Hodgman algorithm and for the Sky Diffuse

Modeling Algorithm the Simple Sky Diffuse Modeling provided by the software have been selected. For which concern the surface convection algorithm the adaptive convection has been chosen, as well as the conduction transfer function for the heat balance algorithm.

The wet bulb and dewpoint temperature of both winter and summer days have been insert as well as the wind speed and the wind direction while the solar model indicator selected is the ASHRAEClearSky provided by the software.

The run period of the simulation is an entire year, while for the site ground temperature the data used are shown in the following figure.

```
Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario B1, year 2020
Temperature: scenario B1, year 2020
```

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	275	236	106	31057	14139	3
Feb	267	219	113	30188	16339	3
Mar	255	234	95	28888	13617	3
Apr	227	246	73	25623	10480	2
May	198	242	57	22120	8093	3
Jun	178	238	50	19672	7053	2
Jul	182	224	58	20005	8155	2
Aug	208	219	71	22888	9917	3
Sep	245	237	87	27135	12022	2
Oct	267	217	109	29822	15326	3
Nov	279	225	116	31372	15924	4
Dec	277	226	118	31307	16491	3
Year	238	230	88	26673	12296	3

Month	Ta	Td	RH	p	DD	FF
Jan	29.2	25.1	79	1011	90	5.1
Feb	29.2	25.3	79	1011	113	4.6
Mar	28.7	24.8	80	1011	180	4.6
Apr	27.0	23.1	79	1011	180	4.6
May	24.9	21.3	80	1011	180	4.6
Jun	22.6	18.7	79	1011	180	4.6
Jul	22.1	18.6	81	1011	180	4.6
Aug	23.0	19.2	79	1011	90	4.6
Sep	24.8	21.0	80	1011	90	5.7
Oct	26.7	22.7	79	1011	90	5.7
Nov	27.8	23.7	79	1011	90	5.7
Dec	28.7	24.8	80	1011	90	5.7
Year	26.2	22.4	79	1011	124	5.0

Figure 24 – Climate data of Beira

```
Legend:
Gh:        Mean irradiance of global radiation horizontal
Bn:        Irradiance of beam
Dh:        Mean irradiance of diffuse radiation horizontal
N:         Cloud cover fraction
Lg:        Global luminance           Ld:

Ta:        Air temperature            RH:     Relative humidity
Td:        Dewpoint temperature       DD:     Wind direction
FF:        Wind speed                 p:      Air pressure

Radiation in  [W/m²]
Temperature in  [°C]
Pressure in  [hPa]
Wind speed in  [m/s]
Measured parameters (WMO nr: 672970) = Gh, Ta, FF, DD, RR, Td
Uncertainty of yearly values: Gh = 2%, Bn = 5 %, Ta = 0.3 °C
Trend of Gh / decade = -4.6%
Variability of Gh / year = 4.2%
P90 and P10 of yearly Gh, referenced to average = 93.7%, 104.8%
```

Figure 25 – Climate data of Beira Legend

The schedule type limits have been defined as temperature for the thermostat (between -60 and 200 Celsius degrees), Relative Humidity for the dehumidifier system (between 10 and 90 per cent), as on/off for the different system and as the control type between 1 and 4 for the thermostat setpoint selection. While the schedule compact have been used to the definition of the occupancy of the different rooms, followed by the lighting and electric equipment schedules, the dehumidify and humidify step schedules, the activity schedule as required from the software , the heating and cooling setpoint temperature schedule, the dual zone control type schedule for the dehumidifier and the one for the cooling system.

The rooms of the apartments have been divided into categories: common rooms (living room, launch room, kitchen), bedrooms (the three bedrooms), bathrooms and the entering rooms. This classification is fundamental to understand how the occupancy have been scheduled.

The occupancy schedule, the lighting schedule and electric equipment's ones are resumed in the next table by using a fraction between 0 (minimum value) and 1 (maximum value) and defined for each hour of the day.

rooms classification	Occupancy	Lighting	electric equipment
Common rooms	From 6 to 7 a.m.: 0,25	From 00.00 to 6 a.m.: 0	From 00:00 to 6 a.m.: 0
	From 7 to 9 a.m. : 0,5	From 6 to 9 a.m. : 1	From 6 to 7 a.m. : 0,1
	From 9 to 15 : 0	From 9 to 19 : 0	From 7 to 9 : 0,3
	From 15 to 19 : 0,5	From 19 to 21 : 1	From 9 to 19 : 0
	From 19 to 21 : 1	From 21 to 22 : 0,5	From 19 to 22 : 1
	From 21 to 22 : 0,25	From 22 to 24 : 0	From 22 to 24 : 0
	From 22 to 24 : 0		
bedrooms	From 00:00 to 6 a.m.: 1	From 00:00 to 5 a.m.: 0	From 00:00 to 5 a.m.: 0,8
	From 6 to 7 a.m. : 0,75	From 5 to 6 a.m. : 1	From 5 to 6 a.m. : 0
	From 7 to 9 : 0,5	From 6 to 7 : 0,5	From 6 to 7 : 0,2
	From 9 to 21 : 0	From 7 to 21 : 0	From 7 to 20 : 0
	From 21 to 22 : 0,75	From 21 to 23 : 1	From 20 to 21 : 0,2
	From 22 to 24: 1	From 23 to 24: 0	From 21 to 24: 0,8
bathrooms	From 00:00 to 6 a.m.: 0,1	From 00:00 to 6 a.m.: 0,2	
	From 6 to 7 a.m. : 0,25	From 6 to 7 a.m. : 1	
	From 7 to 9 : 0,5	From 7 to 19 : 0	
	From 9 to 15 : 0	From 19 to 21 : 0,5	
	From 15 to 19 : 0,5	From 21 to 22 : 1	
	From 19 to 21 : 0	From 22 to 24 : 0	
	From 21 to 22 : 0,5		
	from 22 to 24 : 0,2		
entering	From 00:00 to 6 a.m.: 0	From 00.00 to 6 a.m.: 0	
	From 6 to 9 a.m. : 0,5	From 6 to 9 a.m. : 0,5	
	From 9 to 19 : 0	From 9 to 19 : 0	
	From 19 to 22 : 0,75	From 19 to 21 : 1	
	From 22 to 24 : 0	From 21 to 24 : 0	

Table 4 – Schedule tables: occupancy, lighting and electric equipment for EnergyPlus

Concerning the humidifier two different setpoints have been scheduled for common rooms and bed rooms defined by specifying the number of the relative humidity in percentages and illustrated in the next table.

rooms	Humidifier’s set point	Dehumidifier’s set point
Common rooms	From 00:00 to 6 a.m.: 10	From 00.00 to 6 a.m.: 90
	From 6 to 9 a.m. : 25	From 6 to 9 a.m. : 60
	From 9 to 18 : 10	From 9 to 18 : 90
	From 18 to 22 : 25	From 18 to 22 : 60
	From 22 to 24 : 10	From 22 to 24 : 90
bedrooms	From 00:00 to 9 a.m. : 25	From 00:00 to 9 a.m.: 60
	From 9 to 21 : 10	From 9 to 21 : 90
	From 21 to 24 : 25	From 21 to 24 : 60

Table 5 – Schedule tables humidifier and dehumidifier set point for EnergyPlus

The last schedules defined were the setpoint of the thermostat define in temperature (°C) and the operational period where 1 is on mode and 0 is off mode, as shown in the next table.

rooms classification	Thermostat’s cold set point	Thermostat’s hot setpoint	HVAC operational period
Common rooms	From 00:00 to 6 a.m.: 100	From 00.00 to 6 a.m.: -50	From 00:00 to 9 a.m.: 1
	From 6 to 9 a.m. : 26	From 6 to 9 a.m. : 20	From 9 to 18 : 0
	From 9 to 15 : 100	From 9 to 15 : -50	From 18 to 24 : 1
	From 15 to 22 : 26	From 15 to 22 : 20	
	From 22 to 24 : 100	From 22 to 24 : -50	
bedrooms	From 00:00 to 9 a.m. : 26	From 00:00 to 9 a.m.: 20	From 00:00 to 9 a.m.: 1
	From 9 to 21 : 100	From 9 to 21 : -50	From 9 to 18 : 0
	From 21 to 24 : 26	From 21 to 24 : 20	From 18 to 24 : 1

Table 6 – Schedule tables for thermostat setpoint and HVAC operational period for EnergyPlus

The materials constituent of the wall, roof and floor have been defined one by one with their specific conductivity, density, specific heat as shown in the next table.

material propreties	gypsum plaster	wood slab	expanded polystyrene	tpo membrane	cement concrete
Conductivity [W/m*K]	0,22	0,14	38	0,2	0,16
Density [kg/m^3]	1680	530	148	900	500
Specific heat [j/kg*K]	1085	900	1110	1700	840

Table 7 –Material proprieties for EnergyPlus

The stratigraphy of wall, floor, internal and external roof have been define as the following table shows.

stratigraphy	wall	floor	roof	internal roof
	gypsum plaster 2 cm	cement concrete 4 cm	gypsum plaster 0,5 cm	ewood panel slab 4 cm
	expanded polystyrene 4 cm	tpo membrane 0,5 cm	expanded polystyrene 7 cm	tpo membrane 0,5 cm
	tpo membrane 0,5 cm	expanded polystyrene 4 cm	tpo membrane 0,5 cm	expanded polystyrene 5 cm
	gypsum plaster 0,5 cm	gypsum plaster 3 cm	wood panel slab 4 cm	gypsum plaster 1 cm
	wood panel slab 2cm	wood panel slab 2 cm	gypsum plaster 0,5 cm	wood panel slab 2 cm

Table 8 – stratigraphy of wall, floor, roof and internal roof

For the window glass's material the Clear 6mm have been chosen with air gas 3mm in between, to better insulate the indoor spaces.

Concerning the lighting the concentrate Fluorescent bulb are selected, these are the most used in Mozambique, with 60 Watt of lighting level for each bulb. 2 bulbs have been installed in the launch room and in the biggest bedroom at the 1st floor, while in all the other rooms only 1 bulb have been selected with a fraction radiant of 0,09, a fraction visible of 0,13 and a return air fraction of 0,78.

While the electric equipment has been defined by following the multi-tier method to estimate the household access to electricity and their consumption, proposed by the World Bank.[14]

In the specific case, in urban context, it is supposed to be in the 3rd tiers with the following consumption's parameter shown in the next table:

Tiers of Capacity of Electricity Supply

CAPACITY		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Power Capacity Ratings (minimum in W or daily Wh)			3 W	50 W	200 W	800 W	2,000 W
			12 Wh	200 Wh	1.0 kWh	3.4 kWh	8.2 kWh
Supported Appliances			Very low-power appliances	Low-power appliances	Medium-power appliances	High-power appliances	Very high-power appliances
Typical Supply Technologies			Solar lantern	Rechargeable battery, SHS	Medium SHS, fossil fuel-based generator, mini-grid	Large SHS, fossil fuel-based generator, mini-grid, central grid	Large fossil fuel-based generator, central grid

Table 8 – Tiers of Capacity of electricity supply [14]

Typical Household Electric Appliances by Power Load

	VERY LOW-POWER APPLIANCES	LOW-POWER APPLIANCES	MEDIUM-POWER APPLIANCES	HIGH-POWER APPLIANCES	VERY HIGH-POWER APPLIANCES
Lighting	Task lighting	Multipoint general lighting			
Entertainment & Communication	Phone charging, radio	Television, computer, printer			
Space Cooling & Heating		Fan	Air cooler		Air conditioner,[a] space heater[a]
Refrigeration			Refrigerator,[a] freezer[a]		
Mechanical Loads			Food processor, water pump	Washing machine	Vacuum cleaner
Product Heating				Iron, hair dryer	Water heater
Cooking			Rice cooker	Toaster, microwave	Electric cooker

[a]*Continuous load*

Table 9 – Typical household Electric appliances by power load [14]

The tier 3 includes already the lighting consumption but is a mean value and really negligible if compared to the total consumption of the medium power appliances, 12 Wh compared with 1.0 kWh. So the choice to consider it both in the tier selected and by insert the lighting directly in the software make a little overestimation of the consumption but have been made to, successively with the energy efficiency, allow the calculation of the consumption saved by changing the bulb from fluorescent to LED.

For the ventilation design flow rate, it has been supposed an air changes/hour with a natural ventilation type and 0,6 air changes per hour.

Concerning the HVAC system, the installation of a cooling system has been thought. In particular it has been chosen a Window Air Conditioner. It is the cheapest and the simplest cooling system, diffuse in the zone, is a unit of zone equipment made up of other components. Each window air conditioner consists of an outdoor air mixer, a fan, and a direct expansion (DX) cooling coil.

These systems have been installed in the ground floor bedroom and living room and in two bedrooms at the first floor. For each one of these rooms a dehumidifier and a thermostat have been also figured. The thermostat has been defined as a dual setpoint control type with a constant radiative fraction input mode.

4. ENERGYPLUS ENERGY MANAGEMENT FOR ENERGY EFFICIENCY

The simulations have been made in three different scenarios. The first has been set with fluorescent bulb and a setpoint cooling temperature of 26 degrees. Following the energy efficiency building report from IEA [15] the second scenario input have been changed with the setpoint thermostat temperature at 28 degrees and the third by changing the bulb with LED ones.[16]

The results in the building consumption divided by cooling, interior lighting, electric equipment and fans are shown in the next figures.

- 1st SCENARIO: thermostat temperature setpoint 26 °C and fluorescent bulb.

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2021-02-03 12:07:17**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	7527.51	87.39	164.21
Net Site Energy	7527.51	87.39	164.21
Total Source Energy	23839.61	276.75	520.06
Net Source Energy	23839.61	276.75	520.06

Table 10 – Site and source energy 1st SCENARIO

End Uses

	Electricity [kWh]
Heating	0.00
Cooling	5389.46
Interior Lighting	873.81
Exterior Lighting	0.00
Interior Equipment	479.61
Exterior Equipment	0.00
Fans	784.63
Pumps	0.00
Heat Rejection	0.00
Humidification	0.00
Heat Recovery	0.00
Water Systems	0.00
Refrigeration	0.00
Generators	0.00
Total End Uses	7527.51

Table 11 – End Uses 1st SCENARIO

- 2nd SCENARIO: thermostat temperature setpoint 28 °C and fluorescent bulb.

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2021-02-03 18:14:06**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	6524.18	75.74	142.32
Net Site Energy	6524.18	75.74	142.32
Total Source Energy	20662.07	239.87	450.74
Net Source Energy	20662.07	239.87	450.74

Table 12 – Site and source energy 2nd SCENARIO

End Uses

	Electricity [kWh]
Heating	0.00
Cooling	4700.40
Interior Lighting	873.81
Exterior Lighting	0.00
Interior Equipment	479.61
Exterior Equipment	0.00
Fans	470.36
Pumps	0.00
Heat Rejection	0.00
Humidification	0.00
Heat Recovery	0.00
Water Systems	0.00
Refrigeration	0.00
Generators	0.00
Total End Uses	6524.18

Table 13 – End Uses 2nd SCENARIO

- 3rd SCENARIO: thermostat temperature setpoint 28 °C and LED.

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2021-02-04 11:41:12**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	6044.98	70.18	131.87
Net Site Energy	6044.98	70.18	131.87
Total Source Energy	19144.46	222.25	417.64
Net Source Energy	19144.46	222.25	417.64

Table 14 – Site and source energy 3rd SCENARIO

End Uses

	Electricity [kWh]
Heating	0.00
Cooling	4685.35
Interior Lighting	407.78
Exterior Lighting	0.00
Interior Equipment	479.61
Exterior Equipment	0.00
Fans	472.24
Pumps	0.00
Heat Rejection	0.00
Humidification	0.00
Heat Recovery	0.00
Water Systems	0.00
Refrigeration	0.00
Generators	0.00
Total End Uses	6044.98

Table 15 –End Uses 3rd SCENARIO

5. HOMER PLUS SIMULATION

To sizing the PV system which copes with consumptions sprevious calculated it has been used the trial version of the software HOMER Pro.

The HOMER (Hybrid Optimization of Multiple Energy Resources) Pro microgrid software navigates the complexities of building cost effective and reliable microgrids that combine traditionally generated and renewable power, storage, and load management. HOMER Grid serves the grid-connected market with cutting edge algorithms for optimizing solar, storage, and more to reduce the overall energy costs. [16]

5.1 PV ONGRID SYSTEM SIMULATION

Initially the location, Beira, has been chosen on the world map and the inflation and discount rate have been inserted, in this case Mozambique have an inflation rate equal to 4 % and the discount rate equal to 9,95, as the "Banco de Mozambique" report.[17]

To construct the system in the software different choices have been made. In the first step the output file of the consumptions of the building for the whole 8760 hours of the year from EnergyPlus have been multiplied for the total structures of the apartments, which are 14, and converted from joule to kWh. It has been downloaded in Homer as input xlsx file to generate the curve of the load, generating daily, seasonal and yearly profiles.

The electric load selected and its properties are shown in the next figure:

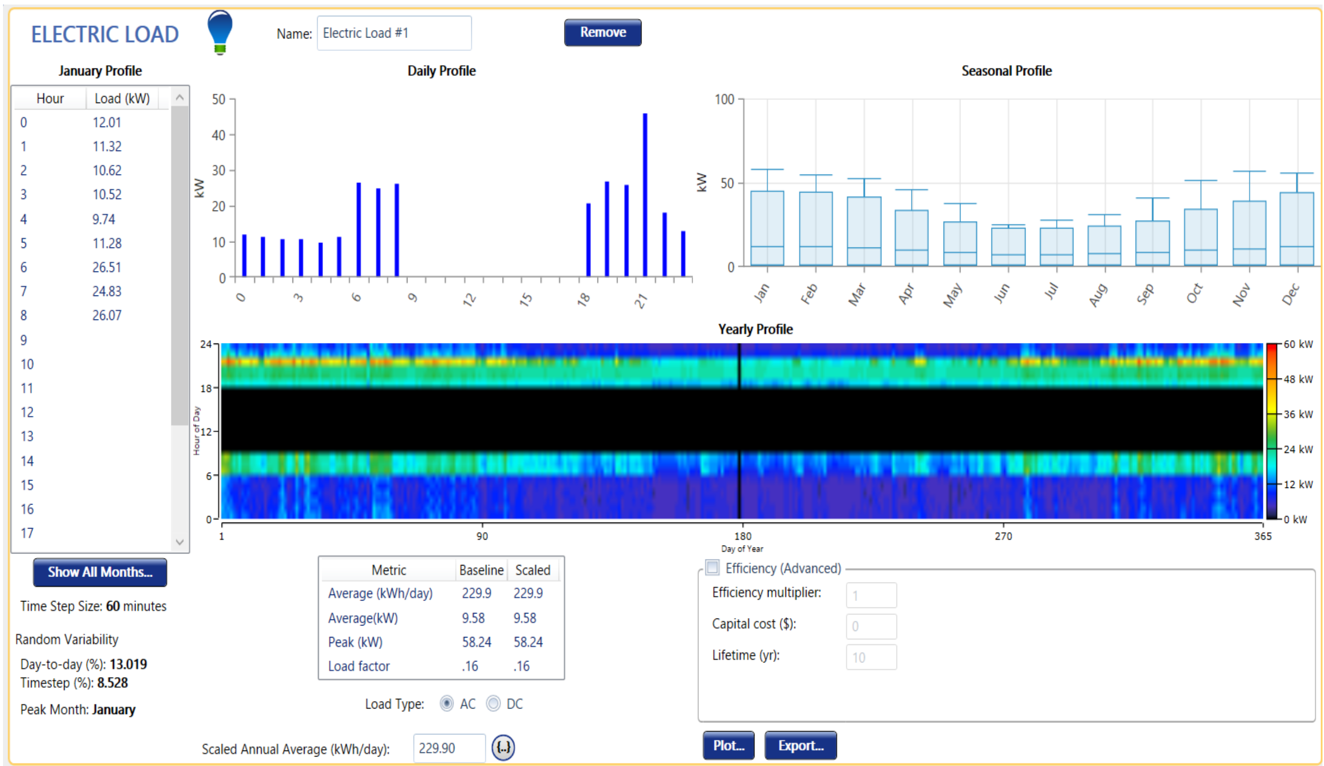


Figure 27 – Electric load input in Homer Pro

After that the components of the system have been selected. The first one is the PV which is a generic flat plate PV with a lifetime of 25 years and for which the cost have been defined as 900 USD/kW with a replacement cost of 100% of the capital and a O&M cost at 3% of the capital, taken from the IRENA report about Africa solar PV cost. [18] The specific site input is the derating factor equal to 80 % and the electrical Bus is chosen to be in direct current since it will be connected to an inverter.

In fact the second component added is the converter which is supposed to have a capital cost of 300 USD/kW the same cost as replacement and no costs of O&M. [18] As inverter input the lifetime is set at 10 years and the efficiency at 95% while for the rectifier input the relative capacity is 100% and the efficiency again at 95%.

The next components to be added at the scheme is the storage, a lead acid battery has been chosen. The following image report all the data about the battery selected, always following the data provided by IRENA report.[18]

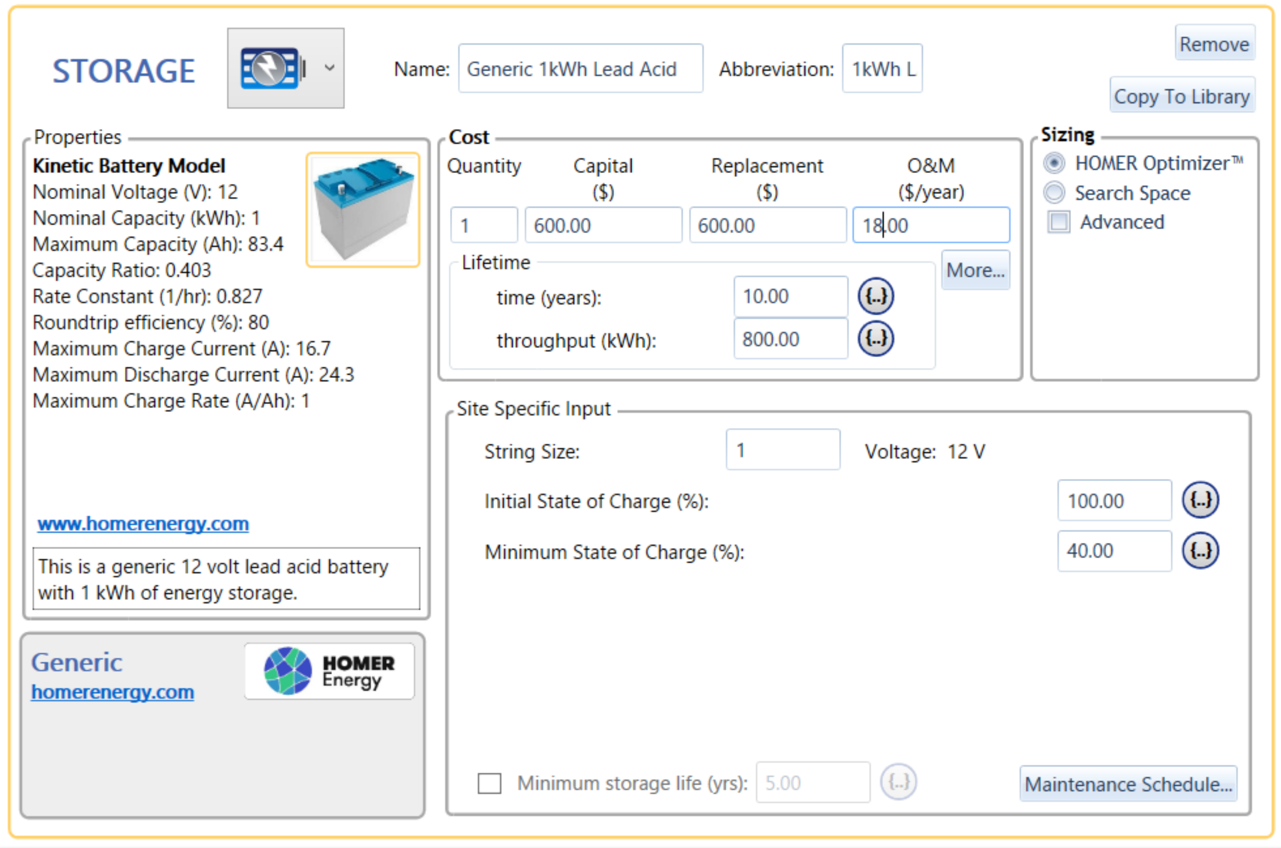


Figure 28 – Storage input in Homer Pro

Only one component is left, the grid. It is inserted as simple rates and the grid power price and the grid sellback price have been inserted, thanks to the IEA report of 2019 about Africa energy [16], the price of grid power has been set at 0,119 and the sellback price is supposed to be at 50% of it. Because of the frequent blackout it has been inserted the reliability of the grid instead of an ideal one.

Before making run the simulation the last data required are about the solar GHI (Global Horizontal Irradiance), thanks to HOMER it is possible to download these data from the source from internet or from the NASA reports or from the National Renewable Energy Laboratory, in this case the second one has been chosen. All the data have been inserted correctly so the simulation results are calculated. Four optimized different solution have been proposed by the software.

Here are shown the optimized results of the first simulation:

Architecture					Cost				System	
PV (kW)	1kWh LA	Grid (kW)	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
230		999,999	149	CC	$64,795	$0.0122	-$8,979	$182,683	84.2	0
230	1	999,999	149	CC	$66,094	$0.0125	-$8,917	$183,162	84.2	0
		999,999		CC	$131,105	$0.119	$9,986	$0.00	0	0
	1	999,999	0.229	CC	$132,530	$0.120	$10,043	$668.75	0	0

Table 16 – Optimized results Homer Pro 1st simulation: Architecture, Cost, System.

PV		1kWh LA				Converter		Grid	
Capital Cost ($)	Production (kWh/yr)	Autonomy (hr)	Annual Throughput (kWh/yr)	Nominal Capacity (kWh)	Usable Nominal Capacity (kWh)	Rectifier Mean Output (kW)	Inverter Mean Output (kW)	Energy Purchased (kWh)	Energy Sold (kWh)
138,000	372,542					0	38.8	63,610	319,917
138,000	372,542	0.0627	0	1.00	0.600	0	38.8	63,610	319,648
								83,914	0
		0.0627	0	1.00	0.600	0	0	83,914	0

Table 17 – Optimized results Homer Pro 1st simulation: PV, Storage, Converter, Grid.

To make some consideration about the results sesitivity analysis have been made.

5.2 SENSITIVITY ANALYSIS

After making the first simulations sensitivity analysis have been done by changing different parameters, in particular the sellback prices of the electricity and the CAPEX of the PV system, to see how these parameters would affect both the Total Net Present Cost and the Renewable Fraction.

To make a clear definition of some of these parameters:

- Total Net Present Cost: the total cost of a project over a specified time period to the total cost today, taking into account the time value of money.
- Renewable Fraction : is the fraction of the energy delivered to the load that originated from renewable power sources. Calculated as:

$$f_{ren} = 1 - \frac{E_{nonren} + H_{nonren}}{E_{served} + H_{served}}$$

Where

Enonren = nonrenewable electrical production [kWh/yr]

Egrid,sales = Energy sold to the grid [kWh/yr]

Hnonren = nonrenewable thermal production [kWh/yr]

Eserved = total electrical load served [kWh/yr]

Hserved = total thermal load served [kWh/yr]

- Sellback price: The price at which the electricity produced from the PV system is sold to the grid.
- Reliability: is defined through a scheduled outage parameters which are the mean outage frequency [1/yr] and the mean repair time [h].

The reliability is an important parameter to let the grid simulation be more realistic. In particular in Mozambique because the outages and blackouts are frequent.[19] For the estimation of the reliability of the grid thanks to the world bank two different parameters have been defined, SAIDI and SAIFI [20]:

- The System Average Interruption Frequency Index (SAIFI) is the average number of interruptions that a customer experiences and is calculated as:
  SAIFI = total number of customer interruptions to total number of customers served
- The System Average Interruption Duration Index (SAIDI) is the average outage duration for each customer served and is calculated as:
  SAIDI = sum of all customer interruptions to total number of customers served.

Concerning Mozambique these data aren't really easy to achieve, the most recent are referred to 2015 year period. [21] Following the data achieved the reliability has been set with a mean outage frequency of 5 times, for a mean repair time of 11 hours.

5.2.1 Sellback sensitivity analysis

The sensitivity analysis done by changing the sellback price starting by the half of the COE and increasing it, so the values are 0,06; 0,067; 0,075; by the supposition to have some incentives to have more renewable and clean energy production give the following results:

Sensitivity	Architecture					Cost				System	
Sellback Rate ($/kWh)	PV (kW)	1kWh LA	Grid (kW)	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
0.0600	229	72	999,999	154	LF	$232,322	$0.0439	$405.53	$226,998	84.2	0
0.0670	230	72	999,999	151	LF	$202,636	$0.0384	-$1,826	$226,608	84.2	0
0.0750	229	72	999,999	116	LF	$182,976	$0.0378	-$2,463	$215,317	82.8	0

Table 18 - Optimized results Homer Pro Sellback sensitivity anlysis: Architecture, Cost, System.

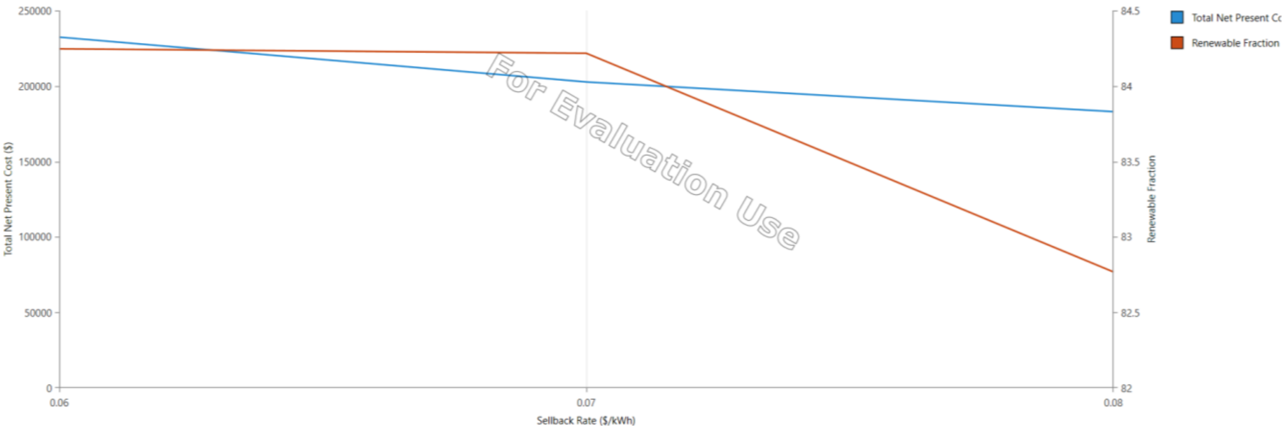


Figure 29 – Sellback sensitivity analysis graph

The trade-off between a higher renewable fraction and a lower Total Net Present Cost is the one with a sellback price of 0,067.

5.2.2 CAPEX for PV sensitivity analysis

With this value the sensitivity analysis on the CAPEX for the PV is done by changing the value between the range parameter given by the IRENA report [18]. So the value considered are 600 USD/kWh, 750 USD/kWh, 900 USD/kWh and the results of the analysis are the following:

Sensitivity	Architecture					Cost					System	
PV Capital Cost Multiplier (*)	PV (kW)	1kWh LA	Grid (kW)	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
1.00	229	72	999,999	154	LF	$232,322	$0.0439	$405.53	$226,998	84.2	0
1.25	227	72	999,999	167	LF	$269,734	$0.0507	$495.98	$263,222	84.3	0
1.50	128	81	999,999	77.2	LF	$305,578	$0.0932	$9,013	$187,247	73.6	0

Table 19 - Optimized results of the PV CAPEX sensitivity anlysis: Architecture, Cost, System.

PV		1kWh LA				Converter		Grid	
Capital Cost ($)	Production (kWh/yr)	Autonomy (hr)	Annual Throughput (kWh/yr)	Nominal Capacity (kWh)	Usable Nominal Capacity (kWh)	Rectifier Mean Output (kW)	Inverter Mean Output (kW)	Energy Purchased (kWh)	Energy Sold (kWh)
138,000	372,542	4.51	118	72.1	43.2	0	38.7	63,486	318,332
172,500	372,542	4.51	118	72.1	43.2	0	38.7	63,486	318,814
182,203	327,914	4.70	121	75.1	45.0	0	33.5	63,931	273,806

Table 20 - Optimized results of the PV CAPEX sensitivity anlysis: PV, storage, converter, Grid.

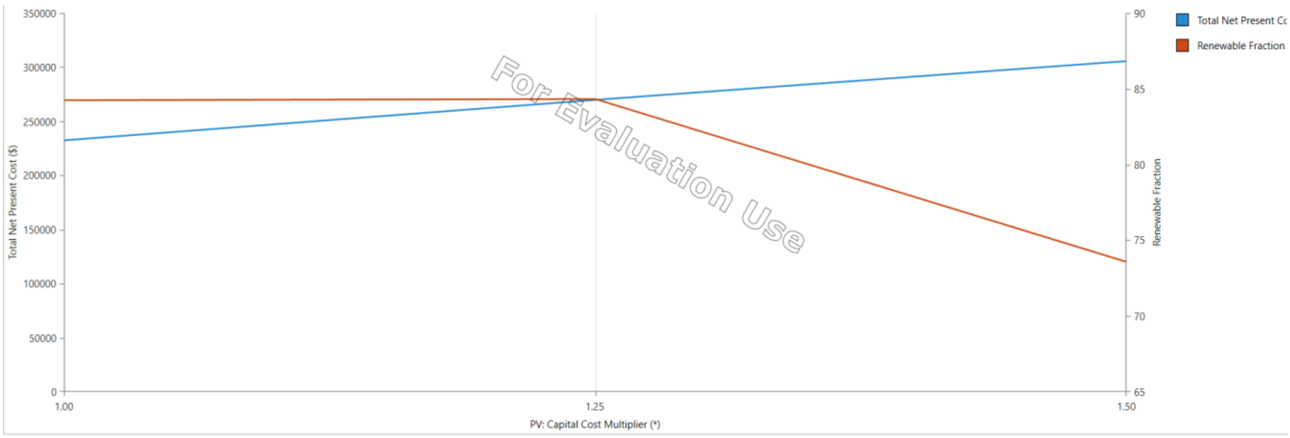


Figure 30 –PV CAPEX sensitivity analysis graph

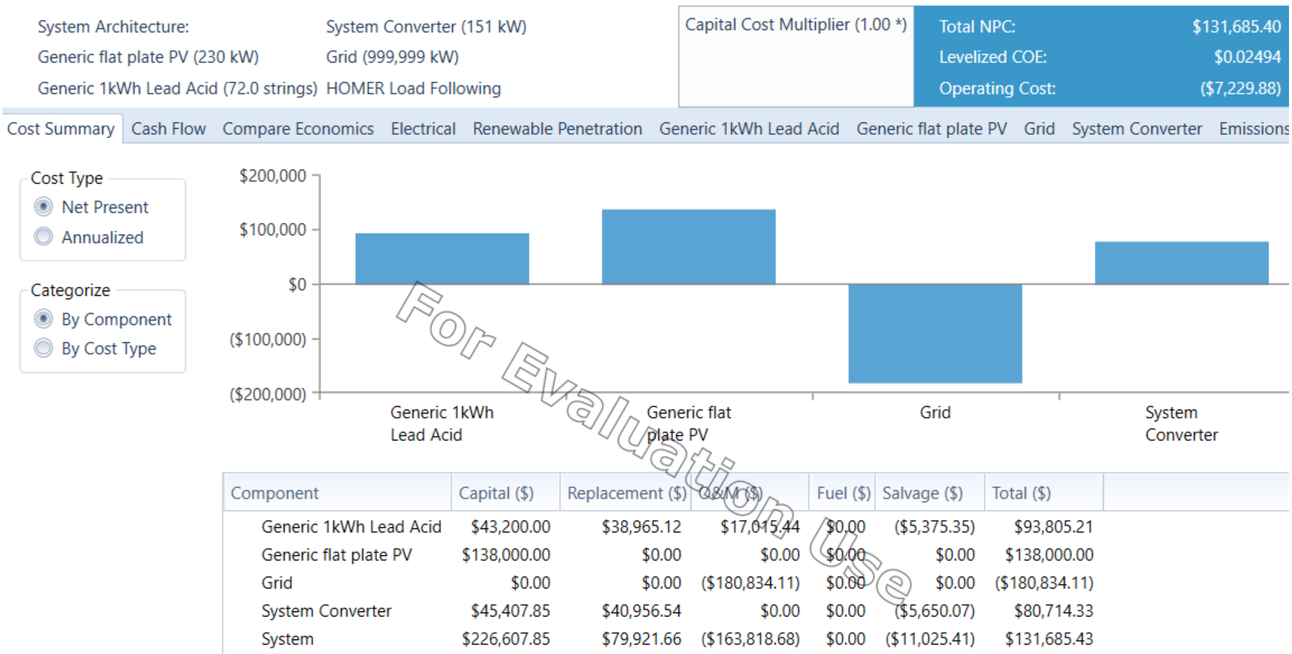
The three different capital costs are defined by a multiplier, so starting by 600 USD/kWh with the three different multiplier coefficient (1; 1,25;1,5) the three values are achieved.

5.2.3 Sensitivity analysis conclusions

From these results we can conclude that the costless is the best solution one both in terms of Net Present Cost and both in renewable fraction, this is thanks also to the fact that Homer is a software based on economical parameter and convenience. So if the cost of the PV system is too high Homer supposed that the electricity would be taken from the grid, which is not a renewable sources and for this reason the renewable fraction will decrease.

The simulation also generates another kind of results about the system and its components which are shown in the following figures and tabs.

For the economic parameters the cost summary of the whole system divided by batteries, PV, grid and inverter and its dimensioning is reported in the next figure:



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 1kWh Lead Acid	$43,200.00	$38,965.12	$17,015.44	$0.00	($5,375.35)	$93,805.21
Generic flat plate PV	$138,000.00	$0.00	$0.00	$0.00	$0.00	$138,000.00
Grid	$0.00	$0.00	($180,834.11)	$0.00	$0.00	($180,834.11)
System Converter	$45,407.85	$40,956.54	$0.00	$0.00	($5,650.07)	$80,714.33
System	$226,607.85	$79,921.66	($163,818.68)	$0.00	($11,025.41)	$131,685.43

Figure 31 – Final solution economic parameters results

Another important economic aspect to take into account is the cashflow shown in the figure below, it considers the capital invested at the beginning the operating and replacement cost during times and show when salvage start to be positive. In the project after 25 years the salvage is equal to 44.303,93 USD so it can be a good investment, not only from an environmental sustainability aspect but also to an economical one.

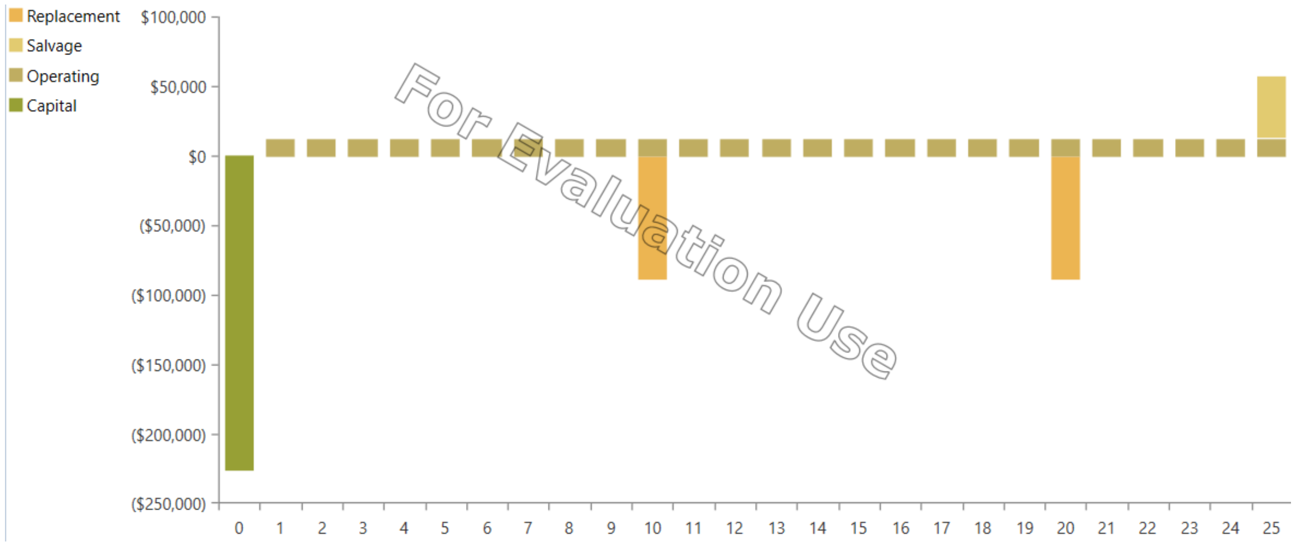


Figure 32 – Final solution economic parameter during time results

While concerning the dimensioning, in the electrical section, all the data about the electricity produced and consumed and the relative percentage from the grid and from the PV installed are shown, both monthly and yearly.

Production	kWh/yr	%
Generic flat plate PV	372,542	85.4
Grid Purchases	63,486	14.6
Total	436,028	100

Consumption	kWh/yr	%
AC Primary Load	83,890	20.8
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	318,814	79.2
Total	402,704	100

Quantity	kWh/yr	%
Excess Electricity	15,443	3.54
Unmet Electric Load	24.0	0.0287
Capacity Shortage	82.7	0.0986

Quantity	Value	Units
Renewable Fraction	84.2	%
Max. Renew. Penetration	592	%

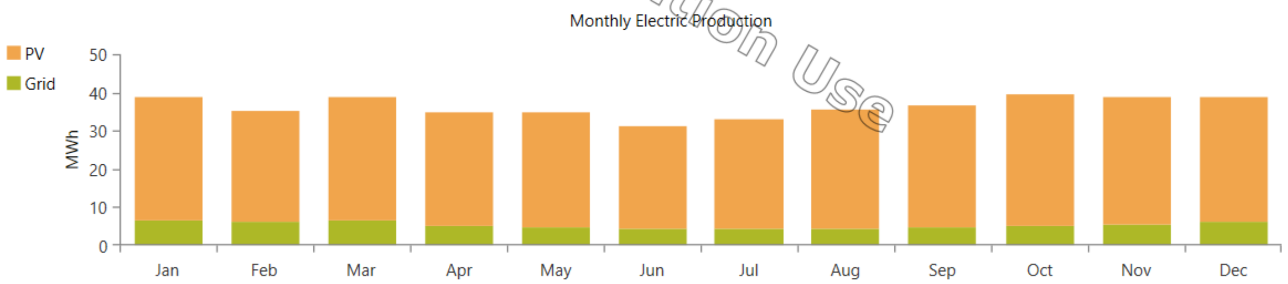


Figure 33 – Final solution Electric parameter results

Looking at the PV section all the data about its operation and its outputs are reported. The total production is shown (372,542 kWh/yr) as well as the hours of operation during the whole years, which is nearby six months (4370 h/yr). In the graph which represent the production of the PV day by day for the whole year is clear that the most of the production is in the summer season while during winter the kW in outputs are decreasing.

Quantity	Value	Units
Rated Capacity	230	kW
Mean Output	42.5	kW
Mean Output	1,021	kWh/d
Capacity Factor	18.5	%
Total Production	372,542	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	223	kW
PV Penetration	444	%
Hours of Operation	4,370	hrs/yr
Levelized Cost	0.0282	$/kWh

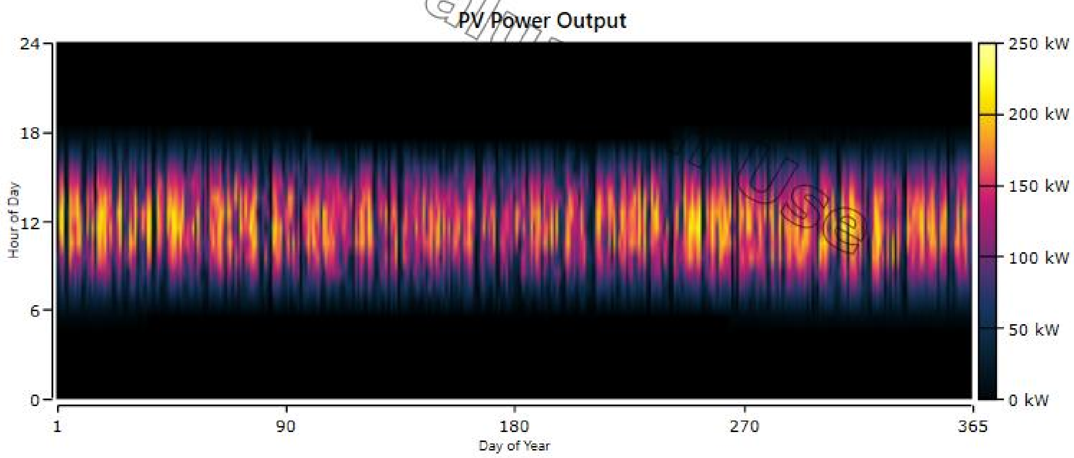


Figure 34 – Final solution PV power Output results

The last interesting section of results is the one which describes the grid and differentiate about the energy purchased from the grid and the energy sold to the grid for each month of the year. It is evident that the one sold is higher than the one purchased over the whole period, and in winter both the energy sold and the one purchased are lower respect to the summer period in which there is more energy produced and sold to the grid and more energy consumed also by the apartments, and consequently more energy purchased from the grid.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
January	6,664	26,647	-19,983	58	($992.29)	$0
February	6,089	24,611	-18,521	55	($924.28)	$0
March	6,526	27,561	-21,035	53	($1,070.03)	$0
April	5,250	24,950	-19,700	46	($1,046.86)	$0
May	4,816	25,578	-20,762	38	($1,140.66)	$0
June	4,208	23,647	-19,439	25	($1,083.58)	$0
July	4,216	25,731	-21,514	28	($1,222.22)	$0
August	4,388	27,454	-23,066	32	($1,317.25)	$0
September	4,599	27,576	-22,977	41	($1,300.29)	$0
October	5,184	29,650	-24,467	51	($1,369.71)	$0
November	5,297	28,190	-22,893	57	($1,258.40)	$0
December	6,247	26,736	-20,489	56	($1,047.88)	$0
Annual	63,486	318,332	-254,846	58	($13,773.4	$0

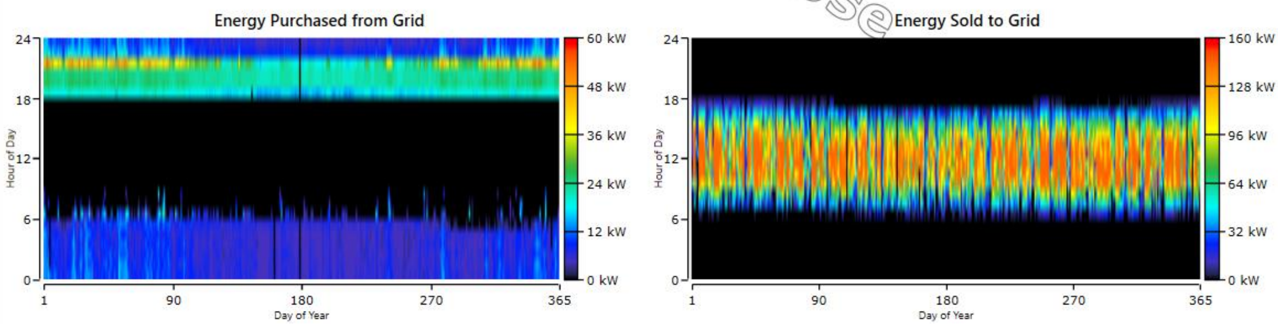


Figure 35 – Final solution Grid results

6. CONCLUSIONS

6.1 Consumptions simulation using EnergyPlus

In conclusion about the three different scenarios analyzed in EnergyPlus we can make some consideration. The main objective of this project is surely to build a set of apartments that ensure an adequate and sufficiently high standard of living but it is important to achieve this scope in the more efficient way as possible, with lower cost and lower consumption and emissions as possible.

The next table reports all the value obtained by the simulation and the consumption by comparing the different scenarios supposed. To recap:

-1st SCENARIO: Thermostat setpoint at 26 °C and fluorescent bulb as interior lights.

-2nd SCENARIO: Thermostat setpoint at 28 °C and fluorescent bulb as interior lights.

-3rd SCENARIO: Thermostat setpoint at 28 °C and LED as interior lights.

Scenarios:	**1st scenario**	**2nd scenario**	**3rd scenario**
Total Site Energy [kWh]	7527,51	6524,18	6044,98
Net Source Energy [kWh]	23839,61	20662,07	19144,46
Electricity: Cooling [kWh]	5389,46	4700,4	4685,35
Electricity: Interior light [kWh]	873,81	873,81	407,78
Electricity: Interior equipment[kWh]	479,61	479,61	479,61
Electricity: Fans [kWh]	784,63	470,36	472,24

Table 21 – Results comparison between three scenarios for energy efficiency.

It’s shown how both the total site energy and the net source energy diminish through the three scenarios by making energy efficiency, with a reduction of about the 20% of the initial consumptions.

The differentiation between the specific consumption through different sector (Cooling, Interior light, interior equipment, fans) allows us to better understand how much the optimization will be traduced in consumption reduction.

The electric equipment aren’t interested by this energy efficiency analysis, they are supposed to be the same in all the scenarios.

While is evident a decrease in the cooling and fans consumption between the 1st and the 2nd scenario of respectively 689,06 [kWh] and 314,27[kWh]. The cooling aspect is important for region of Africa, because of greenhouse gas emission the global warming is increasing the temperature, and in zones that are already this can be a problem for the population in terms of health. [22]

Is a big challenge to cooling up Africa in a sustainable way to achieve the ripple effect but is important also to improve the life quality and to make it with low cost as possible. [23]

For this reason, this trade-off is represented by the choice of a window air conditioner system and to put the thermostat setpoint temperature at 28 °C, which is reasonably low but permit to reduce the cost and the energy consumption.

In the third scenario the thermostat setpoint temperature is always set on 28 °C but this time the interior lights have been changed. In the first two scenarios the fluorescent bulbs have been chosen, they are the most diffused there nowadays. [24]

The results show how much the LED are more efficient than the fluorescent in terms of consumptions in fact it has been reduced from 873,81 [kWh] to 407,78 [kWh], with a saving of 467 [kWh] and a reduction in the cost of the bulbs themselves. [25]

In conclusion the third scenario is the one in which the consumptions are minimized and the higher efficiency is obtained. Another one solution could be interesting instead of the window air conditioner cooling system; The Cooling roof which are a coating roofs with a durable, reflective membrane which reflects the heat of the sun. They are a really efficient and low cost technology. But in this project the window air conditioner has also been selected because the roof had to be free to give space to the PV system.

6.2 PV system simulation using HOMER

6.2.1 Dimensioning

From the data received by EnergyPlus about the consumption of one of the apartments are obtained the ones of the all the 14 apartments by multiplying the consumption for the apartments number. So the final consumption during the whole year calculated as Scaled Annual Average [kWh/day] is 229,90 with a peak of 58.24 [kW].

Given this consumption figures this system can be considered as a mini grid and since Beira is an already big and developed city where the grid is present, it is thought to be on grid.

Instead of there are different problems with the reliability of the present grid, in fact in a report of center for global development of 2018, for Mozambique has been estimate 1,8 outages in a month with a correspondent average of 2,7 hours for outage.[26]

To simulate a realistic grid and not an ideal one in fact have been entered outage parameters. For all these unreliabilities of the grid it has also been considered to put a system with batteries to ensure in case of blackout some hours of autonomy from the grid for the apartments.

The results of the first simulation are reported here:

	PV 230 kW
NPC ($)	64795
COE ($)	0.0122
Initial capital($)	182683
Renewable Fraction (%)	84,2

Table 22 – outputs of initial simulation Homer Pro.

Defining the different parameters:

- NPC: The net present cost (or life-cycle cost) of a Component is the present value of all the costs of installing and operating the system over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime.
- COE: The levelized cost of energy is the average cost per kWh of useful electrical energy produced by the system. Is defined by the following formula:

$$COE = \frac{C_{ann,tot} - c_{boiler} H_{served}}{E_{served}}$$

Where:

Cann,tot = total annualized cost of the system

Cboiler = boiler marginal cost

Hserved = totale thermal load served

Eserved = total electrical load served

The COE is a little bit higher than the one of the grid but the renewable fraction is considerable, so the sustainability of the project is achieved and nevertheless the system is higher enough to purchased energy to the grid.

6.2.2 Sensitivity analysis

To make some consideration about the cost and the economics aspect of the project two sensitivity analysis have been made.

6.2.2.1 Sellback sensitivity

It has been observed how the NPC of the system change if the sellback price of electricity changes. The initial value starts from the half of the price of electricity from the grid and it is supposed to be higher because of the possibility to have some subsidies and incentives for renewable project which help to reduce GHG emissions.

Architecture's results of the system are shown in the next table:

Sensitivity/Sellback Rate ($/kWh)	Architecture/PV (kW)	Architecture/1kWh LA	Architecture/Converter (kW)	Architecture/Dispatch
0.06	229	72	154	LF
0.067	230	72	151	LF
0.075	229	72	116	LF

Table 23 – Architecture Output Sellback sensitivity analysis

The dimensioning of the PV doesn't change too much, while looking at the cost it is evident that the NPC will reduce as the sellback price will grow. As well as the COE will diminishes and the cost of O&M will not only became completely balanced by the electricity sold but also became savings.

Costs results for the different sellback prices of the system are shown in the next table:

Sensitivity/Sellback Rate ($/kWh)	Cost/NPC ($)	Cost/COE ($)	Cost/Operating cost ($/yr)	Cost/Initial capital ($)	System/Ren Frac (%)
0.06	232322.4	0.04390248	405.535	226998	84,24607
0.067	202636	0.03837186	-1825.84	226607.9	84,21625
0.075	182976.1	0.03781623	-2463	215316.7	82,76821

Table 24 – Cost Output of Sellback sensitivity analysis

Nevertheless, as it is shown in the upper table the percentage of renewable fraction, else if in a really little percentage, will decrease.

System's dimensioning results for the different sellback prices are shown in the next table:

Sensitivity/Sellback Rate ($/kWh)	PV/Capital Cost ($)	PV/Production (kWh/yr)	1kWh LA/Autonomy (hr)	1kWh LA/Annual Throughput (kWh/yr)	1kWh LA/Nominal Capacity (kWh)	1kWh LA/Usable Nominal Capacity (kWh)	Converter/Inverter Mean Output (kW)	Grid/Energy Purchased (kWh)	Grid/Energy Sold (kWh)
0.06	137517	371239	4,513361	118,445	72,0576	43,234	38,76229	63,49695	319,164
0.067	138000	372541	4,513361	118,428	72,0576	43,234	38,66852	63,48572	318,331
0.075	137171	370305	4,513361	118,456	72,0576	43,234	34,82069	63,50508	284,644

Table 25 – System Output of sellback sensitivity analysis

This is due to the fact that both the electricity purchased from the grid increase and the one sold decreases because the one produces by the PV is lower as well. But also the Capital cost of the PV decrease so the initial capital cost is lower and the project results cheaper as shown in the graphs below.

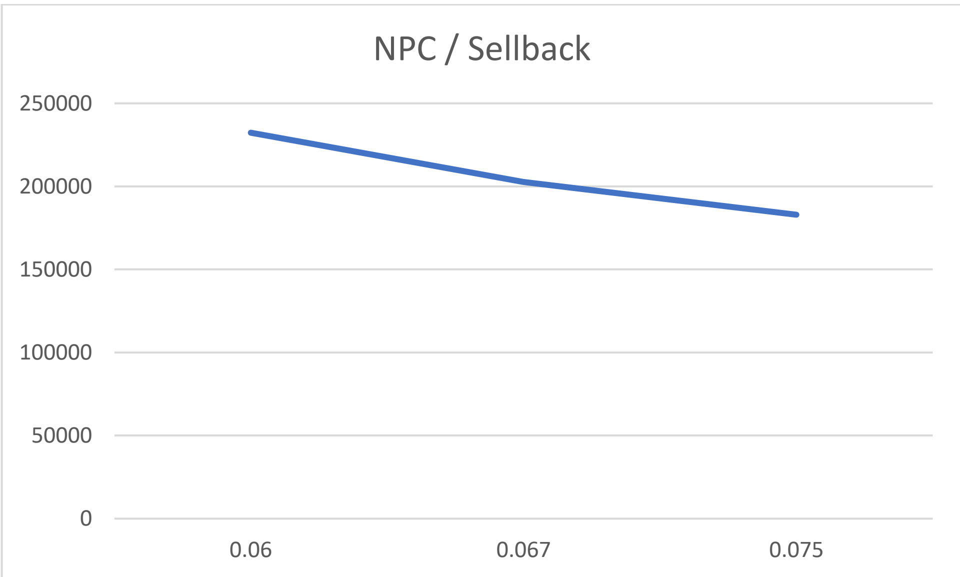


Figure 36 – Final solution NPC over sellback graph

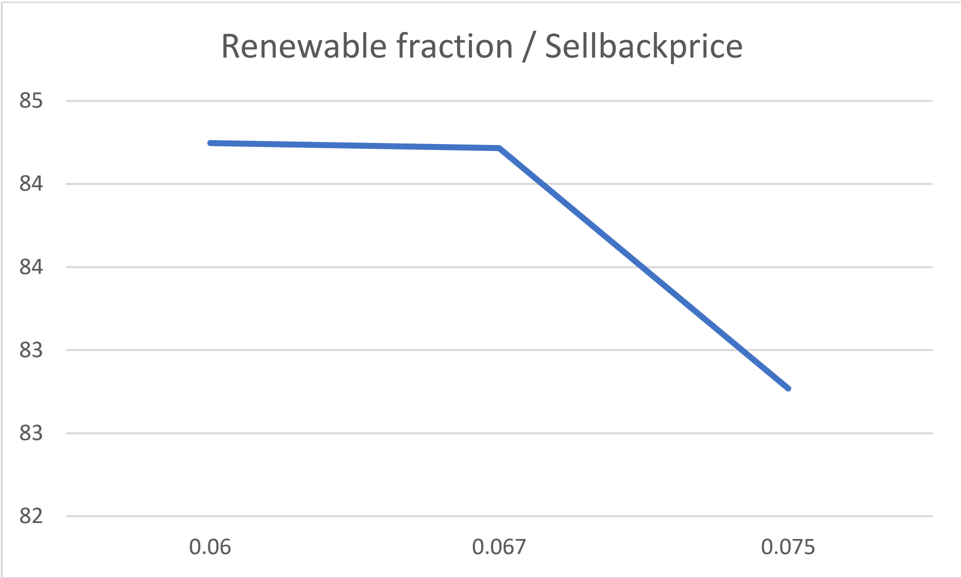


Figure 37 – Final solution renewable fraction over sellback graph

6.2.2.2 PV capital sensitivity

Once the best sellback price has been individuated, equal to 0,067 (USD/kWh), the other parameter chosen for the next sensitivity analysis is the PV Capital cost. It is a really variable parameter for which the range of its variability has been chosen following the data collected in the IRENA report. [14]

Three different capital costs are defined by a multiplier, so starting by 600 USD/kWh with the three different multiplier coefficient (1; 1,25;1,5) the three values are achieved.

Architecture's results of the system are shown in the next table and the optimal solution is highlighted:

Sensitivity/PV Capital Cost Multiplier (*)	Architecture/PV (kW)	Architecture/1kWh LA	Architecture/Converter (kW)	Architecture/Dispatch
1	229	72	154	LF
1.25	227	72	167	LF
1.5	128	81	77.2	LF

Table 26 – Architecture Output PV CAPEX sensitivity analysis Homer Pro.

Concerning the architecture of the project the PV dimensioning decreases as the capital cost increases, this because HOMER is a software which is based on the affordability of the project, so to do not make the initial capital cost too higher and do not have enough earnings the architecture of the whole system will be reduced.

Cost's results of the system are shown in the next table and the optimal solution is highlighted:

Sensitivity/PV Capital Cost Multiplier (*)	Cost/NPC ($)	Cost/COE ($)	Cost/Operating cost ($/yr)	Cost/Initial capital ($)	System/Ren Frac (%)
1	232322	0.0439	405,53	226998	84,2
1.25	269734	0.0507	495,98	263222	84,2
1.5	305578	0.0932	9013	187247	73,6

Table 27 – Cost Output PV CAPEX sensitivity analysis Homer Pro.

For this reason, in the upper table is shown as the renewable fraction will get lower as the capital Pv cost will increase, reducing the dimension of the system, the quantity of energy produced by the PV in a clear way will be reduced and so the electricity coming from the grid will increase.

System's dimensioning results of the system are shown in the next table and the optimal solution is highlighted:

Sensitivity/PV Capital Cost Multiplier (*)	PV/Capital Cost ($)	PV/Production (kWh/yr)	1kWh LA/Autonomy (hr)	1kWh LA/Annual Throughput (kWh/yr)	1kWh LA/Nominal Capacity (kWh)	1kWh LA/Usable Nominal Capacity (kWh)	Converter/Inverter Mean Output (kW)	Grid/Energy Purchased (kWh)	Grid/Energy Sold (kWh)
1	138000	372542	4,51	118	72,1	43,2	38,7	63486	318332
1.25	172500	372542	4,51	118	72,1	43,2	38,7	63486	318814
1.5	182203	327914	4,70	121	75,1	45	33,5	63932	237806

Table 28 – System Output PV CAPEX sensitivity analysis Homer Pro.

In the graphs below is shown how the NPC and the renewable fraction will vary by changes the capital cost of the PV, it is clear that no one parameter will get better as the capital cost increase, the NPC will increase while the renewable fraction will decrease.

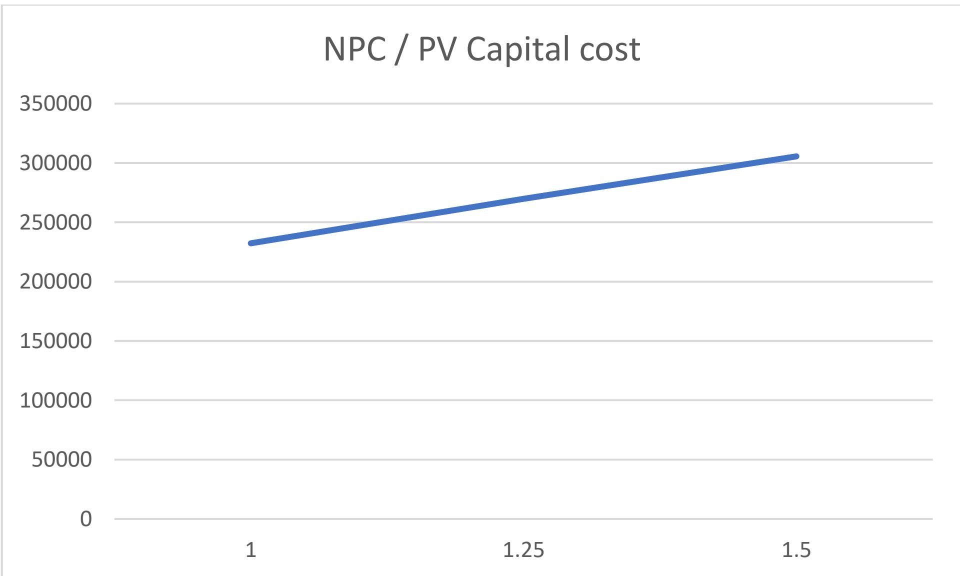


Figure 38 – Final solution NPC over PV capital cost graph

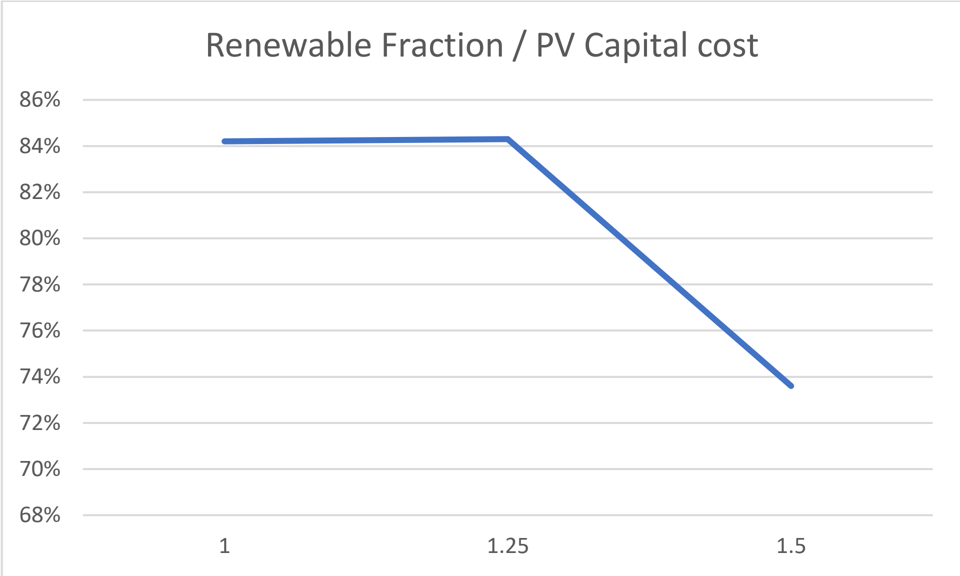


Figure 39 – Final solution renewable fraction over PV capital cost graph

So the optimal solution both economically and the less pollutant one is the first one with a PV capital cost of 600 USD/kWh as highlighted in yellow in the previous tables (table 26, table 27, table 28).

FINAL CONSIDERATION

The aim of this project is to show how it is possible to rethink about how, in a post disaster situation as the one in Beira, some places and spaces can be rethought and renovated based on the concepts of sustainability and resilience. The integration of the whole work between architects and engineers allowed both the capacity to choose material and building characteristic as resilient as possible and most simple and integrative taking also into account the not really comfortable economic situation of the site. The compromise of the economic capacity and the sustainability is trying to be achieved in the most efficient way as possible, to guarantee a better standard of life of the people which nowadays have not a house and live in really bad health and hygiene conditions.

To bring them electricity and the possibility to have a place to improve their quality of life in communities is important to make them able to redeem themselves. The possibility also to create a mini grid system to provides to the grid renewable energy and that allow the person living there to cope with the blackouts, outages and unreliability of the grid is a step forward. Hoping that this should be an example of the direction which now need to be taken to fight the climate change and its effects that have been really tangible and dramatic especially in this country.

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