T.C. BAHÇEŞEHIR UNIVERSITY

ADAPTING PASSIVE DESIGN STRATEGIES FOR SUSTAINABLE URBAN DEVELOPMENT:

A BIM MODEL FOR DAKAR

Master's thesis

OUMAR SOW

ISTANBUL, 2016

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GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
MASTER OF ARCHITECTURE

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Supervisor: Assoc. Dr. Suzan Girginkaya Akdağ
Co-Supervisor: Dr. Bengü Uluengin

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Title of the Thesis:	Adapting passive design strategies for sustainable urban development: A BIM model for Dakar
Name and surname of the student:	Oumar Sow
Date of Thesis Defense:	11.01.2016

This Thesis has been approved by the Graduate School of Natural and Applied Sciences.

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This is to certify that we have read this thesis and that we find it fully adequate in scope, quality and content as a Master's thesis.

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ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to my thesis advisor Dr. Suzan Girginkaya Akdağ and co-advisor Dr. Bengü Uluengin for their constant guidance and encouragements, without which this work would not have been possible. For their unwavering support during the whole process I am truly grateful.

I would also like to thank Mr. Serkan Emin from Altensis and Prof. Dr. Salih Ofluoğlu for taking the time to share their knowledge on the matter of sustainable design. I am also gratefull to all the lectures in the Department of Architecture for their impact towards the successful completion of my studies.

I would also like to thank my family, friends and colleagues for the moral support which made my stay and studies in Turkey more enjoyable. To them I say "we meet to part one day, but WE part to meet again – see you next".

Istanbul, 2016 Oumar Sow

ÖZET

SÜRDÜRÜLEBİLİR KENTSEL GELİŞİM İÇİN PASİF TASARIM STRATEJİLERİ UYARLAMAK: DAKAR İÇİN BİR YBM MODELİ

Oumar Sow

Mimarlık

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February 2016, 76 sayfa

2050 itibariyle dünya nüfusunun yüzde 70'ini ağırlayacak olan şehirler (Birleşmiş Milletler Kalkınma Programı, 2014) - doğanın zarar görmesinden sorumlu olan sera gazlarının önemli bir miktarını ürettiklerinden- sürdürülebilirliğin sağlanabilmesinde önemli bir rol oynarlar. Kentsel sürdürülebilirlik sorunu, 1992'de Birleşmiş Milletler (BM) tarafından düzenlenen "Rio Dünya Zirvesi"nden beri, toplumda artan çevre bilinci etkisiyle, dünya çapında bir soruna dönüşmüştür. Dünya üzerindeki birçok ülke (bilhassa Avrupa'dakiler), eko-kent ilkelerine göre inşa ederken, en düşük seviyedeki ekolojik etkiyi yaratmayı ve gelecek nesilleri tehlikeye atmadan şimdiki neslin ihtiyaçlarını karşılamak için en az miktarda kirliliği üretmeyi hedeflemektedir. Afrika kıtası ise -sorunun önemi düşünülünce- çok az sayıdaki teşebbüs ve ütopik projeyle, özellikle kentsel yoksulluğun başlıca sorun olduğu yerlerde, bu planın oldukça gerisinde kalmaktadır.

Tez, kentsel sürdürebilirlik gelişimi açısından bakıldığında, Dakar'da (Güney Afrika ülkesi olan Senegal'in başkenti) hali hazırda inşa edilmiş olan "Mixta: Résidence de la Paix" adındaki modern bir yerleşmenin sürdürülebilirliğinin mimari açıdan analizine odaklanmaktadır. Tezin içeriğinde, yıl boyu sıcak ve nemli olan tropikal bir iklim bölgesinde, kentsel sürdürülebilirliğin sağlanması için kullanılacak pasif tasarım stratejileri belirlendikten sonra, alan çalışması için örneklem olarak "Mixta" yerleşiminden çok aileli bir konut belirlenmiştir. Yapı Bilgi Modellemesi (YBM) yazılımı olan Revit kullanılarak, yerel hava durumu verisi, ana cephelerin kardinal yönleri, güneş ışığı yönü ve inşa malzemelerinin termal özellikleri göz önüne bulundurularak; bina modellenmiş ve enerji ve aydınlatma performansını belirlemek adına ilgili analizler gerçekleştirilmiştir.

Enerji analizinin sonuçları, binada birincil ölçüde, duvarlardan kaynaklanan ısı transferi ve ikincil olarak, pencerelerden kaynaklanan güneş ısısı kazanımı sebebiyle, neredeyse tüm yıl boyunca önemli bir serinletme ihtiyacı olduğunu göstermiştir. Sonrasında uygulanan aydınlatma analizinin sonuçları, pencerelerin Doğu-Batı doğrultusunda konumlandırılmaları ve gölgelendirme elemanlarının eksikliğinden ötürü, iç mekanın rahat bir görüş konforu için gerekenden fazla miktarda ışık aldığını ve bunun sonucunda, fazla ışık satürasyonuna, yani kamaşmaya sebep olduğunu göstermiştir.

Bu nedenle, bina içerisindeki ısı ve görüş konforu seviyelerinin kontrolü için, ilk olarak, bina duvarlarının inşasında kullanılmış ısı geçirgenliği yüksek olan cüruf briketleri, düşük ısı geçirimine sahip geleneksel bir yapı malzemesi olan toprak-saman alaşımı bloklarla değiştirilerek, duvarlardaki ısı geçirimi, azaltılmıştır. Sonraki adımda ise, camlardan güneş ısısı kazanımını azaltmayı ve bina içindeki aydınlatma miktarını düşürmeyi amaçlayan, birkaç tasarım denemesi gerçekleştirilmiştir:

a. Senegal'in koloniyal mimarisinden esinlenilerek terasların derinliğinin arttırılmış,
b. Doğu-Batı doğrultusunda konumlandırılmış olan ve bu nedenle doğrudan güneş ışığına maruz kalan pencereler için uygun gölgelendirme araçları olarak, dış cepheye düşey panjurlar yerleştirilmiş,
c. Son olarak, var olan tekli cam sistemi, görüş geçirgenliğinin yanı sıra güneş ışığı kazanımını düşüren renkli çift camlı pencereler ile değiştirilmiştir.

Eski binanın ve alternatifinin karşılaştırılması, enerji kullanımı ve maliyet verimliliği yönünden kayda değer bir değişim olduğunu göstermiştir. İç mekan içerisindeki ısı ve görüş konforu düzeylerini arttırmada kullanılan bu yöntem, bina ölçeğinden başlayarak kentsel ölçeğe genişleyen bir çerçevede sürdürülebilirliğin sağlanmasında bir yönerge olarak kullanılabilir. Dahası, tezde Senegal'in geleneksel ve koloniyal mimarisinin çevreci unsurları çağdaş mimariye uyarlanarak, sürdürülebilir bir kent için, güncel teknolojilerinin yanı sıra geleneksel ve yerel mimarinin pasif tasarım unsurlarının göz önüne alınmalarının gerekliliği ortaya konmuştur.

Anahtar Kelimeler: Sürdürebilirlik, Eko-kent, Termal konfor, Görsel Konfor

ABSTRACT

ADAPTING PASSIVE DESIGN STRATEGIES FOR SUSTAINABLE URBAN DEVELOPMENT: A BIM MODEL FOR DAKAR

Oumar Sow

Architecture

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Co-supervisor: Dr. Bengü Uluengin

February 2016, 76 pages

Cities – which are to host 70 percent of the world's population by 2050 (UNPD, 2014) – play a key role in the quest of sustainability due to the fact that they produce an important amount of Green House Gases (GHGs) responsible for the degradation of the environment. The issue of urban sustainability has become a worldwide concern due to the growing awareness of the society since the "Rio Earth's Summit" organized by United Nation (UN) in 1992.

While many countries around the world (mostly in Europe) have started building according to the principles of Eco-city – which aims to create the smallest ecological footprint and produce the lowest quantity of pollution possible in order to meet the needs of this generation without endangering future generations – the African continent, with few attempts and utopic projects is however behind schedule considering the significance of the issue; more specifically, in countries where urban poverty is of major concern.

Under the perspective of urban sustainable development, this thesis focuses on the analytical investigation of an already built neighborhood called "Mixta: Résidence de la Paix" in Dakar (capital of Senegal, West Africa).

After specifying the passive design strategies to be used in order to achieve urban sustainability in a tropical climate zone (hot and humid the entire year), a multifamily building from "Mixta" was selected as a case study. Building Information Modeling (BIM) software Revit was used to simulate the building and conduct energy and lighting analyzes to determine respectively the energy and lighting performances of the building taking into consideration the local weather data, cardinal directions of the main facades, the sun path and thermal properties of the construction materials.

The results of the energy analysis showed an important cooling demand in the building almost the entire year mostly caused by heat transfer through walls followed by solar heat gain through windows. Then, the results of the lighting analysis revealed that due to the fact that windows were East and West oriented and the lack of shading device, the inner spaces receive a lot more illuminance than required for visual comfort causing a saturation of light; a glare.

Hence, in order to control the thermal and visual comfort within the building, first, heat conduction through walls was reduced by replacing the cinderblocks (material of high thermal conductivity used for the building envelope) with earth-straw composite blocks given its low thermal conductivity and availability. Then the next step consisting of reducing solar heat gain through windows and simultaneously reduced the amount of illuminance within the building required few design approaches:

a. the increase in depth of the terraces taking reference from Senegalese colonial architecture,
b. the use of exterior vertical louvers as the proper shading devices for East and West oriented windows hit by direct sunlight and
c. finally, the use of tinted double glazed windows reducing visual transmittance and solar gain simultaneously.

The comparison of the initial building and the alternative in BIM showed a considerable change in terms of energy use and cost effectiveness. The method that is used to increase the thermal and visual comfort levels in interior space, can be used as a guideline for sustainability in a variable context starting from building scale expanding to urban scale. Moreover, Senegal's traditional and colonial architecture adapted to the contemporary architecture in the thesis demonstrated that, along with the benefits of current technology; such as new building materials, BIM software etc., passive design elements of traditional and vernacular architecture should be a major consideration of design for a sustainable city.

Keywords: Sustainability, Eco-city, Thermal comfort, Visual Comport

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ABBREVIATIONS

BIM:	Building Information Modeling
DESAPD:	Department of Economic and Social Affairs Population Division
EUI:	Energy Use Intensity
GHGs:	Green House Gases
HSA:	Horizontal Sun Angle
Low-E:	Low Emissivity
PV:	Photovoltaic
UN:	United Nation
SHGC:	Solar Heat Gain Coefficient
UNFCCC:	United Nation Convention on Climate Change
VLT:	Visible Light Transmittance
VSA:	Vertical Sun Angle
WCED:	World Commission for Environment and Development
WWR:	Window to Wall Ratio

1 INTRODUCTION

Due to the growing awareness of the society - including the scientific community, the governments, and the general public - most threats on the environment are widely known. Global warming, one of the most eminent and an undisputed fact, can be explained by the severe effect of Greenhouse Gases (GHGs) emitted by humans in a variety of ways. The most common one being the combustion of fossil fuels used in cars, factories and for electricity production. However, the world is also facing various other issues such as energy overuse, global food security, decrease in biodiversity as well as poor social and economic conditions. In other words, problems the environment is facing are caused by ways people have established a lifestyle with poor consideration for the environment. The consequences of either the overuse of non-renewable resources or the failure of integrating the built environment into the natural environment are putting the comfort and needs of this generation and that of the future generations at stake.

As stated by Hulot (2005), this issue of environmental problems can be studied from two different angles; one of which asks the question, *how did we get here*? And the other, *how do we deal with it?* While the latter tries to understand the cause and effect relationships, allowing better predictions and proper management, the former looks for adverse effect without regard to their origin in order to detect trends allowing more profound investigations (Devuyst et.al.).

Managing these issues would then require a reevaluation of our ways of living; our habits as consumers and producers, our economic model, the relationship we have established between the built environment and the natural environment etc. Reshaping or building cities, in accordance with nature, revolves around solving these issues or notably counter-balancing the most important one being global warming by reducing GHG emission.

Furthermore, United Nation's (UN) report of the Department of Economic and Social Affairs Population Division (DESAPD) shows that the urban populace constantly growing since 1950 is expected to exceed 70 percent of the world's population by 2050 (See Appendix – 1). On the 2014 revision, the urban populace is already at 53.6 percent (DESAPD, 2014).

In order to house the expected number of urban populace without causing more damages to the environment, concepts like Eco-city flourished in the 20th century, focusing on the three main aspects of sustainability: Environmental, Economical, and Social aspects. The aim of this concept consists of creating the smallest ecological footprint and produce less pollution as possible by reducing the energy demand.

The concept of Eco-city is nowadays widely studied all over the world, with one of its most promising attempts being *Hammarby Sjöstad* - in Stockholm/Sweden. Adopting its principles in the African urban structure has therefore been addressed as a key solution to the continents' most dominant problem: urban poverty. Thus, several new eco-city or sustainable urban development projects have been either built or proposed in Africa.

Starting with Johannesburg[1] where the Eco-City program – focusing mostly on the social aspect – has mobilized the disadvantaged and unemployed people of Ivory Park according to the United Nations Environment Program. More than 300 jobs were created between 1991 and 2001 in this eco-village, disadvantaged people were used to form co-operatives, grow and buy food, recycle wastes, build homes, use and promote green energy solutions, become eco-tourism guides, etc. Furthermore, Kenya/Nairobi[2] will soon welcome *Konza*, already being hailed as Africa's Silicon Valley, and *Tatu City*, a project located just off the region's new Thika Super-Highway. Just outside of Accra[3], *Appolonia* (see **Figure 1.1**) nicknamed the "City of Light," is a planned, mixed-use city that broke ground in 2014 and is conceptualized as a "work-live-play" community. Lagos[4] however, is eyeing the construction of *Eko-Atlantic*, a city for 400,000 people, built on land reclaimed from the ocean. And Lusaka, Zambia is welcoming *Roma Park*, a residential and commercial development being built on 118 hectares of Greenfield.

While Eco-city deals with the three aspects of sustainability, on an architectural point of view, this thesis focuses on the environmental aspect, more specifically on eco-construction, with the use of passive design strategies.

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[1] Johannesburg: Largest city in South Africa
[2] Nairobi: Capital of Kenya
[3] Accra: Capital of Ghana
[4] Lagos: City in Nigeria

Figure 1.1: Appolonia; City of light

Source: GH, 2015

The thesis is based on the analytical investigation of a building from a chosen neighborhood called Mixta: Résidence de la Paix in Dakar[5] - a neighborhood composed of multifamily buildings which is becoming a new trend of social housing in Dakar as the land ownership becomes more expensive. The three-story multifamily building with the main façades facing East and West – the most critical facades in a tropical climate zone – will be simulated using Building Information Modeling (BIM) software Revit. In order to conduct the energy analysis and end up with accurate results, the thermal properties of each material used will be entered in Revit material properties. Beside, a lighting analysis will be conducted to determine the effect of sunlight within the building. This lighting analysis will assess whether or not the inner areas receive enough daylight for a visual comfort.

The energy and lighting analyzes will help determine the energy and lighting performances of the building in order to develop better performing alternatives in terms of thermal and visual comfort. Using passive design strategies to achieve thermal and visual comfort without

[5] Dakar: Capital of Senegal

the implementation of mechanical means would also result in the reduction of energy demand and use; hence a step forward into a sustainable urban development.

Taking into consideration the outcome of COP21[6] - which demanded a review of every country's contribution to the global climatic challenge every five years and to aim for carbon neutrality by the half of the century (UNFCCC,2015) – the use of passive design strategies to achieve comfort and reduce the emission of GHGs is crucial in the building sector.

Therefore, using the same logic, the issues of the built environment can be determined in order to build or rebuild better performing buildings.

[6] COP21: United Nation conference on climate change (December, 2015), Paris.

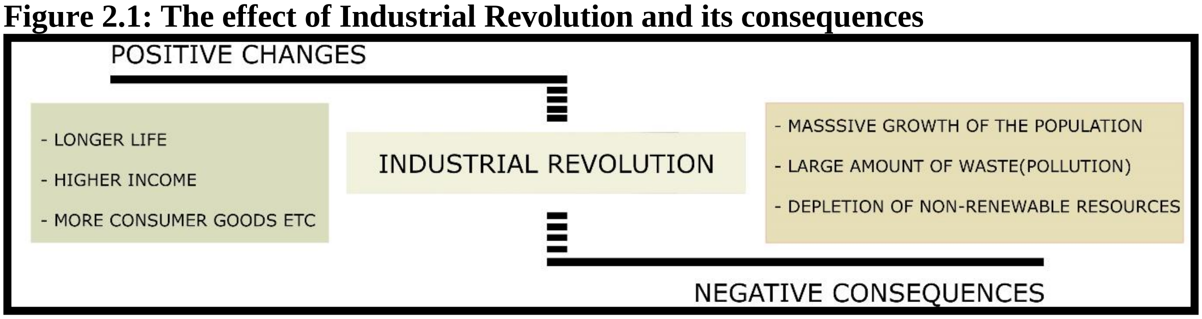
2 SUSTAINABLE DEVELOPMENT AND PASSIVE DESIGN STRATEGIES

This chapter consists of reviewing the background of sustainability from when it was just a utopia to it becoming a worldwide concern. Sustainability is now considered to be one of the major keys to preserve the environment. Therefore, solving its problems would require focusing on Sustainable Urban Development given that cities play an important role in the deterioration of the environment. Therefore, an account of what have been done in terms of Eco-city and its principles are determined. Furthermore, focusing on eco-construction, passive design strategies for tropical countries are also determined.

2.1 SUSTAINABLE DEVELOPMENT

Three decades ago, the term Sustainable Development became a widespread phenomenon with the publication of a report called "Our Common future" in 1987 by the World Commission on Environment and Development (WCED). The term sustainability surfaced as a utopia of living in a more harmonious world compared the one people had been living in since the Industrial Revolution. A world where revenue was the main concern to the detriment of the environment; a world where mass production and mass consumption were celebrated. Even though the industrial revolution gradually improved the living standards, the production processes had negative side effects as shown in **Figure 2.1**. In the 1990s, with the public awareness of the danger, three major problems had been identified: the massive growth of the population, the pollution and the depletion of non-renewable resources.

Figure 2.1: The effect of Industrial Revolution and its consequences



Therefore, in 1992 in Rio de Janeiro, the United Nation organized a conference on environment called "the Rio Earths' Summit". A conference where the world's' leaders met to discuss the urgent global environmental challenges which intended to map out the future path for human development on the planet. The outcome of the Rio Earths' Summit was a set of conventions and a handbook - called Agenda21 - for environmental reform with the ambition to give an answer to the questions raised and identify the three fundamental components of sustainable development which are: social equity, economic growth, and environmental maintenance. Thus, Agenda 21 became a symbol for a new initiative for sustainable local and regional communities.

The term sustainability, however, is very ambiguous and is defined differently by many scholars after three decades since the term rose to prominence.

For instance, Button defined sustainability as an ecological term which means "the capacity of a system to maintain a continuous flow of whatever each part of that system needs for healthy existence" (Button, 1988).

Bachman defines it as a broad term for the healthy habitation of nature. Also, according to him, "The systems model of sustainability addresses biological patterns as well as the physics of building energy use" (Bachman, 2003).

However, the most common definition is that of "Our Common Future" report: "sustainable development is a development which meets the needs of our present generation without compromising the ability of the future generations to meet their own needs" (WCED, 1987). This definition contains two key concepts:

a. The concept of 'needs', in particular, the essential needs of the world's poor, to which overriding priority should be given; and,
b. The idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs (WCED, 1987)

Sustainable development remains though a broad concept giving way to sub-concepts such as sustainable urban development which can also be referred to as eco-city or sustainable city "a city that is user-friendly and resourceful, in terms not only of its form and energy efficiency but also its function as a place of living" (Elkin, et al., 1991). Basically, it means applying the concept of sustainability in urban areas, aiming to improve the present generation's living quality without leaving a burden on the future generations.

2.2 ECOCITY APPROACH TO SUSTAINABLE DEVELOPMENT

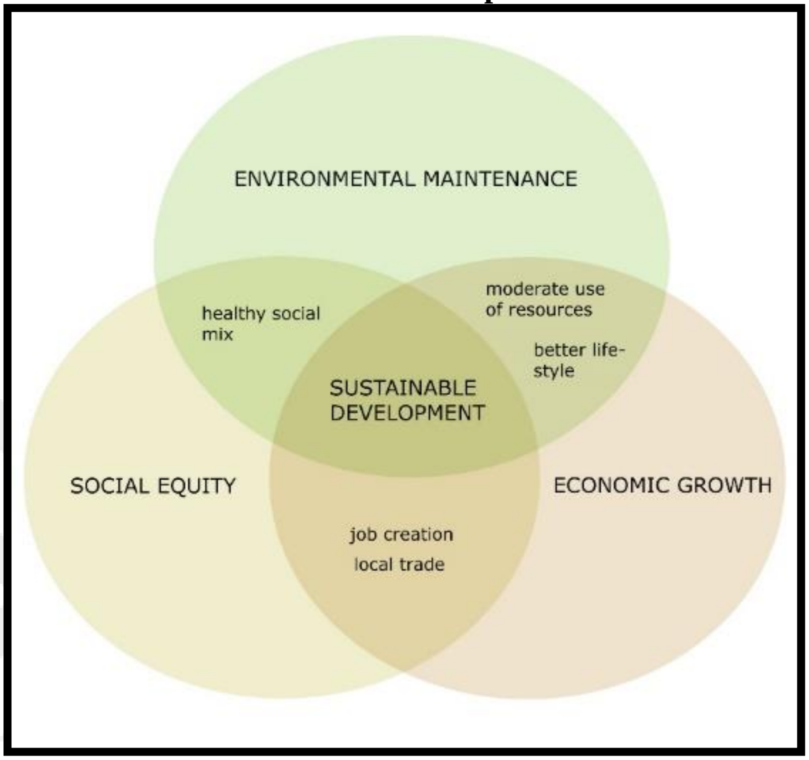
Cities play a great role in the quest of sustainability. Nowadays, the population living in urban areas is much larger than the rural populace and is still growing. Thus, they generate an important amount of GHGs causing global warming and ozone depletion.

The term Eco-city is however traced back to Richard Register, an urban design specialist and activist who founded a non-profit organization called Urban Ecology in Berkeley in 1975. The aim of this organization is "to rebuild cities in balance with nature". It flourished with the publication of Register's book 'Eco-city Berkeley' (1987), a guideline on how Berkeley could be ecologically rebuilt. It then bloomed with an initiative that became the key component of the Eco-city movement: the international Eco-city conference, held in Berkeley in 1990 and in five different continents every two years since then.

Another pioneer of Eco-city is David Engwicht, an Australian community activist who published 'Toward an Eco-City' (1992) shortly before the second Eco-City conference. For Engwicht, a city is "an invention for maximizing exchanges and minimizing travel". Like Register, he supports the idea that eco-cities should be, places where people can move via foot and bicycle, mass transit and interact without fear of traffic and toxins (Devuyst, et al., 2001).

Eco-city being a sub-part of sustainable development, focusses on the three fundamental aspects of sustainability: economic, ecological and social aspects as shown in **Figure 2.2**. The main goals of an eco-city are to create the smallest ecological footprint and to produce the lowest quantity of pollution possible; in other words, reduce carbon waste and avoid excessive use of non-renewable resource. It also aims to incorporate the environment into the city, simulate economic growth and reduce poverty through a social diversity and a local sustainable economy. In order to reach such goals, the three aspects of sustainability have to be in phase, balanced. Therefore, an integrated approach - which takes into consideration the human's needs, the environment's concerns and technology – should be the focal point.

Figure 2.2: Relationship between the three fundamental aspects of sustainable development



To achieve sustainability, an eco-city takes into consideration three main aspects called the "three Es of sustainability" – Environment, Economy, and Equity (see **Table 2.1**).

The Environmental aspect deals with energy savings, water consumption, wastes treatment, the issue of mobility, and eco-construction at a local level making each building eco-friendly. The Economic aspect, however, deals with the establishment of new services and multifunctional commerce, promoting local trading. The creation of equipment, infrastructures accessible to everyone. It tends to the birth of a lively and diversified city with job creations fueled by new economic and trading dynamics. The Social aspect or Equity follows the principle of socio-economic, cultural and intergenerational diversity, and an easy access to sports and cultural activities. The participation of the people living in the city or neighborhood to maintain it is necessary to achieve sustainability through the social aspect. Eco-City concept is developing alongside other influencing movements such as the 'compact city' – which focuses on densification and on public transport -, the 'diversity approach' – diverse land use, the implementation of eco-technologies, and community planning etc. This thesis, however, on an architectural point of view, focuses on the environmental aspect, more specifically on passive design strategies for tropical countries.

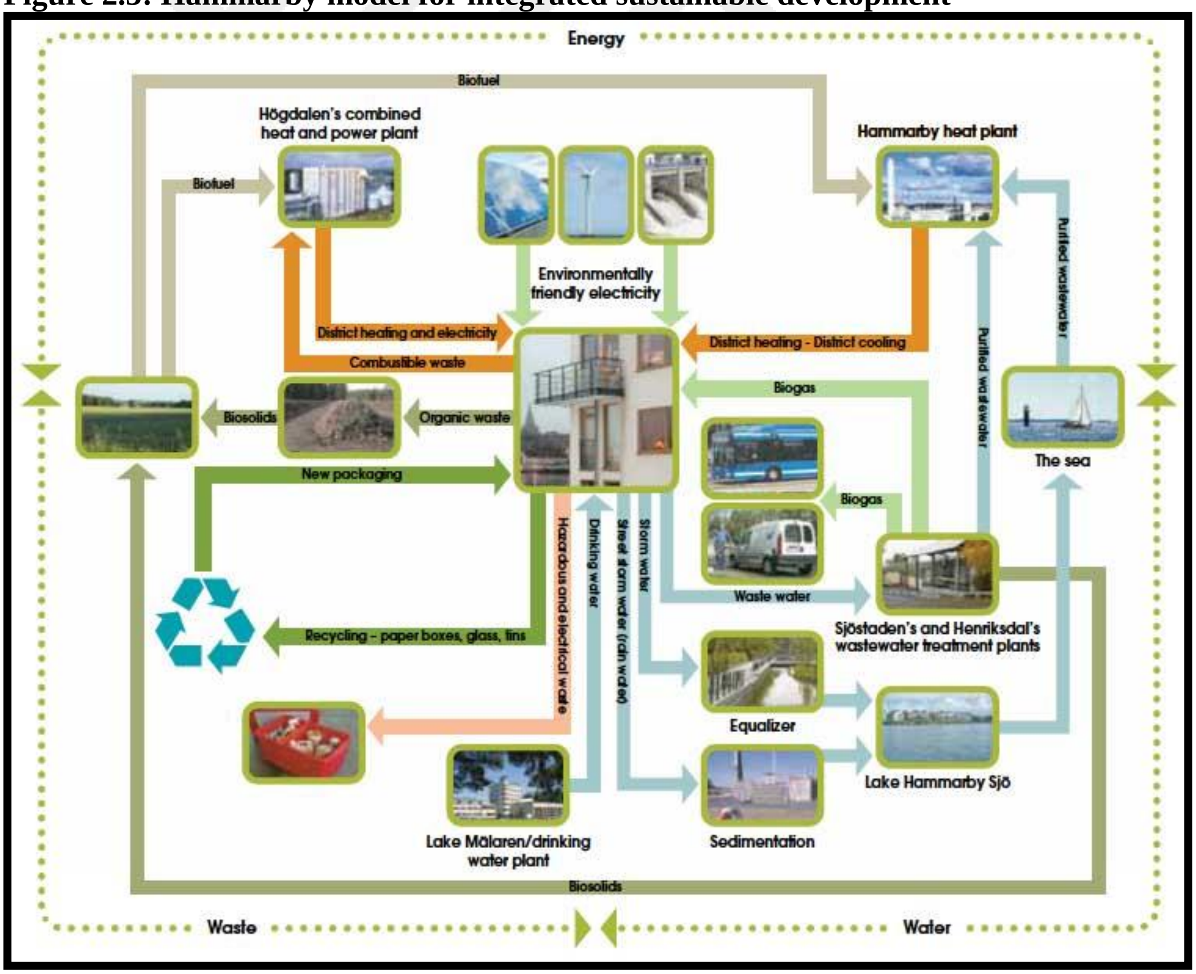
Table 2.1: Eco-city design principles with the three main aspects to achieve sustainability

ECO-CITY DESIGN PRINCIPLES		
Ecology (Environmental Sustainability)	Eco-construction	• Passive design strategies • Use of local and recyclable materials
	Eco-mobility	• Promoting public transportation, • Fuel-free vehicles • Walkable streets, cyclist friendly etc.
	Moderate use of resources	• Promote the use of renewable resources, • Less dependency on non-renewable resources like fossil fuel etc.
	Water and waste management	• Reduction of water consumption through eco-friendly installations, • Rainwater harvesting and reuse;
Economy (Economic Sustainability)	Local trade	• Installation of new commercial activities and facilities etc.
	Local jobs	• Job creation within the neighborhood
Social/Equity (Socio-cultural sustainability)	Social diversity	• Availability of houses with different price range, • Provide basis for a healthy social mix etc.
	Functional diversity	• Spaces able to accommodate different functions, residential or work. • Mix land use creating jobs to promote the local economy and reduce landscape fragmentation etc.
	Community living	• Promote a sense of community with the creation of park areas, common spaces and community activities involving people of all age and from all social ranks.
	Neighborhood management	• Education to acknowledge technologies • Techniques used in the neighborhood for a better management. • Involvement of the inhabitants in the maintenance.

2.3 ECOCITIES AROUND THE WORLD: CASE STUDIES

Since 'Eco-City' concept arose by the 1990s, many countries have started building model eco-cities among which ***Hammarby Sjöstad*** - in Stockholm/Sweden - is known to be one of the most ambitious sustainable development projects in the world. Located in the South of Stockholm, not far from the city center, Hammarby is to provide 10000 apartments for 25000 inhabitants on an area of 200ha. Hammarby is a planned area, able to recycle materials and has its own sewage and waste treatment station. Energy is produced locally in the district heating plant with renewable fuels. Combustible waste is also recycled in the form of heat. **Figure 2.3** shows the Hammarby model with its unique eco-cycle system that integrates energy, solid waste, water and wastewater etc.

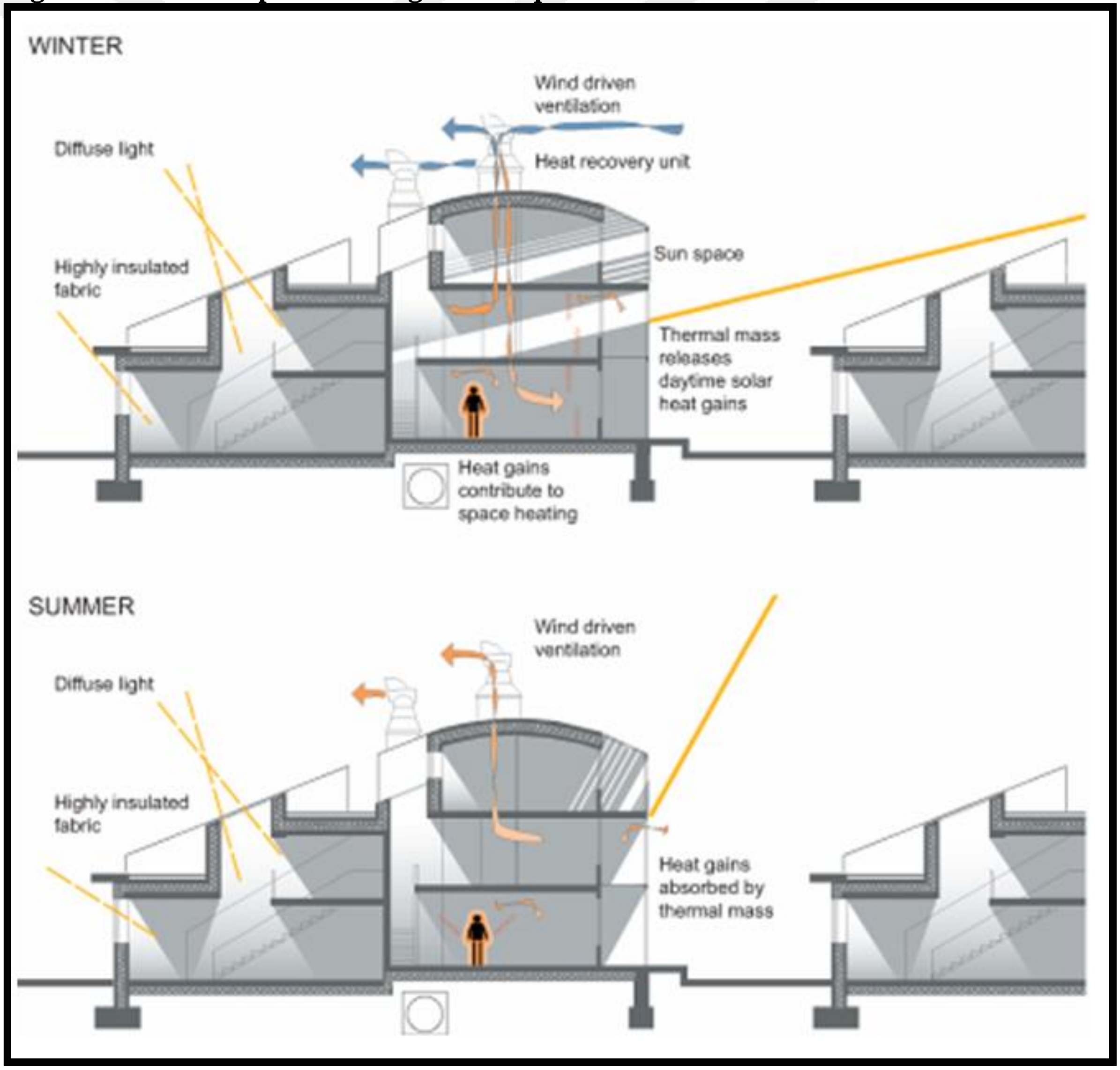
Figure 2.3: Hammarby model for integrated sustainable development



Source: (Faller, et al., 2010)

Furthermore, ***BedZed*** is the first and largest British carbon free project located in a residential suburb in Sutton, forty minutes away from London (temperate, oceanic climate). BedZed was designed and developed with the intention of creating a 'net-zero fossil energy neighborhood' producing at least as much renewable energy as it consumes. It is a low-car development with a green transport plan which promotes walking, cycling and public transportation. In terms of energy saving, buildings are constructed using passive solar gain strategies with houses arranged in the south facing terraces to maximize heat gain as shown in **Figure 2.4**.

Figure 2.4: BedZed passive design techniques



Source: OpenBuildings, 2015

Thermally massive materials are used as well, to store heat during warm conditions. To reduce water use to 76 liters/day, rainwater is recycled and reused, low flush toilets and smaller bathtubs.

Vauban district was developed 3km south from the city center of Freiburg/Germany (temperate and marine climate), with the aim to accommodate more than 5000 people and to create 600 jobs. From the very beginning, all the problems (mobility, energy, housing, social, etc.) were discussed in working groups open to residents. Informing the public regarding the planning of this area was a crucial point since it was necessary to convince people that what was undertaken was not only for their own immediate ecological benefit but would also be cost efficient in the long-term. Buildings in Vauban were designed to have the lowest energy consumption possible with most of them using the passive house standard. The neighborhood makes great use of solar power; its solar settlement comprises a group of 59 homes which allows the neighborhood to display a positive energy balance as seen in **Figure 2.5**.

Figure 2.5: The eco-village of Vauban in Germany

Source: Redpepper.org.uk, 2015)

In Vauban, the excess of electricity produced is sold to the grid, generating an income for the residents. When it comes to transport, the neighborhood's philosophy is based on a "car free" principle. Everything in Vauban was designed according to cyclists and pedestrians. Residential streets are free from parking spaces, however, pick up and deliveries are permitted. By 2009, 70 percent of the residents had given up their cars.

In Finland (temperate coniferous-mixed forest zone), ***Eco-Vikki*** was built between 1999 and 2004. The district is located 8km from the center of Helsinki, near a vast agricultural area that forms a vital green belt for an important wetland nature reserve as seen in **Figure 2.6**. The Planning and Construction of Eco-Vikki followed some exceptionally strict ecological criteria which have been defined by external consultants. These criteria mainly concern five major issues: the reduction of pollution, the use of natural resources, health, biodiversity, and nutrition. As a result, two local solar heating schemes were installed covering a total of 10 properties, low energy housing design, co-generation based district heating network and 200m^2 of solar energy panels.

Figure 2.6: Eco-Viikki, ecological living right next to the campus

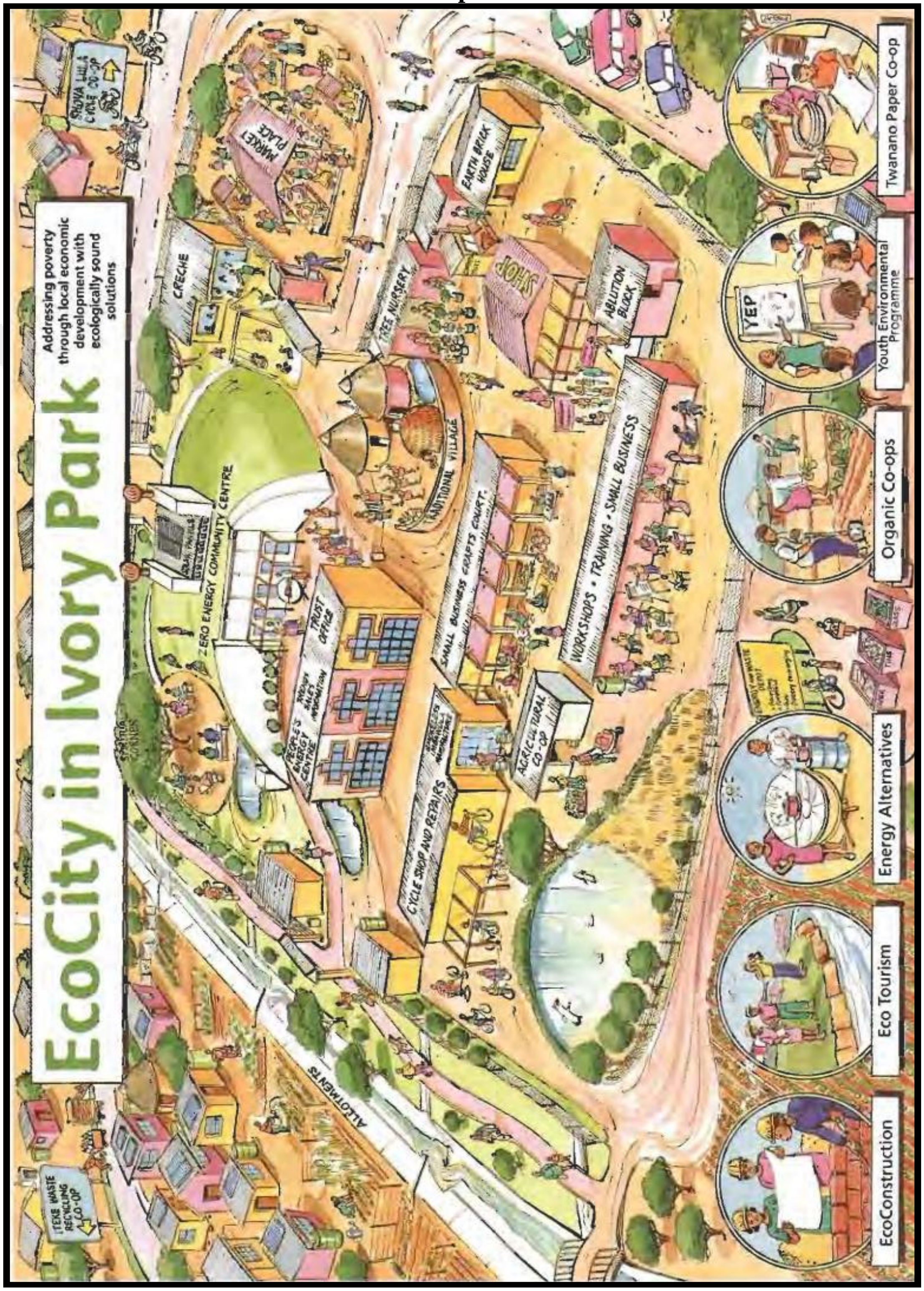
Source: Guidebook of sustainable neighborhoods in Europe, 2008

African countries are still behind schedule with few attempts and utopic projects, one of which is 'Ivory Park Urban Eco-Village' in South Africa (subtropical climate zone). The eco-village focuses more on the on the community living and the use of local materials. By gathering the disadvantaged and unemployed people of Ivory Park, cooperatives were created to grow and buy food, recycle, repair bicycles, build homes, promote green energy solutions making them eco-tourism guides. An initiative has been installed to educate people on how to collect rainwater, recycle all contaminated water and minimize water wastage. Solar energy and low-smoke biomass were used for energy. One of the most efficient techniques used was the building orientation, passive design strategies contributing as much in building efficiency, while, in terms of transport, bicycles are mostly used. Organic food is grown by the community members and sold or exchanged among them (see **Figure 2.7**).

As seen in the examples, each eco-city – depending on the environmental conditions and needs – has a different approach from one another, however sometimes similar. Whether it is the production of energy with renewable fuel in Hammarby, the use of passive solar gain strategies to produce energy in BedZed, the use of passive house standards in Vauban for the construction of building with low energy consumption or the use of local materials in Ivory urban eco-village in South Africa, the outcome remains the same: small ecological footprint, low pollution production and the promotion of renewable resources.

Struggling with urban poverty, most African cities need ecological approaches and techniques while building or rebuilding cities in order to catch up with the rest of the world. Building cities in accordance with nature requires the use of several approaches as in **Table 2.1**. However, one of the most important steps in order to achieve urban sustainability is the building level approach to sustainable development: eco-construction with the use of passive design strategies.

Figure 2.7: Ivory Park Eco-Village addressing poverty through local economic development.



Source: GMAC contract

In order to achieve urban sustainability, the focus of this paper is Eco-construction and passive design strategies as mentioned as highlighted in **Table 2.1**. Therefore, this next part discusses the passive design strategies – specific for tropical climates – to be used, as the chosen case study is located in Dakar which is in a hot and humid climate zone.

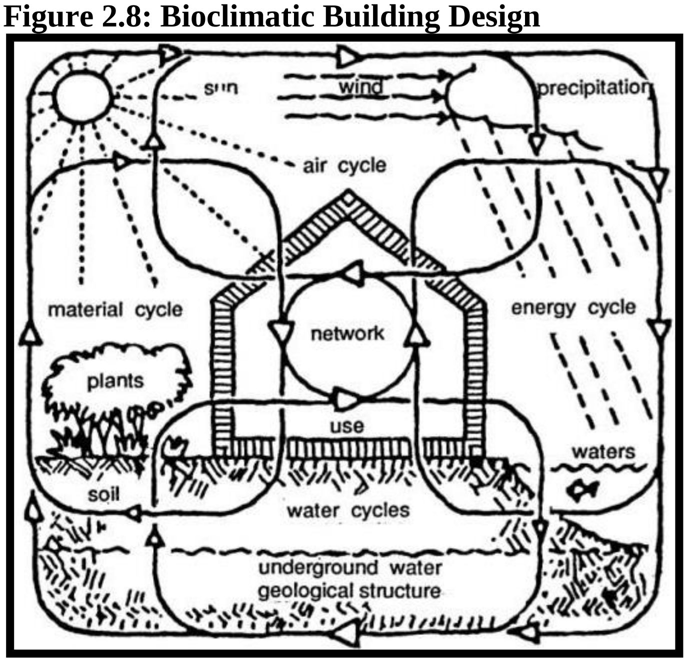
2.4 PASSIVE DESIGN STRATEGIES IN TROPICAL COUNTRIES

The passive design takes advantage of local climate resources to provide a comfortable indoor environment. In doing so, it aims to reduce the need for energy that would be provided through mechanical means such as heating, cooling or lighting.

The main goal of a passive building is to be integrated into the cycle of nature as in **Figure 2.8** without much interference; in a way that thermal comfort could be achieved through passive means – during design stages - before the use of mechanical systems.

Thus, to achieve a thermally and visually comfortable indoor, the architect has to consider the following means: orientation and shape of the building, wall, and roof thermal masses, thermal transmittance and color, solar radiation, wind, opening size, type of glazing (Roulet, 2013). In tropical countries, solar radiation has to be kept out because solar gains increase temperature.

Figure 2.8: Bioclimatic Building Design



Source: Blanco, 2014

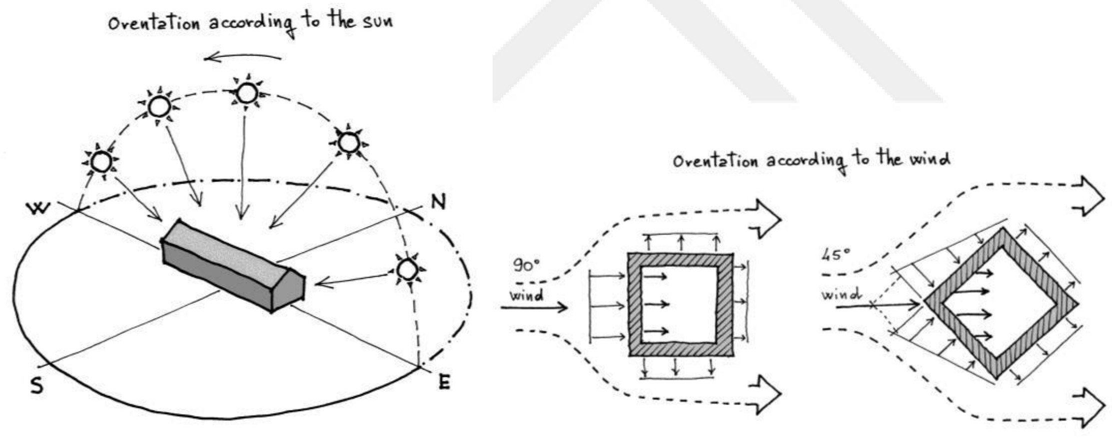
2.4.1 Building Orientation

To avoid overheating, the main facade should be oriented according to the sun path and prevailing winds.

In tropical climates, the East and West facades are hit by direct sun either in the morning or in the afternoon. Therefore, living and working rooms should be either oriented in the North or South facades (see **Figure 2.9**). The facades hit by direct sunlight must be protected against solar radiation by shading devices without blocking the natural light from getting in the building.

If the winds are strong, the building and its surrounding should be protected by plantations or adapting the shape of the building accordingly. In case they are weak, natural ventilation is improved by placing the openings upwind and downwind (Blanco, 2014).

Figure 2.9: Orientation according to sun and the wind



Source: Blanco, 2014

2.4.2 Building Materials

In order to be a passive building, the building materials used must comply with the following characteristics (Mourtada, 2013):

a. Be selected from materials extracted or manufactured locally.
b. Embodied energy shall be as little as possible.
c. Be abundant and come from a source and manufacturing process with minimal effect on the environment

d. Generate little waste and be reusable and recyclable
e. Be resilient and able to be repaired with local means
f. Selected according to local climate
g. Finishes materials used must be resistant to aggressive agents of the environment

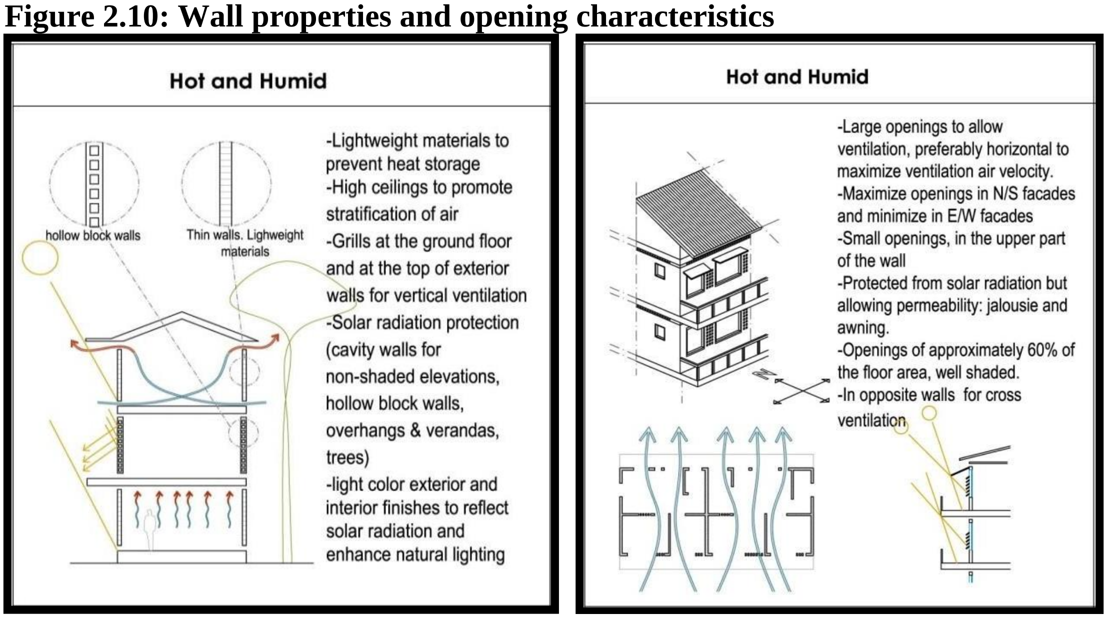
2.4.3 Building Envelope

The first element to be considered when changes - based on the climate and immediate environment in order to control the indoor environment - are to be made is the building envelope.

Given that tropical countries are subject to hot and humid climates; it is necessary to design the building envelope in a way that it minimizes solar gains without causing internal gains to be trapped. Including all walls, roofs, floors and openings separating the occupied spaces from outdoor space, the building envelope shall protect the occupants from external nuisance, contribute to thermal comfort and minimize heat gain by reducing the cooling load when required (see **Figure 2.10**).

Nearly 40 percent of unwanted heat comes through the windows; therefore, direct sunlight in tropical climates must be excluded by the use of proper solar devices and adequate orientation (Napier, 2015).

Figure 2.10: Wall properties and opening characteristics



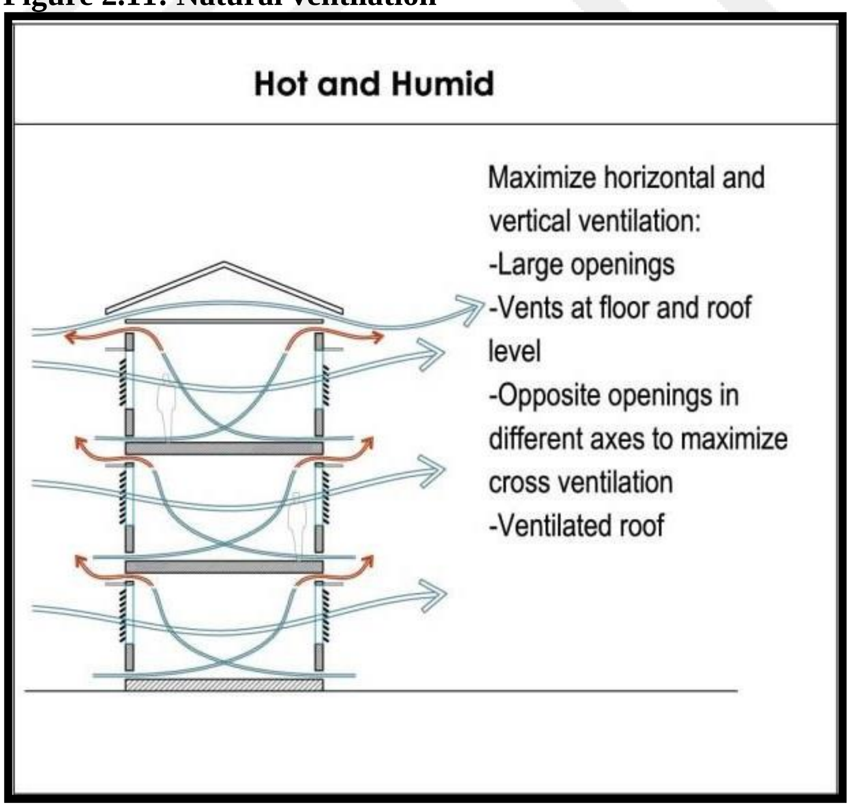
Source: Blanco, 2014

2.4.4 Natural Ventilation

Natural ventilation is a way to provide thermal comfort by assisting in the maintenance of heat balance and body cooling in hot and humid climates. In order to achieve natural ventilation, the building in question should be oriented at any convenient angle between 0^o – 30^o from the perpendicular winds of the hot season. Windows and doors should be located opposite each other to perform a better ventilation (See **Figure 2.10** and **Figure 2.11**). Also, if the openings cannot be provided in two walls room width should be limited up to 6.5m; otherwise, a depth up to three times the ceiling height may be naturally ventilated (Routlet, 2013).

In a residential building, the ventilation opening in each room should be equal to 5 percent of the net floor area; 10 percent if it opens to an enclosed area, a balcony or a gallery (Blanco, 2014). Natural ventilation must be considered by the architect before the installation of artificial ventilation in order to achieve a proper passive design.

Figure 2.11: Natural ventilation



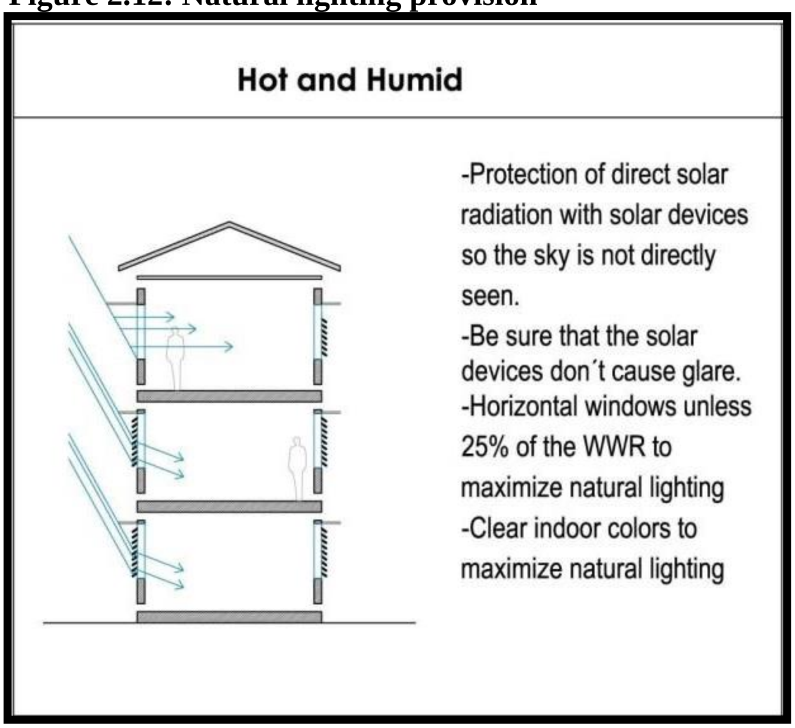
Source: Blanco, 2014

2.4.5 Natural Lighting

Reducing energy use for artificial lighting through passive design also mean being able to allow buildings to have adequate natural lighting. Windows must be made and located in appropriate position and screened such that direct solar heat gain is avoided. To get the effective area of daylight openings, transparent area multiplied by light transmission coefficient without mobile solar protection shall be between 20 percent and 30 percent of the net floor area of the room. 25 percent of the window to wall ratio is the optimum rate for natural lighting (Blanco, 2014). Capturing a good daylight is subject to the consideration of the following means according to the sun path, from the early design stages (Mourtada, 2013):

a. Orientation and space organization
b. Shape and size of glazing
c. Internal surface properties
d. Protection from solar gain
e. Solar and thermal properties of windows

Figure 2.12: Natural lighting provision



Source: Blanco, 2014

Instead of increasing the size of windows - in order to simultaneously increase the amount of daylight penetrating a building - adding small windows gives better daylighting performance because large windows cause more glare and, therefore, require more shading. Clear colors of interior walls and ceiling enhance natural and artificial lighting due to a higher reflectance.

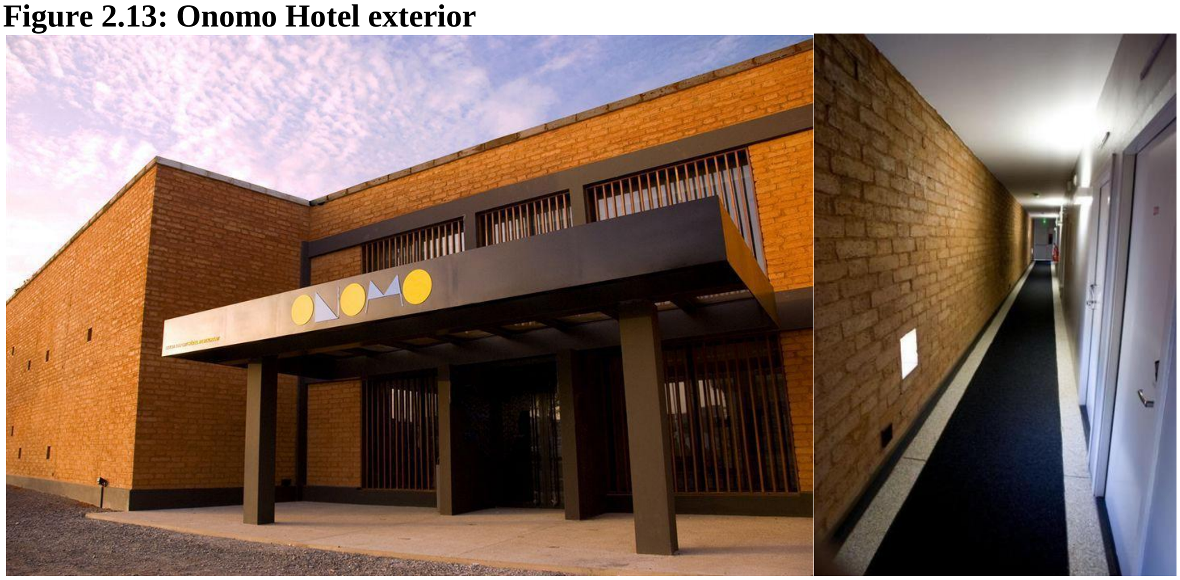
2.5 PASSIVE DESIGN EXAMPLES IN DAKAR

With thermal comfort and energy costs being major problems in Dakar, several architects have been adapting passive design strategies to their design in order to solve this problem. In this part of the thesis, two examples of designs using passive strategies to protect from the constraints of Dakar are given.

Onomo Hotel

'Onomo' hotel – by Arnaud Goujon Architectes an architecture firm in Paris – is the first hotel in Dakar built in 2012 that emphasized on ecology and sustainable development for its design, offering economic solutions by emphasizing on the use of local materials and local expertise. Furthermore, it aims to lower energy consumption but also be environmentally friendly by promoting the thermal quality of the building, the use of local materials with low ecological footprint, the use of solar energy to provide domestic hot water, natural lighting, abundant vegetation, and an effective treatment of wastewater.

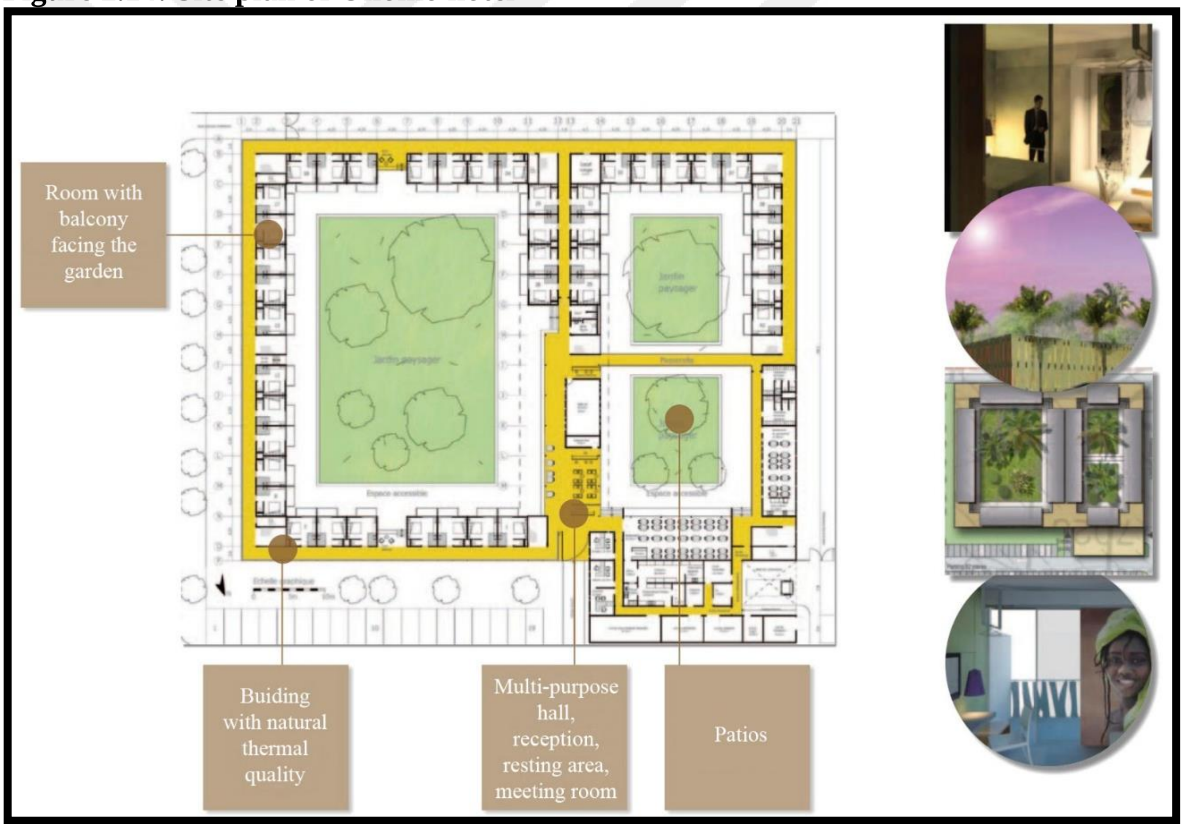
Figure 2.13: Onomo Hotel exterior



Source: onomohotel.com

From the outside, the hotel built with clay bricks is similar to the forts built by military engineers in the 18th-century colonial architecture (See **Figure 2.13**). However, it is designed as such with the intention of protecting the inner environment from the constraints of the environment of Dakar – massive heat gain potential, direct sunlight causing glare, and a noisy environment. The building is turned inward, organized around patios with lush vegetation, each room is protected from the outside urban environment and overlooks a garden that brings peace, security and visual amenity (See **Figure 2.14**). The contrast between very simple forms, local materials and advanced equipment is noticeable.

Figure 2.14: Site plan of Onomo hotel



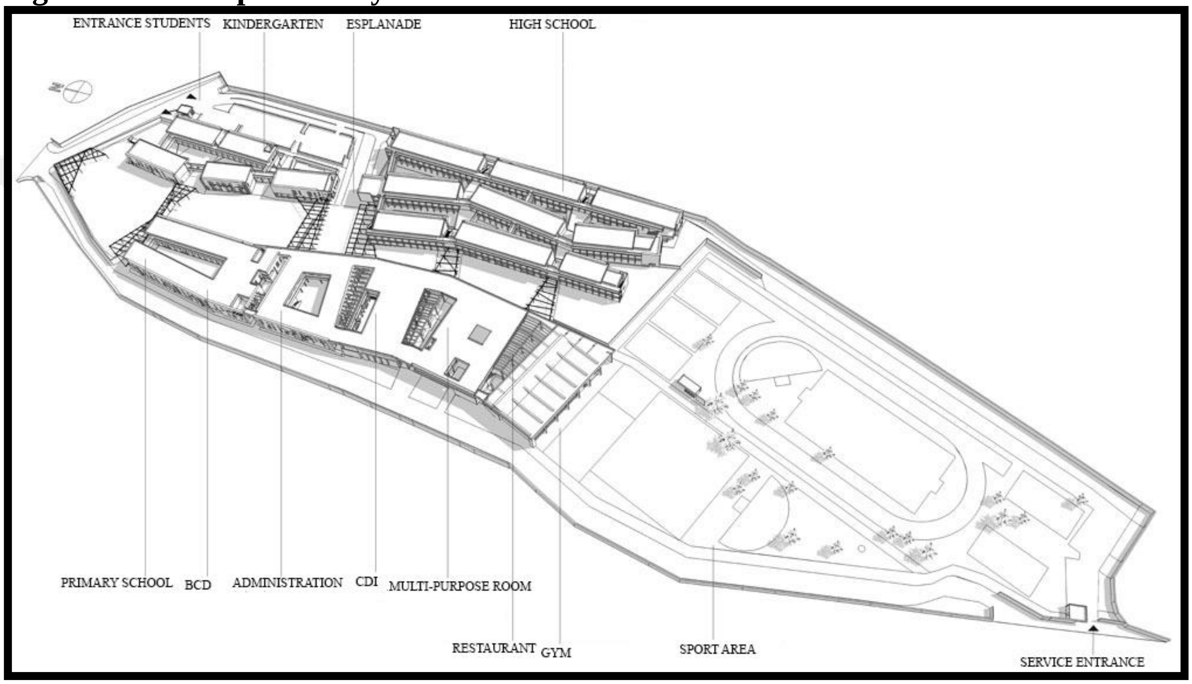
Source: onomohotel.com

Jean Mermoz High School

The interlacing of solid and void generates many transitional spaces between the different entities of the school. The implementation of tightened straps educational buildings creates inter-shaded, narrow and elongated courtyards refreshed by the plantations, whose shape promotes air circulation (See **Figure 2.15**).

Natural air circulation enhanced by positioning the main building in confined strips between two features which results in the formation of the inner islands by wood and shade.

Figure 2.15: Site plan of 'Lycée Jean-Mermoz De Dakar



Source: Darchitectures.com

Given the climate, all the routes are external, both living places full of architectural promenade and sunscreens. Rocks, vegetation, soils drawing materials are also part of the project, as well as sunshades and pergolas, courtyards vegetated. Passive cooling and direct solar protection includes the external distribution corridors, ventilated double walling, sunshades, large inertia roofs etc. (see **Figure 2.16**). Products manufactured and distributed locally are used as finishing materials, such as locks, basalt pavers for outdoor floors, terrazzo tiles, and porcelain tiles for interior floors. Solar panels for hot water and a stand-alone treatment plant for recycling wastewater to irrigate outdoor spaces.

For each building, several passive solutions were applied, i.e. sunscreen and cooling combine preserving natural lighting and acoustics. In front of classrooms, galleries and awnings prevent the sun to impact on the facades during the hottest hours. In back cover, ventilated double walls keep the interior walls from heating up and form thick walls and tinted windows that limit direct sunlight.

Figure 2.16: Pictures of Jean Mermoz high-school

Source: Darchitectures.com

3 SUSTAINABLE URBAN MODEL FOR DAKAR

This part is composed of three subparts consists of proposing a BIM model alternative for a better thermal and visual comfort in the selected building.

Firstly, it is necessary to understand the environment of Senegal-Dakar in order to accurately make proper suggestions. Therefore, insights on Dakar are given, talking about the historic background, the urban environment, the urban structure and the architectural context.

The second part consists of explaining the methodology to be used in order to develop alternatives for a better performing building.

Finally, as the last part, the case study is chosen and a BIM model is created to conduct energy and lighting analyzes that would help determine the thermal and visual performance of the building.

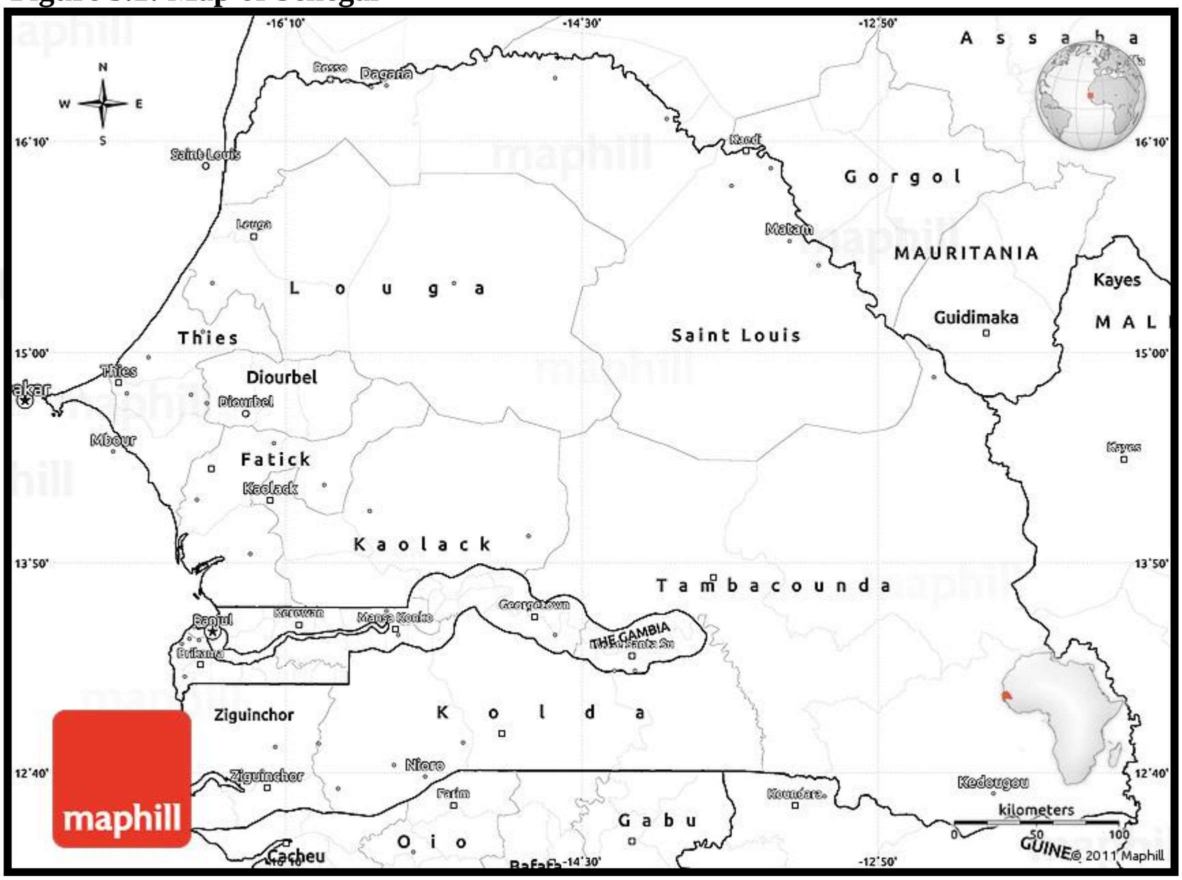
3.1 INSIGHTS ON SENEGAL – DAKAR

This part, as mentioned by the title, gives insights on Dakar for a better understanding of its environmental context. It starts with the historic background of the country to understand why the city is now set as it is. Then follows the urban environment: geography, topography, and climate. Finally, the architectural context of Dakar defines the different phases of architecture in the capital.

3.1.1 Historic Background

Unlike European and American countries, African countries have not been quite ravaged by the effects of industrialization. Instead, their drawback were the consequences resulting from colonization (the 1810s - 1960s) - a period when most of them experienced a huge urbanization with the creation of a network of new cities, set in a way to exploit resources in a massive extent. The coastal regions, welcoming more people held the political and economic power; whereas regions inland depended on them. Senegal, like most West African countries, kept – after its' independence - the urban structure dating from the colonial period. In Senegal, as in many African countries, various forms of architecture coexist in many different aspects sharing the urban area of both the city and the countryside. The organization of the villages and cities corresponds to physical situations and specific needs which themselves vary with the times.

Figure 3.1: Map of Senegal



Source: Team, Maphill.com

Today, three forms of architecture can be spotted in the Senegalese built form:

a. Traditional architecture, practiced by indigenous people, based on models and standards left by the ancestors, with contents of work, materials, and tools taken from the environmental and manufactured by the population itself. Always dominant in the country, especially in rural areas, it is the most authentic expression of the Senegalese art of building; its models, forms, materials, and tools etc. vary depending on the population but also on the location and locally available materials.

b. The colonial architecture, introduced by the colonial power, which shapes and designs, materials and tools also varied throughout history.

c. Senegalese modern architecture - relatively young with barely thirty years; the dynamism and creativity of the young Senegalese architects from the school of fine arts, including the school of architecture and urbanism is printing a new brand to the urban landscape of the Senegalese cities.

Dakar - the actual capital - was created in 1857. Its urban configuration, however, has changed during the years. Before the arrival of the French settlers, the peninsula was composed of a vast scope of villages inhabited by an ethnic group called Lébou[7]. Unfortunately, that indigenous architecture disappeared along with its knowledge with the impact of the French settlers.

3.1.2 Urban Eenvironment of Dakar

3.1.2.1 Geography

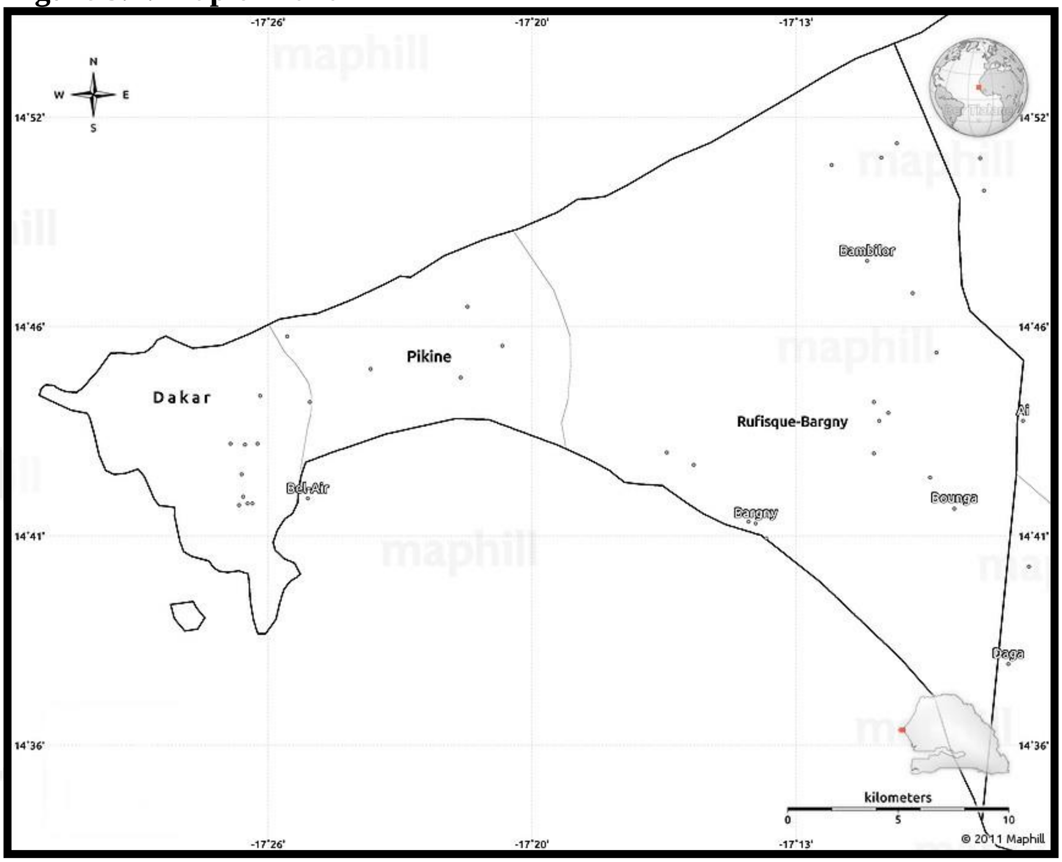
Dakar, based on the peninsula of "Cape Verde" (See **Figure 3.2** **Figure 3.2**), is located on the tip of the western extremity of the African continent between the 14th and the 16th degree North latitude - where the Sahara Desert begins - and 16th and 18th degree West over an area of 550km2 (Barblan, D., Hernach, G., 2014). The peninsula of Cape Verde is positioned as a crossroad for ships and planes making the connection between Europe and America. The city is delimited on the east by another city named "Thies", and by the Atlantic Ocean on its northern, western and Southern parts.

The capital of French-speaking West Africa since 1902, Dakar has, for decades, been considered, as a symbol of an empire as certified by its morphology. However, the collapse of the colonial empire reduced Dakar to a more limited role; being the capital of a small country: Senegal, even though, the city was organized to be the capital of a vast territory.

Despite the loss of its prestige from before the independence, its reduced size and limited means - compared to other African cities like Johannesburg, Rabat, LeCaire etc. - Dakar has an international aura rarely equaled in Africa due to its geographic position.

[7] Lébou: Indigenous people living in Dakar in traditional settlements before the arrival of French settlers.

Figure 3.2: Map of Dakar



Source: Maphill.com, 2015

Also as a national metropolis, Dakar plays a key role in the development of Senegal. It has an absolute supremacy in the urban hierarchy. The city has gradually taken over the activities previously distributed in various parts of the country, despite the spatial planning policy, regional development and decentralization (Direction de l'urbanisme et de l'architecture, 2002).

3.1.2.2 Topography

Its topography is almost flat, with the exception of some volcanic landforms in the West; the most important one being "Les Mamelles[8]" (see **Figure 3.3**). The localities of Rufisque[9] and Bargny[10] extend over uplands with surfaces consisting of Eocene limestone and marlstone.

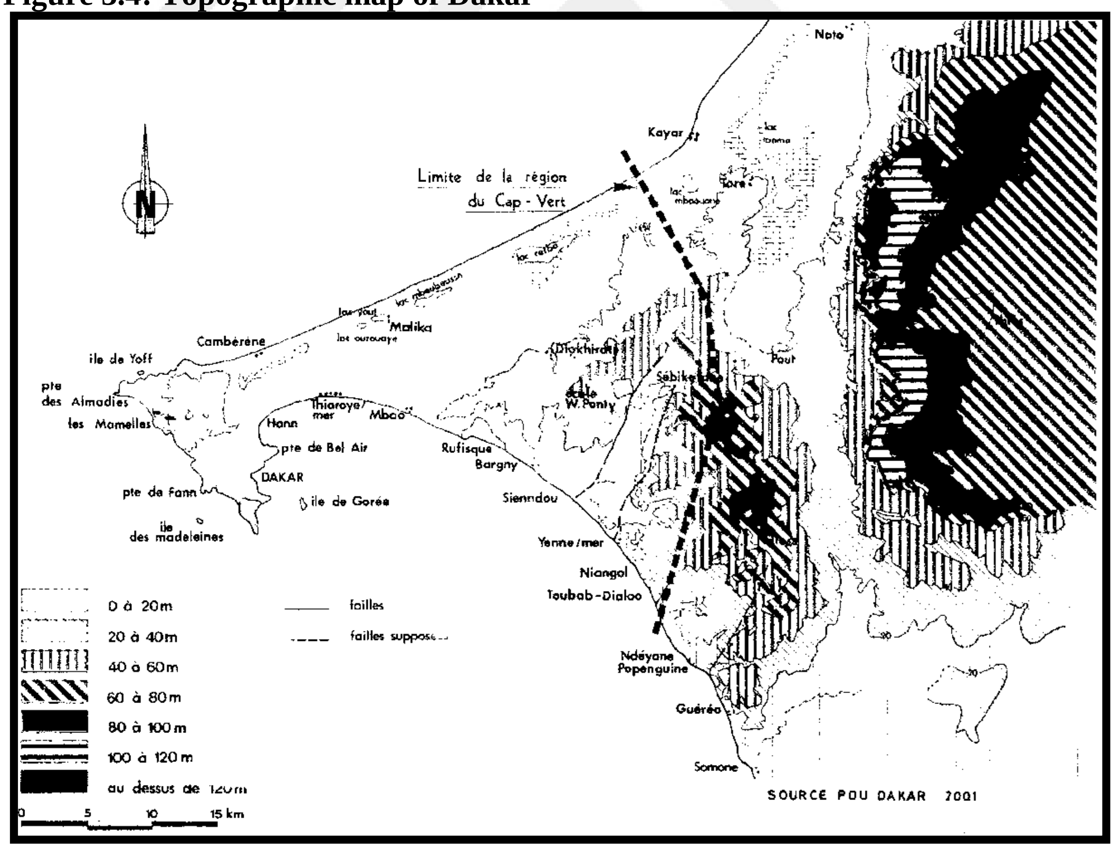
[8] Les Mamelles: Two volcanic landforms in the West of Dakar rising to 105m
[9] Rufisque: Rufisque is a department in the Dakar region of western Senegal
[10] Bargny: A settlement located about 15km to the east of the city center

This part of the peninsula also includes a set of hills and uplands with increasing altitudes from the coast to Sébikotane[11]. The coastal plain is characterized by dune formations oriented North-East and South-West, marked by the presence of non-leached ferruginous soils (Direction de l'urbanisme et de l'architecture, 2002).

Figure 3.3: Picture of 'Les Mamelles' of Dakar

Source: Wikipedia.com

Figure 3.4: Topographic map of Dakar



Source: Plan Directeur d'Urbanisme de Dakar horizon 2025

[11] Sébikotane: An arrondissement of the Rufisque department

3.1.2.3 Climate

Dakar is located in a Sudano-Sahelian climate zone characterized by the alternation of a short rainy season - which lasts three to four months (June to October) when maximum temperatures average 30^{o}C and minimums 24^{o}C - and a dry season dominated by hot and dry wind the rest of the year. However, from December to February, maximum temperatures average 25.7^{o}C and minimums 18^{o}C (Barblan, D., Hernach, G., 2014. Because of its prominent position on the Atlantic, the climate is moderated by a refreshing microclimate seven over twelve months a year - marked by a maritime trade wind generated by the Azores high. Indeed, the regime of The North winds sector predominates from November to May. From March, the harmattan North West blows intermittently. West to Southwest Monsoon winds changes only during the short rainy season. The raised temperatures vary depending on the time of the year; they swing between 17^{o}C and 25^{o}C during the cool period (from mid-December to mid-February) and 25C to 35C during the hottest periods from April to November (Direction de l'urbanisme et de l'architecture, 2002).

3.1.3 Architectural Contexte of Senegal - Dakar

In the villages, traditional architecture continues to be carried out according to the same standards and the same techniques, whereas in the cities, developments, changes, and renewals are more frequent and faster. Which leads to striking architectural contrasts.

As mentioned earlier, three forms of architecture are apparent in the Senegalese built form: traditional architecture, colonial architecture, and modern architecture. This latter architecture presents itself as a synthesis, as it is the heiress of the colonial architecture and participates in the western tradition of building, with its rules, its forms and technicity. However, it also borrows from the traditional architectures' forms and strives to integrate its materials.

3.1.3.1 Senegalese Traditional Architecture

Despite ethnic and regional disparities, the Senegalese people have practiced a form of architecture that has common characteristics. The main characteristic of Senegalese traditional architecture is the use of materials available in the surrounding. For a long period, the materials used were not fundamentally transformed for adaptation purposes or production of materials technically better developed, as it has been done in western countries. Even if there were changes to the materials, adaptations or combinations, these changes were basic (Sylla, 2000). For instance, clay has been combined with water in some cases and used as such; in other cases, it has been mixed with water and cow dung, used as a binder, which supposedly ensures greater strength and thus greater durability of the obtained product. Rough stone was also used as building material and when it has been modified, the changes often consisted of basic size cuts, in order to obtain more convenient geometric shapes to incorporate in construction.

The materials used in traditional architecture varied according to the regions; however, the variety is not infinite because, apart from clay and stone, the main materials used belong to the vegetal reign: wood and bamboo, straw and leaves, bark and vines etc.

Among these materials, the stone was the least used, notably only in the oriental region of the country, where mountains allowed to the populations to include this material into the building of huts mainly, with thatched roof.

Clay was used in almost all the regions of the country, except the central region of the groundnut basin, covered with fine and light sand, easily taken by the wind and with which it is impossible to get a chipboard.

In both regions, southern and eastern - forested regions - materials of vegetal origin were used in the built frame: clay was used, but also wood and bamboo, straw and leaves, barks and vines, etc.

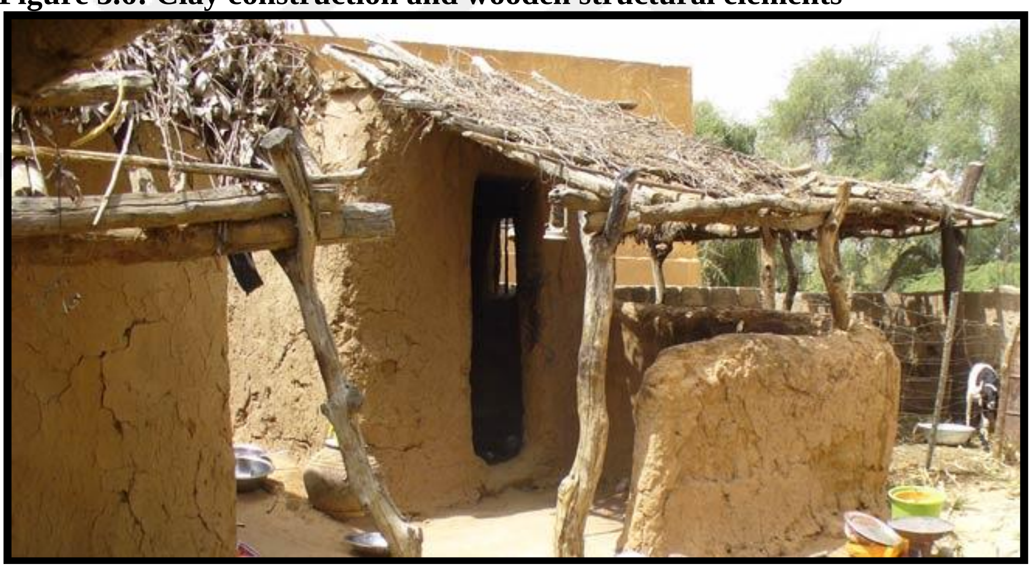
In the North of the country - the desert region - materials used in abundance are clay and wood; clay is used in different levels of buildings: floor, walls and roof - terrace; and to support the clay, wood is inserted at certain levels and places (see **Figure 3.6**).

Whereas in the central regions of the groundnut basin, leaves, straws and grass were the main materials used to build walls and roofs (see **Figure 3.7**).

Figure 3.5: Compound huts made of straw and bamboo in the center of the country

Source: dyxum.com

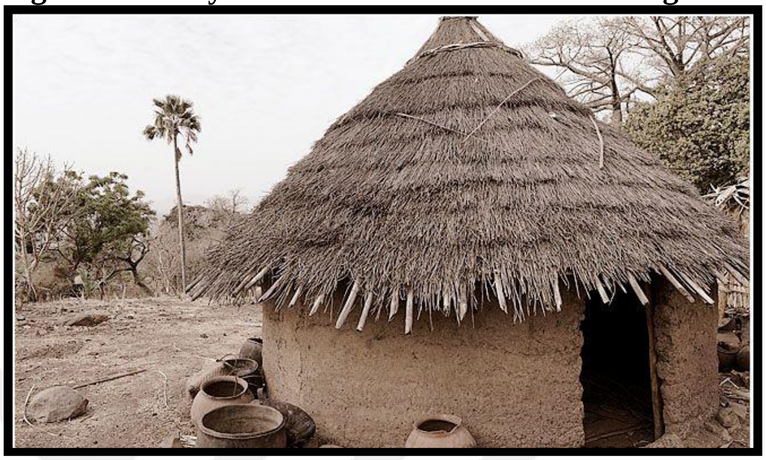
Figure 3.6: Clay construction and wooden structural elements



Source: au-senegal.com

The place and functions of these materials in the building did not vary so much. Used as such or combined with other materials or binder, clay is used at the floor level and walls, more often on terraces in the North of the country. Wood and bamboo were used in frames and roofs, notably in forested regions. Grasses, leaves, and stems are mostly used in the central regions for walls and roofing (see **Table 3.1**).

Figure 3.7: Clay hut in the northern side of Senegal



Source: Maison du monde

Senegalese traditional architecture appears to be determined by the populations way of living but also the environmental conditions and the abundance of local materials. This architecture is notably perpetuated in its forms and some of its materials, but it has experienced an evolution, due to various factors and changes intervened in the society. In fact, in the dawn of the 20th century, with the colonization and the colonial architecture, new materials appeared.

The prototype of the typical traditional African housing is the round hut with small dimension. However, other models exist in Senegal.

a. Cylindrical huts with clay or banco walls, conical straw roof with bamboo frame
b. Rectangular huts with wooden or banco walls and double-sloped roofs
c. Small rectangular huts with straw walls and big togs, conical straw roofs and big leaves

Table 3.1: Materials used in traditional architecture and their usage

MATERIALS	USE	LOCATION	BUILT FORMS
Clay, Wood	Clay ——Floors, wall and roofs Wood——Inserted to support the clay	Norther desert region	Cylindrical huts with clay or banco conical straw roof with bamboo frame
Staws, Leaves, Herbs	Walls and roofs	Central region	Small rectangular huts with straw walls and big togs, conical straw roofs
Wood and Bamboo Straws and Leaves Barks and Vines	Walls and roofs	Southern forest region	Rectangular huts with wooden or banco walls and double slopped roofs

3.1.3.2 Senegalese Colonial Architecture

In function of the needs and necessities of the colonial power and its administration, colonial architecture has taken different forms and used different materials in time. Which leads to the multiple faces of colonial architecture in Senegal. Thus, one can distinguish several phases in the history of Senegalese colonial architecture (Sinou, 1993).

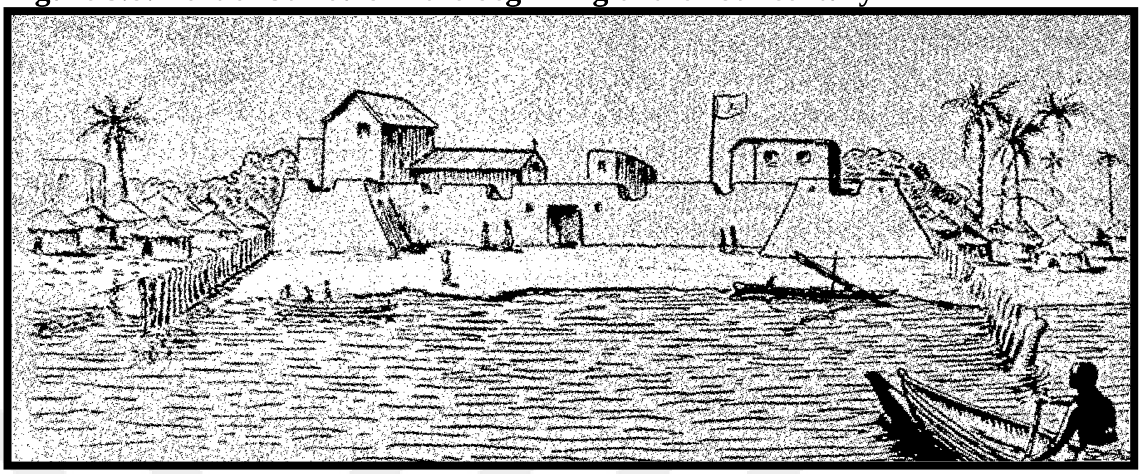
During the first phase (15th – 16th centuries) - that of the colonial countertops installed along the Atlantic coast of Africa - the colonial power implanted in the country makeshift shelters composed of vast hangars and barracks, built with perishable materials such as wood, bamboo, Palmyra and boards. Since then, the colonial architecture contrasts with the traditional architecture, due to the reproduction of geometric forms from western architecture. This first form of colonial architecture was the work of European merchants, businessmen and other characters involved in the triangular trade.

The second phase (18th – 19th centuries) is that of the conquest and pacification of Africa and during which a new form of colonial architecture appears. Indeed, beyond the military cantonments, more or less strong and durable, the conquest and pacification demanded the substitution of huts and sheds with solid buildings and fortifications. Military engineers then built garrisons, strong and impregnable forts; which did require strong materials and, therefore, impressive constructions by their size and strength.

Built by military engineers to withstand enemy attacks, time, and weather, constructions of this generation were built with new materials; the main ones being iron, stone and slate. Iron was used for foundations and openings while the stone was used for walls and slate for roofs, which structures could be made of wood or iron.

Similar to everywhere in Europe, these forts were characterized by their massive forms, height, thickness, and compactness, with few external openings, but a huge central metal door (see **Figure 3.8**). Compared to the first form of colonial architecture, this one innovates by the materials used and the built forms. When this architecture built civil use buildings, it used more abundantly iron and slate; iron has served for the openings but also for railings and staircases; slate was used for roofs and windows awnings.

Figure 3.8: Fort of St Louis in the beginning of the 18th century

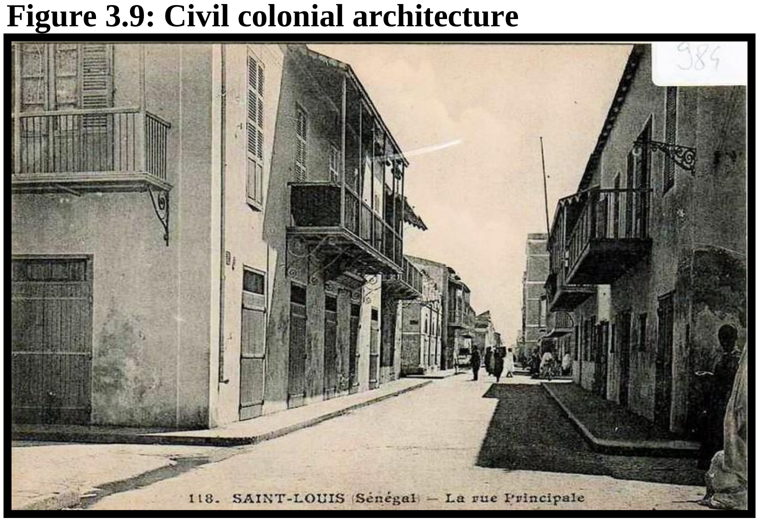


Source: Comptoirs et villes colonials du Sénégal (1993)

This architecture has prevailed until the early 20th century after the pacification of Africa. The requirements for a lasting installation commissioned by colonization imposed the construction of multi-purpose buildings: trade, administration, housing, etc. A new civil architecture is added to the one by military engineering.

In this new civil architecture as in **Figure 3.9**, iron, stone, and tile, expensive and imported materials are being replaced by standard blocks of cement and sand, iron is only used for foundations, frames, and beams the gates of the terraces, while the slate roofs give way to terraces; the wood is still used in carpentry; more recently, new materials are imported or locally manufactured and integrated.

Figure 3.9: Civil colonial architecture



Source: Etudescoloniales.canalblog.com, 2008

Figure 3.10: Colonial architecture in Senegal

Source: Dégragation d'un héritage (2014)

Table 3.2: Materials used in colonial architecture and their usage

	MATERIALS	USE	BUILT FORMS
PHASE I XV - XVI centuries	Wood, Bamboo, Board	Walls and roofs	Sheds and Barracks
PHASE II XVIII - XIX centuries	Iron, Stone, Slate	Iron → Foundations and openings Stone → Walls Slate → Roofs	Forts and housing
PHASE III XX century	Iron, Wood, Cement and sand cinder-blocks	Iron → Foundations and beams Cement, Sand blocks → Wall Wood → Carpentry	Multi-purpose buildings

As seen in **Figure 3.10**, even though colonial architecture has radically contrasted traditional architecture with its form and used materials, it tried to adapt to the climatic conditions using design techniques such as overhanging terraces with slate roofs, terraces all around certain buildings creating intermediate areas, corridors with the same purpose and etc.

3.1.3.3 Senegalese Contemporary Architecture

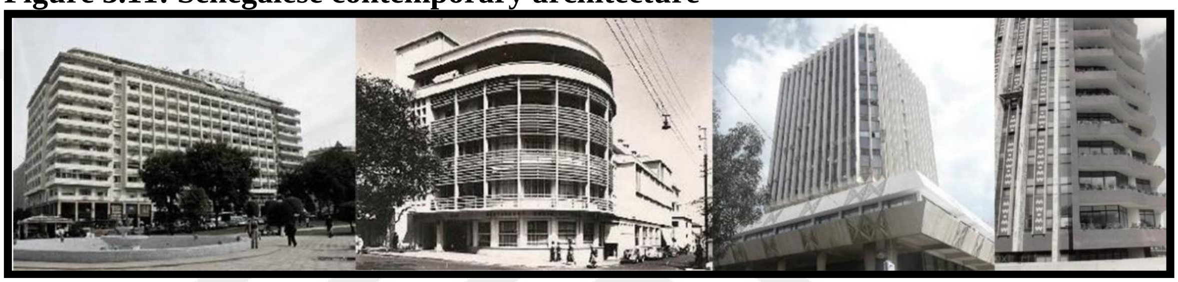
As mentioned earlier, Senegalese contemporary architecture is the heiress of two traditions of architecture:

a. That of the ancestors and the indigenous population, whose values standards and models are still difficult to integrate to the work of contemporary architects.
b. That of the western architecture - introduced in the country for the colonial administrations' needs – which shaped the spaces, where they were implanted, according to the standards and schemes of western architecture to satisfy the needs of the administrative, economic, and political organization of the territory.

Due to the habits, traditions and their formation in the architecture field done by French tutors, the first Senegalese architects had the same architectural style as their European colleagues and tutors and using the same building materials. Thus, in the scientific and technical points of view, as well as in the models, forms and building materials points of view, the dependency of Senegal is almost general.

Even though Senegalese architects have adopted the architecture style of their western peers to the detriment of traditional architecture, they on their turn also tried to adapt their designs to the climatic challenges by the use of shading devices and balconies as in **Figure 3.11**.

Figure 3.11: Senegalese contemporary architecture



Source: Dégragation d'un héritage (2014)

While the architecture sector grows and develops tremendously with the impact of new Senegalese architects, almost 80 percent of the construction materials are imported due to the lack of industrial units specialized in the building sector. The industries present in the sector are SOCOCIM[12] and SENAC-ETERNIT[13] specialized respectively in the production of cement and fiber-cement sidings; therefore, the only elements used in construction and that Senegal does not import are water and sand, cement and fiber cement.

3.2 METHODOLOGY

The scope and framework of this thesis are formulated by a study on how to adequately adapt passive design strategies in the urban environment of Dakar. In order to do so, the focus is put on an already built neighborhood called "Résidence de la Paix" in Dakar, and within that neighborhood, the most common multifamily building is selected. Using BIM software Revit to model the building with the exact materials and their thermal properties, energy, and lighting analyzes are conducted to ascertain the energy performance and the lighting

[12] SOCOCIM: Senegalese cement company founded in 1946 and based in Rufisque.
[13] SENAC-ETERNIT: Senegalese fiber-cement company

performance of the building. The results of these analyzes allowed the determination of the critical factors in terms of thermal and visual comfort that need to be modified to reach the requirements for a passive building.

The hypothesis proposed after preliminary analysis is: through the analyzes of the energy and lighting performances of the multifamily building in question, it is possible to develop a better performing alternative leading to the reduction of energy consumption for cooling or lighting. Furthermore, allowing the required amount of daylight according to the orientation of the building.

3.3 CASE STUDY: RESIDENCE DE LA PAIX - SENEGAL/DAKAR

This part consists of choosing a multifamily building within the selected neighborhood as a primary subject on our analysis in order to determine the critical factors which need improving to achieve a sustainable neighborhood with the use of passive design strategies.

First, an energy analysis – using Revit Energy Analysis tools – will be conducted to determine the energy performance of the chosen building. This analysis will help detect the most problematic factors which are the cause of the energy use demand.

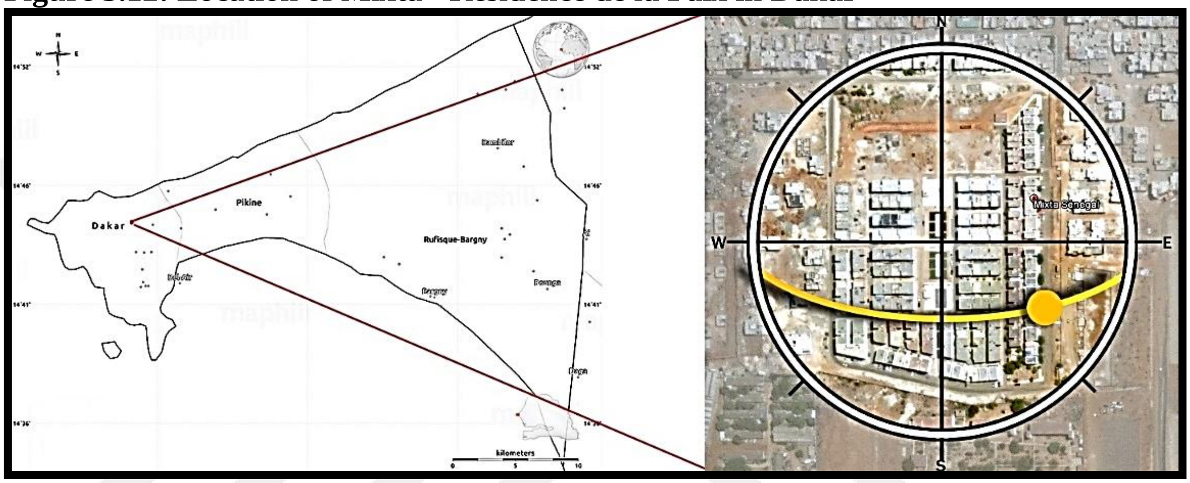
Then a lighting analysis will be conducted to show the effect of solar radiation on the inner spaces in terms of visual comfort. This analysis will determine how much light is entering the building and whether the types and number of openings on the building meet the requirements for a visual comfort.

3.3.1 Case Area

'Résidence de la Paix' – located on the 14.75^o North longitude and 17.45^o West Latitude of Dakar – is described by its developers as being an innovative real estate development project in Dakar (see **Figure 3.12**). It is the outcome of a collaboration between renowned architects Ricardo Bofill, Juan Ramon Freire and Mamadou Berthe, head of the board of architects of Senegal. The neighborhood is composed of three and four story buildings. The apartments on the ground floors each benefit from private gardens while those on the upper floors feature terraces. All services are installed according to international standards:

a. Water sanitation on the entire neighborhood is served by a system of ‘mains drainage’.
b. The removal of rainwater is ensured by pipes provided for this purpose.
c. Water, electricity and telephone networks are buried to the feet of buildings.

Figure 3.12: Location of Mixta - Residence de la Paix in Dakar



In order to benefit from a vegetal canopy over the entire site, the whole surface of the neighborhood was not urbanized, allowing in its hear an illuminated and pleasant tree-lined plaza facing multiple shops. This relaxing venue has quickly become a promenade area for families according to the developers. In addition, parking for residents and visitors is available with almost 300 parking places.

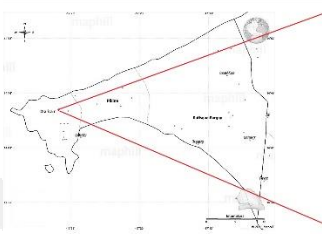
Despite the great advertisement of the developers, occupants of ‘Résidence de la Paix’ complain about far too many issues, leading into questioning the architecture, organization, and management of the neighborhood. Even though the neighborhood is deemed residential, some of the complaint from the residents are as following:

a. Deterioration of few construction materials in the neighborhood faster than expected.
b. Lack of street lighting and a growing unsanitary, being in an overflowing insecurity.
c. The hasty departure of the Trustee that managed security, cleaning of common areas, waste disposal.

d. The indoor of the apartment being too hot, increasing the need for air conditioning and, therefore, electricity cost – which on the point of view of an architect and sustainable design through passive design strategies would be the focus of this thesis.,

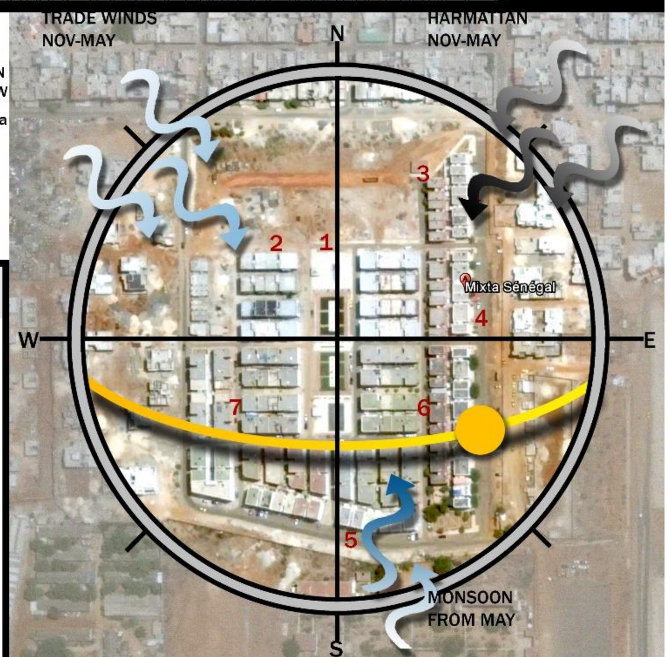
A decade ago, a typical neighborhood in Dakar would have been composed of 90 percent of single family buildings. However, with the city being overly populated, the economic challenges and the rise of the land prices, living in a multifamily building have become a new trend within the city. Therefore, the number of multifamily buildings in newly built neighborhoods has increased considerably, hence the selection of Mixta, a multifamily neighborhood as a case study. Within Mixta, one can distinguish different types of multifamily buildings as they are built in phases with each one a bit different from the other. In order to prove the hypothesis, one of the most common multifamily building is chosen within the neighborhood to conduct the analyzes for the determination of its thermal and lighting performances that will result in developing alternative solutions in terms of thermal and visual comfort and simultaneously reduce the energy consumption with the use of passive design strategies.

SITE ANALYSIS



DAKAR

Longitude....14.74 N
Latitude.......17.45 W
Area.............5.58 ha



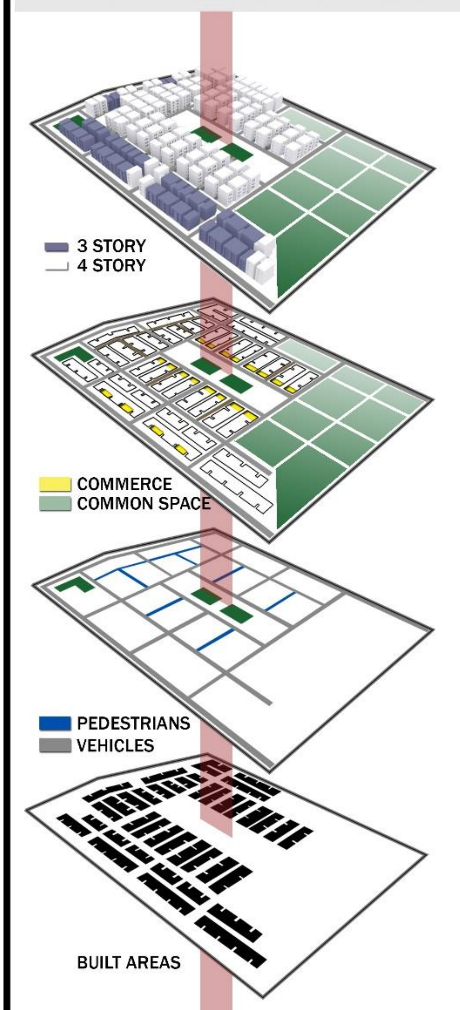
The wind regime is characterized by a seasonal variation in dominant directions:

North - West (November to May): Maritime Trime Winds, strong freshness and humidity.

North - East (November to May): Harmattan Winds, cold, dry and dusty trade winds.

South (from April/May): Monsoon winds, rain-bearing winds during summer.

DIAGRAMS



3.3.2 Building Description

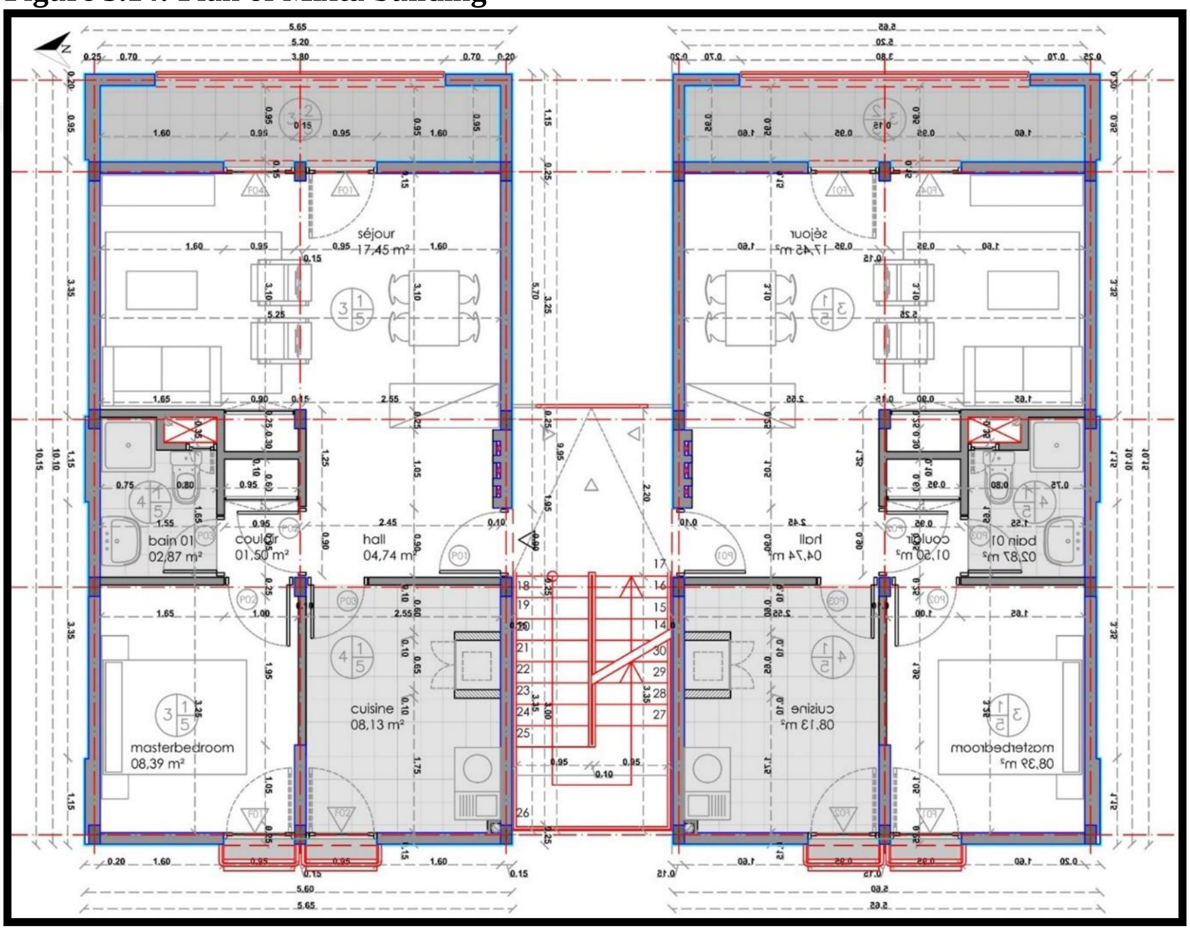
The building in question is a three-story multifamily building with the main façade facing East (See **Figure 3.13**). It is composed of eight 2+1 apartments and a common stair (See **Figure 3.14**). As all buildings in the neighborhood, the apartments on the ground floor each has a backyard while the upper ones have balconies. The living rooms are facing East and the rooms West. North and South facades are blind with no windows.

Figure 3.13: Pictures of Mixta building

The external walls are made of cinderblocks of 20cm thickness without insulation and 10cm bricks for interior walls. Also, the living rooms each have two glass doors to access the balconies and a glass door for each room given on the backyards.

This building is selected for being one of the most critical building within the neighborhood due to its position and orientation as seen in **Figure 3.13**. most buildings are positioned back to back from each other providing protection from direct sunlight for one façade. However, the selected building is not protected by neighboring buildings; its main facades on the East and West are open to direct solar radition.

Figure 3.14: Plan of Mixta building



Source: mixtasenegal.sn

3.3.3 BIM Model with Revit

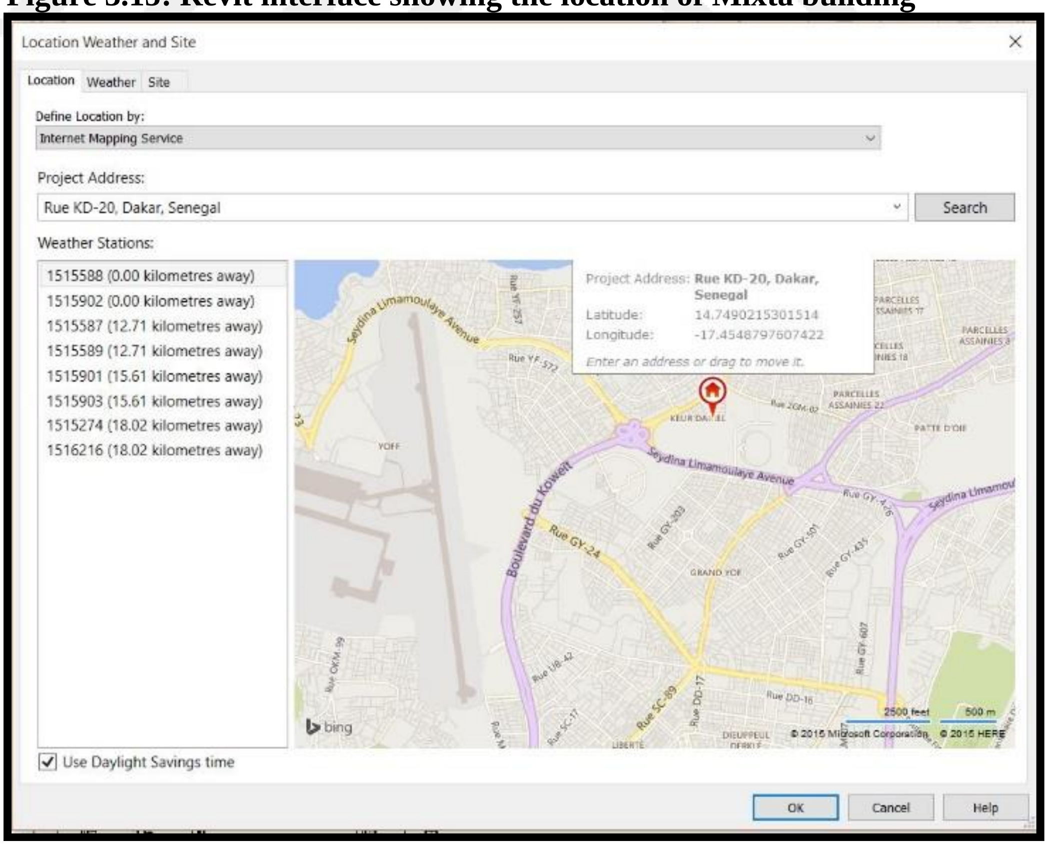
In order to determine the thermal and lighting performance of the building, Autodesk Building Information Modeling (BIM) software Revit is used to simulate and analyze the building (see **Figure 3.16**). Revit, being one of the first BIM software on the market (free of charge for students) – for architects, engineers, designers, and contractors – is able to access building information from the building model database.

The building energy simulation measures the energy use - fuel and electricity - based on the building's geometry, climate, building type, envelope properties, and active systems. It takes into account the interdependencies of the building as a whole system.

Lighting Analysis for Revit however, is a fast cloud service that uses Autodesk 360 Rendering to expose electric and solar lighting results directly on the Revit model. Consequently, when modeling the selected building, every architectural element is specified as it is on the existing building, same for the building materials used and their thermal properties in order to have accurate results on the analysis.

Additionally, the location of the model – which is 14.74º North longitude and 17.45º West latitude Dakar – was set in order for Revit to set the weather station of that area as in **Figure 3.15**.

Figure 3.15: Revit interface showing the location of Mixta building

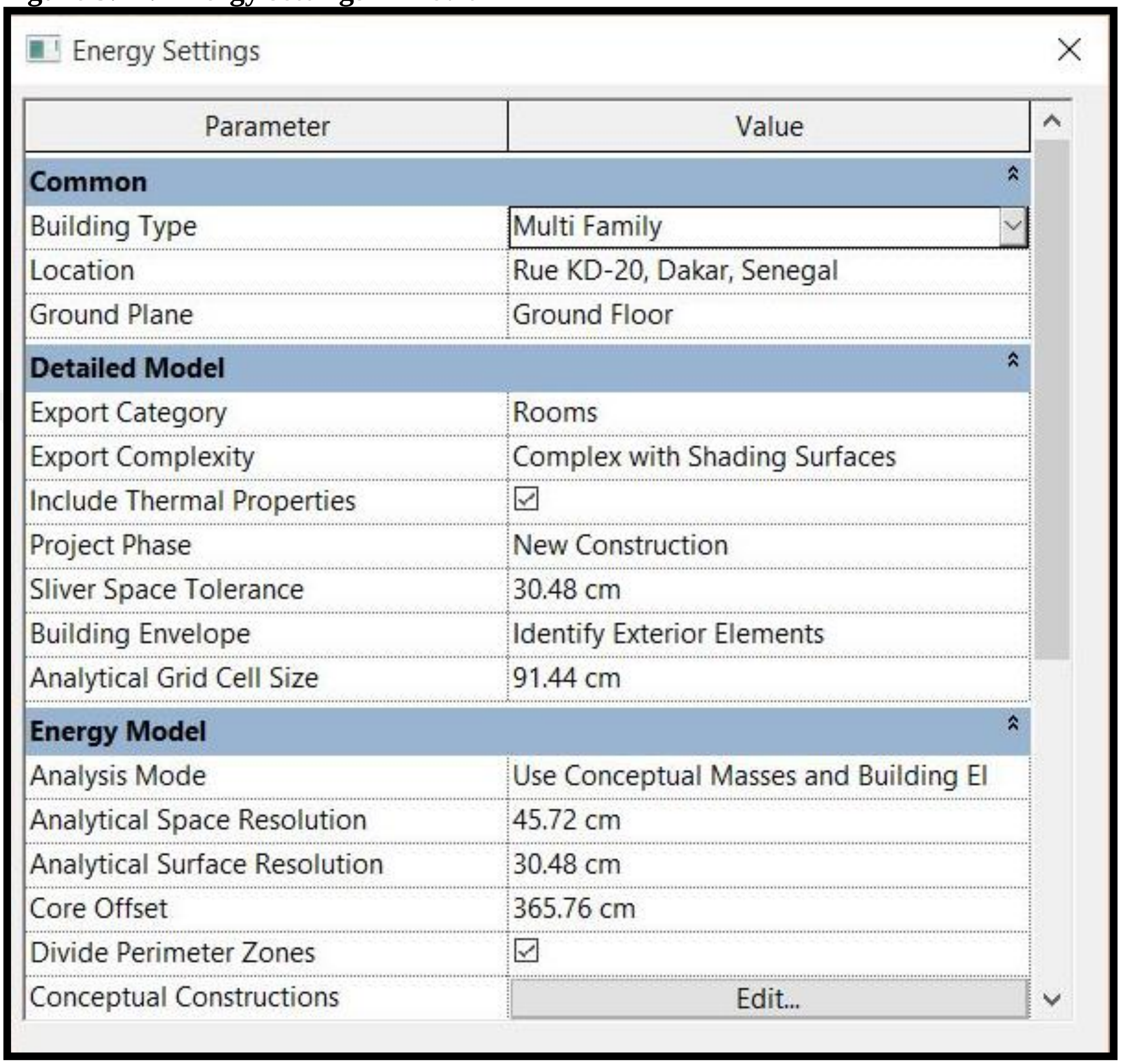


Source: Revit; Location Weather and Site

Figure 3.16: Views of the model from Revit

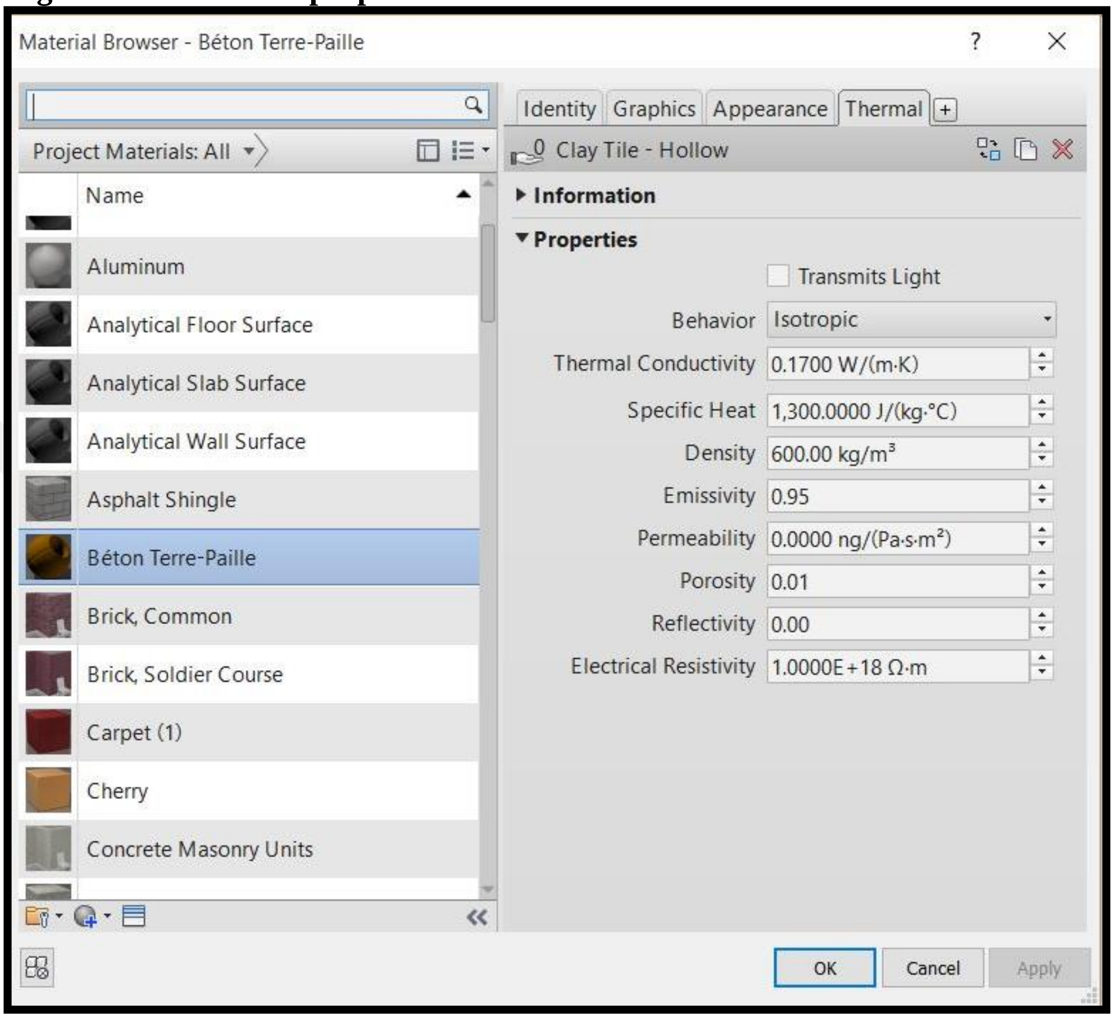
Results of energy analysis depend on various factors including the energy settings which need to be set accordingly as in **Figure 3.17**. building type, location and more importantly energy model settings have a considerable effect on the results of the energy analysis. Under “detailed model”, include thermal properties must be checked in order for Revit to assess the thermal properties of materials used in the simulation.

Figure 3.17: Energy settings in Revit



The following step before conducting energy analysis consist of making sure the thermal properties of each material is added. Doing so consist of clicking on “thermal” on “material browser” (see **Figure 3.18**) and entering the thermal properties of the material in question if they are not already given.

Figure 3.18: Material properties in Revit



3.3.4 Energy Analysis and Results

Understanding the energy performance of a building is crucial in sustainable design. Thus, conducting an initial energy analysis on the modeled building helps determine the problematic factors causing increasing energy use demand. The energy analysis provides the following aspects:

a. Building Performance Factors
b. Energy Use Intensity
c. Life Cycle Energy Use/Cost
d. Renewable Energy Potential
e. Annual Carbon Emissions
f. Annual Energy Use/Cost
g. Energy Use: Fuel
h. Energy Use: Electricity

i. Monthly Heating Load
j. Monthly cooling Load
k. Monthly Fuel Consumption
l. Monthly Electricity Consumption
m. Monthly Peak Demand
n. Annual Wind Rose (Speed Distribution)
o. Annual Wind Rose (Frequency Distribution)
p. Monthly Wind Roses
q. Monthly Design Data
r. Annual Temperature Bins
s. Diurnal Weather Averages
t. Humidity

However, focusing on determining which factors affect the energy use the most and the reason, the results are limited to only a few of these aspects: *Building Performance Factors*, *Energy Use Intensity*, *Renewable Energy Potential*, *Annual Carbon Emission*, *Monthly Heating Load and Monthly Cooling Load*.

3.3.4.1 Building Performance Factors

The energy analysis tool takes into consideration various factors such as Location, Weather Data, Outdoor Temperature, Floor Area, External Wall Area, Average Lighting Power, Exterior Window Ratio, Electrical and Fuel costs as on **Table 3.3**.

Table 3.3: Building Performance Factors of Mixta building

Location:	Rue KD-20, Dakar, Senegal
Weather Station:	1515588
Outdoor Temperature:	Max: 34°C/Min: 15°C
Floor Area:	265 m²
Exterior Wall Area:	608 m²
Average Lighting Power:	6.46 W / m²
People:	6 people
Exterior Window Ratio:	0.10
Electrical Cost:	$0.09 / kWh
Fuel Cost:	$0.78 / Therm

3.3.4.2 Energy Use Intensity (EUI)

A measure of the annual electricity and fuel usage per floor area per year. Total EUI is the measure of the combined electricity and fuel used by the project, per floor area per year.
In this case, the buildings’ electricity EUI is equal to 203KWh/sm/yr while fuel EUI is 148MJ/sm/yr (see **Table 3.4**).

Table 3.4: Energy Use Intensıty of Mixta building

Electricity EUI:	203 kWh / sm / yr
Fuel EUI:	148 MJ / sm / yr
Total EUI:	878 MJ / sm / yr

3.3.4.3 Renewable Energy Potential

Roof surfaces are analyzed for their estimated potential to generate electricity using photovoltaic panels. Wind energy potential is estimated based on the annual amount of electricity that can be generated from one 15-foot-diameter wind turbine of horizontal axis design (see **Table 3.5**).

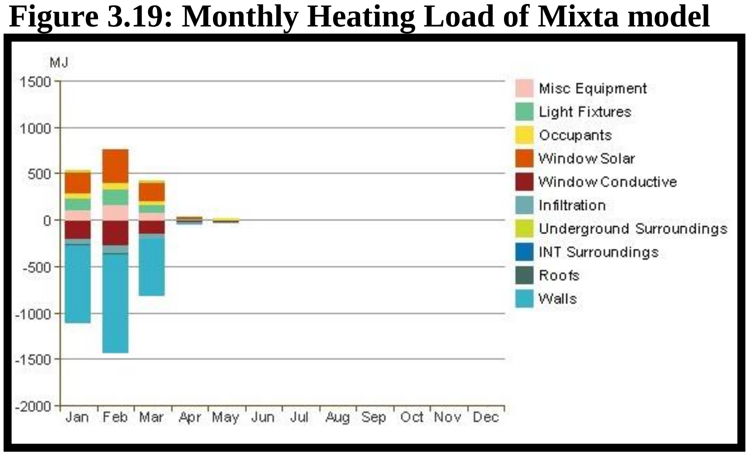
Table 3.5: Renewable Energy Potential of Mixta building

Roof Mounted PV System (Low efficiency):	20,837 kWh / yr
Roof Mounted PV System (Medium efficiency):	41,675 kWh / yr
Roof Mounted PV System (High efficiency):	62,512 kWh / yr
Single 15' Wind Turbine Potential:	2,473 kWh / yr
*PV efficiencies are assumed to be 5%, 10% and 15% for low, medium and high efficiency systems	

3.3.4.4 Monthly Heating Load

Figure 3.19 below - showing the cumulative heating loads on the analyzed model for each month - helps identify the critical components in order to reduce the heating load on the project. Heat loss through walls and conduction through windows represents the largest monthly demand for heat in cold months – from January to March. However, solar gain through windows, light fixtures, and miscellaneous equipment reduces the demand for heat.

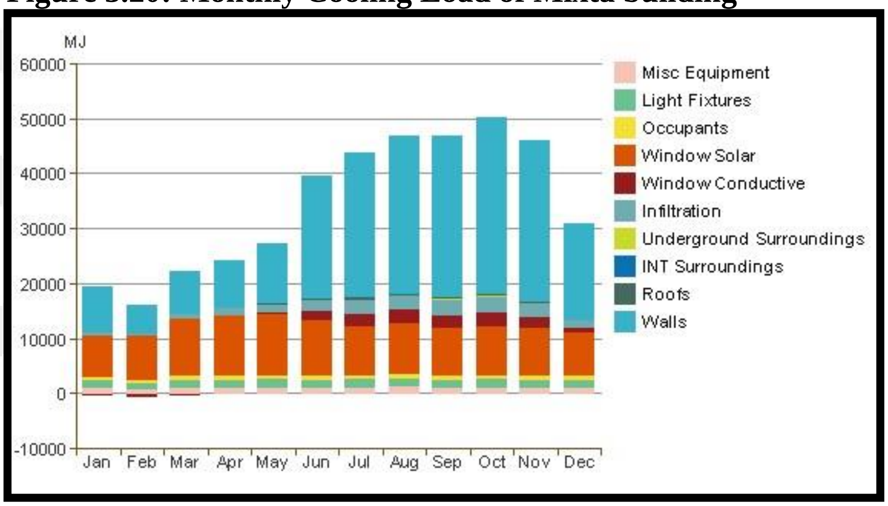
Figure 3.19: Monthly Heating Load of Mixta model



3.3.4.5 Monthly Cooling Load

Figure 3.20 below shows the cumulative cooling loads on the project for each month. Positive values represent cooling demands that must be satisfied by a cooling system or other means while negative values offset the need for cooling. The largest cumulative cooling loads occur with the greatest contribution from wall conductivity and solar heat gain through windows.

Figure 3.20: Monthly Cooling Load of Mixta building



Summery

The results of the Energy Analysis done in the specified location – Dakar, with its weather data, shows that the building in question consumes a great amount of energy per year – 878MJ/sm/yr (see **Table 3.4**). However, with the building located in a hot and humid climate zone and its orientation according to the sun path, its roof has the potential to house photovoltaic panels and counter-balance the energy needs and reduce the CO_2 emission by the use of electricity from the grid. Photovoltaic panels, if mounted on the roof, can potentially produce 31.25 percent more energy than needed and, therefore, reduce 22 metric tons of CO2 over 16 metric tons of CO_2 a year, created by the use of electricity from the grid; leaving 5 metric tons of Net CO_2.

The heating and cooling load charts show the critical factors that increase the need for energy – for either heating or cooling – in the building.

The monthly heating load chart shows that during the cold periods of the year – even with heat gain mostly from solar radiation through windows, lighting fixtures, miscellaneous equipment and a small amount through occupants – the heating demand remain larger due to a huge amount of heat loss through walls mostly, window conduction and a small amount through infiltration (see **Figure 3.19**).

Similarly, in the monthly cooling load graph, the critical components creating the need for cooling are identified. Dakar being in a hot climate zone, a great amount of heat is conducted from the exterior through walls the entire year – making the cooling needs enormous. Solar gain through windows, also, considerably increases the heat within the building.

In order to reduce the heating demand during cold months and cooling demand during the rest of the year, the heat transfer through walls should be reduced to a minimum, keeping thermal radiation out of the building and avoiding at the same time heat loss through walls during cold periods (see **Figure 3.19**).

Heat flow is inevitable in the contact between two spaces of differing temperature, however, the use of thermal insulation materials provides a region in which, thermal conduction is reduced. Therefore, the heat transfers through walls from either inside or outside is reduced, analogically reducing the energy use of the building. Moreover, a more sustainable alternative to reduce thermal conduction through walls is the use of local materials with low conductivity, high insulating capability; for instance, materials used in traditional architecture (improved) such as clay, stone, straw etc.

3.3.5 Lighting Analysis and Results

To reduce the use of electric light, windows provide natural daylight into the rooms, however, it also allows heat gain from solar radiation. In order to retain a good daylight level and reduce the energy use of the building, lighting analysis is conducted to determine the effects of sunlight in the rooms in terms of natural daylighting. The lighting analysis determines the illuminance of the building, which is the amount of light falling on a surface. The average illuminance level for a good visual quality in a workplace or home ranges between 100-1000 LUX (see **Table 3.6**); one LUX being the illuminance at the same point at a distance of 1m from the source.

Table 3.6: Adequate illuminance required per type room and activity

Use	Applications	illuminance(Lux)
Residential	Bedroom	100
	Toilet	100
	Stores and staircases	100
	Lounge	150
	Bathroom	150
	Kitchen	150 – 300
Other uses	Minimum service illuminance	20
	Corridor, passageways, stairs	100
	Entrance hall, lobbies, waiting room	100
	Escalators, elevator	150
	Restaurant, canteen, cafeteria	200
	Museum and gallery	300
	General offices, shops, and stores, reading and writing	300 – 400
	Drawing office	300 – 400
	Classroom, library	300 – 500
	Shop/ supermarket/ department store	200 – 750
Localized lighting for exacting task	Proofreading	500
	Exacting drawing	1000
	Detailed and precise work	2000

Source: Blanco, 2014

Figure 3.21: Lighting analysis results of Mixta building at 9 am

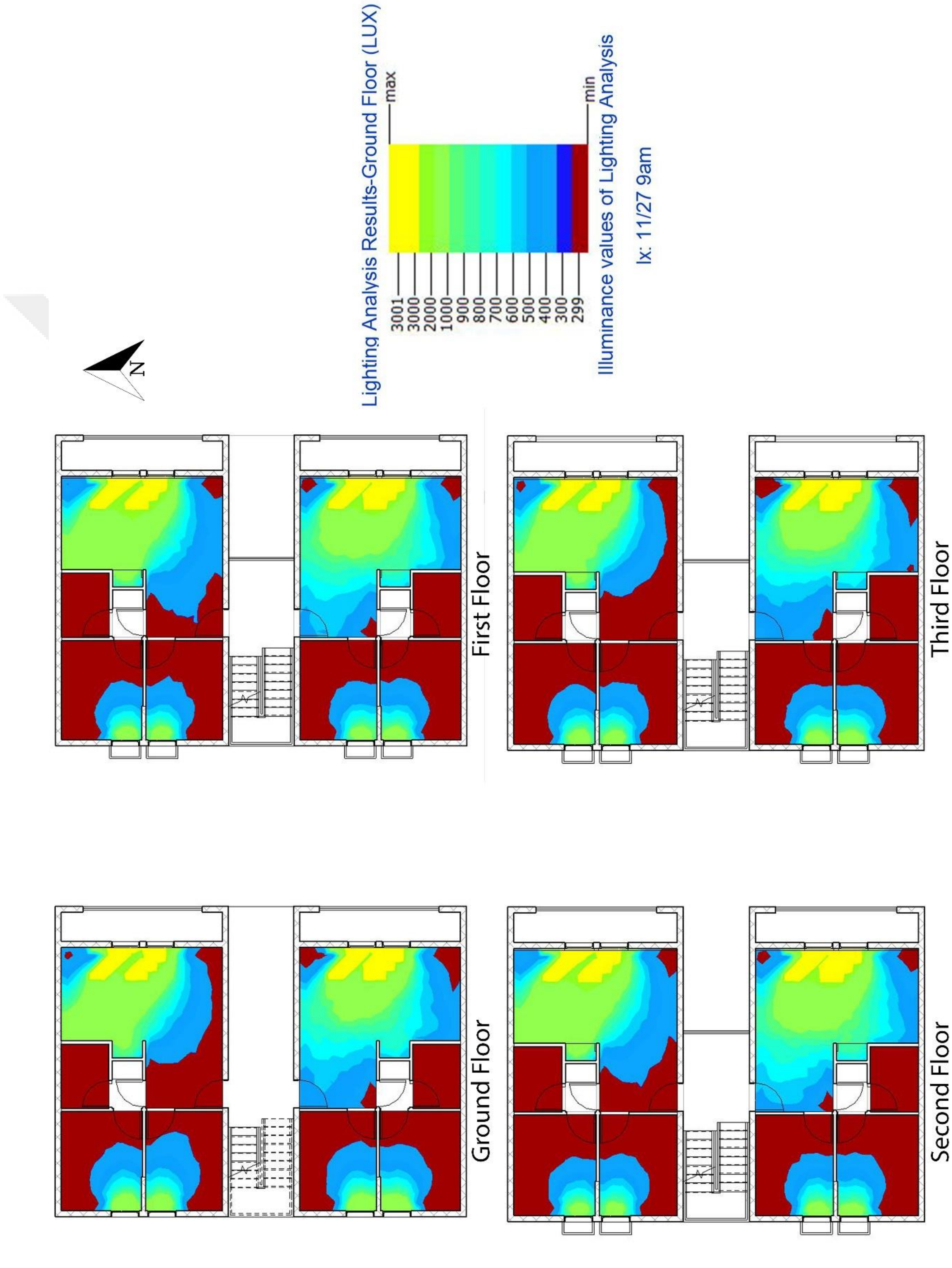
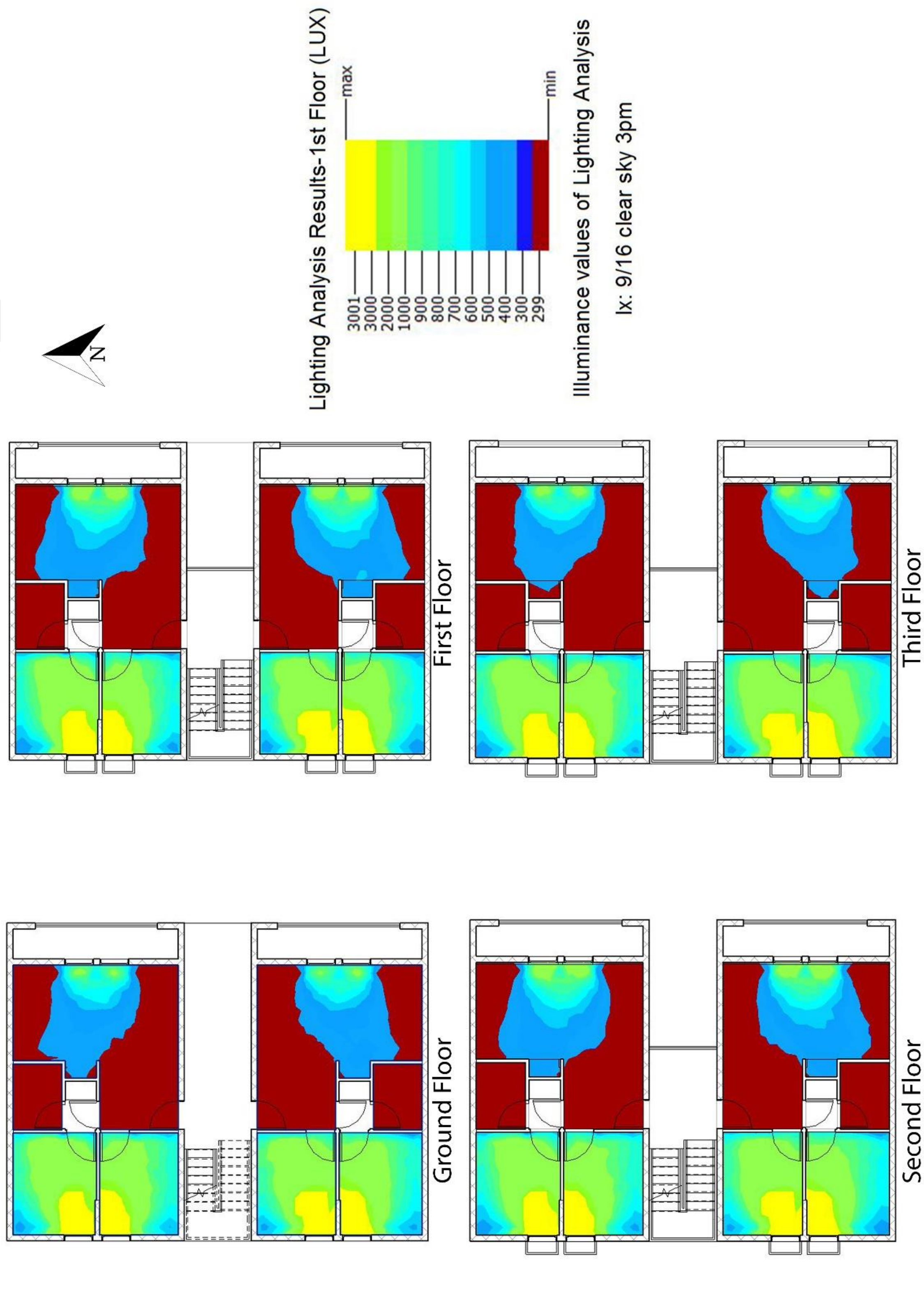


Figure 3.22: Lighting analysis results of Mixta building at 3 pm



Summery

Located in a hot and humid tropical climate zone the main façades of the analyzed building are facing East and West which are respectively hit by direct sunlight in the morning and in the afternoon.

The results of the lighting analysis show that: the living rooms facing East receive an excessive amount of daylight in the morning (see **Figure 3.21**).

a. Even though it reduces the use of electric lighting – which results in energy saving – the living rooms receive a lot more daylight than required for visual comfort in a house. Moreover, windows allowing natural daylight into the rooms to reduce electric light usage, also allow heat gain from solar radiation, resulting in the deterioration of the thermal comfort conditions for occupants by overheating the rooms.

b. Analogically, in the afternoon, the same issues occur in rooms facing West (see **Figure 3.22**). However, due to their small size and lack of shades, the rooms get over-lit and over-heated.

Hence, during design phase the architect should be considering the position of windows such that excessive heat gain and glare are avoided. Besides, especially in warm climates, the energy performance of glazed openings should be carefully studied to achieve a successful facade by specifying the right amount of glazing to harness daylight and carefully manage solar gains. Shading devices are to be considered for openings on the East and West - hit by direct sunlight - for visual comfort.

4 DISCUSSION AND CONCLUSION

As mentioned earlier, in order to find the critical factors causing mostly the excessive cooling demand, an energy analysis was conducted on the selected building. The results showed that heat transfer through walls was the most problematic factor followed by window solar[14] resulting in an important amount of cooling demand during hot months which are nine over twelve in Dakar. Heat demand, however – caused mostly by heat loss through walls and window conduction – is offset by the heat gain from solar radiation through windows, lighting fixtures, miscellaneous equipment, and occupants.

Hence, on one hand, in order to reduce energy consumption, heat transfer through walls must be diminished. The excessive amount of heat transferred through walls is due to the fact that the building is located in a hot and humid climate zone and the fact that the building envelope is made of 20cm cinderblocks with high thermal conductivity alone. Reducing heat transfer through walls can be done in two ways:

a. By adding materials of low thermal conductivity to the cinderblocks as insulation materials reducing the thermal conductivity or
b. By considering the adaptation of local traditional materials – which are mostly of low thermal conductivity and 100 percent recyclable – such as clay, stone, wood, bamboo, straw etc.

On the other hand, in spite of the reduction of heat transfer through walls, to decrease the cooling demand of the building, solar heat gain through windows should be controlled without having a considerable effect on visual comfort. Accordingly, a lighting analysis is conducted in order determine the effect of direct sunlight on the inner spaces.

Comparing the required illuminance per type room and activity provided by Blanco (2014) and the results of the lighting analysis, it is noticeable that the rooms facing East and West hit by direct sunlight respectively in the morning and afternoon receive an amount of illuminance a lot larger than what is required for visual comfort. Therefore, by reducing the heat gain through windows, the illuminance of the inner spaces also must be reduced to achieve thermal and visual comfort.

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[14] Window solar: Solar heat gain from solar radiation

Reducing the heat gain through windows while simultaneously controlling the illuminance of inner spaces would require the consideration of the following suggestions:

a. The use of adequate shading devices – according to the windows location – in order to control the illuminance and direct sunlight of the inner areas.
b. The resizing of the terraces creating an intermediate area to reduce solar radiation within the buildings; reference taken from colonial civil architecture.
c. The choice of a proper glazing system capable of reducing heat and light transmission simultaneously.

After the analyzes and the determination of the critical factors causing thermal and visual deterioration within the building, the suggested combination of traditional (construction material), colonial (resizing of the terraces) and modern (technology development) elements, will help achieve the development of a better performing alternative: a passive building.

4.1 REDUCTION OF HEAT TRANSFER THROUGH WALLS

The energy analysis shows that the most problematic factor of the analyzed model is the wall, through which a large amount of heat is lost during cold months and conducted from the exterior, overheating the inner spaces during the rest of the year. This drives the occupants into using mechanical means to either heat or mostly cool the spaces.

These results are due to the high thermal conductivity of the cinder blocks (0.952W/m.K) used as construction materials for exterior walls. In order to reduce the amount of heat conducted through them, materials with low thermal conductivity can be used for thermal insulation (See **Table 4.1**).

However, looking back at traditional architecture, most materials used by indigenous people were of low thermal conductivity, strong and totally recyclable, for instance: clay, stone, wood straw, bamboo etc. Even though they were, then, used in their natural, rough, untransformed state, research on promoting ecology in the construction sector as well as minimizing the environmental footprint lead to the use of such materials which in some cases are combined, i.e. daub, rammed earth, adobe, COB, banco, earth-straw, peat, etc.

Table 4.1: Table of few law conductivity thermal insulation materials

Insulating Materials	Density (kg/m^3)	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)
Expanded Polystyrene	18	0.039	1450
Extruded polystyrene	34	0.039	1450
Polyurethane foam 30kg/m^3	34	0.029	1450
Fiberglass panels 160kg/m^3	120	0.042	3000
Aerated concrete panels	115	0.040	864
Fiberwood panels >150kg/m^3	175	0.070	1700

In Dakar, cinderblocks have emerged as the default construction material for a long time due to its availability, its reduced price and the trust people have on it. However, clay - with its stability quality over time and natural aggression, and with the mastery of its current techniques of implementation - could be introduced in the construction sector. It meets high requirements of thermal and sound quality at a cost equivalent to a cinderblock construction. Complementary to clay in urban areas, lime plasters have waterproofing properties equivalent to those of cement plasters. Lime plasters with their covering capacities are adapted to both living and inert materials that fit perfectly in mixed constructions.

Moreover, various concrete composites have been proven to meet the thermal and ecological requirements. **Table 4.3** and **Table 4.2** below show respectively thermal properties of various ecological materials compared to cinderblocks used in 'Residence de la Paix' and the availability of raw materials in Senegal.

Table 4.2: Raw local materials available on the territory

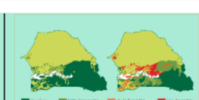
	CLAY	STRAW	WOOD	TEXTILE	STONE	LIME
COST	REASONABLE	MEDIUM TO HIGH	MEDIUM	MEDIUM	MEDIUM TO VERY HIGH	REASONABLE
MATERIAL TYPES	CLAY LATERITE	STRAW BAMBOO TYPHA	EUCALYPTUS FILAO NEEM	COTON	LIMESTONE BASALT MARBLE	
GEOGRAFIC REPARTITION						

Table 4.3: Construction materials and their thermal properties

MATERIALS		DENSITY (kg/m³)	THERMAL COEFFICIENT (W/m.K)	SPECIFIC HEAT (J/kg.K)
CONCRETE BRICKS	Cinderblock bricks 20cm 	1185	0.952	1080
	Pumice blocks 25cm 	600	0.156	1000
	Mono-wall terracotta (37cm) 	740	0.120	1008
COMPOSITE BLOCKS	Lime-Hemp blocks (wall/floor) 	450	0.100	580
	Earth- Straw blocks 	600	0.170	1300
	Natural pumice blocks 	400	0.120	1000

Given the availability of clay and straw on the territory, the recyclability, the low thermal conductivity and high specific heat[15] of Earth-straw blocks, the energy analysis of the same building will be conducted again using Earth-straw as construction materials for the exterior walls. The **Table 4.4** below shows the technical characteristics of the earth-straw block.

Table 4.4: Technical characteristics of earth-straw block

Componants	55-60 % Clay , 10-15 % Straw, 8-12 % water , 15-20 % Cement
Density	1000 kg/m³
Thermal conductivity	0,263 W/m.k
Coefficient of heat tranfer	0,44 W/m².k
Thermal resistance	2,3 m².k/W
Mechanical resistance	7 MPa minimum
Noise Insulation	Excellent results
Fire resistance	MO
Standards sizes	Bloc : 120x60x50cm

Source: Patrickceschin-btp.com, 2015

[15] Specific heat: the amount of heat per unit mass required to raise the temperature by one degree Celsius.

4.2 CONTROL OF HEAT GAIN THROUGH WINDOWS

As seen on the on the variation of the monthly cooling and heating energy demands, windows have a significant influence on building energy performance. A proper window design can highly reduce the energy consumption and increase the visual comfort of the building. These effects of windows on the energy and lighting performances are due to factors such as location and orientation of the windows, the thermal conduction (U-value), Solar to Heat Gain Coefficient (SHGC[16]), Visible Light Transmittance (VLT[17]), shading devices and window to wall ratio.

In order to control heat, gain through windows – to reduce energy usage for mechanical cooling during hot periods – and simultaneously regulate the illuminance of inner spaces, the following techniques can be considered for the analyzed model:

a. Use of the proper shading devices given the geographic location of the building and the orientation of the windows,
b. Resizing the terraces creating an intermediate area before the sun hits the inner spaces,
c. The use of adequate glazing system able to reduce heat gain and transmitted light.

4.2.1 Use of Shading Devices

According to Blanco (2014), 40 of unwanted heat in a building is gained through windows, therefore, in a tropical climate zone, the penetration of direct sunlight through windows should be avoided through proper orientation and adequate solar devices.

Comparing the analyzed building to the colonial civil architecture of the 19th century, it is noticeable that they share features like the veranda or terrace used in the civil buildings of that period. In the 19th century, these spaces (verandas) were built for the purpose of solving the issues of living in a tropical climate zone – heat, humidity etc. – for French officials who were not used to living in such conditions. This technique has been used over the time by Senegalese architect for the same purpose (regulating thermal comfort within) even though it has changed in construction materials, form or usage.

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[16] SHGC: The fraction of incident solar radiation admitted through a window

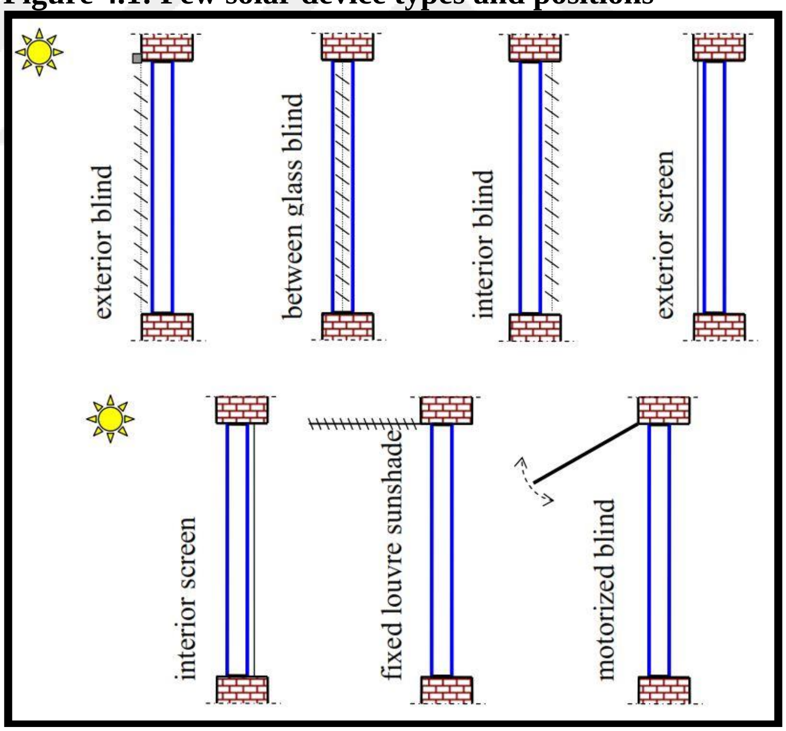
[17] VLT: The amount of light in the visible portion of the spectrum that passes through a glazing material.

On the analyzed model, each floor is dotted with a terrace, supposedly for the purpose of having an intermediate space to reduce solar heat gain that penetrate the building. However, with the architectural limitation of the analyzed building (windows on East and West facades), controlling the penetration of direct sunlight would need the revision of these terraces in terms of depth and the use of solar devices and appropriate glazing types.

The aim of the use of solar devices is to control solar radiation in order to ensure thermal comfort, as well as to control the illuminance of the inner spaces providing visual comfort and simultaneously reduce energy consumption.

Shading devices like shutters, pull-down shades, overhangs, drapes, blinds, wing walls etc. (See **Figure 4.1**) can reduce overheating during hot periods and allow natural light through the windows.

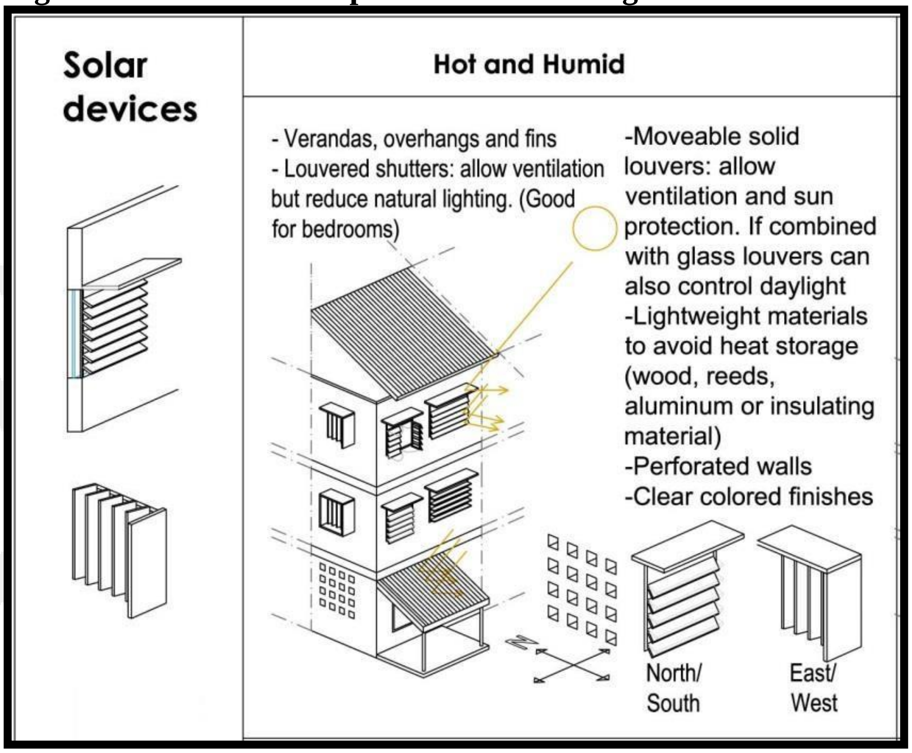
Figure 4.1: Few solar device types and positions



Source: Haese, 2010

In a hot and humid climate zone such as Dakar where sun protection is of outmost importance for East and West windows, mobile external shading is the most effective as it would cut off direct sunlight and allow more flexibility for lighting control after the sun faces opposite orientation. However, external shading devices should be designed according to the orientation of facade (See **Figure 4.2**).

Figure 4.2: Solar devices preference according to the location of the window



Source: Blanco, 2014

For instance, on The North facade, minimum or no shading is required to allow the penetration of natural daylight without overheating the inner spaces. However, the analyzed building does not have North-oriented windows, making it a challenge to shade windows oriented on the East and South facades.

The glazing system of the windows on the Mixta building is single glazed units with clear glass. To avoid solar heat, gain through the openings, external shading devices should be installed. Windows on facades, facing different cardinal directions, should be provided by the shading devices which can cut the direct incident solar radiation for the critical solar angles.

4.2.2 Adaptation of Proper Glazing Types

Due to the design limitations of the analyzed building, the windows are facing East and West, locations hit by direct sunlight in a tropical climate zone, resulting in overheated inner spaces and a saturation of daylighting, deteriorating visual comfort of the occupants.

Thermal conductance measures the insulating capability of the windows with the rate of heat transfer per unit area, per unit temperature difference from the hotter to colder side of the window. The U-value is influenced by various factors: the number of glazing, the air gap between glazing, the gas fill between glazing, the coating on the glazing and the frame construction as seen in **Table 4.5**.

Table 4.5: U-values for various glazing constructions

Construction type	U-value		R-value	
	W/m^2•K	BTU/(h °F ft²)	m^2•K/W	h °F ft²/BTU
Single pane	4.8	0.85	0.21	1.2
Double pane, air filled	2.8	0.49	0.36	2.0
Double pane, low-E	2.1	0.37	0.48	2.7
Double pane, low-E, Argon filled	1.9	0.33	0.53	3.0
Triple pane	2.1	0.37	0.48	2.7
Triple pane, low-E, Argon filled	1.4	0.25	0.71	4.1
Quadruple pane, very low-E, Krypton filled	0.74	0.13	1.35	7.7
Quintuple pane, very low-E, Xenon filled	0.51	0.09	1.96	11.1

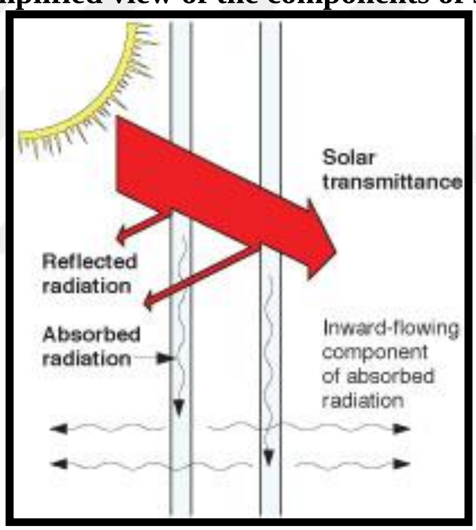
Source: Sustainabilityworkshop.autodesk.com

Even though thermal conductance has a significant effect in the energy performance of the building, in warm climates – as shown in the analysis – the conduction through windows is not as important as the SHGC due to the amount of heat gains from solar radiation.

SHGC is the ability of a window to control heat gain through windows originating from direct or diffuse solar radiation. Also influenced by the types of glazing, number of panes and glass coating, some radiations are transmitted through the glazing, some absorbed in the glazing and some are reflected as seen in **Figure 4.3**.

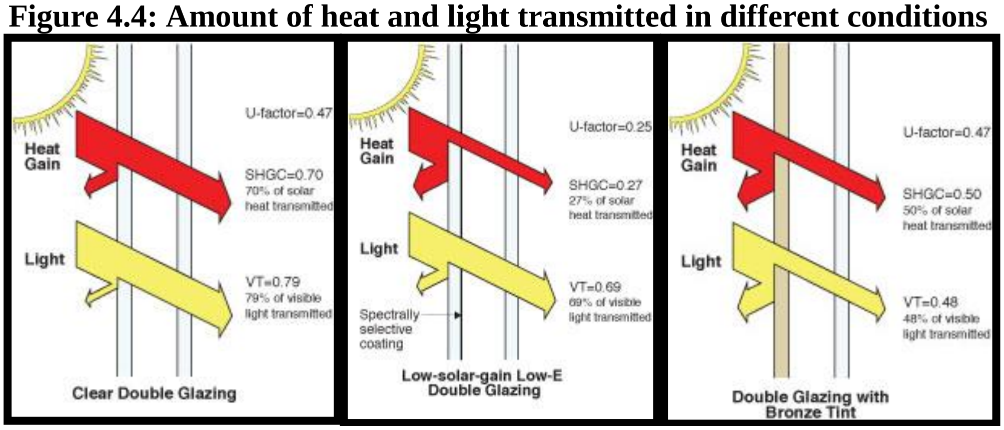
The SHGC is expressed as a dimensionless number from 0 to 1. However, it actually ranges between 0.8 for the water-white clear glass to 0.2 for highly reflective coating on the tinted glass. A typical double pane has a SHGC of around 0.7. This value decreases by adding Low-E coating but increases with the addition of tint as shown in **Figure 4.4**. In a warm climate, the ideal SHGC is below 0.4 for the windows on facades hit by direct sunlight (Blanco, 2014).

Figure 4.3: Simplified view of the components of solar heat gain



Source: commercialwindows.org, 2015

Figure 4.4: Amount of heat and light transmitted in different conditions



Source: Commercialwindows.org, 2015

Spectrally selective coating is also another way of reducing heat transfer through windows without preventing the transmission of daylight. The spectrally selective coating reflects Infrared and Ultraviolet rays – responsible for the generation of heat – and simultaneously admits as much daylight as possible due to their virtually clear appearance.

This technology is very effective for residential and non-residential facilities with high coating loads as in the analyzed building case. However, with the windows location on the building the saturation of daylight within, spectrally selective coating would only be effective on windows on the North or South facade not hit by direct sunlight. Moreover, using double glazed Low-E or tinted glazing – reducing the solar heat gain and decreasing the transmitted light – on openings would result in the reduction of cooling loads and the regulation of the visual comfort.

4.3 RESULTS AND COMPARISONS

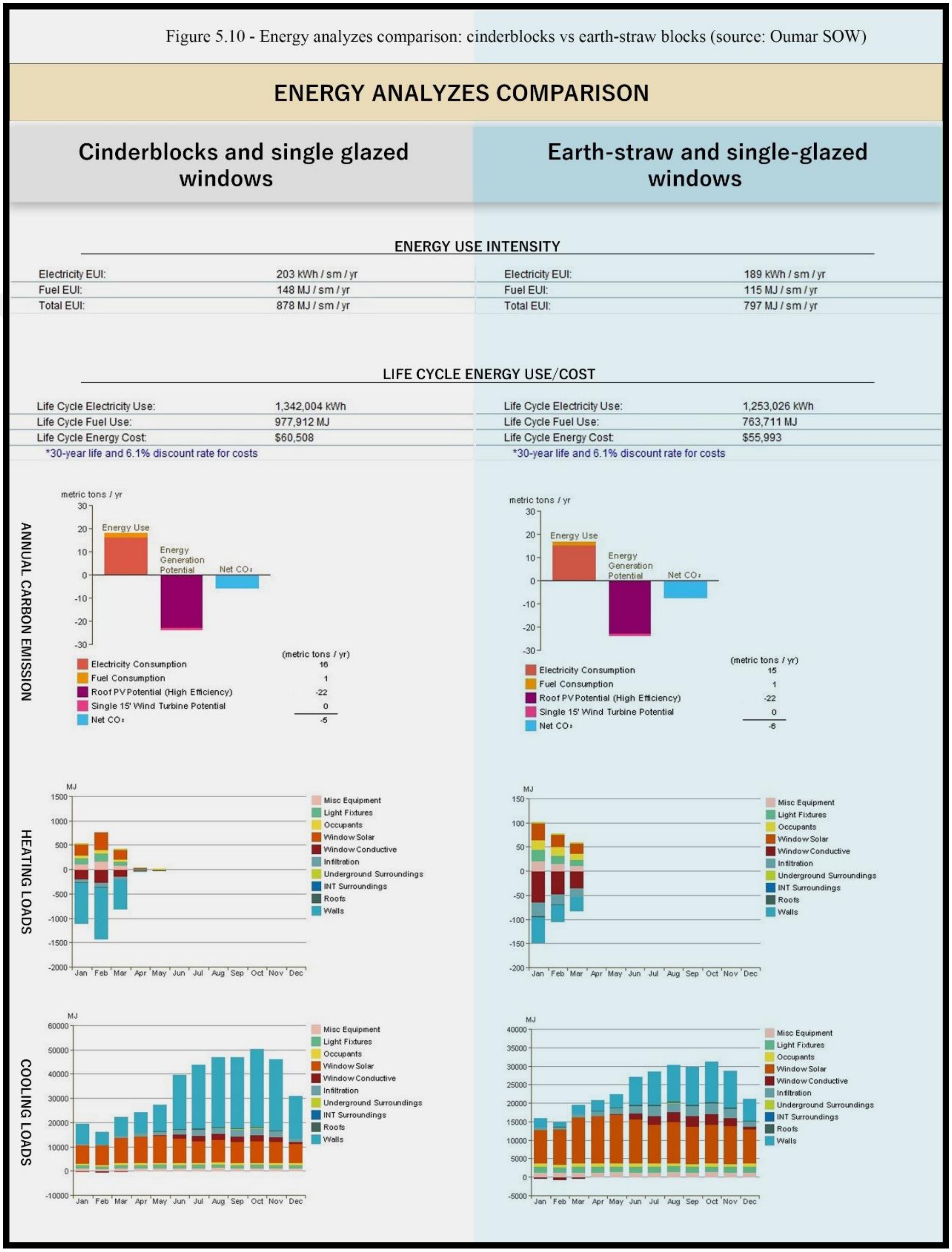
The change in the construction material shows quite a significant impact on the energy consumption. The comparison between the energy analyzes when the building envelope was made of cinderblocks and when it was made of earth-straw blocks shows a decrease in Energy Use Intensity which then leads to the heating and cooling loads to determine the reason of this change.

With cinderblocks, the most critical factor on the monthly heating loads was the wall through which a significant amount of heat was lost during cold months. However, with the use of earth-straw blocks and their low thermal conductivity, the heat loss through wall decreases considerably. The most critical factor becoming window conduction (See **Figure 4.5**).

Analogically, the change in construction materials has also a big effect on the cooling loads. The energy analysis of the building with cinder blocks showed a huge amount of heat conduction through walls overheating the inner spaces, however, when earth-straw blocks are used, a important reduction of heat conduction is noticeable (See **Figure 4.5**). The most problematic factor in terms of heat transfer during cold months becomes window solar.

As mentioned earlier, in order to further reduce the heat conduction through walls, the use of thermal insulation materials is to be considered.

Figure 4.5: Energy analysis comparison of the same building with cinder blocks and earth-straw used as construction materials in Revit



After changing the main construction material from cinderblocks with 0.952 W/m.K thermal conductivity to Earth-straw blocks of 0.17 W/m.K thermal conductivity, the heating and cooling loads resulting from heat conduction through walls has decreased considerably for about 2000MJ. However, the cooling loads caused by heat gain through windows remained a problem which lead to previously suggested steps in order to reduce heat gain while simultaneously reduce the amount of illuminance within the rooms determined earlier by the conducted lighting analysis.

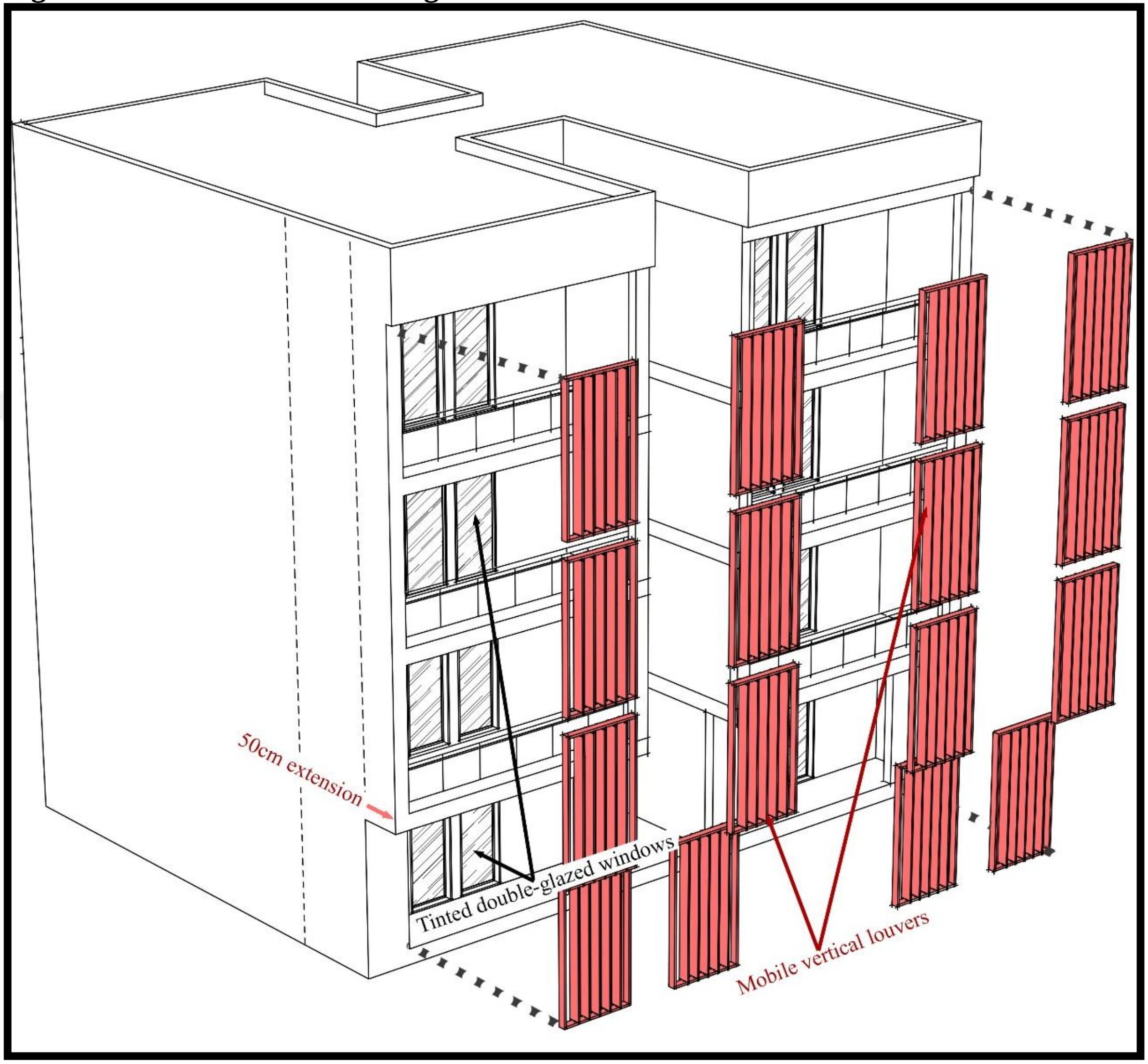
With the intention of reducing the cooling loads caused by window solar, three steps were followed. These steps intend to reduce heat gain and simultaneously reduce inner illuminance, as the lighting analysis suggested a saturation of light in the rooms either in the morning or in the afternoon.

The first step consisted of increasing the depth of the terraces from 1.00m to 1.50m, making it a larger intermediate space for solar radiation before reaching the East-oriented rooms.

The second step, however, consisted of using the adequate shading devices for windows according to their cardinal orientation (See **Figure 4.2**). For windows on the East and West facades, external vertical shading devices are more effective as shown in **Figure 4.6** considering the fact that the sun rises and sets almost directly facing them. However, on the East, instead of using external vertical louvers on the windows, they were implemented on the terraces, reducing heat and controlling direct sunlight before getting through the windows. In order to keep the rooms on the East illuminated when the sun reach the West in the afternoon, the vertical louver system was made mobile, meanwhile giving the main façade a more dynamic sense (see **Figure 4.6**).

The next and last step involved choosing the proper glazing system capable of reducing the heat gain through windows and the excessive amount of light. As shown in **Figure 4.4**, several glazing systems can be used as long as they have a low U-value. However, with the steps one and two already reducing the amount of light and heat gain, the use of expensive glazing system is unnecessary. Therefore, a tinted double glazed system capable of reducing a decent amount of heat and simultaneously the amount of light as shown in **Figure 4.4** is used.

Figure 4.6: Model of the building with modifications



After following the above-mentioned steps conducive to a better control of thermal and visual comfort, another energy analysis was conducted to determine how these changes would affect the heating and cooling loads leading to the reduction of the EUI.

Figure 4.7: Energy analyzes comparison in Revit

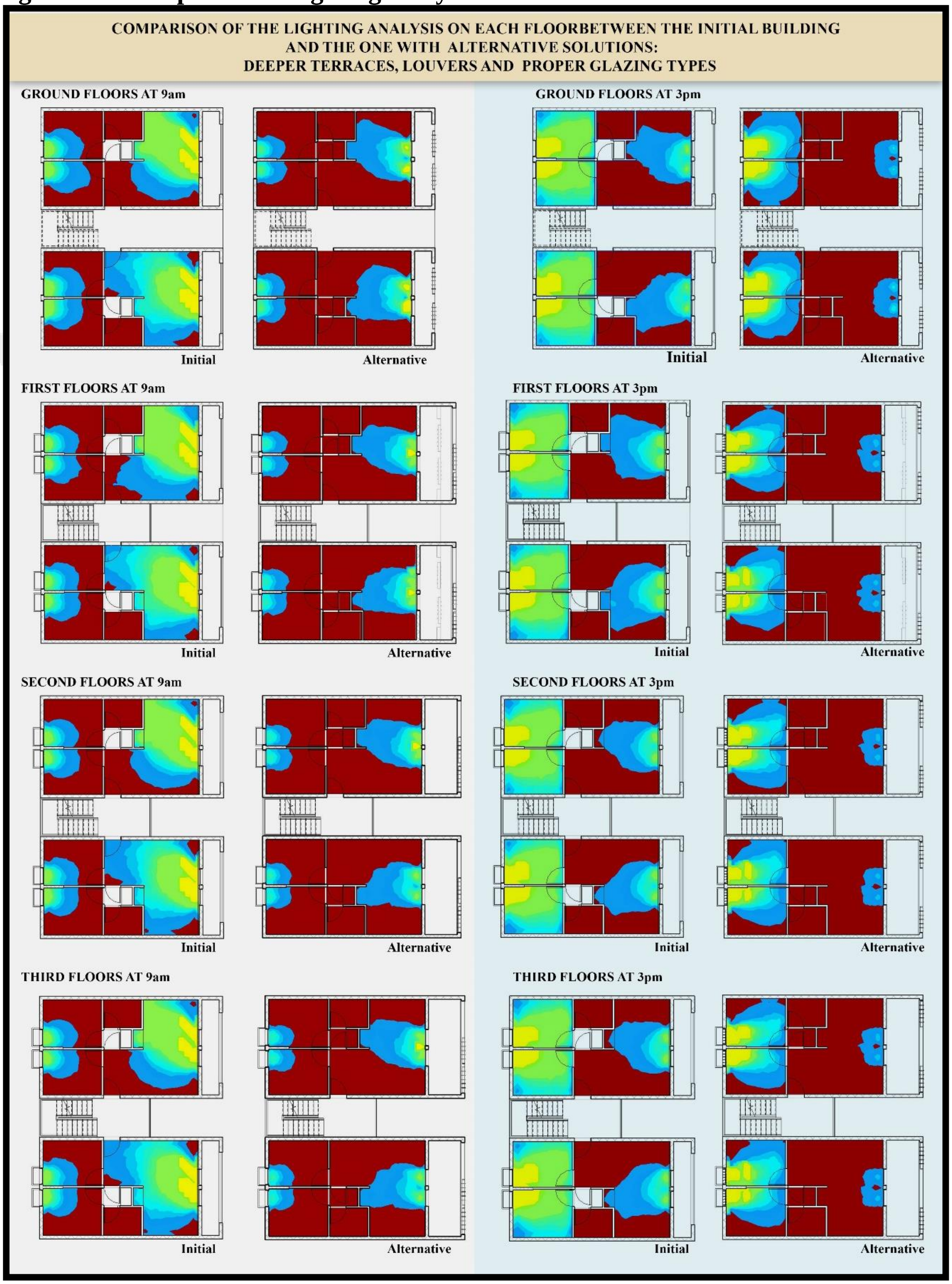
The energy analysis showed a massive reduction of the cooling loads caused by window solar of about 3000MJ (see **Figure 4.7**) and became the least problematic factor of the analyzed building. However, these results push into questioning whether these changes have a good effect on visual comfort and whether the inner spaces would receive enough lighting.

Answering these questions consisted of conducting another lighting analysis in order to determine the amount of light penetrating the envelope of the building post changes.

The comparison of the lighting analysis showed a considerable change in lighting – between the initial and the alternative design – in the East and West facing rooms respectively at 9 am and at 3 pm.

Initially, in the morning, the living rooms – facing East – received a lot more light than what is required for visual comfort in a residential building (See Table 3.6). Initially, the illuminance in the living room ranged mostly between 400LUX to 2000LUX (See **Figure 3.21**) where the required illuminance should be 100 to 150 LUX. However, on the alternative design, at 9 am the living rooms show an illuminance ranging from 50 to 290LUX which is acceptable. Analogically, at 3 pm the illuminance in the rooms has decreased to an acceptable range even though not as much as the rooms facing East (See **Figure 4.8**).

Figure 4.8: Comparison of lighting analysis in Revit



4.4 CONCLUSION

The aim of this study consisted of adapting passive design strategies to the contemporary buildings in Dakar where sustainable design should be of major concern. Hence, the case study was held on an already built neighborhood composed of various types of multifamily buildings. Considering the complaints of the occupants, the most common type of multifamily building was chosen to conduct analyzes with the purpose of determining the problematic factors and transform it to a sustainable alternative by using passive design strategies referring from local architecture.

As the first step of this process, BIM software Revit was used to model the chosen building and by entering the exact thermal properties of the construction materials used, an energy analysis was conducted. The results of the analysis suggested that the most critical factors were: wall and window solar.

The energy analysis revealed that in cold period, heat is lost through walls and during hot periods (9 over 12 months in Dakar) heat conduction through walls followed by solar heat gain through windows cause a huge cooling demand. Therefore, suggestions to reduce the cooling demand were proposed.

First, in order to heat conduction through walls, the use of earth-straw concrete composite blocks instead of cinderblocks showed a major reduction of heat transfer through walls. These results are due to the fact that earth-straw blocks are low in thermal conductivity. On an ecological point of view as well, it is a material that could be manufactured locally given the availability of its components. Moreover, the material is 100 percent recyclable.

As solar gain through windows was the second most problematic factor, with the reduction of heat transfer through walls, it became the most critical factor. However, before making any changes, a lighting analysis was conducted to determine the effect of sunlight within the building. The results suggested that in the morning, glare occurs in the living rooms and in the afternoon, the same thing happens in the bedrooms. These results could be explained by the fact that the main façades with the windows are facing East and West respectively hit by direct sunlight in the morning and in the afternoon.

Given these results, suggestions to reduce solar heat gain through windows would have to simultaneously reduce the illuminance of the inner spaces in order to achieve visual comfort. The following steps were:

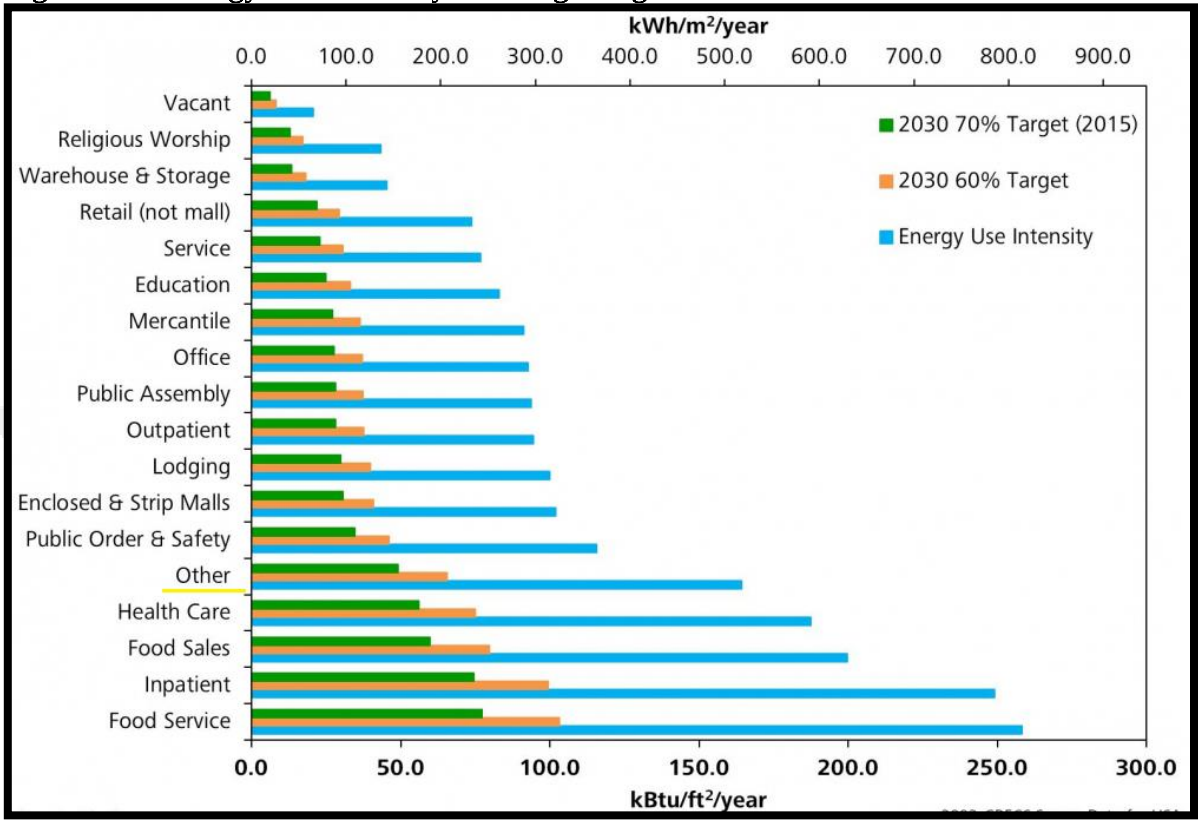
a. Increasing the depth of the terraces creating a larger intermediate area before the sun rays reach the inner spaces
b. The use of mobile vertical louvers cutting down solar radiation and allowing light to enter the building when the sun goes to the opposite direction
c. The use of double-glazed tinted windows also reducing the heat transfer and light transmission through the windows.

After following these steps, another energy analysis was conducted to see how these changes have affected the EUI and the cooling loads. It is noticeable that the solar gain has considerably decreased and became the least problematic factor. However, to be sure that these changes did not have a negative effect on the visual comfort, another lighting analysis was conducted. The results show that the inner spaces receive an acceptable amount of light in the morning and in the afternoon.

To conclude, the BIM model provided an efficient tool for finding the critical factors and improving them with prechosen passive design measures. Through the analyzes of energy and lighting performance, a better performing alternative – in terms of thermal and visual comfort – was developed. It simultaneously leads to the reduction of energy consumption for cooling, heating and lighting, which also means, a reduction of GHG[18] emitted from the building. Consequently, the Electricity EUI of the building has decreased from 203 to 137kWh/m^2/yr which, according to **Figure 4.9**, is within the range of the 2030 EUI challenge targets.

[18] GHG: Greenhouse Gases

Figure 4.9: Energy Use Intensity challenge targets for 2030



Source: Sustainabilityworkshop.autodesk.com (2015)

This methodology can be used to figure out the issues on existing designs – in terms of eco-friendly buildings – in order to build or rebuild better performing buildings and therefore, more sustainable urban developments.

Achieving urban sustainability with the use of passive design strategies is a step forward into the global issue of climate change due to the GHG emissions generated by human activities. Consequent to the issue of global warming, scientist have set a threshold on temperature raise equal to 2^{o}C and have asserted that a greater increase would be dangerous.

However, during the United Nation conference on climate change held in Paris from the 30th of November to the 12th of December, the evaluation (by UNFCCC[19]) of the action plans published by 186 countries showed that despite the efforts and mobilization, global warming would still be between 2.7^{o}C and 3^{o}C above the threshold. Therefore, the Paris agreement

[19] UNFCCC: United Nation Framework Convention on Climate Change

demanded that all countries review their contribution every five years starting from 2020 and to aim for carbon neutrality by the half of the century (UNFCCC, 2015). To achieve such goals, energy efficiency measures should be planned for the building sectors. hence the adaptation of traditional architecture properties which meet the sustainability requirements, the use of passive design strategies together with new technologies.

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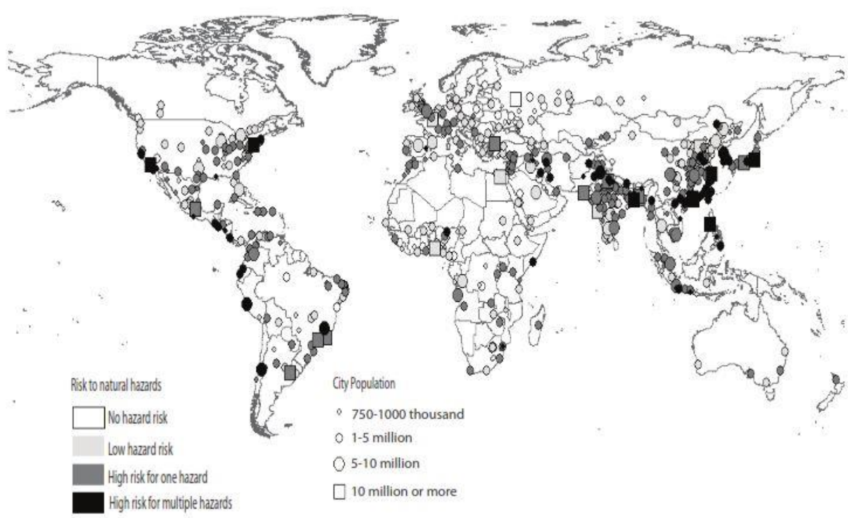
APPENDICES

APPENDIX – 1, Urbanization and city growth

Distribution of cities by population size and risk of natural hazards, 2011



[9] *World Urbanization Prospects: The 2011 Revision* (United Nations, 2012).

World urban and rural population, 1970-2050