UNIVERSITE JOSEPH KI-ZERBO

ECOLE DOCTORALE INFORMATIQUE
ET CHANGEMENTS CLIMATIQUES

BURKINA FASO

Unité-Progrès-Justice

MASTER RESEARCH PROGRAM

SPECIALITY: INFORMATICS FOR CLIMATE CHANGE (ICC)

MASTER THESIS

Subject:

Green Building Models for Climate Change Adaptation and Mitigation in Urban Areas of Benin:

Case of Natitingou and Parakou

Student:

Crespin MOUTO

Major Supervisor

Dr Ousmane Coulibaly

Associate Professor at

Université Joseph KI-ZERBO

Co-Supervisor

Dr Benewindé J-B Zoungrana

Senior Lecturer at

Université Joseph KI-ZERBO

Academic year 2021-2022

ACKNOWLEDGEMENT

I want to start by thanking the Almighty God for making it possible for me to be able to study in Burkina Faso and go through this research project. His love, grace and mercy upon my life have seen me this far, and for that, I appreciate His holy name.

Most importantly, my gratitude goes to WASCAL team for the confidence placed in me by selecting and financing my studies in this program. May God Almighty bless this team abundantly.

I'm thankful to the Professor Tanga Pierre ZOUNGRANA, the Director of Ecole Doctorale Informatique et Changement Climatique" (ED-ICC) for all the efforts he is making for the success of this program. In addition, I recognize the entire staff and administration of EDICC-IC and those of the Universite Joseph Ki-Zerbo for the different helps they have been providing to us from the beginning of the program until now. I'm grateful.

Also, I want to acknowledge the help rendered by the Deputy Director of ED-ICC in the person of Dr Coulibaly Ousmane and the Scientific coordinator in the person Dr Benewindé J-B Zoungrana. Indeed, they are my supervisors and they are resourceful and very helpful in guiding and monitoring, the data collection, data analyses, the designing and the writing process.

This is also an occasion for me to thank the Dr Gabin Aclombessi the Director of Direction Departementale du Cadre de Vie et du Developpement Durable de l'Atacora-Donga (DDCVDD) different helps and orientations during my internship and for the success of this research work.

I cannot forget thanking Mr. Apollinaire Alohou, Inspector of Environment of DDCVDD who has been a constant source of support and encouragement during my internship and during the challenges of this thesis work.

I thank my parents, Adrien MOUTO and Odette KOGO who have always loved me unconditionally and whose good examples have taught me to work hard for the things that I aspire to achieve. This gratitude is also for my entire family for their endless supports and prayers during the process of this program.

Finally, my colleagues and some of my friends, I also want to acknowledge their efforts in every way that they were able to come through.

ABSTRACT.

The aim of this study is to develop models of green buildings ensuring the efficient management of energy, the greening of urban areas, and then the adaptation to global warming and the mitigation of this global warming in the urban areas of Natitingou and Parakou. To achieve this objective, we went through data collection, site analyses, the design of green building models and their analyses. For the data collection, different methods have been used such as: observations, measurements, pedestrian crossings, map analysis, model analysis, site analysis and internet searching. Climate data, Population data, sun system data and vegetation data are analyzed respectively with climate consultant software, Microsoft excel, Rhino grasshopper and iTree tools. The design is done with SketchUp. The result from the analyzes of the models shows that they are rentable in term of energy, comfortable (100% in Natitingou and 86% in Parakou), adapted to the increase in urban vegetation (60% of the built area), carbon sequestration (1.818 thousand tons of carbon in Parakou and 579.1 tons of carbon in Natitingou per year), carbon storage (27000 tons of carbon in Parakou and 8600 tons of carbon in Natitingou), Oxygen production (4.848 thousand tons of oxygen in Parakou and 1.544 thousand tons of oxygen in Natitingou per year) and then to the adaptation and mitigation of climate change.

Keywords: Climate change, Adaptation and mitigation, Green Building model； Energy efficiency, Urban area.

RESUME

L'objectif de cette étude est de développer des modèles de bâtiments verts assurant la gestion efficace de l'énergie, le boisement des zones urbaines, puis l'adaptation aux réchauffements climatiques et leurs atténuations dans les zones urbaines de Natitingou et Parakou. Pour atteindre cet objectif, nous sommes passés par la collecte de données, par des analyses de site et par la conception de modèles de bâtiments écologiques et leurs analyses. Pour la collecte de données, les méthodes utilisées sont : observations, mesures, marches, analyse de carte, analyse de modèle, analyse de site et recherche sur Internet. Les données climatiques, les données sur la population, les données sur le système solaire et les données sur la végétation sont analysées respectivement avec les logiciels Climate Consultant software, Microsoft Excel, Rhino GrassHopper and iTree. La conception est réalisée avec SketchUp. Les analyses des modèles révèlent qu'ils sont économes en énergie, confortables (100% à Natitingou et 86% à Parakou), adaptés à l'augmentation de la végétation urbaine (60% de la surface bâtie), à la séquestration du carbone ($1818000t$ de carbone à Parakou et $5791000t$ de carbone à Natitingou par an), au stockage de carbone ($27000t$ de carbone à Parakou et $8600t$ de carbone à Natitingou), la production d'oxygène ($4848000t$ d'oxygène à Parakou et $15440000t$ d'oxygène à Natitingou par an) puis à l'adaptation et l'atténuation de changement climatique.

Mots-clés : Changement climatique, Adaptation et atténuation, Modèle de construction verte； Efficacité énergétique, Zone urbaine.

LISTE OF TABLES

LISTE OF PICTURES

Introduction

Context of the study

In society, man's primary need since his existence on earth, if it can be said without fear, was to protect himself, to shelter himself from different weather conditions, dangerous animals and hunger. This need was to build houses and those infrastructures. As the population increases and human beings' needs increase with improvement of living standards, the proportion of buildings density towards urban area development with human activities is increasingly becoming imminent. This results in urban sprawl, high energy consumption, and greenhouse gases emission. Climate change is in large part the result of greenhouse gas (GHG) emissions (Pachauri, R.K. and Reisinger, A., 2008). Approximately 43% of World carbon dioxide (CO2) emissions result from the energy services required by residential, commercial, and industrial buildings, while transportation accounts for 32% and industry accounts for 25% (Brown et al, 2005). However, even if GHG emissions are reduced enough to stabilize their concentration, climate warming will continue for centuries (Desjarlais, C. et al, 2010). Thus, assessments of GHG reduction have itemized the many ways that building services could be provided in a more energy-efficient manner. Cities are particularly vulnerable to climate change because of the concentration of population, infrastructures and material goods set on their territory (ONERC, 2010). It is also important, however, to consider other GHG impacts affiliated with the built environment, including: the effects of alternative urban designs; the use of on-site power generation; and the life-cycle GHG emissions from building construction, materials, and equipment. On the other hand, Urban greenery and energy use reduction are considered as important factor in relation to sustainable development, people's quality of life and climate change adaptation in the city (Yusuke Kumakoshi, et al., 2020). Vegetation plays an important role in local climate by sequestering carbon, by refreshing the air, by providing shading, by reducing temperature and provoking rains. It is then clear that urban vegetation is key point in climate adaptation and mitigation. This perspective leads to climate change strategies that address not only how buildings in the future are to be constructed and used, but also how they will interface with the electric grid and where they will be located in terms of urban densities and access to employment and services (Marilyn A Brown, Frank Southworth, 2006).

Problem Statement

After some investigation and observation of some habits in Benin urban areas especially in the cities, it is shown that more the number of buildings increases, more the vegetation cover in the city decreases (The World Bank, 2021). The way people build houses doesn't help to preserve the urban areas green and reduce the energy consumption. They remove the trees, plants and herbs to implant their buildings. This happens to such an extent that vegetal coverage areas are replaced by new buildings. This results in the increase of urban temperature and an increased use of air conditioners for comfort in buildings (Yuangao WenZhiwei Lian, 2009). This situation in the cities of Benin republic may potentially worsen or exacerbate urban heat and increase more energy demand if no new approaches are found from the design stage for building houses and those facilities in the cities.

Green buildings and smart growth strategies are key to reducing global greenhouse gas (GHG) emissions in the future (Marilyn A Brown, Frank Southworth, 2006). The first green buildings arose in response to the shortage of energy and the need for resource efficiency. The intentions were clearly based on an environmental perspective, apparent in the label "green building" (Marius Sachs, 2016). Gradually, the awareness manifested that besides energy efficiency, a building and its surrounding must be viewed from a holistic perspective. So, according to Elkington (1999), "A green building is meant to be a building that contributes, through its characteristics and attributes, to sustainable development. By safeguarding and maximizing functionality and serviceability as well as aesthetic quality, a green building should contribute to the minimization of life cycle costs, the reduction of malicious impacts on the environment, the protection and the increase of capital value. It can also contribute to the reduction of land use, resources, raw material and resource depletion; the protection of health, comfort and safety of workers, occupants, users, visitors and neighbors; and (if applicable) to the preservation of cultural values and heritage. Green buildings can be considered as both adaptive and mitigation strategy because they help reducing the energy demand of household (Pathak et al. 2013). A reduction of sick time was noticed when comparing staff working in a conventional building to the one in green construction because having those benefits that are the utilization of natural light, scalable and adequate ventilation and lighting, the absence of toxic emitting interiors and a comfortable temperature (Miller et al. 2009). Bitter is our finding that most homes in the urban areas of cities are in a dilapidated state and are not designed to adapt and mitigate global warming to which we are the most vulnerable. And this danger in these cities is not capturing the attention of our decision makers. Moreover, there are not many research publications on this issue in West Africa. Housing has an important role to create the balance of human life in urban areas while creating the social links between different urban fabrics. To address this situation, key techniques should be applied from the design stage of the buildings. These techniques should be included in building regulations conurbation. All this will efficiently improve the energy performance of the buildings and favor the increase of the urban vegetation. These are the reasons that motivated our choice of the topic: Green buildings models for climate adaptation and mitigation in urban areas of Benin.

Research questions

The present study has the following principal research question: what approaches can be adopted for urban facilities (houses, roads, …etc.) buildings to minimize energy consumption and urban vegetation destruction in Benin (Natitingou and Parakou)?

Specifically, it attempts to know:

- How have the building practices and urban planning affected urban vegetation and climate over the past thirty years in the two study areas in Benin?
- What are the advantages of green building model proposed for climate clange adaptation and mitigation at the building or city scales?

Research hypotheses

The main research hypothesis is that green building models contribute to the adaptation and mitigation of climate change effects in Natitingou and Parakou cities.

The specific hypotheses are:

- In the past thirty years, the building practices and urban planning have favored vegetation cover loss and temperature increase in the cities of Benin.
- Green building model proposed improves urban vegetation cover, people life style, and climate change mitigation and adaptation.

Objectives of the study

The main objective of this study is to develop a model of buildings ensuring urban areas greening, energy consumption reduction, adaptation and mitigation of climate change.

Specifically, the study aims to:

- determine the effects of building practices and urban planning on urban vegetation and climate over the past thirty years in Benin's cities.
- access, at the building and city scales, the advantages of the green building model developed in urban areas and building interior comfort for climate adaptation and mitigation.

Chapter 1 : Literature Review

1.1. State-of-the-art

The negative consequences of climate change in the news and the associated negative effects are spread almost daily around the world. Decades of research have shown that greenhouse gases released into the earth's atmosphere make a significant contribution to climate change (USEPA 2016). From being an issue associated with pollution (Revkin 2018), greenhouse gas emissions have now become central to climate change debate, and ongoing researches continue to find a way out of the current crises (IPCC 2018; Revkin 2018). Buildings can have significant environmental impacts, and the built environment's energy intensity needs to improve by 30% by 2030, in order to meet the goals of the Paris Climate Agreement aiming to limit global temperature rise to 1.5 degrees Celsius (IPCC 2018, pp. 127–129; UNEP 2017, pp. 18–21). Due to the high amount of energy consumption during their life cycle, particularly during their operational phases, buildings release attendant greenhouse gases across their lifecycle, leading to detrimental effects on the environment (EPA 2009). In addition to the negative environmental causes as a result of buildings operations, the very act of building impacts resources uses. Various materials and resources, including the use of mining to make commonly used materials such as steel, concrete, and glass are consumed by building industry (WGBC 2018, Pramenik et al. 2019). Water is also extensively used in buildings, during the process of construction, post-construction, and in operation (Al-Qawasmi et al. 2019). Buildings also generate a huge amount of waste, again during the construction process and are in center of urban areas land use. (Wu et al. 2019).

In order for an urban area to function effectively, all the needs of its citizens must be met. So, urban planners divide the land up into six types of land uses such as: residential, transportation, institutional, Open space, industrial and commercial (Clark et al, 2006). The residential land use is where people live. The type of housing in an area is based on residential density defined by Number of housing units in a hectare. The transportation land use is the one used for moving people and goods from one place to another including sidewalks, roads, highways, subways, streetcars, railroad tracks, freight yards, airports, marinas and any other land that is used for transportation. In addition, the land that is occupied by schools, hospitals, government offices, and places of worship is classified as institutional land use. The industrial land is used for industries like factories, warehouses, power plants, or places of resource extraction. The commercial land use is set aside for commercial activities including any land used for buying, selling, or trading goods and services. The urban areas greening is generally centered in open space land use by planners (Uwe R. Fritsche et al. 2017). Open space land use concerns the land that is now vacant, or left in a natural state (like a woodlot), or land that is for recreational use. Being in small proportion in urban areas because of population density, the open spaces are not able to house too much vegetation cover that can cover the needs of urban residents. In addition, In the planning of some areas in the world like Turkey, Japan, China, Singapore and New York urban areas, planners make the use of Building Coverage Ratio (BCR) and Floor Area Ratio (FAR) reduction to efficiently minimize the land occupation by buildings and limit building density (Moon et al 2022). This can help to have open spaces in built areas that the land owners can decide to use for vegetation cover or not. It does not give any specification about the built area greening, energy saving and doesn't favor certainly the urban area greening. So, it urges to find a strategy for urban building industry to build such a way that cannot impact negatively the environment, but to build and increase the urban vegetation and save energy. Consequently, it is very important, for built environment professionals and building users to start thinking about better design, build and operational approaches, while also thinking about the end of buildings' life, in terms of where the deconstructed building materials end up (Usha Iyer-Raniga et al. 2021). This thinking leads to what is called green building.

1.2. Green Building Definition

The concept of sustainable development and green building is relatively new; indeed, over the past two decades it has become one of the most researched and controversial topics in the field of property development and building design and construction generally. Some people take their cue from the environmental movement, arguably begun by Rachel Carson's 1962 book Silent Spring, earth-friendly architecture, environmental architecture, natural architecture, biomimicry and even organic architecture have aspects of green architecture. Also called Eco-friendly building, environmentally friendly building, environmentally safe building, High performance building, Nonpolluting building, green architecture, ozone-friendly building or sustainable building and construction, the green building has many definitions. One definition offered by the Office of the Federal Environmental Executive (OFEE) for green building is "*the practice of increasing the efficiency with which buildings and their sites use energy, water, and materials, and reducing building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and removal the complete building life cycle*" (Howard JL. 2003). The

Environmental Protection Agency (EPA. 2009) defines green building as, "*the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction.*" Jacob Kriss of the U.S. Green Building Council (USGBC, 2013) defines green building as: "*a holistic concept that starts with the understanding that the built environment can have profound effects, both positive and negative, on the natural environment, as well as the people who inhabit buildings every day. Green building is an effort to amplify the positive and mitigate the negative of these effects throughout the entire life cycle of a building.*" Green design is the knowledge of building that treats environmental factors as design objectives and not as constraints. Once constructed, the green building continues to reduce environmental impacts; create economic benefits; and improve social and well-being outcomes. It is only when all economic, environmental and social aspects are integrated in the building system throughout its life cycle, that a building can serve its purpose of being green (Usha Iyer-Raniga et al. 2021). A green building is a building that, in its design, construction, or operation, reduces or eliminates negative impacts and can create positive impacts on the climate and natural environment.

Figure 1: Green Building

Source: https://www.worldconstructiontoday.com/articles/improvising-through-green-buildings-and-green-infrastructure/

When we talk of sustainable building, we mean to get rid of the harmful reaction on the environment and also the protection of people living in the building. According to Chan, et al., (2017), the main specifications of the green building technologies are: efficient utilization of resources (energy, and water); enhancing and protecting the health and well-being of the occupants of buildings, and; reducing negative impacts on environment (waste, sewage, and pollution). So, for a building to be qualified as green building especially in the context of our study, some features are required. Some of these as documented by Das, et al., (2016) include the following:

- Energy efficient equipment for air conditioning, lighting system and use of onsite renewable energy;
- Reduction of building footprint to minimize the impact on environment;
- Use of recycled and environmental-friendly building material;
- Efficient use of water recycling;
- Indoor air quality improvement for the safety and comfort of human;
- Installation of high efficiency irrigation methods and selection of vegetation which have low water consumption;
- Recycling of construction debris to other sites;
- Use of rapidly renewable materials;
- Providing daylight and views for the occupied areas.

1.3. Green building Adoption aims

Figure 2: Sustainable Development Goals.

Source: *https://www.worldgbc.org/news-media/green-building-improving-lives-billions-helping-achieve-un-sustainable-development-goals*

Green building can be a way for countries to make their nationally determined contributions required in the Paris Agreement (Yayun Shen and Michael Faure 2020, p. 2). On account of the important role green building plays in environmental protection and resource conservation, more and more people have started to pay attention to it. Green Building promotes the efficiency of buildings with regards to the use of water, and other materials which are very vital for maintenance (see Figure 4). But mostly under this area, the design is put forward to solve the social insecurity and the inequality that has been created because of the rise in the human needs and demands in a certain area. Green Building is all about the complete building life cycle; it is also regarded as sustainable building or environmental building (see Figure 5). The term “Green Building” is often used in combination with high-performance building, sustainable design and preserving precious resources, aligning to the sustainable development goals (Wienerberger, 2009).

1.4. Green building evolution

Green building has seen a growth in many jurisdictions such as Europe, the USA, Canada, China, India, and Australia (Dodge Data and Analytics 2018, p. 7), where various legal and policy instruments are in place to stimulate green building (Annunziata et al. 2013; Howe and Gerrard 2010; O’Neill and Gibbs 2018; Rosenow et al. 2016; Uihlein and Eder 2010). Those policy instruments mostly rely on regulation, liability rules, self-regulation, or a combination of those (Kivimaa and Martiskainen, 2018).

The drive to design, procure, build and operate green buildings reflects the shift to and movement to a new green paradigm (Ahn et al. 2012). The green building movement may be traced the oil crises of the 1970s where energy efficiency and conservation underpinned research influencing building design and operation (Revkin 2018). There was awareness that coal and oil will not last forever, and a recognition to move away from dependence on fossil fuels for energy generation and use (Zhao. 2018). Over the decades since then, phenomena such as change and sustainable development emerged globally, which have further led to various drivers leading to the current approach focusing on holistic sustainability underpinnings through recognizing environmental, economic and social consequences of the impact of buildings (Usha Iyer-Raniga et al. 2021). International agreements to reduce the greenhouse gas emissions such as Paris Agreement signed in 2015 and a dedicated “Building Day” for the first time UNFCCC conference of parties 21 (UNFCCC 2020) signals a clear commitment to recognize the impact of built environment, and engage meaningfully with the built environment community (DEE 2019; UNFCCC 2020). Such efforts follow from previous agreements such as the Kyoto Protocol signed by countries to combat the rise of greenhouse gas emissions and to put policies in place to reduce these emissions (UNFCCC 2015). The setting up of the Intergovernmental Panel on Climate Change (IPCC) by the United Nations is another global effort. The IPCC provides policies and strategies to combat the adverse effects of climate change (UN 2019). Additionally, the UN Sustainable Development Goals (SDGs) that came into effect in 2016 particularly SDG 11, 12 and 13 on Sustainable Cities and

Communities, Responsible Consumption and Production, and Climate Action (IPCC 2018; UN 2019) bring attention specifically to the building sector. The SDGs follow the development of the UN Millennium Development Goals (MDGs) (UN 2017) that came into effect at the commencement of the century. The MDGs focused on social and environmental issues but did not specifically bring focus to the built environment in the way the SDGs have (UN 2019). All these efforts and increasing local pressures faced due to changing climatic conditions have acted as major driving force for adopting greener practices where possible. Due to buildings having a significant impact, the efforts have been streamlined specific to buildings expecting better outcomes, and planning for future projects as well. With an understanding of the shift towards green buildings due to the various drives, this entry moves to discussing several benefits of green buildings.

1.5. The Concept of Green Space

Green areas and thriving city ecosystems have good impacts at the whole community. Trees and different flowers lessen air pollution, offset emissions and decrease the "heat island effect," where, concrete and different infrastructure traps warm temperature in cities. Community gardens and urban farms feed communities, even as costal parks increase resistance to floods, increasing the sea level and the impacts of climate change. Cities are developing unexpectedly and the growing urbanization without responsible administration harms the citizens and threatens neighborhood vegetation and fauna. However, these challenges also offer an opportunity to change our approach to urban living, to embrace nature and the biodiversity that is an essential part of city living (Danielle Shanahan et al. 2014). Around the world, cities are developing innovative plans to make green spaces accessible to all and to expand and protect urban ecosystems. Comprehensive citywide strategies to increase access to green spaces, green infrastructure plans and making ecosystem health and growth a key aspect of all city planning, will be essential for creating livable cities in the decades to come as seen in the heart of Jacksonville, a city located on the Atlantic coast of Florida in United States in the figure 3. Green infrastructure and green spaces can include parks, trails, gardens, urban farms, waterfront revitalization, and green roofs. Planting native species should be a priority for all green space. Urban Forest programs and vacant lot conversion projects are also initiatives that have key benefits for both ecosystem and community health. Green corridor plans enable the movement of species throughout the city and to surrounding areas by linking together green spaces (Bertaud, A. 2004).

Figure 3: Jacksonville
Source: https://www.newprocontainers.com/blog/benefits-urban-green-spaces/

Many cities are starting to work towards spreading green urban spaces because they provide great benefits for urban areas and their inhabitants. Some of the problems faced by cities today are air pollution, urban heat and extreme temperatures in summer and winter. The creation of an urban biodiversity layer is the solution to these problems, as they significantly contribute to the improvement of environmental conditions in cities in many ways: for example, green roofs act as sinks for CO2, the gas responsible for climate change. For each 100 square meters of green roof, the gas responsible for the greenhouse effect is reduced by 1.8 tons per year. Green spaces can reduce the ambient temperature of cities by 1°C, thus reducing the urban heat island and harmful city smog. In this sense, 1°C cooler urban environments prevent the harmful ozone layer that is triggered during intense heat episodes from forming (D. Bradley Rowe. 2010).

According to recent studies, cities with more green areas boost social cohesion and relations, since they are meeting points to share and create links between city inhabitants. In recent years, the number of days in China with "blue sky and white clouds" has increased significantly. Data from China's Ministry of Ecology and Environment showed that the average concentration of PM10 particles in 338 cities at and above the prefecture level dropped by 22.7 percent in 2017 compared with 2013, and the number of days of heavy pollution in 74 key cities decreased by 51.8 percent compared with 2013.China's experience in air pollution control has attracted international attention.

We don't have any other examples in history of countries that have been able to reduce pollution so much in such a short period of time (D. Bradley Rowe, 2010).

Figure 4: Green Spaces methods.
Source: https://www.greenroofs.com/wp-content/uploads/2020/10/newslinks-ARUP-Green_Envelope.jpg

In the figure 4, we can see different ways of implementing green spaces in built up cities. There are multiple ways to incorporate green spaces and create green architecture. For example, vertical gardens on building facades, green roofs, greenhouses, hives and green roads, urban gardens, and many more.

1.6. Green Building Challenges and Barriers

Climate change has been the biggest challenge on the planet and scientists are studying and introducing green building in an effort to solve this problem. The planet will move on for tens of thousands and thousands of years, lengthy after human lifestyles has expired. Climate change, however, can damage the species of lifestyles on Earth that cannot adapt speedy sufficient to new conditions. The building trades have collectively recognized its role in contributing to the greenhouse gases put into the atmosphere. For example, the manufacturing of cement, the basic ingredient in concrete, is reportedly one of the largest global contributors to carbon dioxide emissions (Jackie Craven, 2019). From poor designs to construction materials, the industry is challenged to change its ways.

Despite its many benefits, the Green Building Technologies adoption still encounter various barriers. Advantageous to the successful adoption and promotion of Green Building Technologies is a clear understanding of these barriers, which can help to find ways to address the barriers and thus promote the widespread Green Building Technologies adoption. Like several other countries, Benin encounters barriers in Green Building Technologies adoption. These barriers are due to various reasons ranging from economic and local market conditions to human attitudes. The chief barriers to the Green Building Technologies adoption in Benin, however, are: higher costs of Green Building Technologies; lack of government incentives; lack of financing schemes; unavailability of Green Building Technologies suppliers; and lack of local institutes and facilities for Green Building Technologies research and development (Chan APC et al. 2018). As Berardi substantiated, the most recognized barriers to the Green Building Technologies and practices adoption are economic ones (Berardi U. 2013).

1.6.1. Higher Initial Costs of Green Building Technologies

As an economic issue, cost has been a long-standing major barrier to the widespread adoption of Green Building Technologies and practices (Yudelson J. 2008). Of course, even though the extra cost of adopting Green Building Technologies can be compensated for in a lifecycle perspective, the higher initial cost of Green Building Technologies could be a barrier to the Green Building Technologies adoption. Green Building Technologies typically cost significantly more than non-green building technologies. For example, Hwang and Tan reported that, as a green substitute for conventional plywood, compressed wheat board costs around 10 times more than conventional plywood (Hwang BG et al. 2012). Additionally, energy-efficient technologies may be more expensive. In essence, the higher costs of Green Building Technologies add to project cost and could be a major problem for project stakeholders as long as they remain sensitive to financial issues. Research has established that green building projects cost about 9.37% more than non-green building projects (Vyas GS et al. 2018). A remarkable part of this phenomenon could be attributed to the higher costs of Green Building Technologies. Some also trust that the use of Green Building Technologies can increase project cost by 10% to 20% (World GBC. 2013). In the light of these issues, the higher costs of Green Building Technologies may represent a main impediment to Green Building Technologies adoption in construction projects within especially developing countries such as Benin wherein, poverty is prevalent and entrenched (Cooke E. et al. 2016). In Benin, only some Non-Governmental Organizations are trying to invest in lower-cost building through Nubian

Vault program developed mostly in the northern part of the country. The Nubian Vault (NV) technical concept is an ancient architectural technique which does not require the use of increasingly precious timber or costly and inconvenient imported metal roofing sheets. Built essentially from widely available earth (adobe) bricks and mortar, the Nubian Vault provides a solution for affordable and well-adapted buildings suitable for private and community use, in both rural and urban settings.

Figure 5: Nubian Vault

Source : https://blogifsa.wordpress.com/2017/05/21/the-naubian-vault-association-a-way-towards-an-environmentally-socially-just-society/

While this is a wonderful example of how to reduce emissions, preserve the environment and decrease poverty without financial constraints stagnating progress, there are many other initiatives with great potential which do not yet have a clear picture of how to realize them without financial support (Celina Schelle, 2017). Despite the fact that people think the green buildings are costly, some African countries like Ghana, Nigeria, Senegal, Mali, Burkina Faso,… have also recognized their potentials in climate adaptation and mitigation. But the effort of these countries for green building technologies adoption in the subregion of west Africa isn't sufficient.

1.6.2. Lack of Government Incentives

Indeed, authority's management and function are essential for the adoption and advertising of Green Building Technologies, and that is especially real in developing countries in which the adoption of green building technologies is still in its infancy at its beginnings. Within such countries, the government needs to take a more proactive role in promoting the Green Building Technologies adoption by taking a variety of relevant actions, one of which is providing incentives both financial and nonfinancial incentives to stimulate the Green Building Technologies adoption. An incentive may be described as something that impacts people to act in some ways (Ozdemir MH. 2000). Essentially, in the green building context, government incentives impact people to accept and embrace Green Building Technologies in their construction projects because they help in many ways, including offering compensation for the extra cost and time that the Green Building Technologies adoption might require. However, unfortunately, Benin presently has no government incentive schemes directed toward the use of Green Building Technologies in construction projects, a situation that is largely contributing to the slow pace of Green Building Technologies adoption in the country. Even in the document containing the regulations about buildings which is the base of getting the right to houses building in Benin (Permit de Construire), there is nothing concerning green building. This could mean directly that fighting global warming through green building technologies isn't yet among the priorities of the government and the decision makers of Benin.

1.6.3. Lack of Financing Schemes

Collecting money for projects is always a challenge for every stakeholder (Yudelson J. 2008). This challenge is more important to those who need to collect money for ecological construction projects that include organic construction technologies with higher costs. Thus, over the past decade, there has been an increasing number of third-party financing sources for investing in green projects and hence Green Building Technologies. While this holds true in developed countries such as the USA, UK, Australia, Singapore, and Hong Kong, the opposite situation exists in Benin. So, Beninese practitioners have a difficult time trying to find financing sources for green projects that can defray the high costs of Green Building Technologies. Again, the lack of financing schemes also makes it hard to deal with the cost barrier in the Green Building Technologies adoption in Benin. Bank loans, for example, are one of the most common financing schemes for green projects around the world (Shan M. et al. 2017). Yet, within Benin, it is arduous to find banks and other financial institutions that grant loans for green projects.

1.6.4. Unavailability of Green Building Technologies Suppliers

Suppliers have an important part in the successful adoption of Green Building Technologies. They are not only the vendors who serve the industry with the needed Green Building Technologies, but also the main source of information concerning the Green Building Technologies. But, the unavailability of Green Building Technologies suppliers that result in unavailability of Green

Building Technologies in the local market has been a key barrier to Green Building Technologies adoption in Benin. This barrier is even encountered generally in existing green building projects in west African countries (A. Darko et al. 2020). For instance, it was encountered in the Ridge Hospital project in Ghana where the architect revealed that most of the infrastructure and technologies that support green building in developed countries such as the USA and Canada do not exist in Ghana (Bubbs D. 2017). A similar situation can be found in other developing countries like Benin, implying that the current Green Building Technologies supply chain within developing countries remains immature with a shortage of suppliers (Aktas B et al. 2015).

1.6.5. Lack of Local Institutes and Facilities for Green Building Technologies

This is another important barrier to the Green Building Technologies adoption in Benin. The implementation of green Building is of vital importance as it helps both in developing innovating green Building Technologies and in finding out the advantages of those inexperienced Building Technologies. Nevertheless, the Green Building Technologies adoption and development in developing countries lag behind that in developed countries, owing to that it is usually faced with a lack of Green Building Technologies funds, institutes, and facilities (Zhang X. 2015). The Green Building Technologies requires a great deal of financial support for founding green technology research institutes/centers, educating/training, and recruiting qualified Green Building Technologies experts, and this may be a large amount of money for developing countries such as Ghana to handle. As a result, Ghana has yet to establish accredited Green Building Technologies institutes, resulting in a serious lack of Green Building Technologies capacity in the country. Additionally, the Green Building Technologies education is still not better developed, leading to a lack of Green Building Technologies experts in Benin. In essence, the current Green Building Technologies situation in Benin proves to be a major barrier for Benin in the adoption of Green Building Technologies.

1.7. Urban area definition

An urban area, or built-up area, is a human settlement with a high population density and infrastructure of built environment. Urban areas are created through urbanization and are categorized by urban morphology as cities, towns, conurbations or suburbs. In urbanism, the term contrasts to rural areas such as villages and hamlets; in urban sociology or urban anthropology it contrasts with natural environment. The creation of early predecessors of urban areas during the urban revolution led to the creation of human civilization with modern urban planning, which along with other human activities such as exploitation of natural resources led to a human impact on the environment. "Agglomeration effects" are in the list of the main consequences of increased rates of firm creation since. This is due to conditions created by a greater level of industrial activity in a given region. However, a favorable environment for human capital development would also be generated simultaneously (Baten, Joerg, 2003). So, an urban area is the region surrounding a city including the city itself. Most inhabitants of urban areas have non-agricultural jobs. Urban areas are very developed, meaning there is a density of human structures such as houses, commercial buildings, roads, bridges, and railways. (See figure 6)

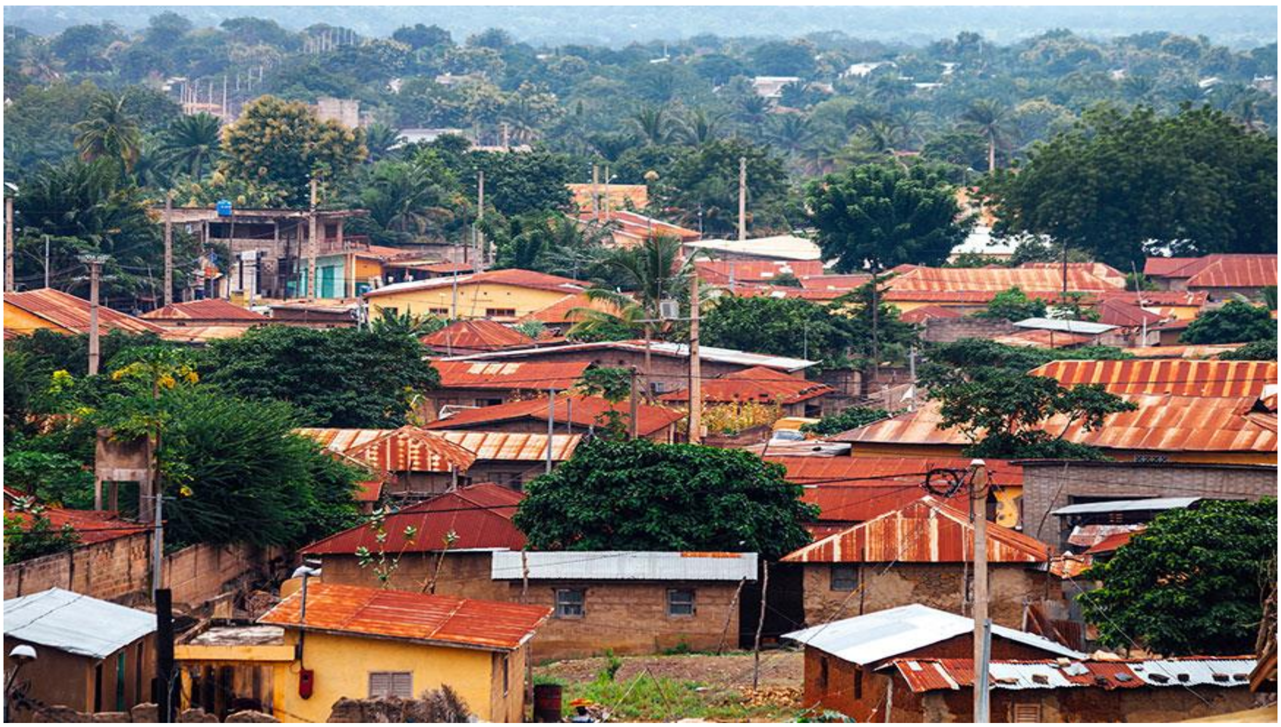

Figure 6: Parakou urban area aerial view
Source : https://www.expatwoman.com/global/benin

Aside from the population, urban places also have common characteristics. Think of 'urban' and many people think of roads, buildings and infrastructure like electricity cables and sewage systems. Others will think of shops, offices and busy transport hubs. Almost all settlements have more than one function, and the larger the urban area is, the more functions it is likely to have. Typical functions of urban function include: Administrative centers, Government services and social amenities, Industrial, Transport, Retail, Residential and Financial (Matt Burdett, 2018). Cities are vital centers of economic and cultural activities. Some causes include rapid rural-to-urban migration, economic stagnation and depression, social conflicts, dense populations, the economic dependence on trade rather than agriculture or fishing (Encyclopedic Entry, 2021). They are already affected by climate hazards such as intense precipitation and heat waves, which under the changing climate are projected to become more intense and more frequent. As the climate change progresses, cities need to adapt in order to remain livable, functional and prosperous in the future.

1.8. Climate Adaptation and Mitigation

Adaptation is the process of adjustment to the actual or expected climate and climate hazards, seeking to reduce the negative impacts or exploit beneficial opportunities. Similarly, as in the case of reducing greenhouse gas emissions, there is also urgency in preparing for the unavoidable impacts of climate change. The framework for adaptation is largely one of first establishing the local level and kind of physical vulnerability to natural disasters, and then encouraging local studies to determine appropriate responses (Pizarro, Blakely, & Dee, 2006). Generally, responding and planning for natural disasters has a much longer and deeper literature than adaptation (see for instance Hamnett, 2006), and thus adaptation benefits from this. For example, the issue of vulnerability measures is picked up by Gurran et al. (2008). Mitigating climate change requires a denser urban environment to reduce vehicle miles traveled and building energy use, while adapting to climate change requires open space available for stormwater management of severe storm events, species migration, and urban cooling, among other goals. The likely best urban form, we argue, must bring greenspace within settlements focused along green transportation routes and floodplains rather than large expanses. Those open spaces must also be designed to achieve multiple goals urban agriculture and floodplain protection, for instance. The urban form which will respond best to the needs of both adaptation and mitigation will be the one where available resource achieve multiple goals. Buildings will need to provide more natural cooling potential, solar power, and moderate density so as to enable transit options (Elisabeth M. Hamin, 2009).

Conclusion of Literature Review

Climate change is becoming widely recognized as the key global challenge of this century. The publishing of the Fourth Assessment Report from the International Panel on Climate Change (IPCC AR4) (Intergovernmental Panel on Climate Change, 2007) and the bestowal of the 2007 Nobel Peace Prize on the IPCC marked the effective end of informed debate on whether climate change is human induced and real. Urban areas are human settlements with a high population density and infrastructure of built environment. The growth and development of our communities and urban areas have a large impact on our natural environment as the erection of mega structures by human beings contributes to the disappearance of many of the earth's resources and the increase of global warming. So, do green building initiatives appear as greater solution. Despite its importance as a solution to climate adaptation and mitigation and the fact that some researchers approached the concept through their publications, the green building technologies adoption is scarce in west African countries especially in Benin because lack of deep knowledge about the concept, higher Initial Costs of Green Building Technologies, lack of Government Incentives, lack of Financing Schemes, unavailability of Green Building Technologies Suppliers and lack of Local Institutes and Facilities for Green Building Technologies. Except the lack of information on the values of green building by Benin building industries and decision makers, there is no many models for the green building proposed to adapt and mitigate climate change hazards in west Africa especially in Benin. Furthermore, a building can look beautiful and even be constructed from very expensive materials, but not be "green." Likewise, a building can be very "green" but visually unappealing. Facing these major challenges, how do we get good green building models for our climate conditions? How do we move toward what Roman architect Vitruvius suggested to be the three rules of building, to be well-built, useful by serving a purpose, and beautiful to look at? We will then propose a model of green building for climate adaptation and mitigation for west African climate change taking particularly the case of a city in the northern part of the Republic of Benin and having in mind that this could help meet the above challenges.

Chapter 2 : Methodology

2.1. Study areas

This study is conducted in two municipalities of Benin republic. We have chosen specifically some cities of Parakou and Natitingou for our work (See figure 20). Formerly known as Dahomey and officially known as the Republic of Benin and formerly known as Dahomey, Benin is located in West Africa in the tropical zone between the equator and the Tropic of Cancer (between the parallels 6°30' and 12°30' of latitude North and the meridians 1° and 30°40' of east longitude). It covers an area of 114,763 Km^2 and is bordered by Togo to the west, Nigeria to the east, Burkina Faso to the north-west, and Niger to the north-east. From North to South, it extends over 700 km; the width varies from 125 km (along the coast) to 325 km (at latitude Tanguiéta-Ségbana) (Francoise K., 2020). (See figure 7)

Figure 7:Benin Location.
Source: https://www.mapsnworld.com/benin/benin-political-map.html

The country is quite flat and is divided into five (05) natural regions :

- A coastal strip, low and sandy, bounded by lagoons (coconut groves);
- A central plain, hilly and monotonous, which gradually rises 200 to 450 m from south to north around Nikki and then lowers to the Niger valley and the Kandi basin ;

- The basin of Kandi in the northeast presents itself as a plain drained by the Sota river and its tributaries, which flow in very wide valleys;
- The Atacora range in the northwest, where the highest point of the country is located, Mount Aledjo (658m);
- The vast Gourma plain in the far northwest, between Atacora and the border with Burkina Faso and Togo . Humid savanna occupies most of the country.

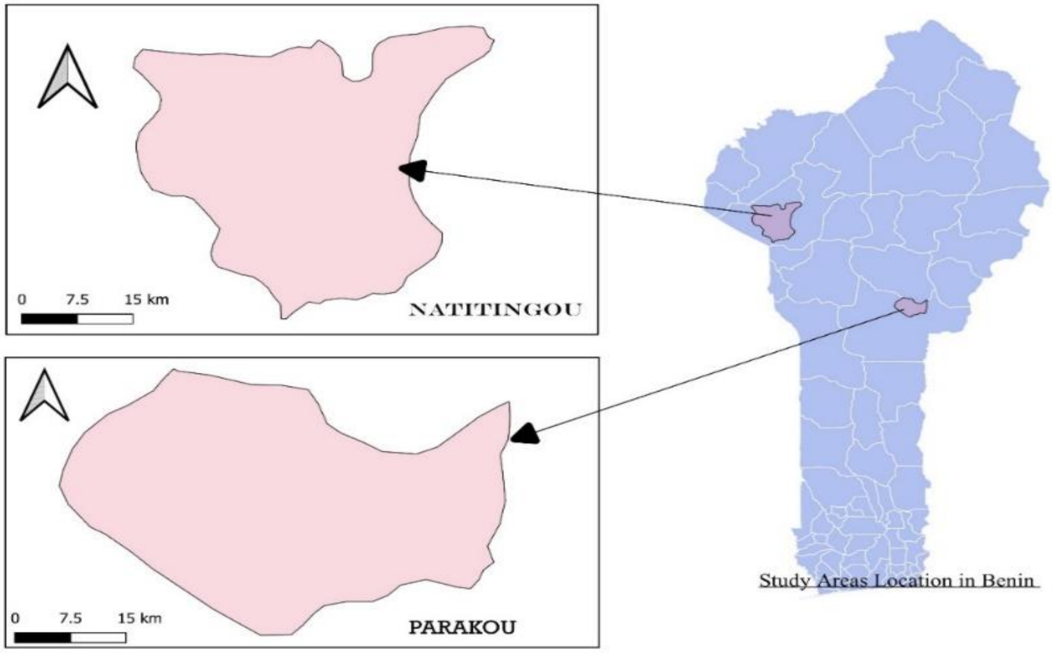

Figure 8: Location of Parakou and Natitingou.
Source: Author

Natitingou, located 650 km from Cotonou, the economic capital of the country, is a very large charming city located in the center of the Atacora department in the northwestern part of Benin. Natitingou is a dusty town and has noisy traffic sloping (Benin Tourisme, 2017). The city of Natitingou has a relief whose forms are varied, ranging from mountain areas to the plateaus and peneplains. It is characterized by a rugged relief, composed mainly of the chain of Atakora, plateaus and hills whose valleys are often steeply sloping (Benin Tourisme, 2017). The municipality of Natitingou is divided into nine (09) districts. Our study area is located in the second and the third districts covering the Neighborhoods such as Ourbourga, Kantaborifa, Yimporima, Tchrimina and Dassagate (See figure 17). It has a nuanced Sudano-Guinean climate because of the Atacora chain (Boko, 1988, p. 109; C. S. Houssou, 1998, p. 68). Monsoon flows and squall lines generating showers are the main rainfall factors. In addition to these factors, there is the presence of the Atacora chain which favors the forced updrafts of humid air generating stormy-type rains.

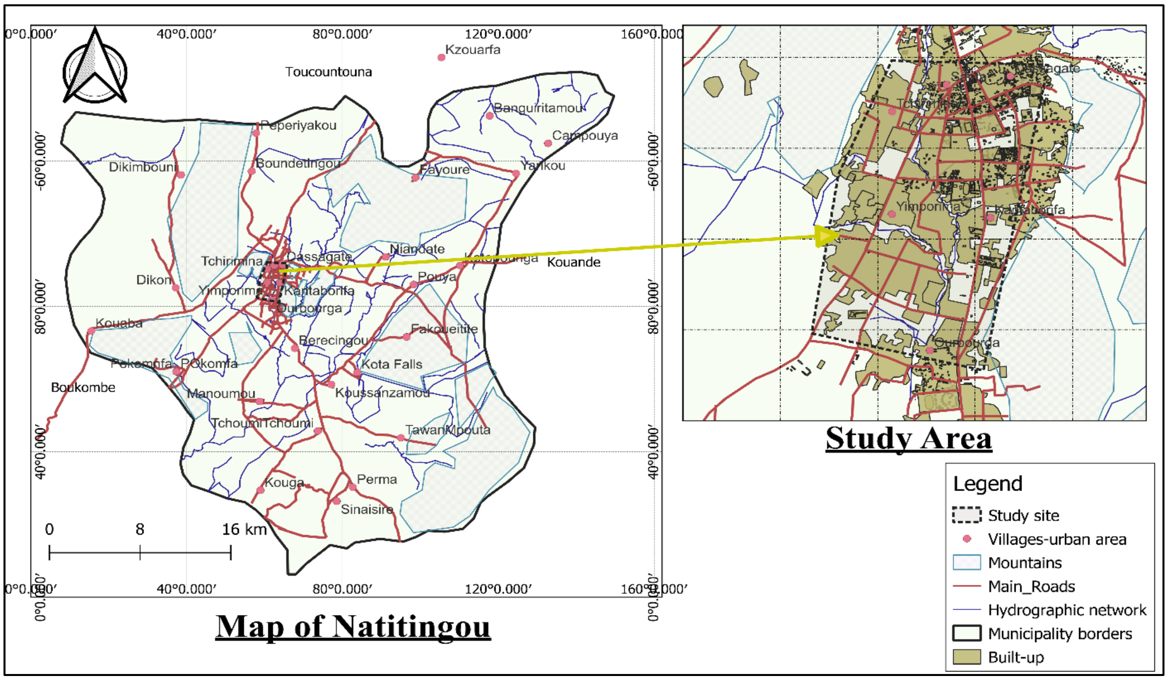

Figure 9: Map of Natitingou highlighting the Study area
Source: Author

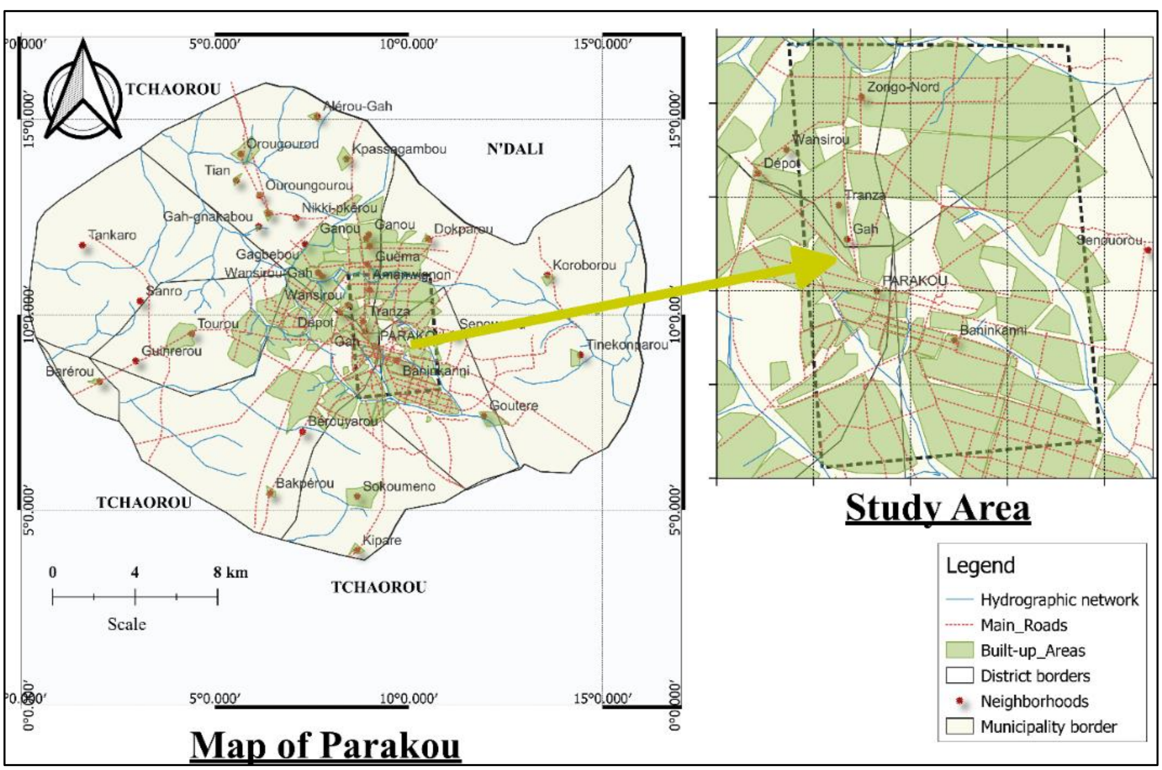

Figure 10: Map of Parakou highlighting the Study area
Source: Author

The city of Parakou, also called City of Kobourou, and located 415 km from Cotonou, in the department of Borgou, is a cosmopolitan agglomeration, an essential crossroads for those who wish to visit the north of Benin and its many tourist sites. Municipality with special statutes, the city of Parakou extends over 441 km^2 and is divided into three (03) districts. The second study site is located in the urban area of Parakou especially in the first district covering the neighborhoods of Baninkanni, Gah, Tranza, Wansirou and Zongo-Nord (see Figure 18). The climate is of the humid tropical type (South Sudanese), with a rainy season (May to October) and a dry season (November to April). The town is located at an average altitude of 350 m. Its relief is quite modest, rather hilly. It is watered by temporary streams or tributaries from the right bank of the Okpara (Wikipedia).

2.2. Data collection

In terms of data collection, observations, measurements, pedestrian crossings, map analysis, model analysis, site analysis and internet searching are the main methods used. But as we cannot get some data specifically for the areas selected in the cities, we have used the data for the whole cities. So, the data gotten and their sources are explained as follow:

- ✓ Vegetation cover and buildings foot printing data for the target two cities of Benin such as Natitingou and Parakou. These data have been downloaded from the Open Street Map website (www.openstreetmap.org). We simply went to the website and find the cities we wanted to download data for. And then we hit the “Export” button.

Table 1: Energy plus Data Summary

WEATHER DATA SUMMARY

LOCATION: **Natitingou, AK, BEN**
Latitude/Longitude: 10.317 North, 1.383 East, **Time Zone from Greenwich1**
Data Source: ISD-TMYx 653190 WMO Station Number, **Elevation 461**
m

Monthly means	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (avg hourly)	533	566	566	538	489	433	406	408	440	467	510	508	Wh/sq.m
Direct Normal Radiation (avg hourly)	589	569	525	435	356	253	204	193	232	333	534	564	Wh/sq.m
Diffuse Radiation (avg hourly)	155	174	179	206	211	234	242	250	253	222	160	155	Wh/sq.m
Global Horiz Radiation (Max hourly)	978	1037	1038	1071	1019	964	955	980	996	970	947	918	Wh/sq.m
Direct Normal Radiation (max hourly)	894	894	868	846	815	765	673	726	764	870	875	884	Wh/sq.m
Diffuse Radiation (Max hourly)	388	447	478	495	479	500	483	476	496	479	437	377	Wh/sq.m
Global Horiz Radiation (avg Daily Total)	6121	6607	6772	6584	6104	5458	5097	5037	5306	5495	5883	5802	Wh/sq.m
Direct Normal Radiation (avg Daily Total)	6761	6634	6279	5334	4454	3189	2563	2378	2803	3916	6150	6443	Wh/sq.m
Diffuse Radiation (avg Daily Total)	1788	2031	2152	2521	2642	2953	3043	3088	3054	2617	1849	1777	Wh/sq.m
Global Horiz illumination (avg hourly)	63426	67425	66944	63435	57314	49986	46763	47036	50700	54045	60091	60194	Lux
Direct Normal illumination (avg hourly)	39583	38423	30953	27328	22057	16543	13919	13176	15763	20548	33029	36418	Lux
Dry Bulb Temperature (Avg Monthly)	25	28	29	29	27	26	24	24	24	25	25	25	degrees C
Dew point Temperature (Avg Monthly)	3	6	20	18	21	22	21	21	21	22	17	7	degrees C

Relative Humidity (Avg Monthly)	24	26	57	55	69	79	84	85	83	80	62	33	percent
Wind Direction (monthly mode)	140	140	0	280	220	140	140	280	200	160	60	140	degrees
Wind Speed (Avg Monthly)	0	1	1	1	2	1	1	1	1	0	0	0	m/s
Ground Temperature (Avg Monthly of 3 Depths)	26	25	24	24	24	25	26	27	27	28	27	27	degrees C

Source: https://climate.onebuilding.org

- ✓ Except the Temperature and rainfall data collected from the meteorological station of Natitingou, the others climate data of the target cities used (wind speed, wind direction, radiations, …) have been downloaded from the USDOE Energy Plus web site (https://climate.onebuilding.org/). The EPW weather data format was originally developed for use with two major simulation programs Energy Plus and ESP-r (Crawley et al. 1999) and has since been adopted as standard format by many other building simulation tools. The format is simple, text-based with comma-separated data (CSV). The table 1 shows a summary of the data as the full data itself is too long and cannot be directly and completely shown in the document
- ✓ The population and houses data have been collected from the INSAE (Institut National de la Statistique et de la Démographie) service.
- ✓ Field camera images of some buildings in the study areas selected randomly are taken using cameras.
- ✓ Vegetation cover generated by the model proposed is also used for the model environment effects assessment.

2.3. Data analysis

For the data analysis and modelling, the activities are organized this way:

- ✓ Before analysis, the gathered data are prepared. The datasets are checked for missing data and outliers.
- ✓ The temperature, rainfall, wind speed, wind direction, and radiations are analyzed and plotted using climate consultant software.
- ✓ The population and urban expansion data are analyzed using statistical software Microsoft Excel.
- ✓ The images are open coded to categorize key themes and identify patterns. Each theme is analyzed to gain a deeper understanding.
- ✓ For the sun Path and radiation rose analysis, we have used grasshopper package in Rhino with parametric design diagram shown in the picture below. After making the diagram in

grasshopper with ladybug tools, we upload the data collected and get the output graphs in Rhino.

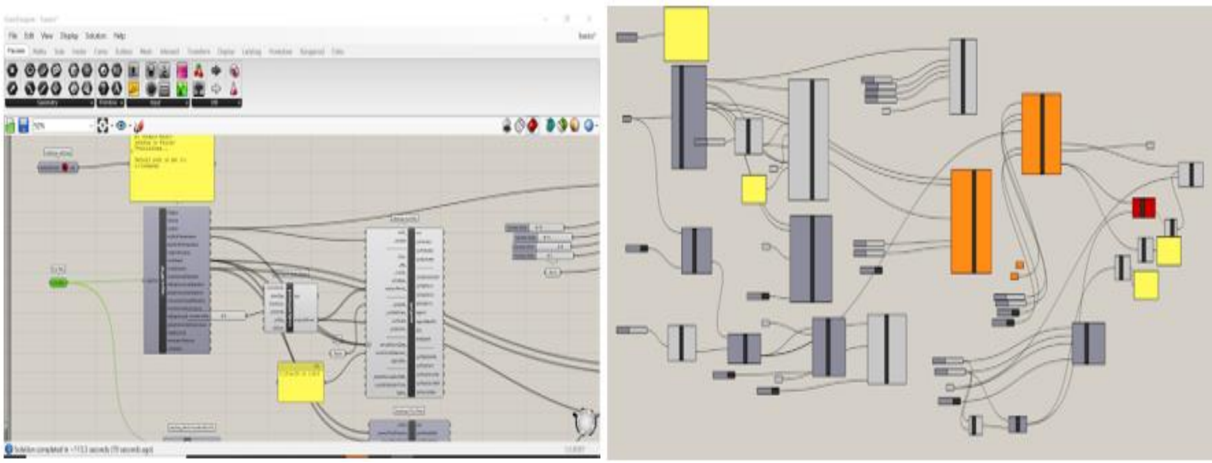

Figure 11: Sun Analysis Diagram in grasshopper Rhino *Source: Author*

- ✓ iTree software is used for urban vegetation assessment. Firstly, iTree database was not updated in Benin, so we went to their website to upload our study areas climate data to their system and then submit. Two months later a message is sent to our mail notifying that the iTree database is set on our study areas and can be used. After that, we have made the data inventory of the trees selected for our model and the number generated. Then, we submit the data inventory to iTree for processing and analysis. After the data analysis, the result is sent to our email.

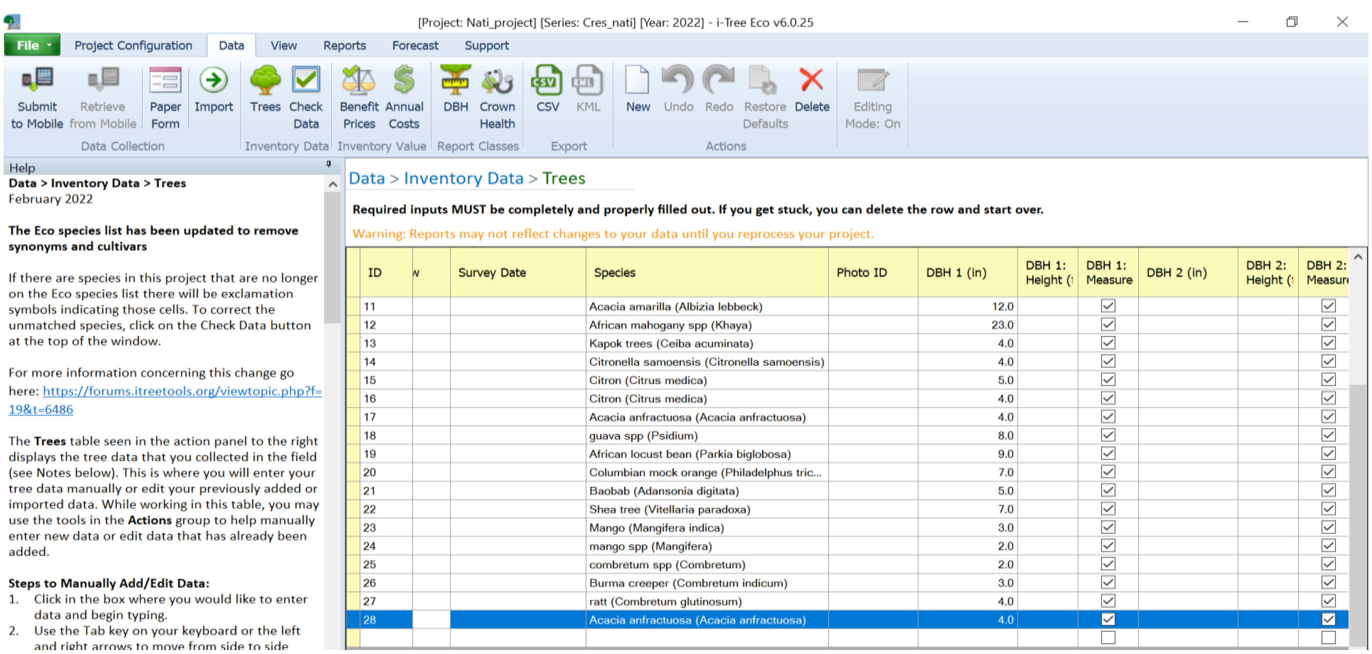

Figure 12: iTree interface for Tree Data inventory *Source: Author*

2.4. Model design

For green building modelling design and for their evaluation, AutoCAD, Rhino Revit and SketchUp are used. Taking in account all the climate conditions of the study areas, the models designed are based on livable communities' principles, energy efficiency techniques, indoor air quality conservation, environment resources conservation, water conservation, land cover land use management, urban vegetation conservation and waste management techniques. In practical terms, our model is a whole-systems-approach to building that include the following points.

- ✓ Creating comfortable environment including essential features that allow residents of all ages and backgrounds to thrive;
- ✓ Using sun and site resources to the building's advantage for natural heating, cooling, and daylighting;
- ✓ Landscaping with native, drought-resistant plants and water-efficient practices; Building quality, durable and sustainable structures.
- ✓ Reducing and recycling construction and demolition waste. For the building dwellers waste management, the bio digester toilet is proposed to digest the wastes, to provide biogas to the building for kitchen usages and to provide nutrient-rich water for plants cultivation.
- ✓ Insulating well and ventilating appropriately. So, we've used adequate insulation, air sealing, efficient windows and intelligent shading devices.
- ✓ Incorporating durable, salvaged, recycled, and sustainably harvested materials;
- ✓ Using energy-efficient and water-saving appliances, fixtures and technologies. All the building is integrated with solar panels and wind turbine to convert respectively solar energy and wind speed to electrical energy useful for the building residents. Each building has at least three sources of energy. Using healthy products and building practices;
- ✓ As the plot of land sold for individual buildings in Benin cities is generally of $500\ m^2$, the building strategy developed here makes the builder, create, save or maintain 60% of the vegetation cover on each piece of land of $500\ m^2$ including roof gardens and vertical vegetations. This means that $300m^2$ of each plot of $500m^2$ will be covered by the vegetation either horizontally or vertically at the end of building including roof gardens. This considers the Building Coverage Ratio (BCR) to be less than 40% or more in cases of roof garden and living wall. According to Coed Cymru (2019), a native, mixed woodland could contain around 1,600 trees per hectare. So, we suppose that each vegetation coverage area could host four (4)

to ten (10) trees on the piece of land of $500\ m^2$. But, for our model, the area of land of $500\ m^2$ built for residence purposes hosts at least four (04) trees.

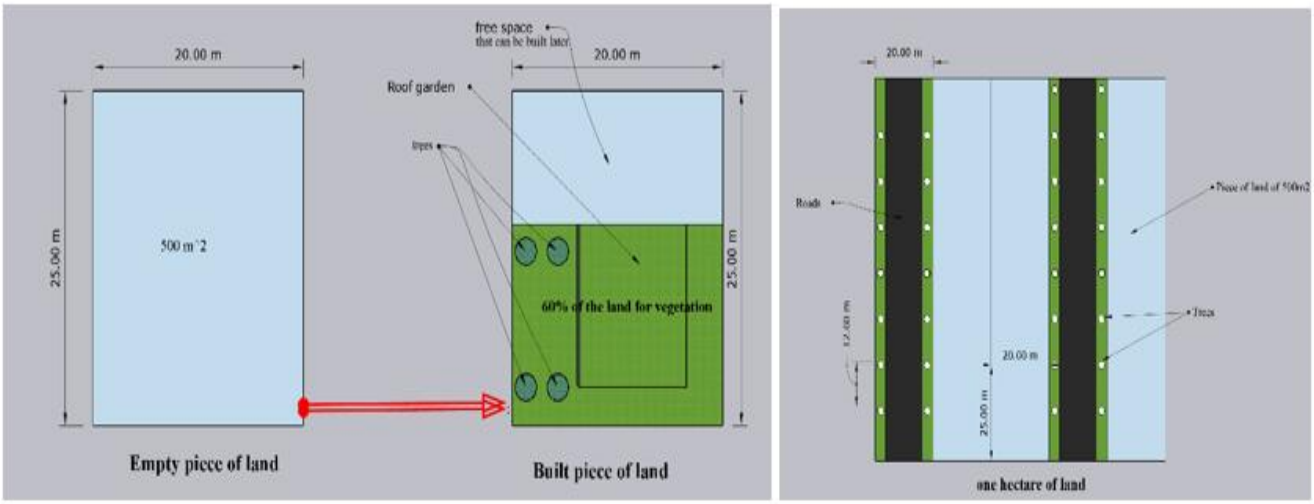

Figure 13: land fragmentation, tree and vegetation management <u>*Source:*</u> *Author*

In one hectare of land, we have twelve (12) pieces of land of $500\ m^2$ and $4000\ m^2$ for road network. For the roads network, we are considering those of 40m and 20 m of width. There are trees parallelly at each 12m on the roads but stopping at 12m before the roundabouts. If it is the road of 20m of width, we are still having 4 trees per $500\ m^2$ on the road while if the road is of 40m, it'll be three (03) trees per $500\ m^2$ (See figure 13). The idea behind this strategy is to make city dwellers contribute to the urban vegetation increasing through their settlement.

Chapter 3 : Site Analyses and Trends

The districts containing the study areas in the two municipalities are mainly composed of residential buildings and not much green areas of community connecting areas. After properly going through 'SWOT' analysis and investigation on some of the strengths and weaknesses of the site, some of the outstanding features that helped in the model design development are as follows:

3.1. Land Topography and Population settlement

The city of Natitingou is positioned in the midst of mountains and has a shape that is almost in the form of a valley. It lies in a semi-valley, formed by mountain ridges that surround it. Natitingou is located on the uphill and its topography is more of a hill from the south to north, and in the reverse from the north to south a slope can be seen. The soils are generally lateritic, gravelly, stony, sandy and clayey. They are mostly leached, resulting in a considerable decline in their fertility due to the strong degradation to which they are subject. Unsuitable farming techniques and weak water management capacity have contributed to this advanced soil degradation. At the East and West of the city is where most of the hills and mountains are located and in the middle of them a lot of residential and building structure. On investigation and findings, one would understand, based on the fact that geographically the district is found amidst mountains that the weather can be unpredictable and unpleasant at times. This can also help in the prediction of the amount of sunlight received in this area, which lets us know the angle and direction to expect the most natural light, and because of this we can also be able to calculate the warmth and heat to be expected and at what time exactly. To be able to calculate and give an estimate on the finding of these facts can help in the planning and designing of this district, with regards to renovation. It gives a clear picture at what time of the year and at what rate and is proven to be very useful due to the fact that you can build and construct with such data, in accordance to these natural phenomena.

The topography of Natitingou city is on an uphill and this brings about challenges and inquiries on how to design and construct a well suitable building that perfectly work with the inclining angle of land covering. This puts in consideration the structure system, the angular views, the road construction and water drainage as the main issues at hand. Within north-eastward of the entire area selected, the specific site in Natitingou has a total area of $7243074.676\ m^2$. One of the many reasons for choosing this site is knowing the fact that there will be high emission of Green House

Gas (GHG) and this research project is geared towards proposing a solution to handle and minimize GHG effect by introducing green building model homes.

Besides, the city of Parakou has a flat topography, making difficult the discharge of wastewater. The entire layout of this site is about 45% sloppy, considering the coordinates of the land with reference to its geographical location, the slope starts at the north-east and condescends on reaching the centre, which appears to be slightly flat. Close to the mountains, this site should exhibit green scenery qualities, but within the process of time and human activity the present condition speaks otherwise. Parakou is a big town in Benin (urban) an is a port town in the North-Eastern region of the country, with a rapid demographic and urban growth due to economic development. The entire area selected, the specific site in Parakou has a total area of $22753907.153\ m^2$. The ground being dotted by several streams is constantly eroded. This leads to land degradations and the difficulties of the population to settle comfortably.

Figure 14: Aerial View of the Study Areas *Source: Google hybrid Map*

The population of Natitingou city is averagely about 104010 (NSAE, 2013) but the study area is about 60% of the population and is believed to be a crowded zone. The density of the population of the Natitingou is averagely about $74.17/km^2$and the annual growth rate is about 2.9% (Table2).

Table 2: Population of Natitingou and Parakou

Natitingou		
Years	Population	Density(pop/km²)
1979	39089	29
1992	57153	43
2002	75620	56
2013	104010	78

Parakou		
1979	60915	138
1992	103577	235
2002	149819	340
2013	255478	577

Source: NSAE 2013

On the other hand, the population of the city of Parakou is about 255.478 (NSAE, 2013) but the study area is about 67% of the population. The density of the population of Parakou is about $579.3/km^2$ and the annual growth rate is averagely about 4.9% (Table 2).

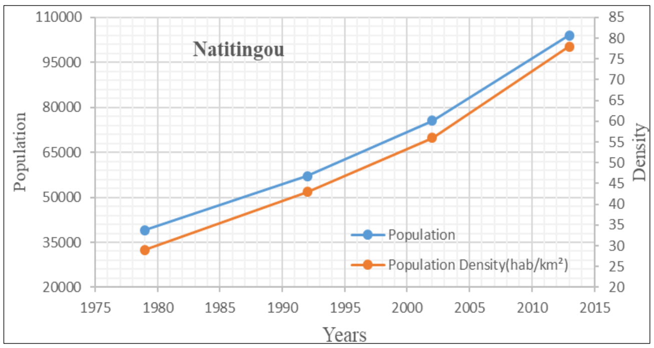

Figure 15: Natitingou population
Source: Author

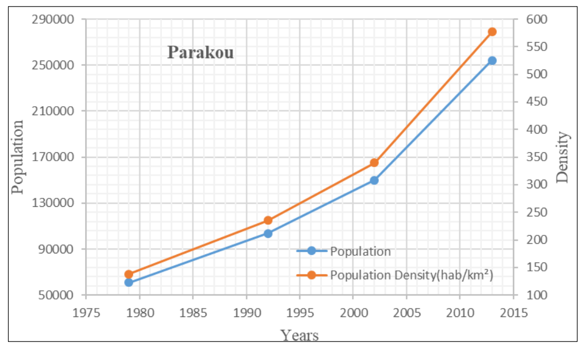

Figure 16: Population of Parakou
Source: Author

In the figure 24, the population of Natitingou has increased fairly from 39089 in 1979 to 104010 in 2013. It has tripled in 30 years. At the same moment, the figure 25 shows that the municipality of Parakou is experiencing a very strong increase in its population: it has doubled in twenty years, since it rose from 103.577 inhabitants in 1992 to 149.819 in 2002 (RGPH3). In the 2013 (RGPH-4), it has 255,478 inhabitants. In addition, the pictures shown in the figure 26 are showing how buildings are clustered in the two study areas. This can be justified by the fact seen in the two graphs highlighting the growth of the population and the population density in the two study areas through the years (See figures 24 & 25).

Besides, Housing in the municipality of Natitingou is generally scattered and very poorly organized with the proportion of isolated houses estimated at 44.8% of cases and that of houses in rows estimated at 41.4% of cases. The highest human concentrations are observed around the district capitals. The walls of these dwellings are mostly made of earth (48.8% of cases) and brick (32.4% of cases). The dwellings are topped with sheet metal in 82.2% of cases and with straw in 13.5% of cases. The soil is mostly made of cement (56.9%) and earth or sand (37.4%). (INSAE, RGPH4).

Dwellings made of permanent materials (cement, sheet metal, iron, etc.) are much more concentrated in the four central districts of the commune, namely districts I, II, III and Péporiyakou.

3.2. Electricity and renewable energies

The sources of energy used by the population for domestic needs are electrical energy supplied by the Beninese Electric Energy Company (SBEE), derivatives of hydrocarbons (petroleum, diesel, gasoline), generators, firewood, charcoal and natural gas supplied by SONACOP stations, ORYX or BENIN-Petro. Wood and charcoal are the energies most used for cooking food in most rural districts of the municipality. The use of gas is very underdeveloped and is mainly concentrated in the urban part of the municipality. The municipalities of Natitingou and Parakou are very little electrified in electrical energy. The supply of electrical energy by the installed thermal power plant is mainly limited to some urban areas. The electricity network has not experienced a significant extension in the municipalities because the kilowatt of this imported electricity is of high cost for the majority of the population. To make up for this cruel lack of electrical energy, some households currently use electrical energy provided by generators, flashlights, oil lamps and few solar energies. These energy problems in the municipalities constitute an obstacle to the proper functioning of the local administration (PDC_Nati & PDC_Pkou, 2017). It constitutes an obstacle to the emergence of new private initiatives and to the development of a stable and reliable industrial, economic, artisanal and commercial fabric. In addition, this lack in term of energy leads the population to the destruction of the surrounding biodiversity by cutting trees to compensate this lack.

3.3. Road Networks and Transportation

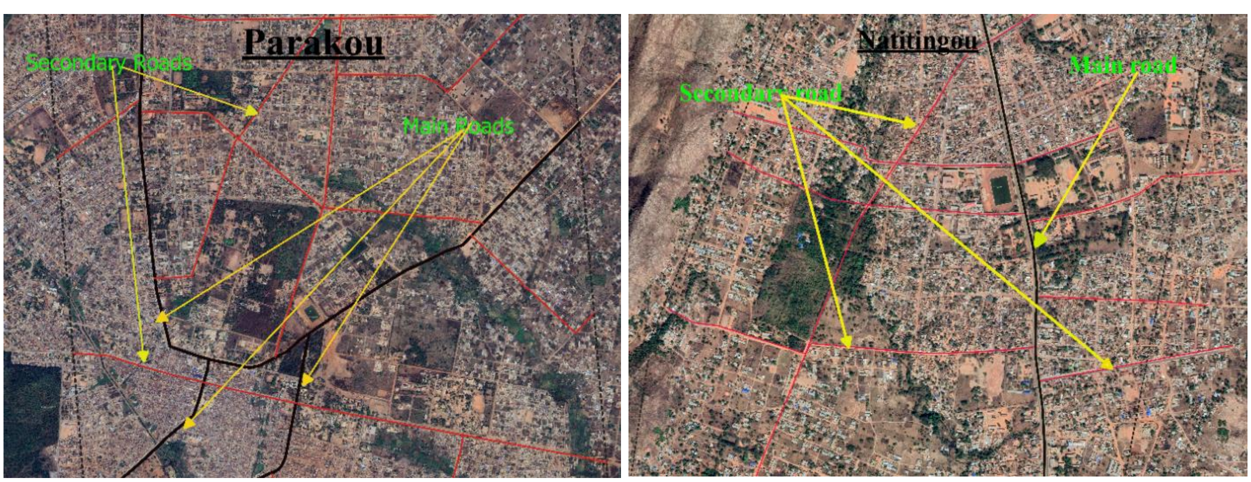

Figure 17: Study sites' road network and transport route
Source: Author

Natitingou and Parakou cities are facing the problem of road multiple accidents every day. People living in these cities are always faced with the challenge of a proper road network; that is free and accessible by almost all sorts of vehicles plying that route. This has resulted in so many impracticable, not well paved or tarred routes and alleys that are about 2.5 to 4 meters wide with maybe or supposedly the disappearance of roads or streets. Natitingou is crossed by one main street or primary route (RNIE 3), as shown. The city of Natitingou has one primary road that crosses through and leads to the centre of the city but has been suffering from degradation due to population increase and is barely more than 20 meters. For the case of Parakou, there are many untarred main spaced roads that if they are crossed, a lot of dust is emitted polluting the city and making passengers sick. Some of the streets are not even practicable in rain seasons. These analyses let us understand that Natitingou and Parakou consist of less wide roads that act as a divider for neighborhoods and residents. This leads to the daily use of these alleys and narrow routes, caused by the overcrowded community and can result in chaos, long and extended traffic, especially at peak hours. There are lots of secondary and feeder routes in this district, as shown in the figures above; this is so because of the poor planning in construction and positioning of the buildings. It can also be because of the concentration of the population. These are examples of streets in the two cities being used not only by cars but also by pedestrians (See figure 28). Some traders also do their business in the streets, making it very challenging to get through. Access to and from the site is possible but can be of a challenge at peak hours due to population demand, for most of the secondary routes are congested.

3.4. Urban Vegetation

The vegetation in Parakou and Natitingou is of the same type. It is characteristic of the wooded, shrubby and herbaceous savannah dominated by woody species such as néré, shea, baobab, false mahogany, tamarind, kapok, caïlcédrat, mango, acassia and rônier (Wickipedia). But the population growth and establishment are not without consequences on the vegetation cover. The figure 18 show that the vegetation coverage area decreases while the built area increases over years. This emphasis the fact that the urban vegetations are destroyed to construct urban areas facilities such as: homes, businesses, and roads to accommodate growing populations. Additionally, as populations increase, more land is used for agricultural activities to grow crops and support livestock and this decreases not only species populations, but also the land covered by the vegetation (INSAE, RGPH4).

3.5. Climate Analysis

To understand deeply the climate conditions of our study areas, we need to do monthly analysis of the past thirty years data to get the standard variations of the weather conditions per each month. So is the analysis of some other climate parameters needed to find the suitable strategies for the model design that can adapt and mitigate the climate change hazards faced by the two cities of our study. The comfort zones and the suitable passive design strategies are determined based on California Energy Code Comfort Model.

3.5.1. Temperature

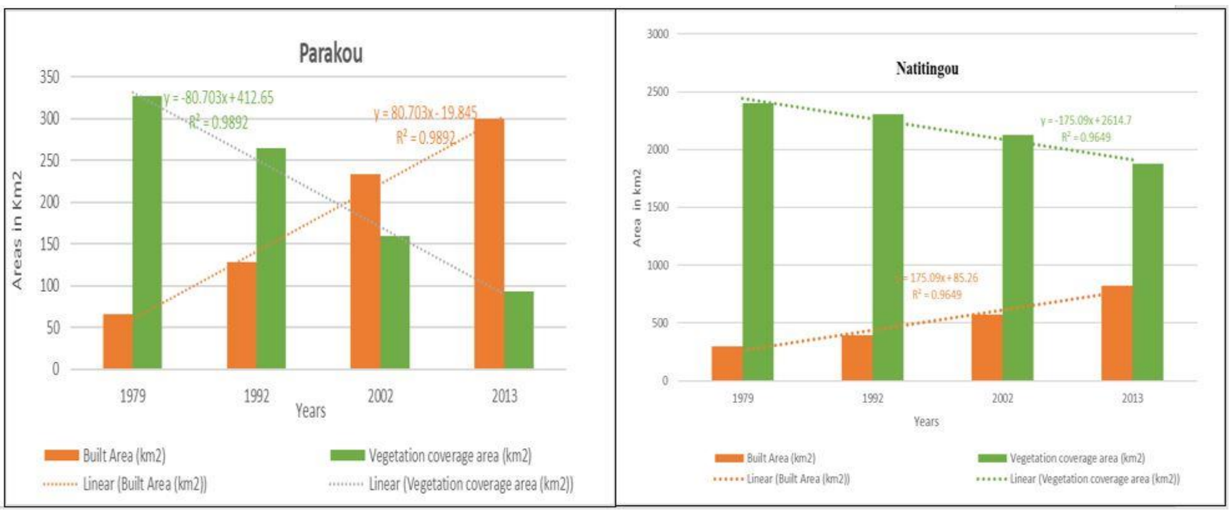

Figure 17a: Vegetation Dynamics *Source : Author*

The temperature data collected and analyzed indicate clearly that the study areas are experiencing global warming situation. The trend lines show that these areas temperatures have considerably increase over thirty (30) years (See figure 18). The term “climate change” refers to long-term variations in temperature and weather conditions. These variations may be a natural phenomenon, but since the beginning of the 19th century they have mainly resulted from human activity (NOAA, 2010). When greenhouse gas emissions multiply, these gases act as a blanket around the Earth and trap the sun's heat. This phenomenon leads to global warming and climate change. Deforestation for farming, pasture, building or other purposes also releases greenhouse gas emissions, since trees, when cut down, release the carbon they have stored. The destruction of forests, which absorb carbon dioxide, also limits nature's ability to prevent gas emissions from entering the atmosphere (IPCC, 2018). This means that this change realized our study areas climate is due to the actions the increasing population is making on the vegetation areas through their different activities.

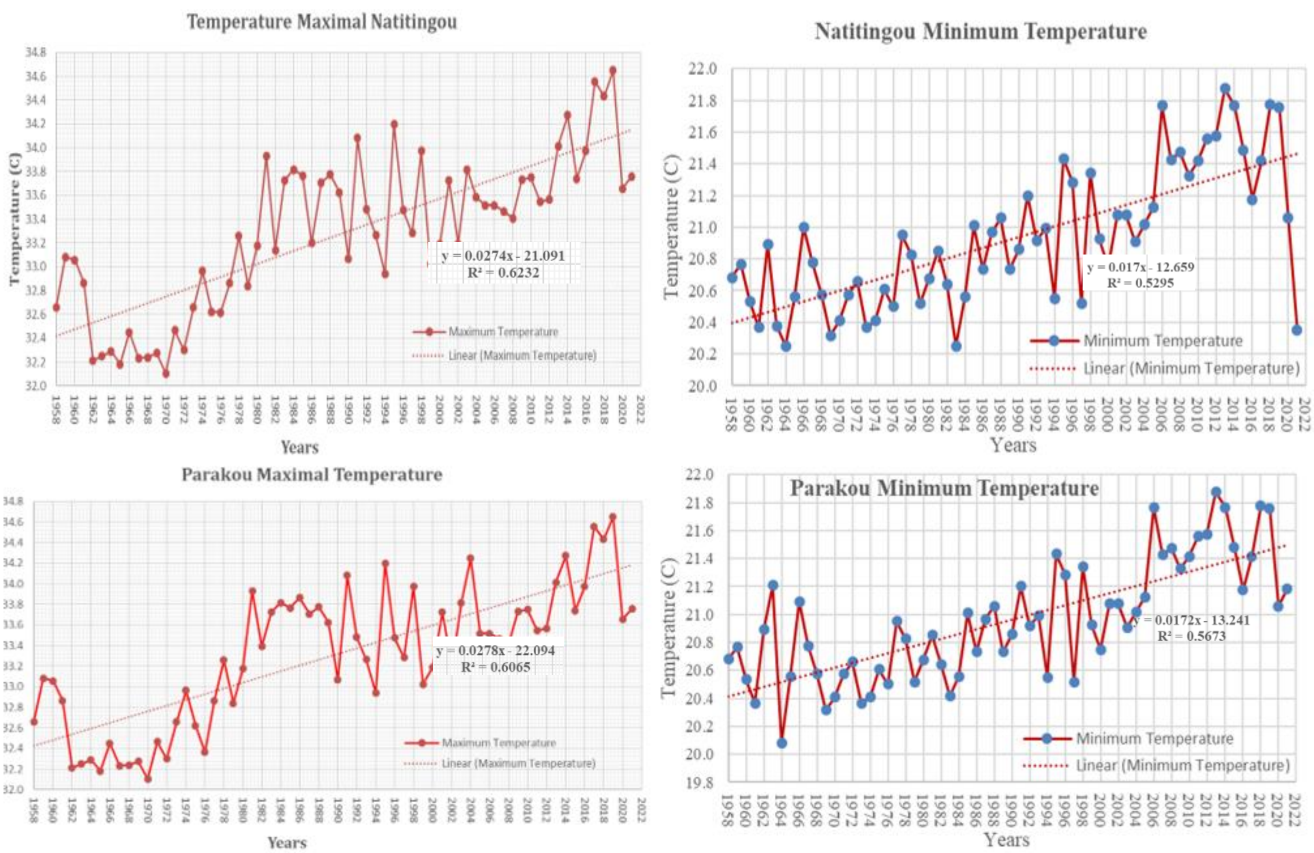

Figure 18: Study Areas Temperature over 30 years *Source: Author*

Natitingou climate is of the Sudano-Guinean type characterized by two seasons: a rainy season which lasts six (06) months (May to October), and a dry season which covers the period from November to April. The climate of Parakou is of the humid tropical type (South Sudanese), with a rainy season (May to October) and a dry season (November to April).

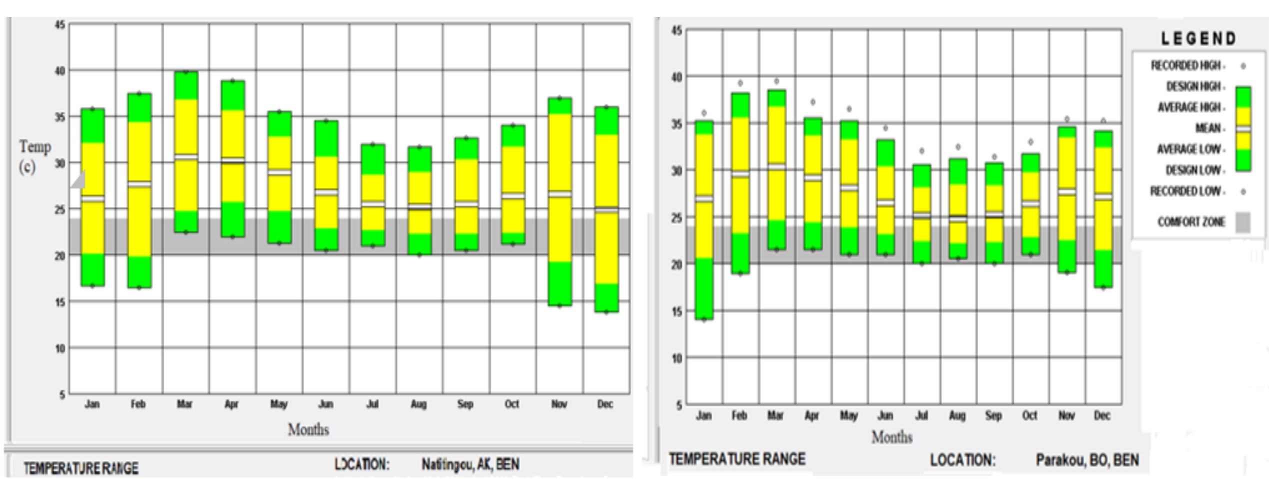

Figure 19: Temperature range of Natitingou and Parakou per month
Source: Author

These charts on the figure 19 show the dry bulb temperature ranges enclosing the Recorded High and Low Temperature (round dots), the Design High and Low Temperatures (top and bottom of green bars), Average High and Low Temperatures (top and bottom of yellow bars), and Mean or Average Temperature (open slot) of Natitingou and Parakou. These values are calculated for each month. Dry Bulb Temperature is the sensible temperature typically measured by a thermometer with a dry bulb. The units are either in degrees C. The highest and lowest dry bulb temperatures that were recorded in each month or over the full year in this particular data file. The Annual Design Temperatures are used to calculate the Heat Loss and the Heat Gain of the building, which is used to size the heating and cooling equipment. The Design Temperature Range is defined as the percent of hours that are used to establish the outdoor design high and design low temperatures. These are the assumed outdoor temperatures used to calculate the size of a building's heating and cooling equipment.

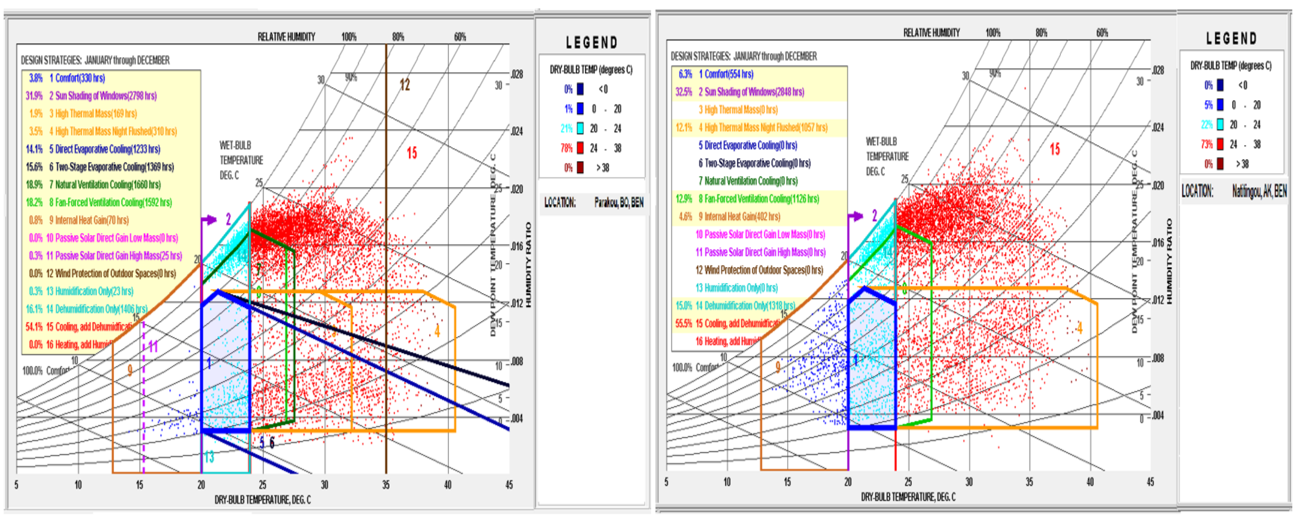

Figure 20: Psychometric charts explaining Parakou and Natitingou Temperature and air state
Source: Author

The figure 20 displays two psychometric charts on Natitingou and Parakou. They show dry bulb temperature across the bottom and moisture content of the air up the side. This vertical scale is also called absolute humidity and can be shown as the humidity ratio in pounds of water per pound of dry air (or grams of water per kilogram of dry air), or as the vapor pressure. The curved line on the far left is the saturation line (100% Relative Humidity line) which represents the fact that at lower temperatures air can hold less moisture than at higher temperatures. Every hour in the climate data file is shown as a dot on these charts and the color of each dot represent whether or not the hour is Comfortable or not. The Design Strategies shown in the box in the upper left are all defined relative to the Comfort Zone, and the specification for each of these zones. The number at the end of each Design Strategy is the number of hours that are likely to be comfortable using this particular strategy in this particular climate. The percentage of hours that fall in each Design Strategy zone is also shown. The total number of Comfortable Hours using the Selected Strategies is given at the bottom. This represents a design that is a composite of all the selected strategies where each hour is counted only once, thus the total number of Comfortable Hours will not exceed 100%. These percentages help identify which passive Design Strategies will be most effective in this climate. From these figures, we can conclude that the hottest months of the year in our study areas are March and April. The lowest temperatures are in the months of November and December in Natitingou and in the month of January in Parakou. In addition, more than 70% of the hours in the year are very hot and uncomfortable.

3.5.2. Solar Radiation and Sun Path

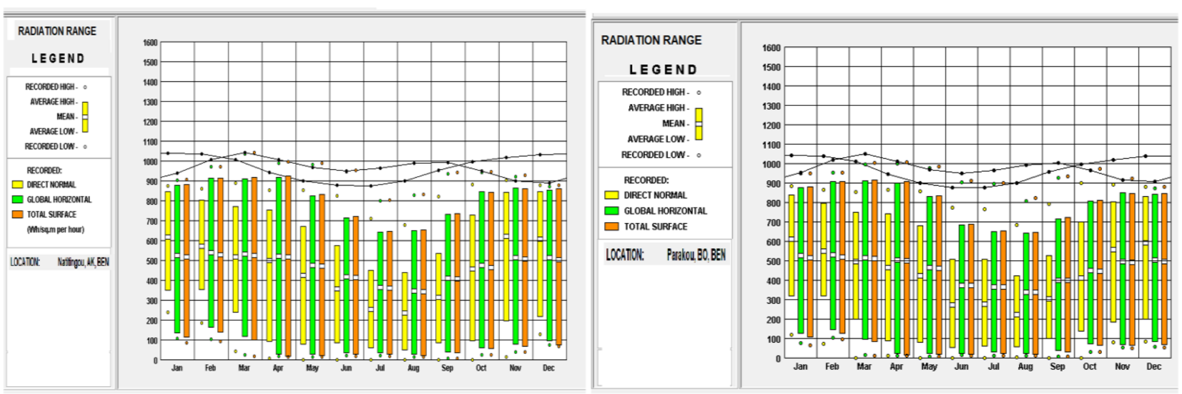

Figure 21: Radiation Range for Parakou and Natitingou
Source: Author

The Charts on the figure 21 show for each month and for each study area, the Direct Normal Solar Radiation (yellow), Global (Total) Horizontal Solar Radiation (green), and Tilted Surface Radiation (orange) for all daylight hours. The Recorded highest hour of radiation shown as a small colored circle. The Average High is the average of the highest value from each day of the month is shown as the top of the colored bar. The Mean or average of all the daylight hours is shown as the break in the colored bar. The Average Low value is the average of all the lowest values of the month during daylight hours. And the Recorded Low value will represent the lowest radiation during that month between sunrise and sunset. The Daily Total Radiation is the total Radiation for each day of the month showing the highest day of the month, the lowest day, and the mean or average day of the month. The units are in Wh/sq.m.

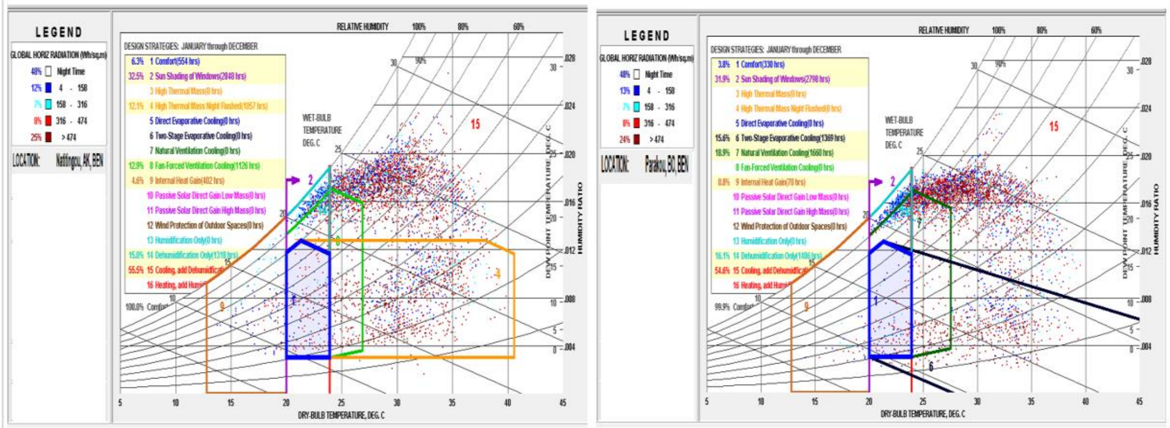

Figure 22: Psychometric Chart highlighting Natitingou and Parakou Radiation characteristics
Source: Author

In theory it is composed of all the diffuse radiation from the total sky vault plus the direct radiation from the sun times the cosine of the angle of incidence. Notice that the Global Horizontal Radiation peaks in summer because that is when the sun is highest in the sky and is thus more perpendicular to a horizontal surface (See Figure 22). These charts indicate clearly that our study areas have a very good range of solar radiation. This can be turned into an advantage for the building model's energy saving by using solar panels that can convert solar rations into electricity usable for building residents.

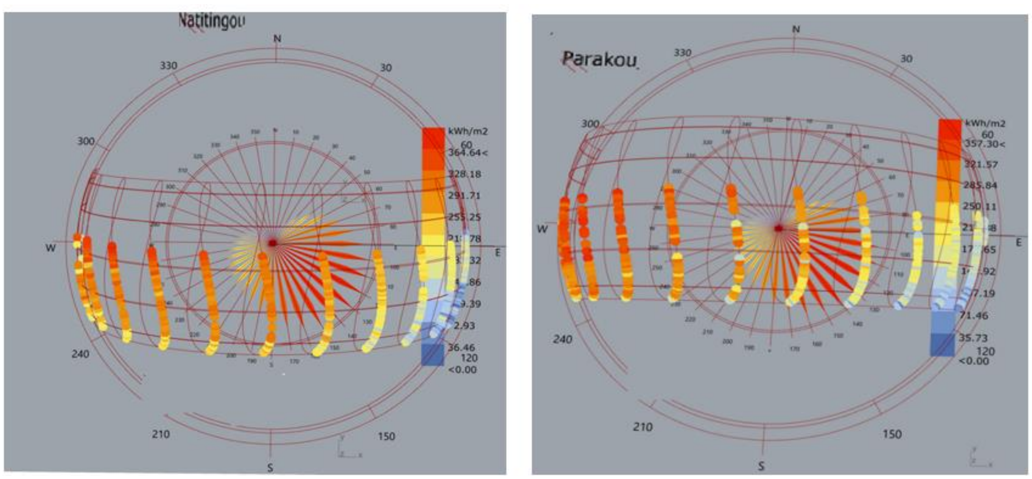

Figure 23: Sun Path Analysis for Natitingou and Parakou *Source: Author*

The figure 23 displays diagrams about Natitingou and Parakou sun path and radiation rose. The red points at the center of the diagrams represents the study areas of each city. We can see in these diagrams that the sun paths in the whole year for any observer in these cities are oriented toward the south. Likewise, the radiation rose is mostly concentrated in the Southeast. So, can we conclude that the building openings placed in the southern façades are more indicated for the building interior natural lightening. In addition, the Photovoltaic Panels should be oriented to the south in these two study areas for more efficiency.

3.5.3. Wind Speed and Wind Direction

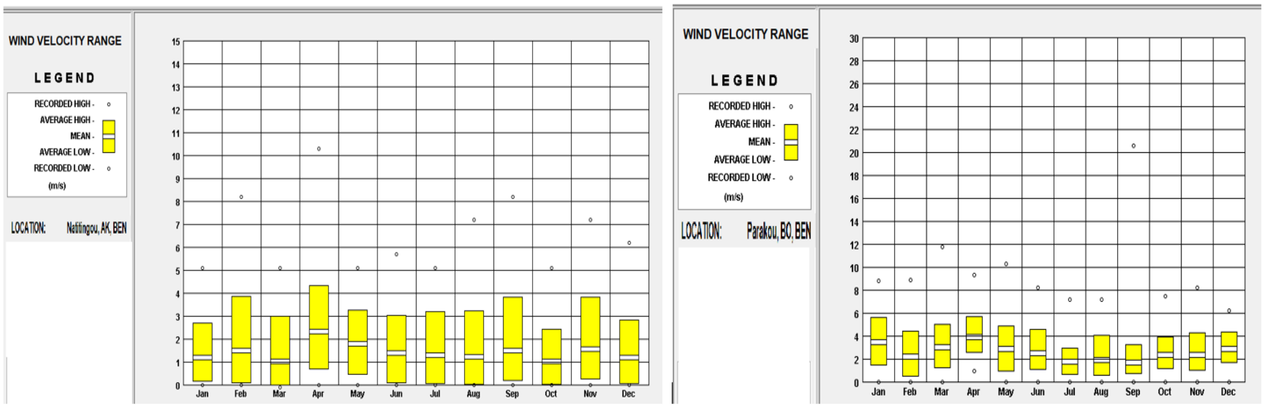

Figure 24: Wind Speed Range of Natitingou and Parakou *Source: Author*

These charts show for each month and for the full year, Wind Velocity in meters per second (mps). The Recorded High value is shown as a small circle. The Average High is the average of the highest value from each individual day of the month or annually and is shown as the top of the colored bar. The Mean or average of all hours during the month is shown as the break in the colored bar. The Average Low is the average of the lowest values from each individual day of the month or annually and is shown as the bottom of the colored bar. The Recorded Low value is shown as the small circle. Natitingou experiments the highest wind speeds in the months of February, April and September while Parakou gets his own in the March, May and September.

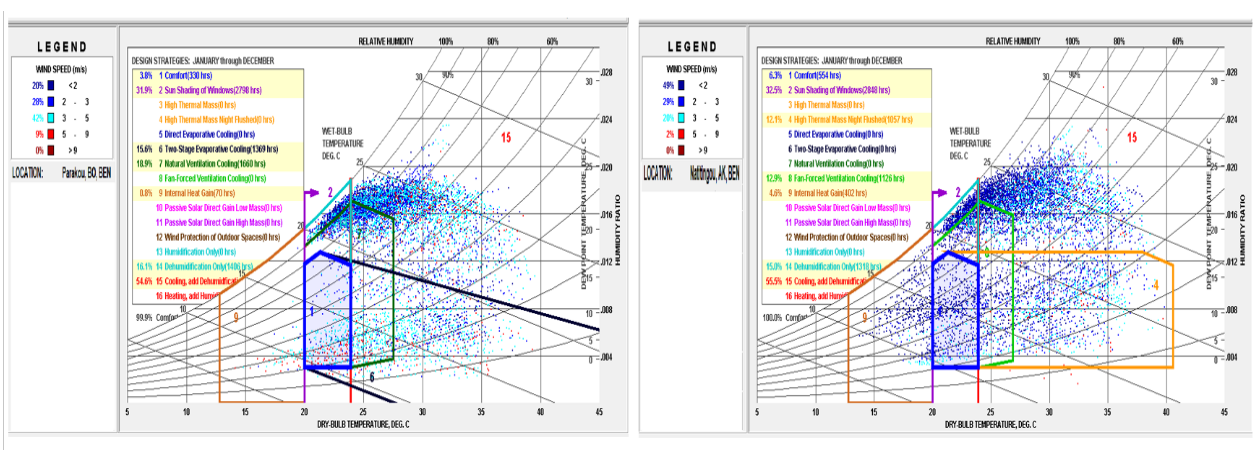

Figure 25: Psychometric Charts highlighting the Wind Speed of Natitingou and Parakou
Source: Author

The wind speed is averagely low in the two study areas. In the city of Parakou, 48% of the hours is under 3m/s, 42% is between 3m/s to 5m/s and 9% between 5m/s and 9m/s. In Natitingou, 49% of the wind speed in lower than 2m/s, 29% between 2m/s and 3m/s, 20% between 3m/s and 5m/s and then 2% between 5m/s and 9m/s. In comparison terms, the wind velocity is higher in the Parakou than in Natitingou but none of the cities has the wind speed higher than 9m/s.

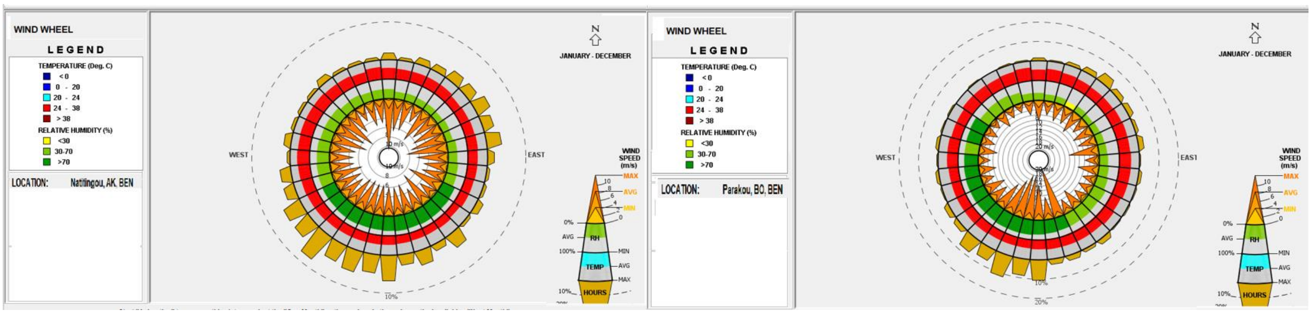

Figure 26: Wind Wheel for Natitingou And Parakou *Source: Author*

The Wind Wheel displays for each wind direction, the Wind Velocity and Frequency of Occurrence along with concurrent average Dry Bulb Temperature and Relative Humidity. The outer ring shows the percentage of hours when the wind comes from each direction. On the next ring the height and color of the bars shows the average temperature of the wind coming from that direction (light blue is in the comfort zone, blue is cool or cold, and red is warm or hot). The next smaller ring shows average humidity (light green is comfortable, yellow is dry, and green is humid). The innermost circle shows the wind velocities that come from each direction; the tallest brown triangle is the maximum velocity for that period, medium brown is the average velocity, and the smallest light brown triangle is the minimum velocity. Hours when there is zero wind speed do not appear on this chart. The graphic key to all this information is summarized in the icon in the lower right labeled Wind Speed, RH, Temp, and Hours (See figure 26). The situation of the wind in these two study areas is a challenge for building industries in these cities due to the disasters it causes to the unwell built homes especially in the times of high wind velocity. So, to build stronger cities that can withstand the effects of disasters and climate change hazards, cities need to incorporate resilience strategies into their planning policies. By integrating disaster resilience into sustainable development, communities can: tackle predictable disasters, better cope with the increasing impacts of extreme weather patterns and mitigate potential damage to people, housing and infrastructure. In addition, for the natural ventilation of buildings in these two cities, it is recommended from the analysis above to make the building external openings mostly to the south and north ().

3.6. Climate change realities in the two study areas

Climate change effects are very perceptive in Natitingou and Parakou. Climate changes in the municipality of Natitingou and Parakou relate to precipitation, temperature and wind. Indeed, the decrease in rainfall levels, increasingly random and sporadic rains and the shift in the seasons with a tendency to reduce the rainy season and more frequent droughts are the main trends of climate change impacts in these cities. As for the temperature, the variations in the municipality are manifested by the increase in heat and the change of the extremes of temperatures which result in hotter or colder periods. Finally, changes related to the wind in the municipality are manifested by increasingly violent and stronger winds in recent years. Table below presents the units of exposure of these climatic trends, their biophysical and socioeconomic.

Table 3: Exposure units and biophysical impacts for climate change trends in Parakou and Natitingou

Major climate trends	**Exposure unit**	**Biophysical, socioeconomic effects**
Downward trend in heights and number of rainy days over the past thirty years (1615 mm to 1087 mm of water height and 119 to 86 number of rainy days): - Random rains; - Sporadic rains; -Late rains; - Dense and intense rains; - Abrupt cessation of the rains; -Reduction of the rainy season; - More frequent dryness	Household income; level of poverty; food production and supply, agricultural production, animal husbandry; water supply, sanitation systems, hygiene conditions; camp, buildings, need for temporary accommodation; health system, epidemics; roads, buildings, power lines, means of communication; schools;	Soaring prices of agricultural and veterinary products. Speculation High cost of basic necessities, Fairly low level of household income, Worsening of the poverty line, Fairly low agricultural yield, Scarcity of foodstuffs, Famine, loss and loss of livestock, Increased need for drinking water consumption, supply of insufficient drinking water, Difficulties in accessing water points, Drying up of water bodies, Resurgence of waterborne diseases, Reduction of camps, insufficient shelter for livestock, high concentration of camps around water points. Social conflicts around water management, Increased risk of epidemics, Sanitary system quite threatened, Reduction of plant cover, threatened schooling. The maintenance of the family unit through her duty as a housewife is threatened
Temperature rising trend in recent years (21.19°C to 22.04°C as minimum temperature and 33.43°C to 33.95°C as maximum temperature): -Increased heat; - Increased warmer period	Household income; level of poverty; food production and supply, agricultural production, animal husbandry; water supply, sanitation systems, hygiene conditions; camp, buildings, need for temporary accommodation; health system, epidemics; roads, buildings,	Soaring prices of agricultural and veterinary products. Speculation High cost of basic necessities, Fairly low level of household income, Worsening of the poverty line, Fairly low agricultural yield, Scarcity of foodstuffs, famine, loss and loss of livestock, Increased need for drinking water consumption, supply Insufficient drinking water, Difficulties in accessing water points, Drying up of water

	power lines, means of communication; schools;	bodies, Resurgence of waterborne diseases, Reduction of camps, insufficient shelter for livestock, high concentration of camps around water points. Social conflicts around water management, Increased risk of epidemics, Sanitary system quite threatened, Reduction of plant cover, threatened schooling, IGAs are threatened. The maintenance of the family unit through her duty as a housewife is threatened
Strong winds	Habitats, granaries, wells, health of the population; socio-community infrastructure (schools, youth centers, hospitals, markets); power lines; living environment, natural resources; security and protection.	Destruction of habitats, granaries; Water pollution from uncovered wells that can lead to waterborne diseases, socio-community infrastructure (schools, youth centers, markets), Increased risk of epidemics, destruction of power and telephone lines, fall of large trees, Degraded living environment, destruction of natural resources, failure to secure goods and abandoned houses

Source: PDC3

<u>Conclusion of the chapter 3</u>

The different analyses in this chapter highlight the different states of our study areas. Studying these sites and their climate conditions, we can conclude that Parakou and Natitingou are facing city planning issues, increasing population issues, temperature increase and climate change issues. These cities receive important solar radiation and wind speed that can be turned into an advantage for building energy. In additions, the sun paths oriented to the south and the wind directions will be determinant for buildings orientation. But the same problems we have been discussing over and over again, that is the problem of the houses being in a disorder state, with bad urban planning contributes to the urban vegetation destruction leading to the urban heating. This confirm the specific hypothesis according to which the building practices and the urban areas planning favor vegetation lost and temperature increase in Parakou and Natitingou urban areas.

Chapter 4: Model Design and its Impact at Building and Conurbation Scale

This chapter deals with the project properly, its designs, plans and strategies. The green building design model is geared towards making use of some of the innovative sustainable elements and techniques so as to maximize their efficiency. This leads to the buildings being energy efficient. A number of features addressed by the design are day lighting, use of energy efficient appliances, reprocessing and implementation of resources, low or no VOC (Volatile Organic Compounds) paints and carpets where necessary and reflective roofs. Day light and natural ventilation maximization are major way of reducing the energy usage of a building and its carbon emission because they reduce the need to use artificial lighting and air conditioning. This can be achieved in the two cities by increasing the amount as well as the size of windows southward and northward so that the interior spaces get as much light and ventilation as possible. Energy efficient appliances in usage will also lead to the apartments being more energetically efficient.

The regulations in the Decree N 2014-205 of March 13th, 2014 regulating the issuance of building permits in the Republic of Benin in terms of building interior spacing, building exterior openings (At least 6% of the interior area), building heights and buildings distancing (2m from land border) are taken into consideration in this work. All the buildings designed here are integrated with renewable energy systems, with good water management systems, with biodigesters for waste and energy management, with green Roof and living walls. In addition, each $500\ m^2$ of land built contains at least 60% of green space.

Moreover, for the building design in the two study areas, we have considered public buildings and residential buildings. Talking about public buildings, we mean administrative buildings, public activity center buildings, school buildings, supermarkets, industrial buildings, mosques, churches and Vodun temples where there could be big noises. The residential buildings are the buildings where people live with their families including hostels. For the roads design, at each kilometer on the road, we have $500\ m^2$ of packing for the roads of 20 meters and $1000m^2$($500\ m^2$ at each side) for the road of 40 meters.

4.1. Proposed Green Building Plans

When developing the design for the buildings, the idea is to have a unique and irregular shaped building that solves the housing problem and meet the needs of the people, but also to be energy efficient and incorporates green architecture concepts. During the construction stage of the apartments, salvaged or onsite materials such as wood and adobe bricks should be used, which is an important aspect of sustainability due to the fact that it prevents environmental damage and construction using adobe bricks has a low carbon footprint as it does not abuse natural resources. Adobe walls are also good sound insulators. Besides, the use of paints and carpets with low or no levels of VOCs has proven to be a sustainable practice. Green spaces have been placed strategically so that the neighborhood can enjoy quality views of the mountain within some parts of the green spaces created, with some garden features and elements such as decorative rocks, rock gardens, plants, trees, flowers and water.

4.1.1- Basic plans

Due to the time limitations, we were not able to go deeply into each building's construction details. We were more interested in building basic plans such as Floor plans, Elevations, perspective views, orientations and openings. Each activity center or public building has its own underground parking and covers more than 2000 m^2.

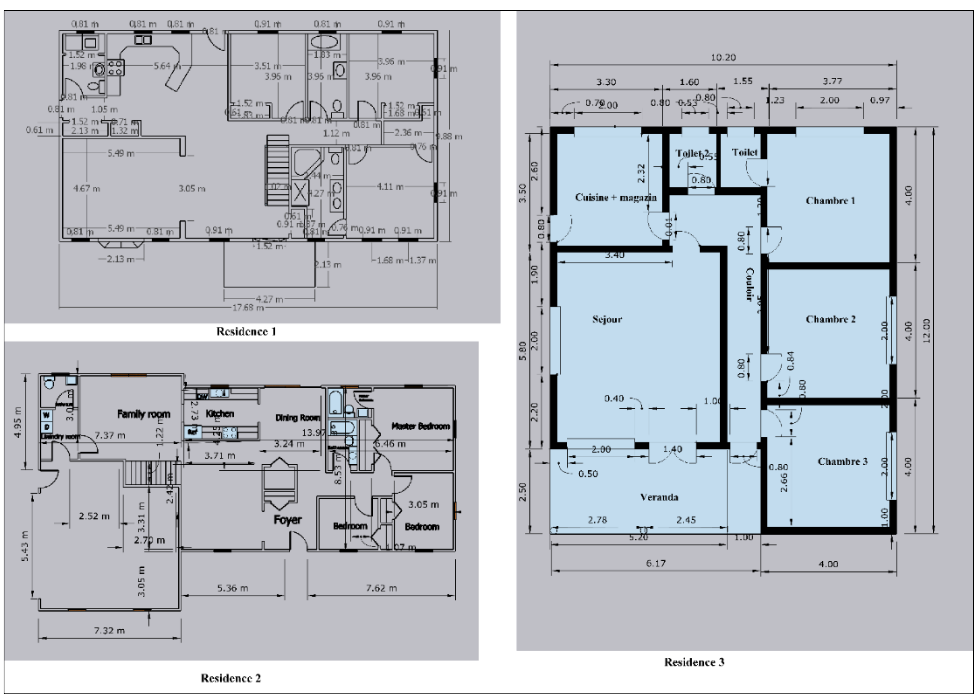

Figure 27: Residential buildings Floor Plan *Source: Author*

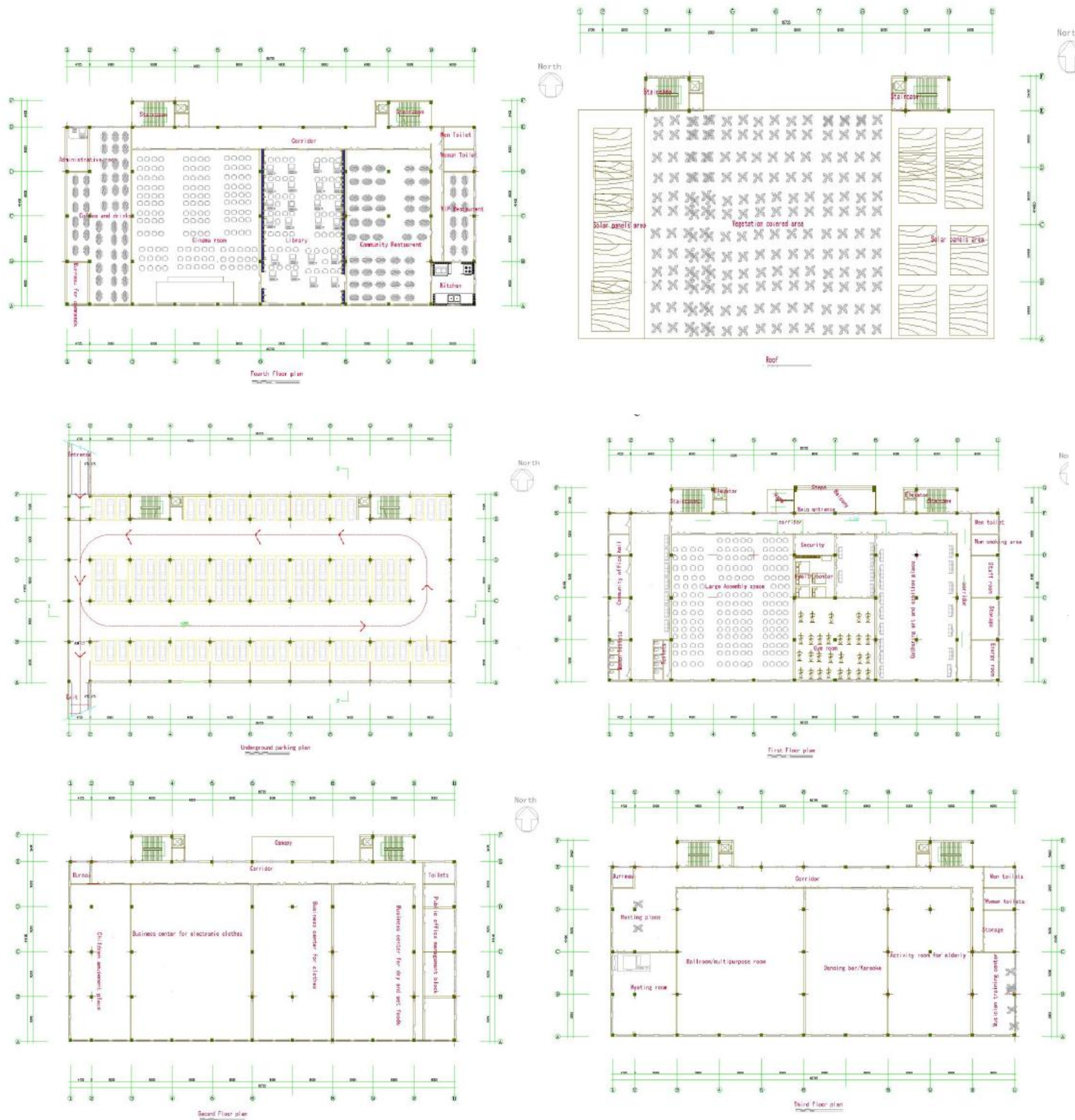

Figure 28: Floor Plan for Public Buildings *Source: Author*

Combining with the green architecture theory, the green residential buildings and public buildings have not only been designed to be energy efficient, but also to be durable, withstanding harsh weather conditions of cold and heat and to enhance a better standard of living by being affordable. The buildings are majority rectangular blocks that were put together to form a smooth pattern. They have also wonderful roof gardens. The residential buildings range from single self-contained rooms to multi rooms of different family sizes, each as a separate unit. The public buildings, are of four storey buildings containing packings, training rooms, meeting rooms, offices and feasting rooms (see figure 35 & 36).

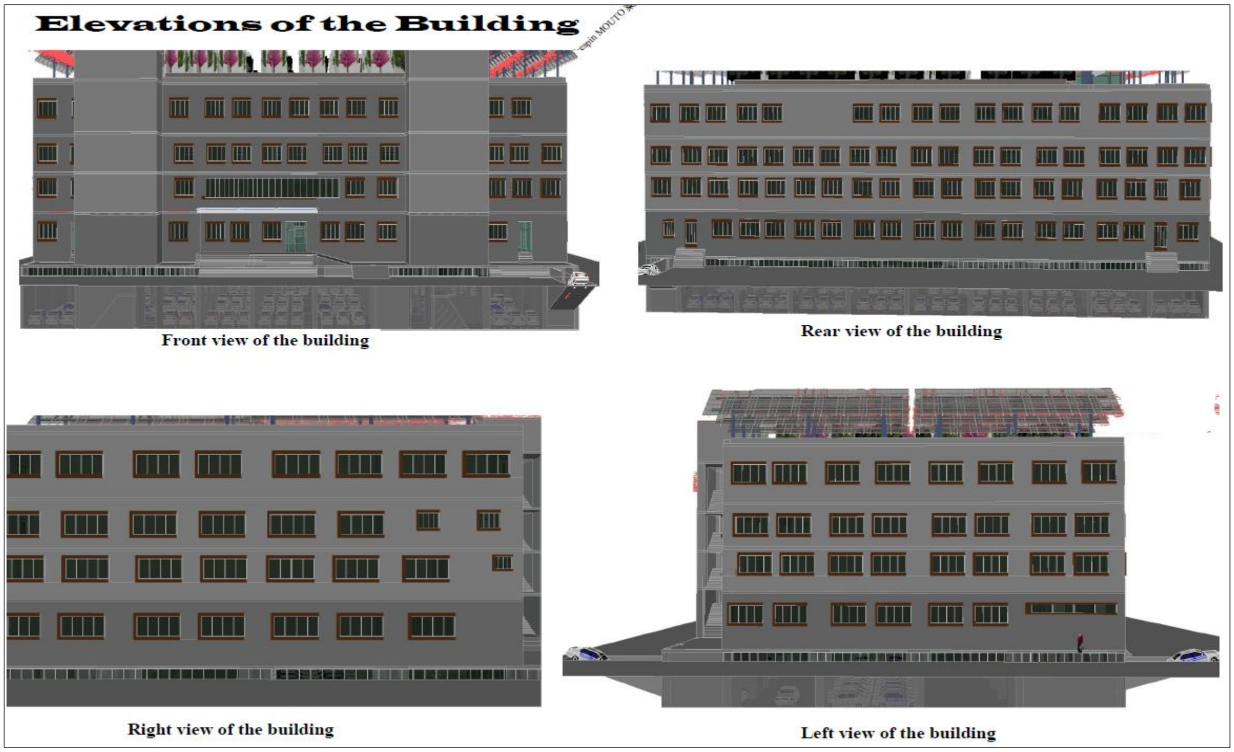

Figure 29: Elevation of Public designed buildings <u>*Source:*</u> *Author*

Figure 30: Residential Buildings Proposed Elevations <u>*Source*</u> *: Author*

The pictures 37 and 38 show the elevations of the public and residential buildings and their aesthetic qualities. Each residential building has two (02) floors and each public building has four (04) floors.

4.1.2- Residential and Public Green Buildings Design Perspectives Views

Figure 31: Residential Buildings Perspective Views *Source: Author*

Figure 32: Public Building Perspective View *Source: Author*

Moreover, the orientations and openings of the facades are done in function of the sun path and wind analyses done in the chapter based on the site analyses. We have put many wide openings especially at the northeastern and Southern facades to favor the natural ventilation and the sunlight to be used for the building interior comfort. In addition, the solar panels are facing the south because the analyses show that the majority of the sun paths are oriented to the south for sun positions observer in Natitingou and in Parakou. This will let the photovoltaic panels to get more sun radiation for more efficiency. On the other hand, having a close look at the perspectives, each building contains at least 60% of vegetation cover and minimum of four trees.

4.2. Proposed Site Design

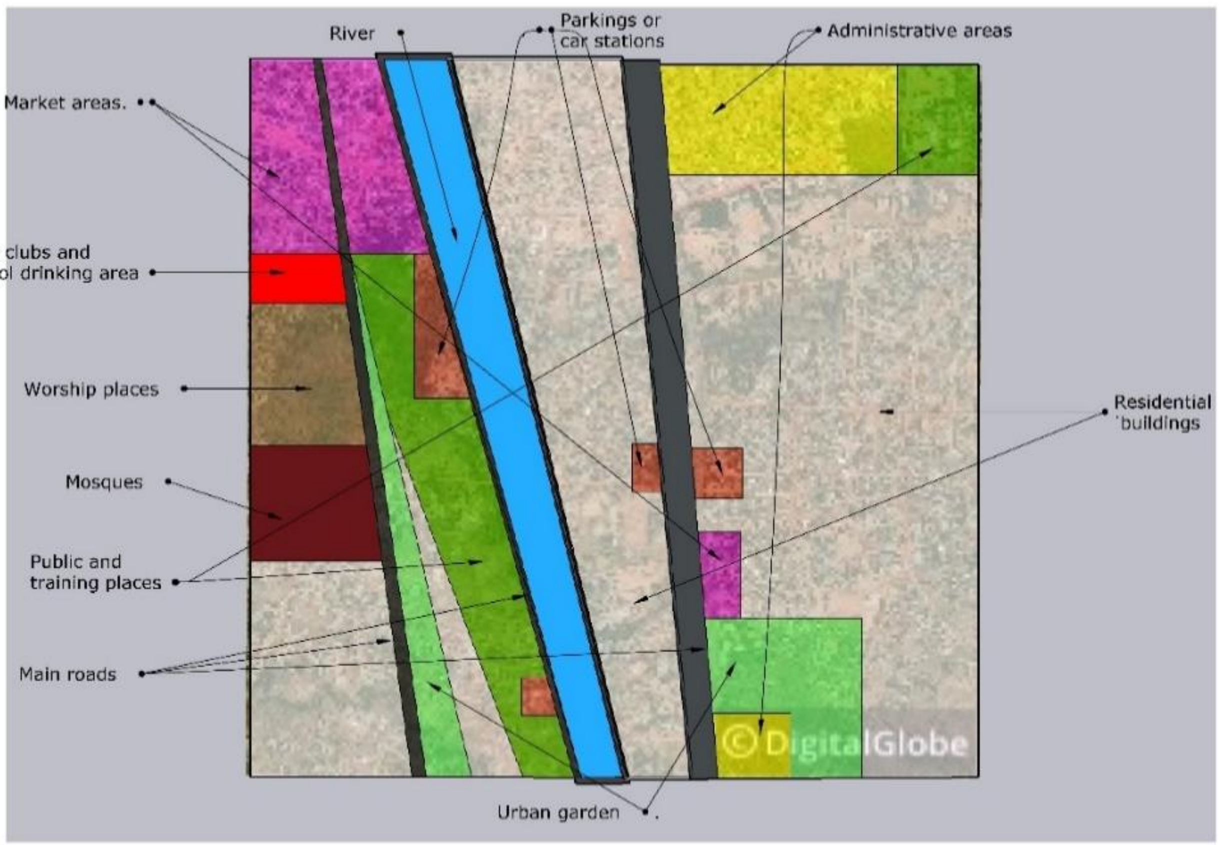

Figure 33: Proposed sites layout development *Source: Author*

The two study sites require a very good planning that allow the increase of urban vegetation, the urban area aesthetic, a good transport infrastructure and efficient land use. The designing and implementation of green building models and the adoption of green building technologies are of paramount importance because the areas filled with the dilapidated houses and the lives of the people are of concern. The model extension at a conurbation scale help resident in the area have very important outdoor space and facilities to enable them to relax and enjoy the environment and scenery. Creating green spaces and providing furniture, garden and playgrounds will eradicate climate change impacts on the urban population. So, in this model, we have put trees on the roads at each 12 km. The residential areas are put 40m from the revers crossing the study areas. There are dustbins under each trees and public bio toilets at each kilometer on the roads to manage efficiently pedestrians wastes. In addition, we have put an amusement centers at the river's sides.

The first proposed design of the master plan as seen above figure 33, shows plainly how the entire land was going to look like, then few things were considered. One of them was the parkings. The original idea was to just maintain the already existing one, but redesigning the master plan I saw the need of expanding and improving it and adding those that can accommodate more cars for the. Also, there was need to create pedestrian pathways. The existing condition does not support pedestrian, except the same small roads used by cars, that is what even the people, cars and other vehicles use.

Figure 34:Rendered images of proposed plan <u>Source:</u> *Author*

Therefore, in this newly proposed master plan we saw the need of developing and designing pedestrian pathways right through and all around the site for access and improved movement of people. Recreational facilities, sport centers and playground were also created on this masterplan.

In the final development of the master plan, as seen in figure 34, the green building concept and idea was now introduced. On the roof, gardens were created which are often called roof gardens or neighborhood gardens, it is seen as green rectangular spaces on the master plan on the top of the buildings. Also, the idea of creating a central garden on the car park came as a result of space management, green architecture implementation and to give more option of movement and interaction with neighbors. Moreover, the garden created surrounding the administrative area is a place created for reflection, quietness and relaxation. This is where you go when you need to write, read and think. It also improves interaction amongst neighbors and create a habitable environment, reducing the hazards of pollution. Areas of green landscape are highly essential and extensively important for the coexistence of both the community and the ecosystem around them and also the preservation of nature.

Figure 35: Areas of green landscape of the model Source: *Author*

When creating the design for Natitingou and Parakou landscapes and the green areas, issues like the mountain terrains, land pattern and form come into play, positioning of the different facilities like garden, outdoor sport and playground are very crucial for both Eco-friendly and also community based.

Figure 36: Ariel view of the car parking designed *Source: Author*

Even though these designs look modern but the cultural heritage of the two cities needs to be kept. Also, noticeably, the connections and road networks of the site were increased for the easy access of both cars and humans. Pedestrian pathways are found everybody and provide access to every part. The unique pattern and combination of apartment buildings with their green spaces should provide the desired result.

4.3. Materials, Techniques and Strategies to be Implemented

When we talk of materials, we refer to different elements that when put together forms a unique building. The properties of these elements are their ability to be able to perform their outstanding functions. We know that is green building construction, we create facilities that enhance the lives in an ecosystem by being efficient and resourceful. The process of selecting materials should be done carefully in order to minimize the negative impact of the built environment when it comes to human health and the resources that support life. Some of the building materials that are typically considered to be green include lumber from forests that have been certified to a third-party forest standard, rapidly renewable plant materials like bamboo and straw, dimension stone, recycled stone, recycled metal and other products that are non-toxic, reusable, renewable and recyclable, adobes bricks and bio digester systems. The use of sunlight through passive solar, active solar, and photovoltaic techniques and using plants and trees through green roofs, rain gardens, and for reduction of rainwater run-off are also considered. Some other materials encourage good thermal performance, resource management and save general construction costs. The materials long-term effects on the environment are a key criterion for selection. Another important property of these materials is the ability to improve the indoor air quality. They must be able to allow all around ventilation and circulation, as buildings rely on a properly designed high vent and cooling system to provide adequate ventilation and air filtration as well as isolate operations from other occupancies. This paper recommends the use of locally obtained and easy to get materials that can be used properly.

There are many technicalities and strategies involved in designing a sustainable structure that fulfils the green building prerequisites, some of which have already been outlined in this paper and not all are acceptable or implemented in the different parts of the world. This is due to building codes and design requirement of such countries; therefore, these techniques vary. For the purpose of this proposed green building design, some of the accepted green building strategies and techniques that are suitable and can be implemented in this project with its location, taken into consideration the climate and land topography, are as follows:

a. **Green roof:**

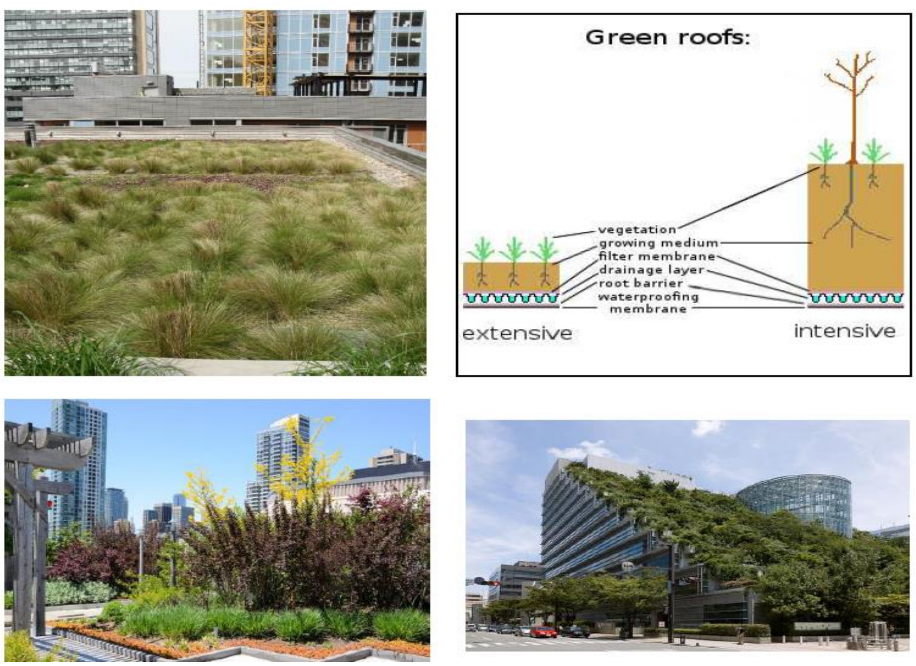

Figure 37: Green roof example and layers *Source: Author*

when we talk of green roof or living roof, we mean a roof partially or completely covered with vegetation and a growing medium, that is mainly planted over a waterproofing membrane. Green roofs provide natural insulation and reduces energy costs and greenhouse gas. This may also include additional layers such as a root barrier and drainage and irrigation systems. Grass, plants, flowers, bushes and other greenery grows on the roofing material as seen below. Stormwater is absorbed into the soil and managed more easily than with a bare roof. Heating and cooling costs are reduced, and the air quality is improved. This will reflect well on the building because of its location (L. B. Safford, 2013).

b. **Stormwater management and greywater reuse:** storm water is water that comes from rain, which also involves snow and ice melts. After rain falls on an untouched site, the water that doesn't evaporate absorbs back into the ground, replenishing the natural water table. However, when a building is placed on the site, along with parking lots, sidewalks, access roads, and other hardscaping, rainfall behaves differently. The water runs off these surfaces and into storm drains. By implementing stormwater management strategies, such as pervious pavement that helps to reduce runoff and retention ponds that capture runoff and slowly release water back into the ground as shown in the image below, the negative environmental impact of buildings can be reduced. And also, greywater is water we get from bathroom, sinks and kitchen, excluding the toilet. Greywater systems reduce the facility's need for fresh water to about 40%, as everything except for toilet streams can be processed for reuse. The most common uses for this water include irrigation and supplying toilets with water (K. Teige, 1932).

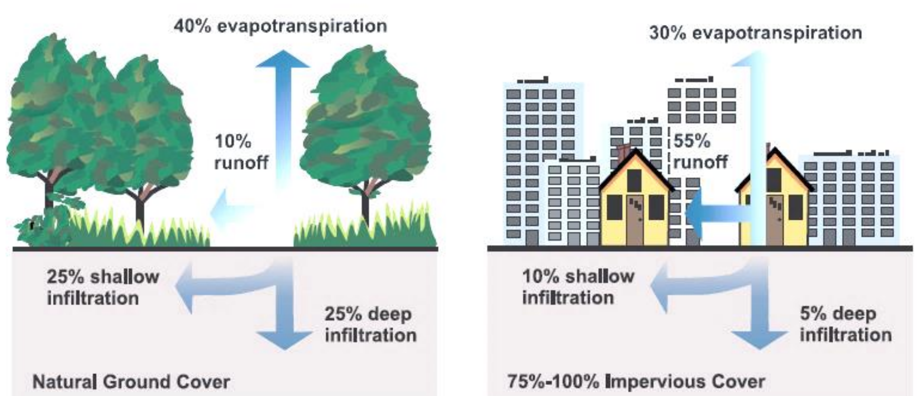

Figure 38: Stormwater management and greywater reuse *Source: Author*

c. **Renewable energy systems:** These are products that provides on-grid and off-grid systems to help you lower your electric bill and use responsible and sustainable energy sources. This is needful because the people are low-income earners. Renewable energy systems, including those that harness solar, hydro and wind energy, are great options for this design, although the wind energy will not be advised here based on the site location and wind characteristics related to the sites. Our aim in this is to use all the energy source available for the building however minimal it may be. These systems are often used in large buildings with high energy consumption rate, in conjunction with passive design strategies (L. B. Safford, 2013).

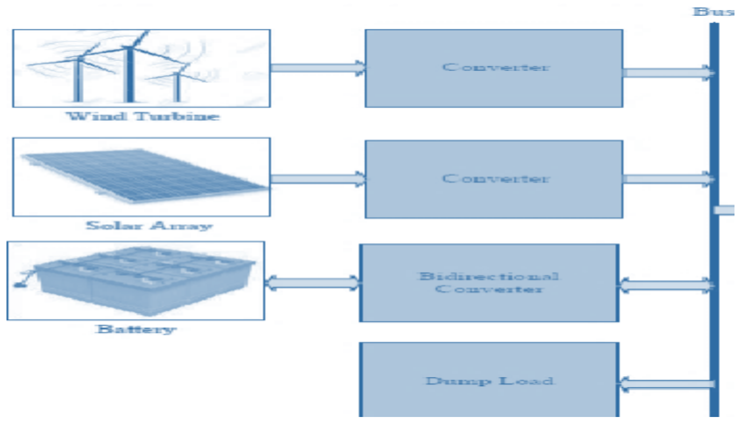

Figure 39: Renewable energy systems *<u>Source</u>: Author*

d. **Passive Sustainable Design.** This seeks to produce an energy balance and performance-based buildings. Some of the passive strategies include considering sun orientation and climate, being thoughtful about window placement and operation. These are used to best manage daylighting and natural ventilation and can go a long way in reducing energy requirements for the building. In certain climates like north of Benin, thermal mass techniques can be used to harness solar energy. In such cases, thick walls absorb heat from the sun during the day and release it into the building at night as demonstrated in the figure 41 (L. B. Safford, 2013).

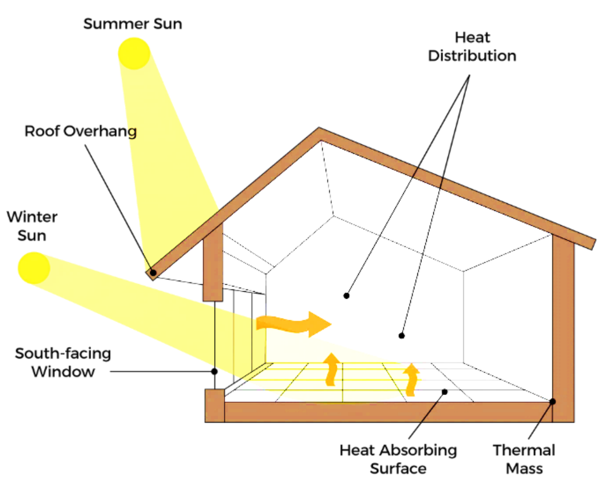

Figure 40: Illustration of Passive Sustainable Design *<u>Source:</u> Author*

e. **Green Building Materials and Finishes.** These are environmentally responsible materials that are made up of properties that are tolerable and harmless to the surrounding, they are also eco-friendly and for this project they are highly recommended. It is therefore a priority when it comes to project implementation to purchase steel, lumber, concrete, and finishing materials, such as carpet and furnishings, from companies that use environmentally responsible manufacturing techniques or recycled materials. Such materials are reclaimed or engineered wood; contains different layers of wood, usually the middle layers are made of wood scraps, softwoods, wood fibers and more. Another is the structural insulated panels (SIPs) which consist of two sheets of oriented strand boards or flake board with a foam layer between them. They are generally available in larger sizes and are used as internal walls for the structure, they are also good for insulation. Other green building materials that we may recommend are insulated concrete forms, composites, natural fiber floor and fiber cement. For most of these materials, if not all are produced here in China and are easy to access (L. B. Safford, 2013).

4.4. Impact Of The Model Built At Building Scale In Climate For Climate Adaptation and Mitigation

Impacts of the model at building scale pertain to the advantages that the building owner or the immediate building occupants would be able to gain from a green building. A number of projects around the world including some of the most advanced energy efficient building are employing green building technologies to improve performance.

4.4.1. Building Energy

Green buildings are energy efficient buildings. Energy-efficient buildings reduce indoor air pollution because they offer cleaner combustion and better ventilation than traditional buildings. And because they use less energy, they also curb outdoor pollution by reducing the fossil fuel pollution created by power generation. Reduction in indoor and outdoor air pollutants can decrease incidence of illnesses such as asthma and lung cancer, as well as lower the rate of premature deaths. This saves not only lives, but also the financial and social costs of medical treatment and lost productivity (Eric Mackres, 2016).

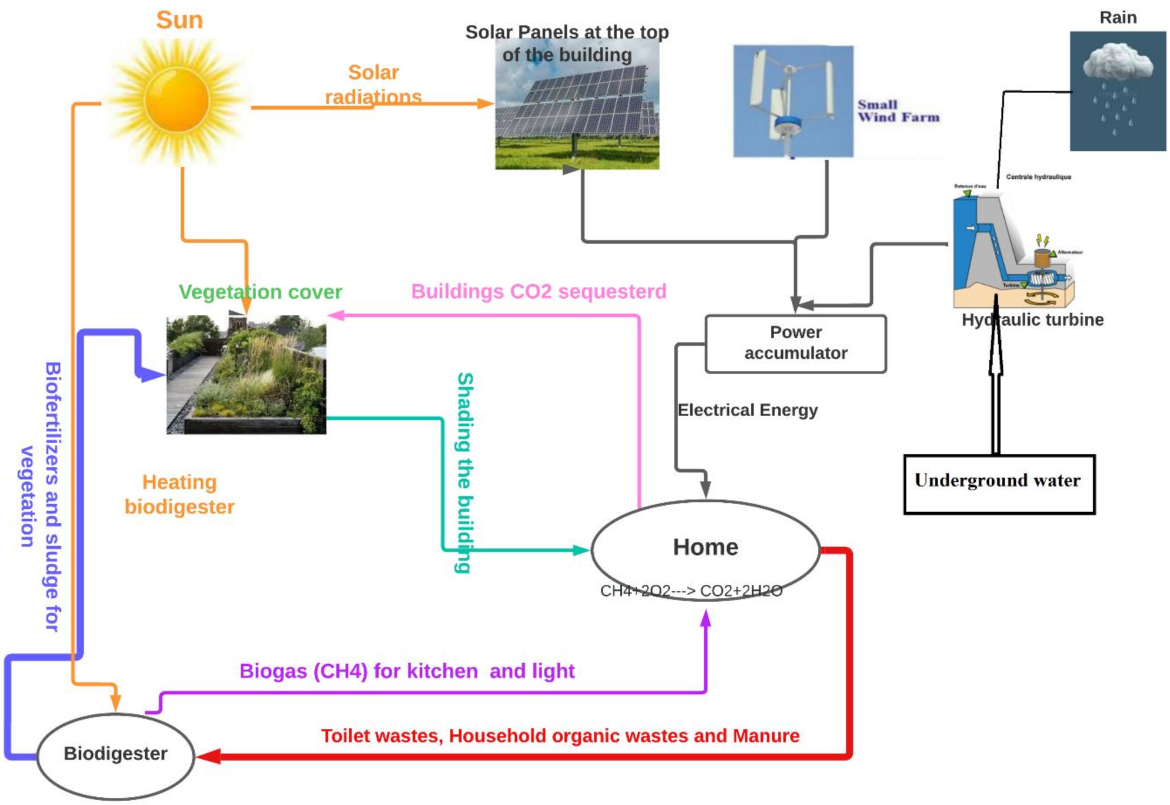

Figure 41: Renewable energy systems *Source: Author*

For the building energy management, we are more oriented to Hybrid renewable energy system (HRES). Renewable energy systems, including those that harness solar and wind energy, are also great options for this design, although the wind energy is not so advised here based on the sites locations and wind velocity in these study areas, we are still using it. Renewable energy system comprises of at least two types of renewable energy resources such as wind potential and solar potential. The main idea about the concept of HRES is to supply cheap and sustainable electricity to the building occupants. The figure 41 shows the conceptual design of a typical HRES in which pumped hydro storage (PHS) is being used as an energy storage system (ESS). There are three types of energy sources mentioned in figure 46, wind, solar and water stored at a particular height. One of the advantages of such HRES is also that it can utilize rainwater very efficiently to produce electrical power. As shown in figure 46 that rainwater can be stored in the upper reservoir (UR) and then it can be allowed to run down to rotate the hydro turbine rotor for producing electrical power. Lower reservoir (LR) collects the water and pump stores it back into the UR (Sajid et al. 2016). With this system used in our models, the buildings will be independent in terms of energy at any period of the year.

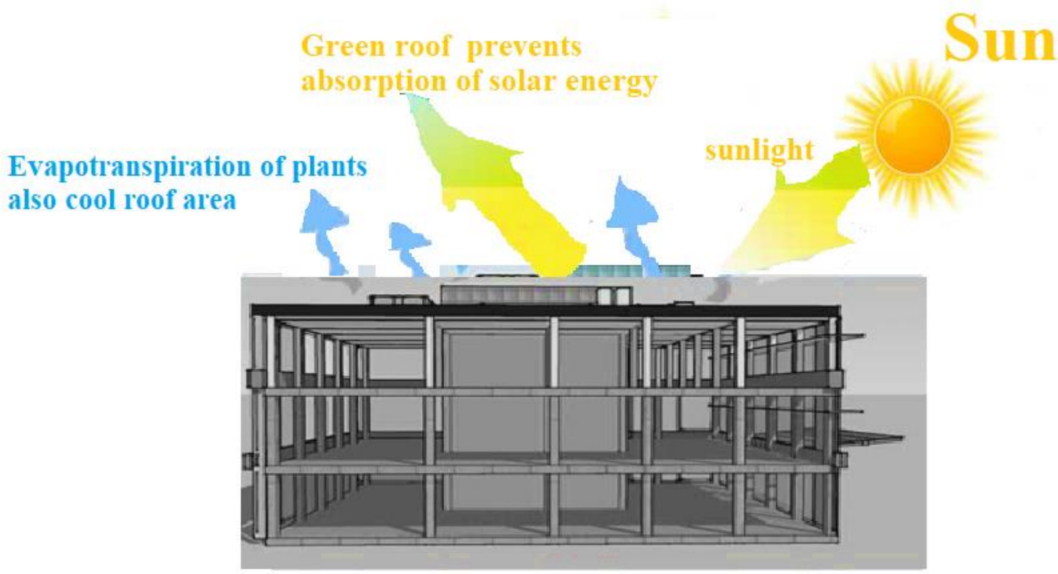

Figure 42: Effects of Roof Garden *Source: Author*

We should notice that the buildings orientation for gaining natural light and ventilation is of a good advantage for us to reduce the energy demand for the buildings. Moreover, the green roofs or roof gardens prevent the building's roofs to receive directly the solar rays that heat up directly the top of buildings. Generally, the heat received by the top of the building is transferred to the building interior that will get hot. So, the roof gardens for the buildings also cools the building interior and reduce the energy demand and increase the building interior comforts in hot climates like the one of our study areas.

On the other hand, we can say that there are two effects from a green roof. Firstly, it prevents the absorption of heat gain directly on to the building structure. Secondly, it provides evaporative cooling effect. In addition, the planting on the outside of the building acts as an insulator so it helps to reduce the amount of energy required to run heating and cooling systems within the building. There is a great micro-climate of cooler air. The air-conditioning system the draws fresh air from the outside providing good internal environmental quality. The evaporative cooling effect means it will be cooling the air in the immediate vicinity of the air intake which also reduces the amount of energy you need to consume to condition. One of the other energy benefits that a lot of people are not aware of though is that green roofs improve the efficiency of solar photovoltaic systems. As the temperature increases on the systems, so as the ambient air surrounding the panels and the actual temperature of the panels themselves increases, their efficiency actually decreases. When you look at the specifications for photovoltaic systems, you will find the rating factors as a function of temperature to tell actual reduction. Since green roofs have the ability to create a micro-climate, reducing temperature in the immediate vicinity, installing solar systems on the roof will allow for higher efficiency and produce more renewable energy compared to a similar system on a non-green roof (ISDM, 2016).

4.4.2. Building Interior Comfort

The design strategy adopted in this project include the considering sun orientation and climate, being thoughtful about window placement and operation. These are used to best manage daylighting and natural ventilation and can go a long way in creating the interior comfort for the building residents. When we consider what makes a room comfortable, we tend to think of temperature first. That's true but there's other things we need to consider also like humidity, air velocity, radiant temperature, metabolic rate, lightening and clothing. The building interior comfort analyzed are plotted on a psychometric chart. In the analysis, all the buildings are considered as the residential building. Each hour is plotted on the Psychrometric Chart as either green if the Design Strategies adopted create indoor comfort, or red if they don't. We should understand that although for a given hour outdoor conditions might be uncomfortable, the design strategy used must be able to create indoor conditions to be comfortable for that hour for residents.

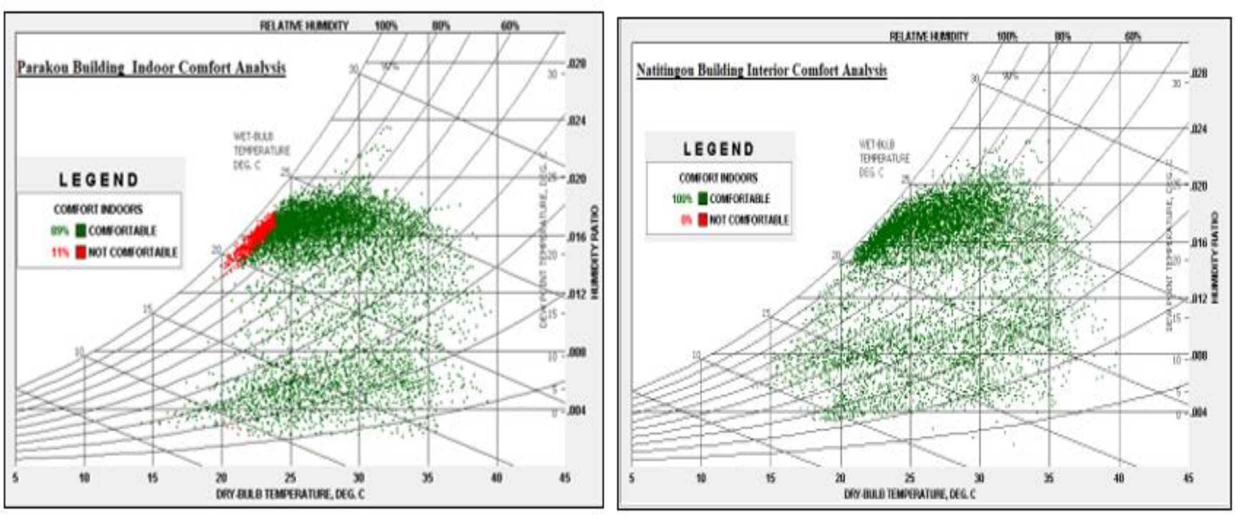

Figure 43: Building Indoor Comfort Analysis for the two cities *Source: Author*

The design strategies used in for the building gives 100% thermal comfort to building residents in Natitingou while it is 89% in Parakou. This means that 11% of the times spent in Parakou buildings will require some additional air conditioning system to guaranty the 100% thermal for building residents.

4.4.3. Building Waste Management and Economy

For the building waste management, we have integrated to the building plans the bio toilets or biodigesters system for the buildings in the two study areas. A biodigester septic tank is a long-term waste and sewerage management system that allows us to recycle water and produce biogas using environmentally friendly procedures. The system consists of a sealed chamber where bacteria break down organic (usually from waste from wastewater) in an oxygen-free environment. The processes inside the bio septic tank produce biogas, useable water, and occasionally bio-fertilizer. This nutrient-rich, organic sludge supports plant growth and enriches and balances the soil.

The concept behind the biodigester septic tank is based on a natural process called anaerobic digestion. Bacteria in the tank break down organic waste matter into a series of chemical elements through a chain of chemical reactions until all you get is methane (commonly known as biogas), carbon dioxide, and water (HomeBiogas, 2022). Our system is proposed to use two digesters to create the right balance and accelerate the process (See Figure 48). All the organic wastes like food waste, leaves, animal wastes, fruits, waste water produced can be put inside this bio system except plastics. In addition, this system requires minimum maintenance compared to a regular septic tank that must be emptied regularly to work.

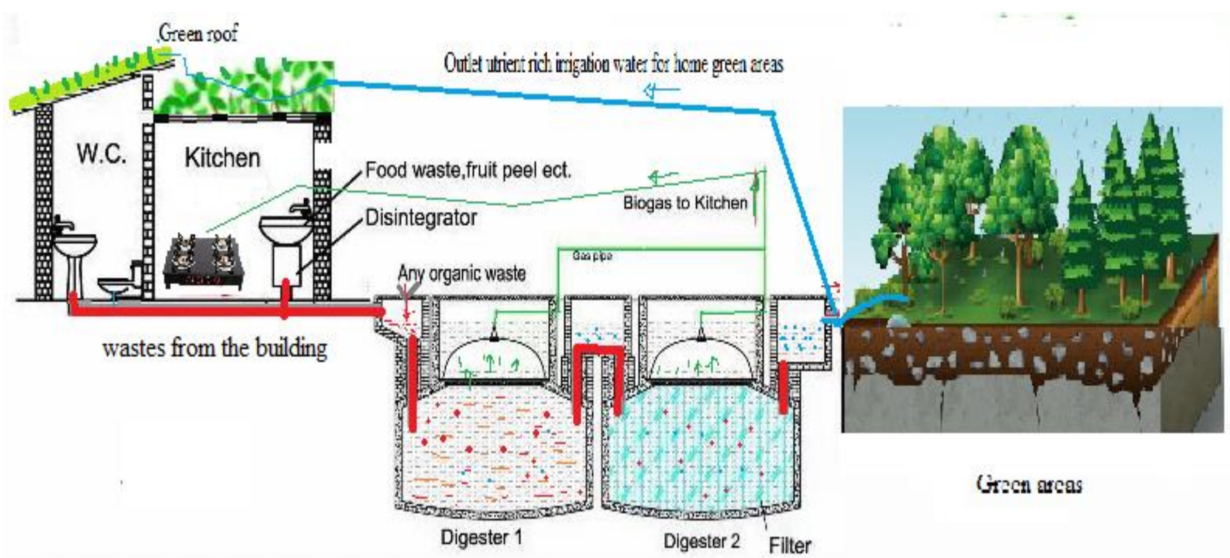

Figure 44: Bio System for Building Waste Management *Source: Author*

Furthermore, green buildings reduce indoor air pollution because they offer cleaner combustion and better ventilation than traditional buildings. And because they use less energy, they also curb outdoor pollution by reducing the fossil fuel pollution created by power generation. Reduction in indoor and outdoor air pollutants can decrease incidence of illnesses such as asthma and lung cancer, as well as lower the rate of premature deaths. This saves not only lives, but also the financial and social costs of medical treatment and lost productivity. Adopting the green building model in the two cities of study, the building residents will not have to pay for electricity, for cooking gas and they will benefit natural ventilation and cool environment.

Another big opportunity that can be gotten from this model is the opportunities of urban agriculture. The benefit of this provision of urban agriculture that goes along with providing public amenity is making healthy food more accessible for people. The thing that can favor more the economy here is to use the green roofs and the green spaces in the homes for agricultural products. Building resident can have access to tomatoes, pepper, groundnuts, maize, ginger and some other agricultural products they will not have to buy at any time of the year. This proves that green building models can lead to a good outcome for economy development.

4.5. Impact of The Model Proposed At Conurbation Scale For Climate Adaptation and Mitigation

This part of the work aims to highlight the impact of the urban expansion of the model at conurbation scale not only in term of land use and land cover, but also in term of urban vegetation generated assessment and its effect on climate.

4.5.1. Land-use Land-Cover

Land use is commonly defined as a series of operations on land, carried out by humans, with the intention to obtain products and/or benefits through using land resources. Land cover is commonly defined as the vegetation (natural or planted) or man-made constructions (buildings, etc.) which occur on the earth surface (Ryan Coffey. 2013). Changes of land use and land cover means that land that was originally dedicated to other purposes for example, agriculture, forest, Greenland and so on, is turned into building areas (Tarja Häkkinen et al. 2013). Changes in land use can have wide-ranging environmental consequences, including biodiversity loss, changes in emissions of gases affecting climate change, changes in hydrology and soil degradation (Marshall and Shortle. 2005). Soil represents one of the most important reservoirs of biodiversity. Soil sealing caused by built-up and land use change because of buildings and other constructions have a relatively high potential effect on the loss of biodiversity amongst several main pressures (as presented by Jeffrey et al. 2010).

As said in the methodology, the model considers that 60% of the built area is covered by vegetation including green roofs and home gardens. We are getting 76 trees and at least twelve (12) houses per the built area of one hectare with the model and the study areas are $724{,}3074676\ ha$ and $2275{,}3907153\ ha$ respectively in Natitingou and Parakou. If the two study areas are fully built with the green model proposed, we will have $434.58448056\ ha$ of green coverage area hosting $55048\ trees$ in Natitingou study area while in Parakou, we have $1365.23442918\ ha$ of green coverage area hosting $172930\ trees.$ Moreover, the energy efficiency of the building combined with the efficient waste management's techniques used will help in reducing the exploitation of the other existing natural resources like fire woods and fuel. With this green building in the two study areas, the urban sprawl will go with the increase of the vegetation cover and the biodiversity conservation instead of its destruction.

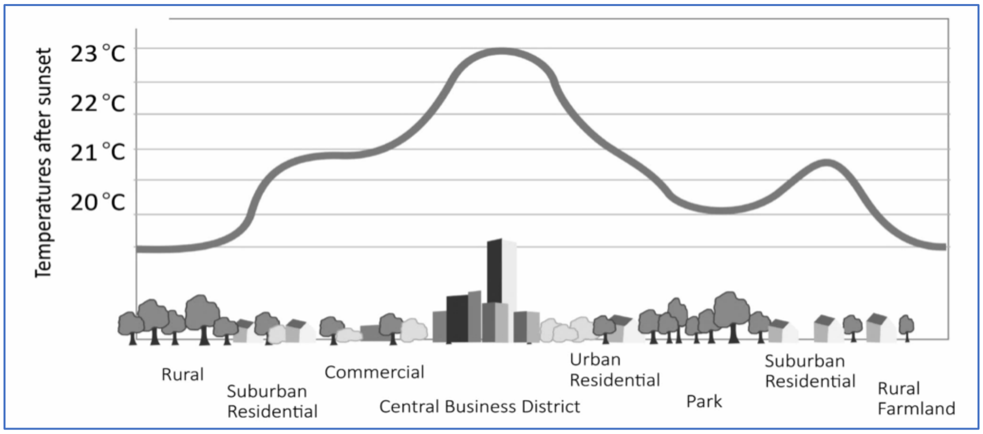

Figure 45: Urban Heat Island Effect *Source: Author*

With these resources included in the model, the increasing population will find solution to his basic needs in his nearest environment. So, the already-existing resources like vegetation will be conserved and this will impact the global warming hazards by reducing urban heat island in Natitingou and Parakou. An urban heat island is a metropolitan area which is significantly warmer than its surrounding rural areas. One of the main causes of the urban heat island is the fact that there is little bare earth and vegetation in urban areas (Jones & Lister, 2010). The figure 45 shows that the area having no vegetation cover are hot with an increasing temperature while the areas covered by the vegetation are cool with low temperature. This means high vegetation in urban areas is of higher solution for global warming adaptation and mitigation. So, as the model favors urban vegetation settlement in our study areas, it is the best solution for Natitingou and Parakou urban areas climate change mitigation.

4.5.2. Urban Vegetation Generated by The Model and Climate for Each Study Area

Understanding an urban forest's structure, function and value can promote management decisions that will improve human health and environmental quality. This chapter summarizes the results of the assessment of the vegetation generated by the model with the plants and herb species proposed and its impacts on the urban climate. The assessment of the vegetation structure, function, and value of the study areas urban forest proposed was conducted using data from 172930 trees and 55048 located respectively throughout Parakou and Natitingou. The data were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station. Here, we'll be interested particularly for the two study areas, according to the green building model proposed, by tree characteristics, carbon storage and sequestration, oxygen production and avoided runoff.

A- Tree characteristics

Leaf area of trees was assessed using measurements of crown dimensions and percentage of crown canopy missing. In the case of our work, these data variables are estimated by iTree.

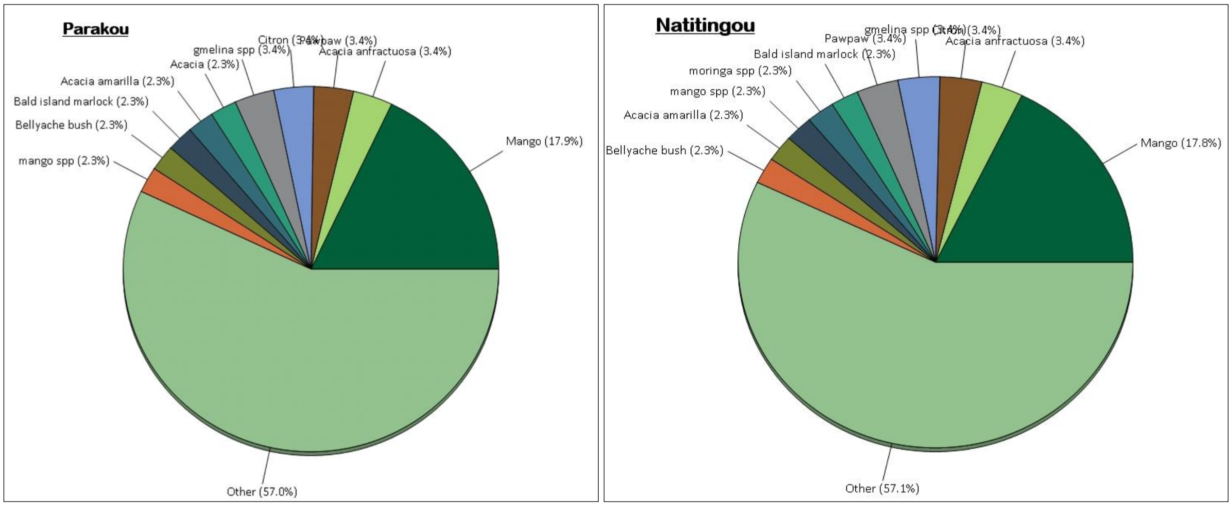

Figure 46:Trees Species Composition *Source: Author*

If built completely with the model proposed, the urban forest of Parakou study area has 172,930 trees with a tree cover of Mango. The three most common species are Mango (17.9%), Acacia anfractuosa (3.4%), and Pawpaw (3.4%). The urban forest of Natitingou study area has 55,048 trees with a tree cover of Mango. The three most common species are Mango (17.8 %), Acacia anfractuosa (3.4%), and Citron (3.4 %) (See Figure 48).

Many tree benefits equate directly to the amount of healthy leaf surface area of the plant. Leaf area quantifies the amount of leaf material in a canopy. By definition, it is the ratio of one-sided leaf area per unit ground area.

Table 4:Parakou study site Leaf Area Most Dominant Species

Species Name	Percent Population	Percent Leaf Area	IV
Mango	17.9	8.6	26.5
Pawpaw	3.4	9.4	12.9
gmelina spp	3.4	6.8	10.2
Acacia anfractuosa	3.4	4.9	8.3
Acacia amarilla	2.3	5.7	7.9
Acacia	2.3	5.0	7.3
Acacia filifolia	1.1	4.6	5.7
African mahogany spp	1.1	4.3	5.5

Citron	3.4	1.9	5.3
African fan palm	1.1	3.8	4.9

Source: Author

In Parakou, the most dominant species in terms of leaf area are Pawpaw, Mango, and gmelina spp. The 10 species with the greatest importance values are listed in Table 4.

Table 5: Natitingou Study Site Leaf Area Most Important Species

Species Name	Percent Population	Percent Leaf Area	IV
Mango	17.8	8.5	26.3
Pawpaw	3.4	9.5	12.9
gmelina spp	3.4	6.8	10.3
Acacia anfractuosa	3.4	4.9	8.3
Acacia amarilla	2.3	5.7	7.9
Acacia	2.3	5.0	7.3
Acacia filifolia	1.1	4.6	5.7
African mahogany spp	1.1	4.3	5.5
Citron	3.4	1.9	5.3
African fan palm	1.1	3.8	4.9

Source: Author

In Natitingou study area, the most dominant species in terms of leaf area are Pawpaw, Mango, and gmelina spp. The 10 species with the greatest importance values are listed in Table 5. Importance values (IV) are calculated as the sum of percent population and percent leaf area. High importance values do not mean that these trees should necessarily be encouraged in the future; rather these species currently dominate the urban forest structure.

B- Carbon Storage and Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power sources (Abdollahi et al 2000). Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. carbon sequestration is the removal of carbon dioxide from the air by plants. To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter ($year\ x$) to estimate tree diameter and carbon storage in year $x + 1$.

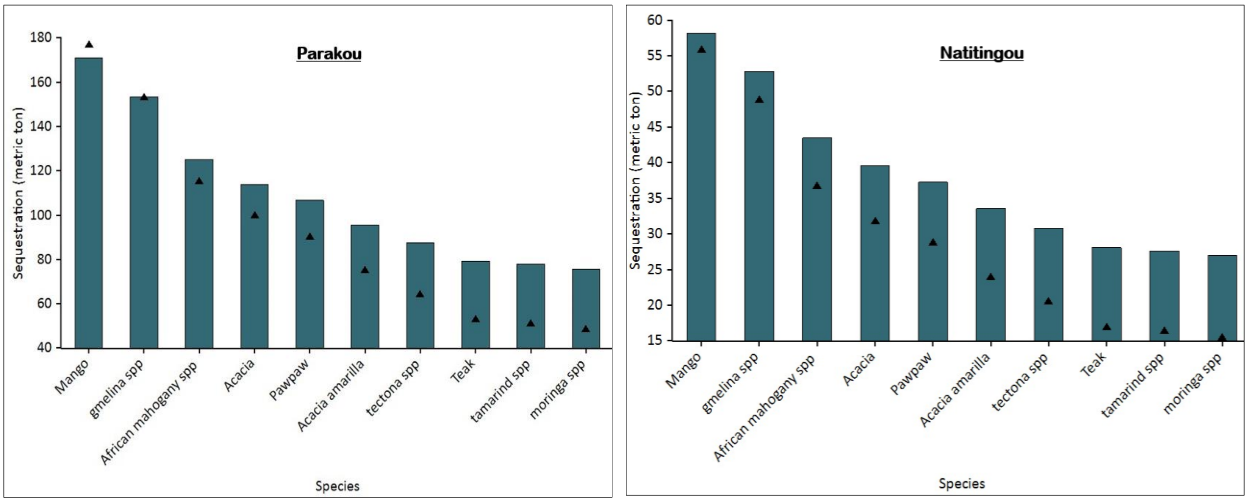

Figure 47: Estimated annual gross carbon sequestration for urban tree species with high sequestration
Source: Author

The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of Parakou study site trees is about 1.818 thousand metric tons of carbon per year. On the other hand, the gross sequestration of Natitingou study site trees is about 579.1 metric tons of carbon per year.

Carbon storage is another way tree can influence global climate change. Carbon storage is the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation. As a tree grows, it stores more carbon by holding it in its accumulated tissue. As a tree dies and decays, it releases much of the stored carbon back into the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees, but tree maintenance can contribute to carbon emissions (Nowak et al 2002). When a tree dies, using the wood in long-term wood products, to heat buildings, or to produce energy will help reduce carbon emissions from wood decomposition or from fossil-fuel or wood-based power plants. To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations (Nowak 1994).

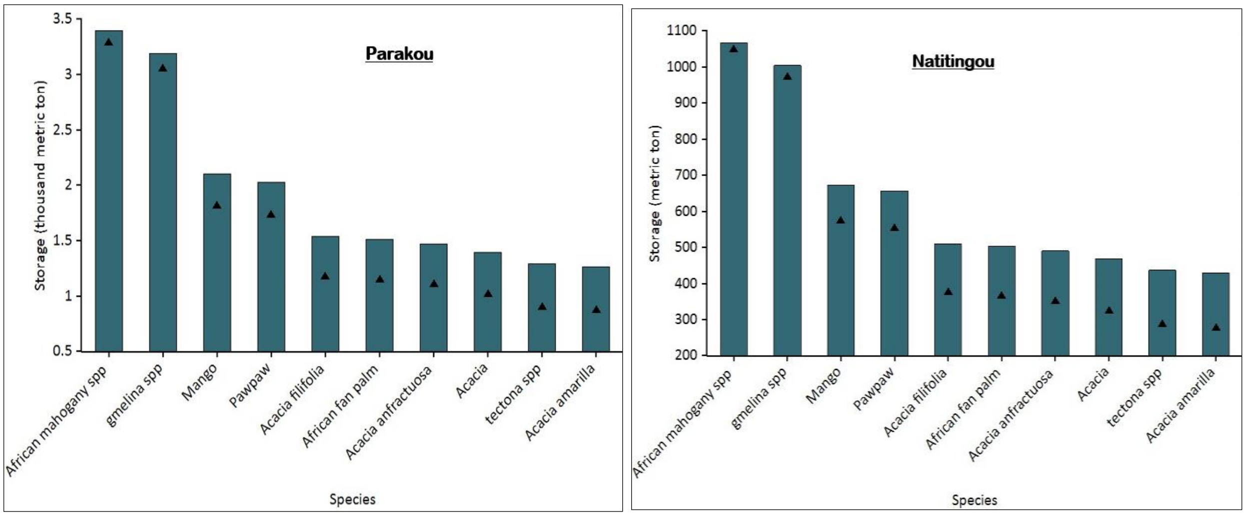

Figure 48: Estimated annual gross carbon storage for urban tree species with high storage

Source: Author

Trees in Parakou study site are estimated to store 27000 metric tons of carbon. Of the species sampled, African mahogany spp stores the most carbon (approximately 12.2% of the total carbon stored) and Mango sequesters the most (approximately 9.72% of all sequestered carbon). For the study are of Natitingou, Trees are estimated to store 8600 metric tons of carbon. Of the species sampled, African mahogany spp stores the most carbon (approximately 12.2% of the total carbon stored) and Mango sequesters the most (approximately 9.62% of all sequestered carbon.).

C- Oxygen Production

Oxygen production is one of the most commonly cited benefits of urban trees. The annual oxygen production of a tree is directly related to the amount of carbon sequestered by the tree, which is tied to the accumulation of tree biomass.

Table 6: The top 20 oxygen production species in Parakou site

Species	*Oxygen*	*Gross Carbon Sequestration*	*Number of Trees*	*Leaf Area*
	(metric ton)	*(metric ton/yr)*		*(hectare)*
Mango	471.30	176.74	31,016	157.73
gmelina spp	408.08	153.03	5,913	125.87
African mahogany spp	306.71	115.02	1,971	79.91
Acacia	265.71	99.64	3,942	92.73
Pawpaw	240.10	90.04	5,913	174.16
Acacia amarilla	199.96	74.98	3,942	104.15
tectona spp	170.98	64.12	3,942	43.21
Teak	141.00	52.88	3,942	43.97

tamarind spp	136.19	51.07	1,971	47.97
moringa spp	128.81	48.31	3,942	43.73
abaca	127.20	47.70	1,971	27.97
Bellyache bush	114.60	42.97	3,942	18.93
Aceitillo falso	112.42	42.16	1,971	49.12
Acacia anfractuosa	110.74	41.53	5,913	90.06
cassia spp	104.50	39.19	1,972	30.27
Angel's trumpet	102.44	38.42	1,971	43.37
Quinine Tree	97.16	36.43	1,971	40.89
Amansa guapo	91.88	34.46	1,971	27.66
shrubby-spurge spp	91.88	34.46	1,971	27.66
Acacia filifolia	91.74	34.40	1,971	84.24

Source: Author

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: $net\ O_2\ release\ (kg/\ yr)\ =\ net\ C\ sequestration\ (kg/yr)\ \times\ 32/12$. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition (Nowak et al 2007). In Parakou study area, trees are estimated to produce 4.848 thousand metric tons of oxygen per year. While in the study area of Natitingou, Trees in are estimated to produce 1.544 thousand metric tons of oxygen per year (See table 5 &6).

Table 7: The top 20 oxygen production species of Natitingou site

Species	***Oxygen***	***Gross Carbon Sequestration***	***Number of Trees***	***Leaf Area***
	(metric ton)	*(metric ton/yr)*		*(hectare)*
Mango	148.60	55.73	9,795	49.72
gmelina spp	130.13	48.80	1,886	40.14
African mahogany spp	97.88	36.71	629	25.50
Acacia	84.66	31.75	1,256	29.55
Pawpaw	76.53	28.70	1,885	55.51
Acacia amarilla	63.76	23.91	1,257	33.21
tectona spp	54.48	20.43	1,256	13.77
Teak	44.93	16.85	1,256	14.01
tamarind spp	43.46	16.30	629	15.31
moringa spp	41.11	15.42	1,258	13.96
abaca	40.53	15.20	628	8.91
Bellyache bush	36.54	13.70	1,257	6.04
Aceitillo falso	35.82	13.43	628	15.65

Acacia anfractuosa	35.30	13.24	1,886	28.70
cassia spp	33.33	12.50	629	9.65
Angel's trumpet	32.64	12.24	628	13.82
Quinine Tree	30.96	11.61	628	13.03
Amansa guapo	29.28	10.98	628	8.81
shrubby-spurge spp	29.28	10.98	628	8.81
Acacia filifolia	29.23	10.96	628	26.84

Source: Author

D- <u>Avoided Runoff</u>

Runoff, also known as overland flow, is the flow of water occurring on the ground surface when excess rainwater, stormwater, meltwater, or other sources, can no longer sufficiently rapidly infiltrate in the soil (Society National Geographic. 2011). Urban runoff is surface runoff of rainwater, landscape irrigation, and car washing created by urbanization. Impervious surfaces (roads, parking lots and sidewalks) are constructed during land development. During rain, storms and other precipitation events, these surfaces (built from materials such as asphalt and concrete), along with rooftops, carry polluted stormwater to storm drains, instead of allowing the water to percolate through soil. Surface runoff can be a cause for concern in many urban areas as it can contribute pollution to streams, wetlands, rivers, lakes, and oceans. During precipitation events, some portion of the precipitation is intercepted by vegetation (trees and shrubs) while the other portion reaches the ground. The portion of the precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff (Hirabayashi 2012).

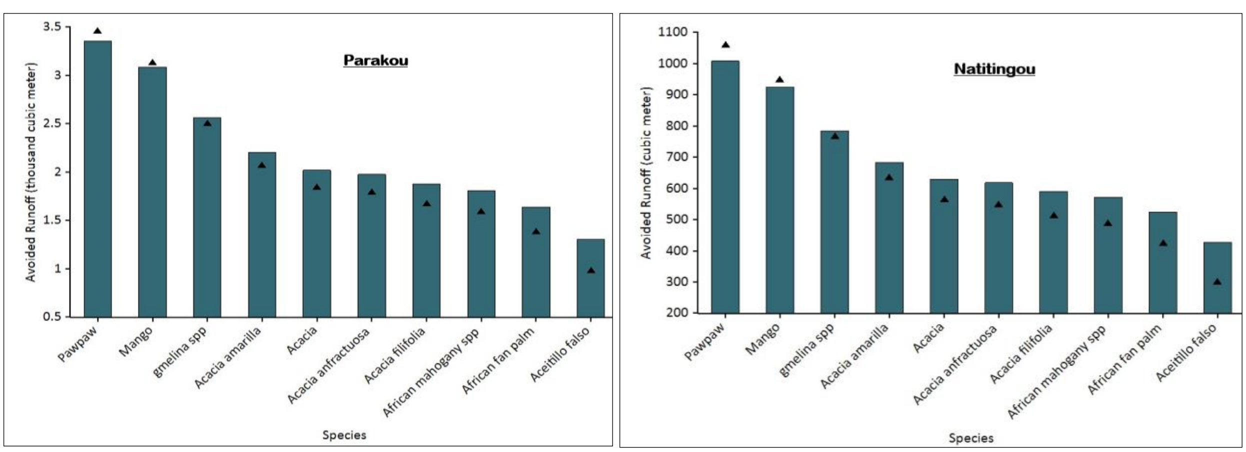

Figure 49: Avoided runoff for species with greatest overall impact on runoff
<u>Source:</u> Author

In urban areas, the large extent of impervious surfaces increases the amount of surface runoff. Urban trees and shrubs, however, are beneficial in reducing surface runoff. Trees and shrubs intercept precipitation, while their root systems promote infiltration and storage in the soil. Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches, and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis. Of the species, Pawpaw, mango and gmelina avoid the most runoff in the two study areas. Shortly, we can say that the trees and shrubs of Parakou study area help to reduce runoff by an estimated 36.6 thousand cubic meters a year. For the case of Natitingou study site, the trees and shrubs reduce the runoff by an estimated 11.2 thousand cubic meters a year (See Figure 49).

Conclusion for the chapter 4

In summary for this chapter, we can say that the green model proposed is of high importance for Natitingou and Parakou cities for climate adaptation and mitigation. The building model proposed has many external openings to favor illumination and ventilation of the building interior. Green roofs, home green gardens and trees are of high importance in this model covering at least 60% of the built land. Each roof is surmounted by photovoltaic panels for energy for solar energy, wind barrage for wind energy and hydraulic turbine for rain water and underground water conversion to electricity. In addition, the buildings are integrated with biodigester toilets for building organic wastes management and their conversion to an energy useful to the building. All the other materials used in these building designs are for the building energy demand reduction. The study sites are designed with roads, packings and the green buildings and many vegetation covered areas.

The building designed has positive impacts on building residents at building scale and at conurbation scale. At building scale, it acts by creating a very good building interior comfort, by making the building independent energetically and by managing the building residents' wastes. At an agglomeration scale, it favors not only the urban vegetation increasing for carbon sequestration and storage, urban runoff reducing, urban heat island reducing, but also urban agriculture opportunity increasing, waste management and economy stability. So, can we say that the second specific hypothesis stating that green building model improves urban vegetation cover, people life style, and climate change mitigation and adaption is confirmed.

Conclusion and Perspectives

This paper proposes green building models for the greening of the urban areas of Natitingou and Parakou to help the decision makers in their fight for climate change adaptation and mitigation. Natitingou is a city and commune in north western Benin and the capital of Atakora Department and Parakou is in the north eastern and the capital of Borgo department. The site analyses reveal that the two cities of our study are overwhelmed by the climate change impacts especially in urban areas due to inadequate method of adaptation and mitigation developed through the urban areas planning or building projects. Despite the alarming situation, the population is growing and its needs and demands from the environment and land use are increasing. Besides, knowing that an efficient management of the energy at building scale and the increase of the urban vegetation through building industry could be a solution for the climate change adaptation and mitigation, we have proposed a green building models for our two study areas. The models are integrated with 60% of vegetation cover for a piece of land of $500\ m^2$ including roof gardens, renewable energy systems and waste management systems.

After analyzing the green building models proposed at building and conurbation scales, it is clearly shown that they provide benefits not only to the building residents but also to the general community to strengthen their climate change adaptation and mitigation. Firstly, it reduces the energy needs for building residents and make them independent energetically. Secondly, It favors the urban vegetation cover grow at the same rate with increase of population settlements. Among those advantages of this model, we can mention the reduction urban heat island effect, air pollution reduction, storm-water management and improved water quality, Urban agriculture opportunities, reclaiming urban wastelands, improved public health and well-being, contribution to aesthetics and urban planning, integration with landscape, biomass and biodiversity. The implementation of green building models will provide residents with affordable housing and improved health condition; this will lead to clean air, hygienic surroundings, enough green spaces for gardens, parks and children's playground. This will also improve social networking within the neighborhood and attract more visitors. At the end, we can assert strongly that the green building model is the best solution for climate change adaptation and mitigation not only in the urban areas of Natitingou and Parakou, but also in all the cities in west Africa.

The research, therefore, addresses the main goal and objective of the project, which to to develop an energy efficient green building models that allow to keep urban area green and favor climate change adaptation and mitigation in the urban areas of Benin. The reader will also eventually understand the use of eco-friendly, renewable and reusable materials in construction for the reduction of greenhouse gas and climate change adaptation and mitigation.

To conclude the research paper, the work was directed at addressing some of the benefits of developing sustainability in architectural structures from a number of different perspectives, such as the building's energy efficiency, water cycling management efficiency, self-sustaining capacity and some of its outdoor and indoor environmental qualities in relation to the green spaces. At this point, it is clear to the reader that the main focus of this research paper that is to develop a model of buildings ensuring urban areas greening, energy consumption reduction, adaptation and mitigation of climate change is reached. Throughout this research work, all the specific hypotheses are confirmed and the main research hypothesis that green building approaches contribute to the adaptation and mitigation of climate change effects in cities is confirmed.

For further studies or future research programs, the following recommendations are made. Firstly, I recommend that there be a provision of enough information about the said project. Secondly, I would like agriculturist and engineers work in the selection of specific plant species that are more suitable for green roofs and home gardens. Moreover, the performance of practical should be encouraged, especially those that have to deal with material selection and testing. Sustainability, renewability, reusability and durability of materials are very important. These are separate but related to areas when it comes to material choice for a particular design. Therefore, testing these materials in the lab and performing practical will help the student to come up with accurate and precise solutions. Even the use of recyclable materials will be tested and proven to be effective. Green buildings must be efficient and effective. We recommend also that next works on this project would be based on the estimation of the cost of realization of the proposed solutions. Our last recommendations go for decision makers, climates Scientifics, city planners, urbanists at any level to adopt and encourage the green building models for their cities development plans to reach the climate adaptation and mitigation goals.

REFERENCES :

Aktas B, Ozorhon B (2015) Green building certification process of existing buildings in developing countries: cases fromTurkey. JManag Eng. https://doi.org/10.1061/(asce)me.1943-5479.0000358, 05015002

Al-Qawasmi J, Asif m, Abd El Fattah A, Babsail MO (2019) Water efficiency and management in sustainable building rating systems: examining variation in criteria usage. *Sustainability* 11:16

Amos Darko, Albert Ping Chuen Chan, De-Graft Owusu-Manu, Zhonghua Gou and Jeff Chap-Fu Man (2020) Adoption of Green Building Technologies in Ghana. https://doi.org/10.1007/978-3-030-24650-1_12

Anh YH,Pearce A, Ku K (2012) Paradigm shift of green buildings in the construction industry. Int J Sustain Build Technol Urban Dev 2:52-62

Baten, Joerg (2003). "Creating Firms for a New Century: Determinants of Firm Creation around 1900". European Review of Economic History. 7 (3): 301–329. doi:10.1017/S136149160300011X. hdl:10419/76463. S2CID 51520898 – via EBSCO.

Berardi U (2013) Moving to sustainable buildings: paths to adopt green innovations in developed countries. Versita, London

Bertaud, A. and Richardson, A.W., 2004. Transit and Density: Atlanta, the United States and Western Europe.

Bubbs D (2017) Lessons in green building from Africa's First LEED-Certified Hospital. https://www.fastcodesign.com/3067054/lessons-in-green-building-from-africas-first-leedcertified-hospital. 4 Feb 2017

Celina Schelle (2017) The Nubian Vault Association – A Way Towards An Environmentally & Socially Just Society, May 21, 2017. https://blogifsa.wordpress.com/2017/05/21/the-naubian-vault-association-a-way-towards-an-environmentally-socially-just-society/

Chan APC, Darko A, Olanipekun AO, Ameyaw EE (2018) Critical barriers to green building technologies adoption in developing countries: the case of Ghana. J Clean Prod 172:1067–1079

Chan, A., Darko, A. & Ameyaw, E., (2017). Strategies for promoting green building technologies adoption in the construction industry dan international study. Sustainability, 9(6), p. 969.

Clark, Bruce W. et al, Making Connections: Canada's Geography. Second ed. Don Mills, ON: Pearson Education Canada Inc. 2006. p. 245.

Coed Cymru (2019) a basic guide to tree planting. https://coed.cymru/images/user/Tree_Planting__Coed_Cymru_2017.pdf

Cooke E, Hague S, McKay A (2016) The Ghana poverty and inequality report: using the 6th Ghana living standards survey. http://africainequalities.org/wp-content/uploads/2016/07/ Ghana_Poverty_and_Inequality_Analysis_FINAL_Match_20161.pdf. 26 Aug 2017

C. Q. L. Xue, BUILDING A REVOLUTION, Hong Kong: Hong Kong University Press, 2006.

D. Bradley Rowe. (2010). *Green roofs as a means of pollution abatement*. Department of Horticulture, Michigan State University, A212 Plant and Soil Sciences Bldg., East Lansing, MI 48824, USA

Danielle Shanahan, Michael Strohbach, Paige S Warren, Richard A Fuller (2014). *The challenges of urban living.* Oxford University Press.

DEE (2019) Paris agreement. Climate change: government and international activities. Department of the environment and energy. *Commonwealth of Australia*. Retrieved 23 Dec 2019, from https://www.environment.gov.au/climate-change/government/international/paris-agreement

Desjarlais, C., Allard, M., Belanger, D., Blondlot, A., Bouffard, A., Bourque, A. *Savoir s'adapter aux changements climatiques*, Québec (Qc) : OURANOS; 2010; 128p

ENCYCLOPEDIC ENTRY (2021) *Urban area, An urban area is the region surrounding a city*, https://www.nationalgeographic.org/encyclopedia/urban-area/#:~:text=Over%20time%2C%20as%20these%20rural,rather%20than%20agriculture%20or%20fishing.

Elisabeth M. Hamin, Nicole Gurran (2009), *Urban form and climate change: Balancing adaptation and mitigation in the U.S. and Australia*. https://research-legacy.arch.tamu.edu/epsru/Course_Readings/Ldev671MARS689/LDEV671_Readings/Hamin_urbanform_habinternational.pdf

Elkington J. (1999) *The Triple Bottom Line of sustainability*

EPA (2009) Building and their impact on the environment: a statistical summary. *Environment Protection Agency*, USA

Francoise Kunsch, (2020) *les 30 ans de jumelage avec natitingou (bénin),* https://francoise-kunsch.org/2020/06/17/archives-les-30-ans-de-jumelage-avec-natitingou-benin/

Jeffrey, S., Gardi, C., Jones, A., Montanarella, L., Marmo, L., Miko, L., Ritz, K., Peres, G., Römbke, J., van der Putten, W.H. (eds.), (2010), *European Atlas of Soil Biodiversity*, European Commission, Publications Office of the European Union, Luxembourg

GSA https://www.gsa.gov/real-estate/design-construction/design-excellence/sustainability/sustainable-design#:~:text=Sustainable%20design%20seeks%20to%20reduce,and%20create%20healthy%2C%20productive%20environments.

Hirabayashi, S. 2012. i-Tree Eco Precipitation Interception Model Descriptions, http://www.itreetools.org/eco/resources/iTree_Eco_Precipitation_Interception_Model_Descriptions_V1_2.pdf

HomeBiogas, 2022; https://www.homebiogas.com/blog/all-you-need-to-know-about-biodgester-septic-tanks/#:~:text=A%20biodigester%20septic%20tank%20is,in%20an%20oxygen%2Dfree%20environment.

Howard JL. Federal commitment to green building: Experiences and expectations. Office of Federal Environmental Executive (US); 2003. 89p. Available from: http://www.ofee.gov/sb/fgb_report.html

Hwang BG, Tan JS (2012) Green building project management: obstacles and solutions for sustainable development. Sustain Dev 20(5):335–349

IPCC (2018) Summary for policymakers, technical summary and frequently asked questions. Global warming of 1.5^{0}C. an IPCC special report on the impacts of global warning of 1.5^{0}C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. V. Masson-Delmote, P. Zhai, H.-O. Portner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Pean, R. Pidcok, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I.Gomis, E. lonnoy, T. Maycock, M. Tignor, and T. Waterfield, *intergovernmental Panel on climate change*

ISDM (2016), *Green Roofs And Living Walls For Architects*; P: 12.

Jackie Craven (2019) *A Primer on Green Architecture and Green Design When "Green" Architecture Is More Than a Color*. https://www.thoughtco.com/what-is-green-architecture-and-green-design-177955

Jones & Lister (2010) *The urban heat island in central London and urban related warming trends in central London since 1900.*

K. Teige, Nejmenší byt, Prague: Václav Petr, Praha 2, Ječná 32, 1932.

Le Matin, *New Town of Zenata, an innovative project* ", Le Matin ,April 3, 2013

Marius Sachs (2016) *Green building certification in Sub-Saharan Africa - An elaboration of sustainable rating criteria*. Master thesis, University of Regensburg, IRE|BS – International Real Estate Business School.

Marshall, E. and Shortle, J. (2005), "Urban development impacts on ecosystems", in Goetz, S., Shortle, J. and Bergstrom, J. (eds.), *Land Use Problems and Conflicts: Causes Consequences and Solutions*, New York, Chapter 7.

Matt Burdett, 17 April 2018 [updated 19 May 2018], *Characteristics of urban places.* https://www.geographycasestudy.com/characteristics-of-urban-places/

Minal Pathak (2013) *Urban Low Carbone Growth: Financing opportunities for Indian cities*. https://e-lib.iclei.org/wp-content/uploads/2015/04/low_carbon_financing_report_31st-January-2013.pdf

Moon, Byunggeor; Ahn, Sungin (2022). "The effects of a FAR regulation in a model of durable building with redevelopment: The case of New York City". Regional Science and Urban Economics. doi:10.1016/j.regsciurbeco.2022.103775. ISSN 0166-0462.

NOAA (2010) *Is Current Warming Natural?* https://earthobservatory.nasa.gov/features/GlobalWarming/page4.php

Nowak, D.J. 1994. Atmospheric carbon dioxide reduction by Chicago's urban forest. In: McPherson, E.G.; Nowak, D.J.; Rowntree, R.A., eds. Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project. Gen. Tech

Nowak, D.J.; Stevens, J.C.; Sisinni, S.M.; Luley, C.J. 2002. Effects of urban tree management and species selection on atmospheric carbon dioxide. Journal of Arboriculture. 28(3): 113-122.

Nowak, D.J.; Hoehn, R.; Crane, D. 2007. Oxygen production by urban trees in the United States. Arboriculture & Urban Forestry. 33(3):220-226.

Ozdemir MH (2000) *An alternative incentive system to improve productivity at the Turkish Naval Shipyards*. PhD Thesis, Naval Postgraduate School, Monterey, CA, USA

Pachauri, R.K. and Reisinger, A. (2008) Climate change 2007. Synthesis report. Contribution of Working Groups I, II and III to the fourth assessment report. http://www.ipcc.ch/ipccreports/ar4-syr.htm

Plan De Developpement Communal Troisieme Generation De Natitingou (PDC3_Nati) (June 2017). P 37.

Pramanik PKD, Mukherjee B, Pal S, Pal T, Singh SP (2019) Green smart building; requisites, architecture, challenges, and use cases. *Green building management and smart automation*. IGI Global, pp 1-50

Revkin A. (2018) climate change first became news 30 years ago. Why haven't we fixed it? National geographic. *National Geographic Society*, USA

Ryan Coffey (January 18, 2013) *The difference between "land use" and "land cover*" Michigan State University Extension. https://www.canr.msu.edu/news/the_difference_between_land_use_and_land_cover#:~:text=Land%20use%20is%20commonly%20defined,occur%20on%20the%20earth%20surface.

Sajid Ali and Choon-Man Jang (2020). *Optimum Design of Hybrid Renewable Energy System for Sustainable Energy Supply to a Remote Island*. P:03 https://www.mdpi.com/2071-1050/12/3/1280

SAYOURI, Regis BERLIER, Monsieur BENYELLOUL, (2014), *Etude d'impact sur l'environnement naturel, humain et socio-économique Projet d'aménagement de la ville nouvelle ZENATA.*

Shan M, Hwang BG, Zhu L (2017) A global review of sustainable construction project financing: policies, practices, and research efforts. Sustainability 9(12):2347

Society, National Geographic (2011-01-21). "runoff". National Geographic Society. Retrieved 2021-02-19.

Tarja Häkkinen1, Tuomas Helin, Carmen Antuña, Susanne Supper, Nicoleta Schiopu, and Sylviane Nibel (2013), *Land Use as an Aspect of Sustainable Building*, P25.

Thefifthestate, https://www.thefifthestate.com.au/innovation/commercial/why-high-performance-buildings-disappoint-and-how-people-outsmart-them/

The World Bank FOR OFFICIAL USE ONLY, Report No: ICR00005416, (2021) https://documents1.worldbank.org/curated/en/100351624901929618/pdf/Benin-Cities-Support-Project-PAURAD.pdf

Thoughtco, https://www.thoughtco.com/what-is-green-architecture-and-green-design-177955

UN (2017) About the sustainable development goals. *United Nations.* Retrieved 23 Dec 2019, from https://www.org/sustainabledevelopment/sustainabledevelopment-goals/

UN (2019) Tackling climate change. Climate action: sustainable development goals. United Nations. Retrieved 3 Jan 2020, from https://www.org/sustainabledevelopment/climate-action/

UNEP & IEA (2017) Towards a zero-emission, efficient, and resilient buildings and construction sector. Global status report 2017, Global Alliance for Building and Construction, United Nations Environment Programme and International Energy Agency

UNFCCC (2015) what is the Kyoto protocol. *United Nations Framework Convention on climate change*. Retrieved 23 Dec 2019

UNFCCC (2020) what is the Paris Agreement? UNFCCC Process-and-meetings: the Paris Agreement. *United Nations Framework Convention on climate change*. Bonn. Retrieved 3 Jan 2020, from https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement

Urban Espora, "5 reasons for creating urban green spaces," 30 APRIL 2019. [Online]. Available: https://www.urbanespora.com/en/5-reasons-for-creating-urban-green-spaces/.

USEPA (2016) Definition of green building. Green building research: green building history in the U.S.U.S. *Environmental Protection Agency*. Retrieved 30 Sept 2019, from https://archive.epa.gov/greenbulding/web/html/about.html

Usha lyer-Raniga and Karishma Kashyap (2021) Green building School of Property, Construction and Project Management, RMIT University, Melbourne, VIC, Australia

Uwe R. Fritsche, Göran Berndes, Annette L. Cowie, Virginia H. Dale and Keith L. Kline (2017) *Energy And Land Use* Copy editing by Margie Peters-Fawcett.

Vyas GS, JhaKN(2018) What does it cost to convert a non-rated building into a green building? *Sustain Cities* Soc 36:107–115

WGBC (2018) About green building. The benefits of green buildings. *World Green Building Council*, London. Retrieved 21 Sept 2019, from https://www.worldgbc.org/benefits-green-buildings

Wienerberger (2019) *Going green with buildings - Building green is not a choice but a commitment for future generations*. https://www.wienerberger.in/green-building/why.html

WorldGBC (2018) Green building: improving the lives of billions by helping to achieve the UN sustainable development goals. http://www.worldgbc.org/news-media/green-buildingimproving- lives-billions-helping-achieve-un-sustainable-development-goals. 28 May 2018

WorldGBC (2013) The business case for green building: a review of the costs and benefits for developers, investors and occupants. http://www.worldgbc.org/files/1513/6608/0674/ Business_Case_For_Green_Building_Report_WEB_2013-04-11.pdf. 9 June 2016

Wu Z, Yu ATW, Poon CS (2019) An off-site snapshot methodology for estimating building construction waste composition – a case study of Hong Kong. *Environ Impact Assess* Rev 77:128-135

Yuangao WenZhiwei Lian (2009) *Influence of air conditioners utilization on urban thermal environment.* https://www.researchgate.net/publication/222326493_Influence_of_air_conditioners_utilization_on_urban_thermal_environment

Yudelson J (2008) The green building revolution. *Island Press*, Washington, DC

Yusuke Kumakoshi, Sau Yee Chan, Hideki Koizumi, Xiaojiang Li and Yuji Yoshimura (2020) *Standardized Green View Index and Quantification of Different Metrics of Urban Green Vegetation.* https://www.researchgate.net/publication/344812409_Standardized_Green_View_Index_and_Quantification_of_Different_Metrics_of_Urban_Green_Vegetation

Zhao H (2018) Energy crisis: "natural disaster" and "manmade calamity". *The economics and politics of China's energy security transition*. Academic, pp 65-98

Zhang X (2015) Green real estate development in China: state of art and prospect agenda—a review. Renew Sustain Energy Rev 47:1–13

TABLE OF CONTENT