RETROFITTING FOR ENVIRONMENTAL SUITABILTY

IMPROVING THERMAL PERFORMANCE OF COMMERCIAL BUILDINGS IN NAIROBI CBD

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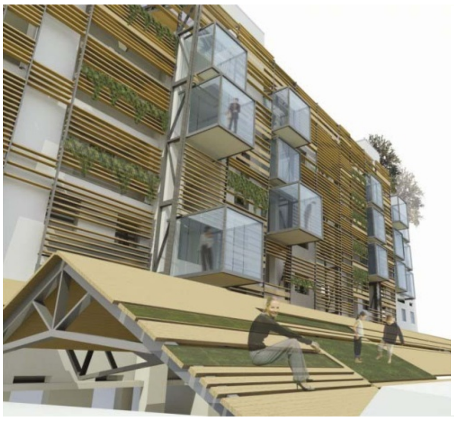

DEDICATION

Architecture is really about well-being. I think that people want to feel good in a space... On the one hand it's about shelter, but it's also about pleasure. The intention is to really carve out of a city civic spaces and the more it is accessible to a much larger mass in public and it's about people enjoying that space. That makes life that much better. If you think about housing, education, whether schools and hospitals, these are all very interesting projects because in the way you interpret this special experience.

-Zaha Hadid-

ACKNOWLEDGMENTS

"And whatever you do, whether in word or deed, do it all in the name of the Lord Jesus, giving thanks to God the Father through him". Colossians 3:17

I would like to thank the Almighty God, for inspiring me on the research topic and giving me the strength and guidance to complete it.

I would like to thank my supervisor, Prof. Edwin Oyaro, for your input into my dissertation and ensuring I deliver a document that will contribute to the industry of Architecture.

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I would like to thank the University of Nairobi for offering me a scholarship to pursue my Master's degree.

Nina Ndichu

2017

DECLARATION

This thesis is my original work and paramount to my knowledge has not been presented for an award of degree in any other institution.

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This thesis is submitted in part implementation of the examination requirement for the award of the Masters of Architecture, Environmental Building Science, Department of Architecture and Building Science, University of Nairobi.

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ABSTRACT

Retrofitting of existing buildings offers significant opportunities for reducing energy consumption and greenhouse gas emissions. This is being considered as one of main approaches to achieving sustainability in the built environment at relatively low cost and high uptake rates. Although there are a wide range of retrofit technologies readily available, methods to identify the most cost-effective retrofit measures for particular projects is still a major technical challenge.

Opposite the University of Nairobi, there is a cluster of glass skyscrapers namely: Anniversary Towers, Kemu Towers, Ambank House and View Park Towers which were constructed in the late 80s – early 90s and are well-known to be Nairobi's first glass skyscrapers. The author used View Park Towers as the primary case study of this thesis which was built in 1989 by Harbans Singh Associates. View Park Towers being heavily criticized in Nairobi by various scholars and architects posed a challenge to explore ways to improve thermal performance consequently making it energy efficient.

A dynamic simulation of the building is carried out to predict the post-retrofit energy performance upgrading. By analyzing four parameters namely - window to wall ratio, sun shading, glazing and wall thickness - and explore them scientifically by mainly using Morris Method for global sensitivity analysis to determine which of the parameters is the most important to be retrofitted to improve the thermal performance of View Park Towers. Retrofitting for environmental suitability is the process of intervening in a building's envelope that is not constructive to its climate and transforming it to a sustainable and environmentally friendly building appropriate for its climate.

From the findings, out of the four parameters investigated, the glazing used for the building’s façade was the most important factor needed to be retrofitted to improve the thermal performance of View Park Towers. The least important factor was the sun shading devices. It showed that, even if external shading devices were added to the building's envelope, the thermal performance would not improve. Nevertheless, all the strategies should be employed to attain the best improvement of thermal performance.

To conclude, this thesis presents a step by step process of how Architects, developers and to some extent the clients/ users of buildings, can scientifically study any commercial building within Nairobi’s Central Business District with similar design challenges as View Park Towers that make them unsuitable for the climate of Nairobi. Suggestions on future work is laid out and should be considered as sustainability and efficiency of buildings represents a crucial issue since the building sector is currently responsible for more than 40% of energy consumption and emissions.

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LIST OF ACRONYMS

ANSI - American National Standards Institute

ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers

BCA – Building and Construction Authority

CBD - Central Business District

DDC – Digital Data Control

GBCSA - Green Building Council South Africa

IES VE – Integrated Environmental Systems Virtual Environment

SimLab – Simulation Lab Software

SALib – Sensitivity Analysis Library in Python

VAV - Variable Air Volume

CHAPTER ONE: INTRODUCTION

1.1 Preamble

Retrofitting of buildings is currently achieving increased attention in many countries across the globe. The fundamental reason for this, is the high consumption of energy used up by buildings and increased greenhouse gas emissions that contribute to global warming.

Several studies carried out in the past, focused principally on adopting passive design strategies for buildings at their inception. Regardless of this knowledge, buildings constructed did not streamline with these basic principles. With this, several buildings ended up being displaced within their various climates. For demographic reasons, several commercial buildings in Kenya require retrofitting for environmental suitability in order to reduce energy consumption and improve thermal performance. Retrofitting for environmental suitability is the process of intervening in a building's envelope that is not constructive to its climate and transforming it to a sustainable and environmentally friendly building appropriate for its climate.

Even though the need for retrofitting existing buildings is increasing, there are still fairly limited actual renovation activities going on in most countries. The author discovered that most case studies showcased, emanate from countries in Europe, Asia, Australia, as well as, the United States of America. So far, the author has come across few retrofitting examples done in Africa (most retrofitting studies and publications are based within South Africa)[1]. Regrettably, the author has not come across any studies for sustainable retrofitted buildings in Nairobi, which experiences Tropical Upland Climate.

Although there are a wide range of readily available retrofit technologies, approaches to distinguish which retrofit measure is the most lucrative for which project, poses major technical difficulties. This thesis investigates four parameters to be used to retrofit of a commercial building in Nairobi's CBD, in order to improve its thermal performance.

The case studies selected in this research were buildings that have been constructed whilst not applying passive design strategies that have led the buildings to accumulate a high carbon footprint thus making them energy inefficient. The energy efficient retrofits carried out, improved their thermal performance, reduced the running costs of the building and consequently reduced the emission of greenhouse gases. The author focused on View Park Towers as the main case study of the research, highlighted in Fig 1-1, which is located along Utalii Lane and Uhuru Highway in Nairobi CBD.

[1] Mariaan, W (2014), The case for green retrofitting in South Africa, Retrieved from: http://www.engineeringnews.co.za/article/mittal-pulls-back-from-bee-deal-confirms-r11bn-newcastle-loss-2011-10-07

Fig 1- 1: Location of View Park Towers (highlighted with red star) is the building under study in this dissertation. Source: Author, 2016

Nairobi is situated at 1°09′S 36°39′E and 1°27′S 37°06′E and occupies 696 square kilometers. Nairobi has grown from its Central Business District. This has taken an almost trapezoidal shape as illustrated in Fig 1-2. It follows the boundaries along Uhuru Highway, Haille Selassie Avenue, Nairobi River near Kirinyaga Road, and University Way. It features many of Nairobi's important buildings, including the City Hall and Parliament Building. The city square is also located within that perimeter.

Fig 1- 2: Map showing the boundaries of Nairobi Central Business District. Source: Author, 2016

1.2 Problem Statement

A major quandary facing Architects in Nairobi today is most client's and developers are seeking to construct buildings that are fully glazed, with the illusion that they impose a more corporate look, but in actual fact perform better in other climates. As a result, these buildings are deemed inappropriate for the climate of Nairobi and in the long run do not perform efficiently.

During the late 1980s, there was an evident transformation of the Architecture in Nairobi's CBD. From environmentally sensitive buildings to the sudden burst of glazed skyscrapers. These glazed skyscrapers have continued to be present in Nairobi's ever changing skyline. The question then springs up, why do Architects, developers and clients keep insisting on these 'corporate glass style' buildings, if they do not mash well with the climate of Nairobi?

Nairobi experiences Tropical Upland Climate which does not favor the sort of buildings that are being constructed. Heavily glazed facades, lack of high thermal mass walling, ignoring sun’s orientation and having buildings facing East-West direction is the bearing of building construction in Nairobi’s CBD.

Glass reflects, admits and absorbs solar radiation in different proportions depending on the type. For normal clear glazing, the reflected component is about 15% of the incident value but this value increases strongly when the angle of incidence increases beyond 600. The transmitted component is about 80% of the incident radiation, absorbing about 5%.

Based on this background, the central aim of this research is to investigate the parameters that affect the building's envelope of commercial buildings in a tropical climate. Arjan. T (2009) argues that for sustainability and especially the potential for climate integrated design, the building envelope is the most essential component. The building envelope being that component of the building that forms a stockade between the internal office atmosphere and the external weather conditions which greatly affects a building’s resistance to overheating. Parameters of the building envelope that influence the thermal performance have been investigated with a focus on retrofitting for environmental suitability. A scientific study based on View Park Towers as the main case study of this thesis will be undertaken.

View Park towers is about 12,000 square meters of lettable space over 22 floors above ground and 2 basement levels for 116 cars.

1.3 Aims and Objectives

1. To explore retrofitting strategies and establish how they can be employed to mitigate inappropriately designed commercial buildings constructed for Nairobi's Central Business District.
2. To examine the thermal performance of the building under study before retrofitting and the improvement after energy efficient retrofitting strategies have been applied.
3. To provide an architectural guideline of retrofitting strategies to be adopted by buildings which are constructed but are climate insensitive for Nairobi.

1.4 Research Questions

1. What retrofitting strategies can be employed to mitigate inappropriately designed commercial buildings in Nairobi's CBD?
2. How does the thermal performance of the building under study improve after retrofitting strategies are applied?
3. Under what architectural framework can energy efficient retrofitting strategies be applied to an already constructed commercial building in Nairobi?

1.5 Scope and Limitations

The author investigates how Architects in Nairobi and largely in Kenya have not fully adjusted to the concept of sustainability (due to stigmatic reasons) thereby designing buildings that are inappropriate for its climate. They out rightly copy recklessly, buildings suited for other climates without making any adjustments for Nairobi's climate. By doing so, many of the buildings have a low thermal performance making them energy inefficient buildings.

The scope of study will scientifically examine View Park Towers as constructed and thereafter apply retrofitting strategies identified hence determining if the thermal performance of the building has improved.

Due to the increase of insecurity in the country, the author found difficulties in the ease of access to areas within the building of study.

Software used for retrofitting and sensitivity analysis are new to the author. The process of keying in data, modeling of the building, simulation and thereafter analysis is challenging and may be time consuming.

Retrofitting is a wide scope in research. The author will be focusing on the building's envelope studying the following parameters namely; window to wall ratios, sun shading elements, glazing and wall thickness.

1.6 Hypothesis

Commercial buildings in Nairobi are heavily influenced by buildings sourced from the internet, magazines or visits to other countries. These buildings are mainly from Asia, America and Europe which experience various climates that are not necessarily climate of the tropics. Therefore, for Architects to blindly copy and paste these buildings for Nairobi without tweaking them to ensure their suitability for the tropics, specifically, tropical upland climate is unfortunate. Most of the commercial buildings in Nairobi's CBD need sustainable retrofitting strategies applied to them to make them appropriate for Nairobi's climate and thus improving their thermal performance in order to make them energy efficient.

1.7 Significance of the Study

1. Construction of inappropriate designed buildings in Nairobi has continued due to lack of application of the vast knowledge on environmental building design into their buildings.
2. Transformation of buildings in Nairobi show there was knowledge on appropriate design for the tropics. Buildings that came up in the late 80s to present are not using this application of appropriate design.
3. The research will study and thereafter go in depth with a scientific study of View Park towers showing some of the retrofitting strategies employed to improve its thermal performance.

1.8 Justification of Study

Architecture has evolved over the years. Today the façade plays an important role in defining the architecture/form of the building. With modernity, glass has become eminent material for façades for its aesthetic appeal and functionality.

However, the inappropriate or inefficient use of glass may result in unwanted heat gain inside the building. In choosing the right energy efficient glazing solution, the façade design needs to incorporate the building location and an understanding of solar geometry with respect to the building as it helps to:

a. Perform passive building design (for heating & cooling)
b. Orient buildings properly
c. Understand seasonal changes in the building & its surroundings
d. Design shading devices
e. Ensure optimum daylight in various zones

A comprehensive façade design helps in both the passive and active design aspects of a building:

i. Passive design results when a building is created and simply works "on its own". The plan, section, materials selections create a positive energy flow through the building and "save energy".
ii. Active design uses equipment to modify the state of the building, create energy and comfort; i.e. fans, pumps, etc.

Modernism (In architecture, it's defined as a design language with an emphasis on form rather than ornament; structure and materials rather than picturesque constructions; and the rational and efficient use of space. While the highest-style examples of modern architecture in the United States typically date to the early- and mid-20th centuries, Modernism continued to influence every day and vernacular design well into the late 20th century. Famous Modernist architects include Frank Lloyd Wright, Philip

Johnson, Ludwig Mies van der Rohe among others[2]) led to new technologies of construction, particularly the use of glass, steel and reinforced concrete. Most of these glass façade buildings perform better in temperate climates than in the tropics where most of Africa lies. Most designers argue that the glass skyscrapers reflect architecture in the present and most clients feel relevant with current trends if they perceive their buildings with the use of glass. This has unfortunately led to the improper use of glass as a material in the tropics, whereby most of the buildings are inhabitable and require air conditioning units to enhance air circulation as most of the glass skyscrapers have no openable windows to allow natural ventilation through the building. This has in the long run created energy inefficient buildings, large electricity bills and emissions of carbon at an alarming rate.

The author is not saying that glass cannot be used in the tropics, she is merely stating that when the conscious decision is made to use glass as a material, then as designers, the environment and climate need to be taken into account. The solutions like double glazing, solar glass and sun shading are quick solutions given and most of the time are an expensive solution and do not deliver their promised results.

During the late 80s, there was a emergence of fully glazed buildings in Nairobi's CBD starting by and large with the cluster of buildings opposite the University of Nairobi namely, Anniversary Towers, Ambank House, Kemu Towers and View Park Towers. These buildings have to rely heavily on air conditioning to cool the interiors and therefore increasing the carbon footprint and the emission of greenhouse gases which

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[2] Crews, M. (2017) National Trust for Historic Preservation, Retrieved from: https://savingplaces.org/modern-architecture

overall affect global warming. Natural ventilation and natural lighting of the buildings is compromised in order to have a look that clients and developers consider as architecture of the now.

The author settled with View Park Towers as the scope of this study as this building comprises of the first glazed skyscrapers in Kenya and in Nairobi's Central Business District. The building has also received previous criticism in regards to its glazed façade and its placement with the climate of Nairobi (Kimeu 2015). The building was completed in 1989 by Architects Harbans Singh Associates.

Granted temperature and relative humidity collected in the field were not of the hottest or coldest months in Nairobi's climate, this does not have a direct impact on the results of the scientific study. Climate plays a key role in the performance of any building so it is important to use the appropriate location settings for any analysis. For Apache dynamic simulations in IES VE a simulation weather file is required. These files contain data for variables including dry bulb & wet bulb temperature, wind speed & direction, solar altitude & azimuth, cloud cover etc for each hour of the year. This weather file selected should be from the closest meteorological station to the site under study to ensure accuracy[3].

To conclude, this thesis sets out to investigate what parameters of the building's envelope can be retrofitting in order to improve the thermal performance of the building. The main aim of retrofitting for environmental suitability is to reduce the

[3] Integrated Environmental Solutions (2011-2017) Retrieved from https://www.iesve.com/support/weatherfiles

running costs, find alternatives to burning fossil fuels and generally conceive a building that is energy efficient in Nairobi's Climate.

1.9 Summary of Chapters

Chapter One: Introduction

This chapter serves as the introduction and highlights the problem statement, aims and objectives of the study, the scope and limitations as well as why this study is important.

Chapter Two: Literature Review

This chapter serves as the literature review starting by stating the importance of building suitably for the tropics and its effect on thermal comfort. Retrofitting is highlighted from the definition, the history, its benefits and what strategies are considered suitable and energy efficient. These strategies are studied in depth identifying which ones are important to the building's envelope.

Chapter Three: Research Method

This chapter identifies and catalogues all the instruments used during field work and outlines methods used for presentation, data collection and analysis. Simulation software will be introduced and basics interpreted.

Chapter Four: Discussion of Results

In this chapter, the scientific study results will be discussed in the form of a sensitivity analysis by Morris Method. Simulations which were done in the previous chapter, will be analyzed and results explained. the hierarchy of importance of the retrofitting strategies employed will be disclosed.

Chapter Five: Conclusion and Recommendations

The final section of the research thesis forms the conclusions and recommendations. It highlights relevant conclusions deduced from retrofitting and the overall output of the building. Recommendations will be illustrated, lessons learnt from the case studies of sustainable retrofitted buildings from the history section of the thesis and how these results can be used locally for commercial buildings in Nairobi's Central Business District.

2.0 CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter gives an introductory discussion based on insights from various scholars concerning broader issues on energy efficient retrofitting of buildings and how retrofitting is more sustainable than demolition. An overview of the strategies of retrofitting will be highlighted and explained in depth showing how energy efficient retrofitting came about in the other continents like the United States of America, Europe, Asia as well as Africa.

This chapter will also point out why in most countries we have a large stock of offices and other non-housing buildings that are certainly not efficient to run nor necessarily comfortable to work and yet there is material and well known strategies to build sustainably. Reference is made to different scholars and papers written on the same.

2.2 Building Suitably for Climates and Climate Sensitive Architecture

2.2.0 Building Suitably for Tropical Climates

Building sustainably and environmentally conscious is directly proportionate to the welfare of human beings. Be it from outside the building or within the building there should be always comfort as the number one rule to design. Our ancestors built with the environment in their minds and came up with suitable architecture for our climate in Kenya. Whether you were to enter a Mijikenda Kaya or a Maasai Manyatta, the conclusion was always the same; they were suitable for the environment. If we were to examine the buildings around the world in countries within the tropics, there are exemplary designs between the years 1960 and 1980 which also coincides with the independence of most colonized countries in the tropics.[4]

Architecture in different climatic zones should vary. Architects should be sensitive to climate and when designing should take this into account.

Many developing countries are situated within the tropics. Kenya, being one of these countries has been experiencing economic growth and rapid urbanization. Consequently, there has been a construction boom having many commercial buildings being constructed as seen in the ever-changing Nairobi's skyline. Unfortunately, most of these buildings are 60-75% occupied. This has been attributed to the comfort levels in the buildings, high electricity bills and in some cases building sickness.

As concerns over climate change and resource constraints grow, many cities across the world are trying to achieve a low carbon transition. Although new zero carbon buildings are an important part of the story, in existing cities the transformation of the current building stock and urban infrastructure must inevitably form the main focus for transitioning to a low carbon and sustainable future.[5]

Tropical climate experiences do not have seasons per say, there is evidence of hot months and cold months, rainy weather and dry weather.

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[4] Kimeu, M (2015), Environmental Building Design Guidelines for Practitioners, Financiers & Developers in East Africa: A paper presented at The Eastern Africa Real Estate Infrastructure Development & Finance Conference

[5] Dixon D., Eames M., Lannon S., Hunt M. (2014), Urban Retrofitting for Sustainability: Mapping the transition to 2050, London and New York, Routledge

Nairobi lies within the part of Eastern Africa influenced by the monsoonal systems of Asia and the Indian Ocean. The Climate here is controlled by the large sale pressure systems of the Western Indian Ocean and the adjoining continents. Nairobi's weather is as a result of the day-to-day variations of these pressure systems. The differences in topography leads to diversity of climates with Nairobi's higher side being cooler than the lower zones with air temperatures falling by 0.6^0C for every 100 meter rise in altitude[5]. The Nairobi area experiences four distinct seasons:

i. Hot season (North-East monsoon): This season is experienced between December and March and is characterized by persistent north-easterly winds between 15 Knots and 25 Knots. This is advantageous as it diminishes the effect of heat resulting from the sunny warm to hot days. Temperatures drop rapidly at sunset.

ii. Rainy season: Occurring from late March to May this is the period of the 'long rains'. Periods of rain are interspersed with dry periods while winds are light and variable or light easterly, usually north-easterly at first followed by south-easterly.

iii. Cold season (South-East monsoon): Occurring from June to October, this season is characterized by cloudy or overcast and cool or even cold conditions at higher altitudes. The high incidence of cloud cover diminishes incoming radiation and reduces evaporation rates. There is little rain in the first half of the season which increases during the other half. Some 10 to 15 Knots of moist, cool and stable airflow is experienced without any marked gustiness.

iv. Rainy season: This season occurs in November and is moderately warm with light easterly winds changing from south-easterly to north-easterly. Similar alterations of weather as those in April and May occur with a few days of rain and a few days of dry spells.[6]

The temperature data logged was not collected from the hottest or coldest months underlined above because IES VE uses an hourly weather data file that is selected to drive the simulations. The data used is from a site that is close and similar to the one under study so that the assumed impact of the sun, wind and rain etc. on the building is a close match.[7]

2.2.1 Passive Design Strategies for Environmentally Suitable Commercial Buildings

Sustainable architecture is architecture that seeks to minimize the negative environmental impact of buildings by efficiency and moderation in the use of materials, energy, and development space.

Climate-responsive architecture can be defined as architecture aimed at achieving occupant thermal and visual comfort with little or no recourse to non-renewable energy sources by incorporating the elements of the local climate effectively. (Yannas, 2003)

Architecture has evolved over the years. Today the façade plays an important role in defining the architecture/form of the building. In recent past, glass has become the

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[6] Njoroge, B. (2015), Towards a Climate-Responsive Architecture: A sensitivity analysis of passive design strategies for a free-running building in the Tropical climate of Nairobi, Department of Architecture, University of Cambridge, Unpublished

[7] Integrated Environmental Solutions (2011-2017) Retrieved from https://www.iesve.com/support/weatherfiles

prevailing material for facades due to its functions and in some cases the aesthetic appeal.

Passive design strategies use ambient energy sources instead of purchased energy like electricity or natural gas. These strategies include daylighting, natural ventilation, and solar energy.

There are general strategies for prevention of heat gain and/or provision of cooling strategies need to be considered when designing a building. Some of these strategies are discussed below:

Buildings orientation:

An ideal building in the tropics should be designed so that the long axis is along the East-West axis as illustrated in Fig 2-1. Suitable placement of a building can increase the energy efficiency, making it more comfortable and more cost effective.

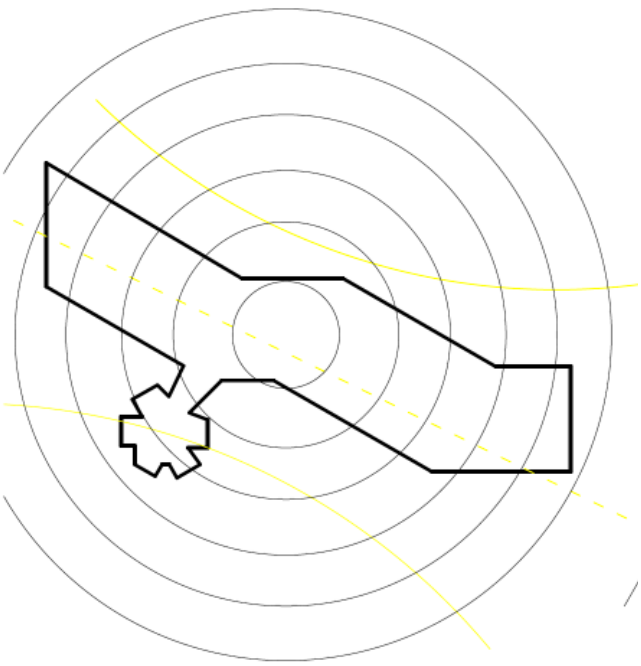

Fig 2-1: Building Orientation for Optimum Energy. Long axis East-West. Source: Author redrawn, 2016

Design buildings that are narrow in plan:

In Fig 2-2 the Mijikenda Kaya was a good example of narrow plan buildings. They had four of five kayas around a courtyard which enhanced cooling of the buildings. The principle of designing a narrow-planned building is to help achieve maximum natural lighting penetration into the buildings and also good cross–ventilation.

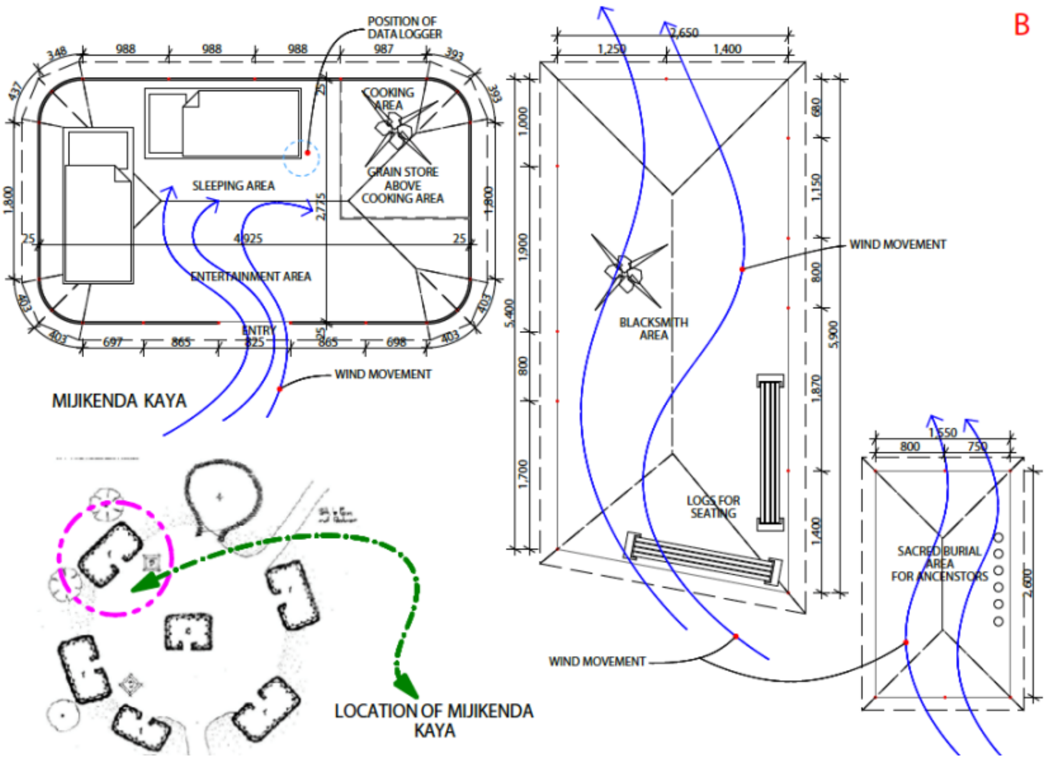

Fig 2-2: Building with a narrow plan ensures cross ventilation and natural lighting into the spaces. Source: Author, Human Thermal Comfort, A comparative Study of Mijikenda and Swahili Living Environments, 2010

Sun-shade all glazed areas:

This should be realized by use of vertical and horizontal sun-shading elements, deep roof overhangs, balconies and perforated timber screens etc. Table 2-1 illustrates examples of commercial buildings in Nairobi's CBD and the sun shading devices employed by them

Vertical sun shading	Horizontal sun shading
Kenindia House	Nyayo House
	
Sheria House	
Egg crate sun shading	
	

Table 2- 1: Above shows the different types of sun shading elements used in some buildings in Nairobi CBD. Source: Author, 2016

Use natural ventilation to provide cooling:

Natural ventilation can be achieved throughout the building by using openable windows, thermal chimneys, metal or timber louvered fenestrations and perforated timber (mashrubiyya) screens on openings. Fig 2-3 demonstrates the f low of natural ventilation in Jomo Kenyatta Memorial Library with the principle that hot air rises.

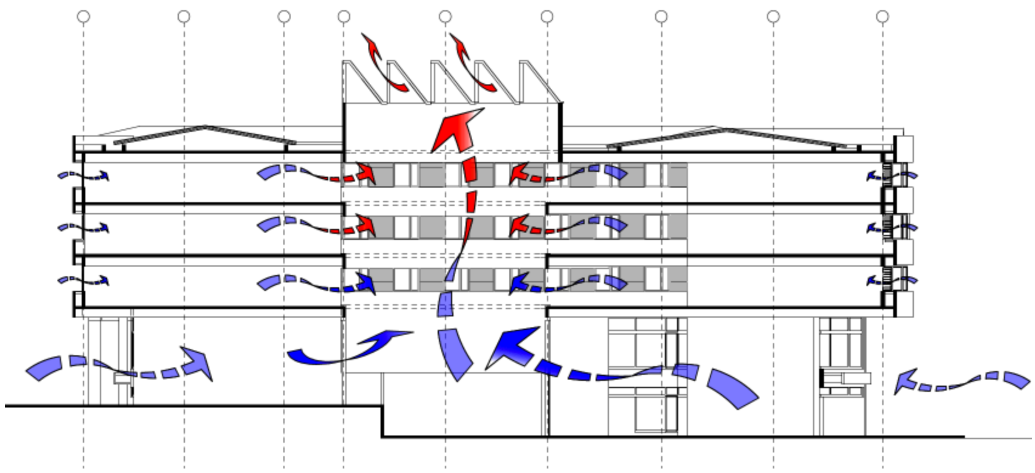

Fig 2- 3: Natural ventilation illustration of Jomo Kenyatta Memorial Library at University of Nairobi.

Source: Author, 2015

Locate building services on the East and West facing facades:

Spaces where the least amount of time is spent, such as elevators, lobbies, toilets, stores, building ducts among others should be located on the East-West façade of the building.

Have minimal window openings:

It's recommended that all buildings located within the tropics, should have minimal window openings. The wall to window ratio should be determined to obtain an optimal indoor thermal comfort.

Use external finishes that are smooth and light colored to reduce solar heat absorption:

In the tropics, the temperatures get quite high therefore it is recommended that light colors for external finishes with a combination of light materials aids in the reduction of heat gain within the building. This combination allows for reflection of the sun's rays away from the building.

Use high thermal mass on walls (thick walls):

All external walls should be at least 200mm thick. The thicker the walls the less the time lag for allowing heat to penetrate into the building. Buildings in old town had thicker walls up to 600mm (example Stone Town in Zanzibar).

Placement of window openings on the North and South facing walls:

This ensures the windows are away from the suns path. More windows can be placed on the North-South façade allowing also for maximum natural light/ daylighting into the building.

Choice of Materials:

The use of locally available materials with low embodied energy, with none or minimal maintenance, materials that are sustainably harvested, non-toxic as well as those with minimal internal pollution and damage to health and with easy to recycle and to reuse should be considered. Additionally, alternate building materials may be used. Alternate building materials are those which can be used economically by replacing the conventional building materials. Alternate building materials are made from waste products and thus minimizing environmental pollution.

Renewable energy:

Renewable energy can be used as an alternative source of energy in commercial buildings such as solar, wind, biogas and others. Different types of renewable energy are illustrated in Fig 2-4 below:

Fig 2-4: Renewable energy illustrated. Source: Renewable Energy Standard, Colorado, 2004

Rain water harvesting:

Having extra water for the buildings firefighting as well as for different usages in the building like cleaning, flushing toilets and landscaping of plants in or outside the building. This rain water can be collected from the building roofs themselves into tanks located strategically around the building.

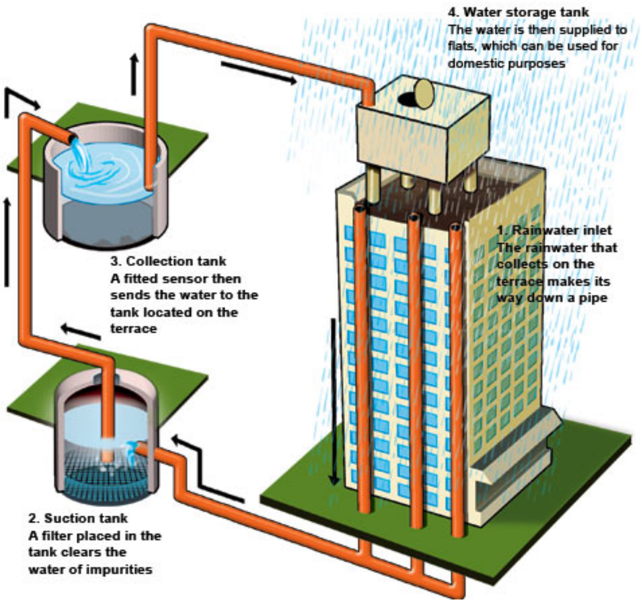

Fig 2-5: Roof-top rainwater harvesting: The roof acts as the catchment area in case of roof-top harvesting. This water is then stored using pipes and gutters. Source: Iconhomz website, Rainwater harvesting.

<u>Sanitation:</u>

Use of environmentally friendly toilets and sewerage systems like bio-digesters, reed beds and oxidation ponds can be used to break down grey water in the building and disposed of safely into the environment without affecting it. Nairobi River is an example of a much-polluted water source because of dumping and disposing of waste into the River. This can be avoided with good systems incorporated when designing buildings.

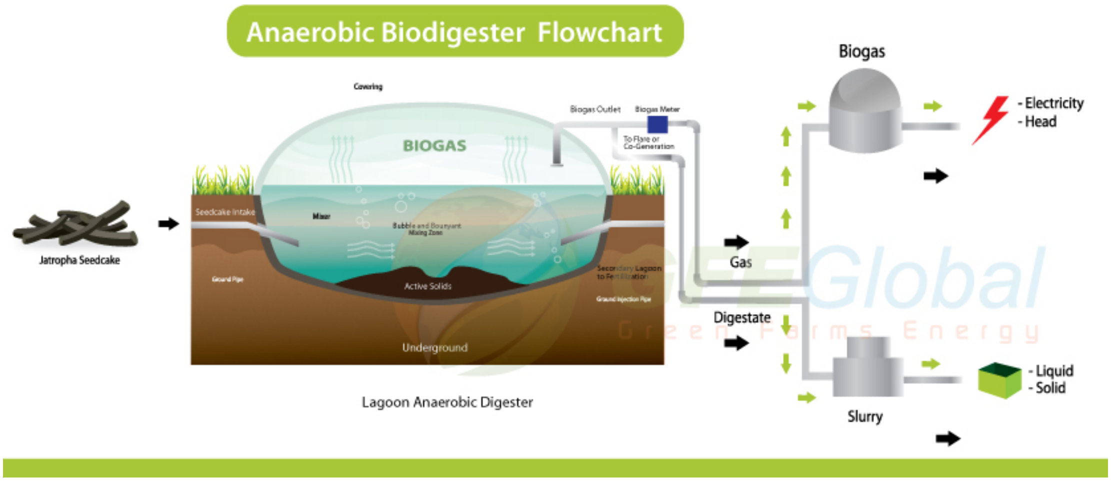

Fig 2-6: Diagram of a Biogas Plant: Waste is collected, digested in a holding tank where gas is tapped for use and the by-product is a bio-slurry. Source: Bioresource Technology, Volume 74, Issue 1, August 2000, Pages 3–16

<u>Solid waste management:</u>

Solid waste management is the process where biodegradable waste used to produce biogas and the non-biodegradable waste is recycled. In Nairobi today, there is evidence that different companies are providing solutions for separating waste as illustrated in Fig 2-7. Some of the recycling bins are solar powered. This will minimize waste at damping grounds such as Dandora. Waste can be isolated on basis of biodegradable or non-biodegradable waste or alternately dividing waste into dry and wet which leads back to the different solutions found in various cities all over the world.

Fig 2-7: Solar waste management found in Nairobi CBD. Source: Author

<u>Landscaping</u>:

Any upcoming construction should incorporate soft landscape into their design – this includes indigenous trees and small shrubs and bushes. Adding landscaping within the building is an added advantage although after developer's hand over to the tenants, there is a possibility that the tenants may not keep the internal landscaping that the architect intended to incorporate into the building. When integrating landscaping into the building it is advised to use local plants rather than exotica and to use plants that require little to no maintenance, which includes watering, trimming and little exposure to light.

<u>2.2.2 Reasons Why There No More Environmentally Suitable Buildings Being Designed</u>

Although there is sufficient information on strategies to employ when designing a new building to ensure that it is environmentally suitable for its climate, several designers and developers do not follow these guidelines as they are supposed to. This often leads to having several buildings being developed that are unsuitable for their climate. In the paper "Six Myths of Sustainable Design by Lance Hosey" some key misperceptions have been highlighted below to help explain why green building hasn't gained more traction.

The public believes that the initial running costs of the construction will be expensive and therefore do not venture in investing to respond to climate and therefore end up designing climatic non-responsive building. Ironically, the first nine strategies listed above are free from any cost and can be done with basic design.

After World War II and the introduction of new materials such as glass, steel and reinforced concrete being used in buildings around the world. Here in Kenya, we were not left behind and notably the transformation of architecture in Nairobi around the late 1980s went from environmentally sensitive buildings (IPS building) to fully glazed buildings (View Park Towers). This surmises that the public perceives climate responsive buildings as not 'modern' nor aesthetically pleasing.

Architects often protest that taking the time to design a green building consumes too much time. With limited schedule and fees, architects state that the time taken for research into alternative building materials or analysis of a building to make it 'green' is not worth the hassle. However, the process known as integrated design, which brings all major professionals at an early stage in the design work can acquire the right direction and a consensus on the building. But in actuality, most of the professionals required to give their input for sustainable building design are brought in later and the bottom line leads to architects failing to design appropriately.

Remarkably, another explanation shows that smart building design or adding solar panels or wind turbines, will make the building environmentally friendly. This reflects the narrow thinking geared toward global warming, whose main cause is from greenhouse gas emissions from old-fashioned energy mechanisms, and the solution is to install smarter mechanisms.[8]

Fact…"Green" and "Design" are separate issues. This boils down to the same excuse we hear over and over in the industry "it's not my responsibility". When designing and constructing a building, no one involved wants to claim that sustainable design is a part of their job description. Many architects have dismissed the notion of green design because they argue that the two aren't actually related. Studies indicate "that 80-90 percent of the impact of a building or product is determined in the earliest stages of development". The design of a building will change drastically who uses the building and what it will take to build it.

Green Roofs and Green Walls: Perhaps time will prove us wrong, but green roofs and green walls strike us as more of a trend than a lasting solution. And yes, this is a slightly ironic statement since green roofs have been around since prehistory in many parts of Europe, but the modern understanding of green roofs, and certainly green walls is a fairly recent phenomenon. Green roofs and walls help with water filtration and with temperature control, but if installed incorrectly (using the wrong plants for a particular region) they can wind up wasting far more money and energy than their shingled relatives. Green walls in particular can be very costly to maintain in that water needs to be properly circulated so the plants don't die. Commonly, the designer and user may

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[8] Hosey, J. (2015), Six Myths of Sustainable Design: A half-dozen misperceptions help explain why green building hasn't gained more traction, Retrieved from: http://www.greenbuildingadvisor.com/blogs/dept/guest-blogs/six-myths-sustainable-design

not agree on the plant material on the roof or walls, therefore zero maintenance is carried out and plants die and in the end the building ceases being a "green" building as there are no more green roofs or green walls but bare walls and bare roofs.

Green Design = Environmentalism: Certainly, one of the ruling thoughts about sustainable design is that it is geared toward helping the earth and the environment. But the focus on this one aspect of sustainable design has led many to believe that green buildings are only good for earthy-crunchy tree-huggers. In fact, sustainable design is supposed to coincide with the "triple bottom line" of environmental, social and economic interests. Sustainable buildings should be good for the planet, the people that live there, and improve profits.[9]

With the aforementioned explanations, the concept of retrofitting for environmental suitability occurred. The author has deduced that this concept is popular because many architects, contractors and developers have neglected their responsibility to design responsively for their climate. Furthermore, this concept for retrofitting is widespread in Europe, Asia and America but fairly new in Africa where case studies are mainly from South Africa.

Retrofitting an existing building can in most cases be more cost-effective than demolishing a building and constructing one from scratch. Buildings consume a noteworthy amount of energy (with regards to commercial buildings in the tropics, energy consumption comes from cooling purposes) and it would be important to initiate

[9] Builtr (2015), Eight Myths About Green Design, Retrieved from: http://www.builtr.io/eight-myths-about-green-design/

sustainable retrofits that improve the thermal performance and energy efficiency of the building. Designing retrofits for existing buildings to include sustainability initiatives will reduce operation costs and environmental impacts, and can increase building adaptability, durability, and resiliency.

2.3 The Current Thermal Performance of Commercial Buildings in East African Region: Kenya

2.3.0 Thermal Comfort

Definition: According to the ANSI/ASHRAE Standard 55-2010, thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation. "Also, known as human comfort, thermal comfort is the occupants' satisfaction with the surrounding thermal conditions and is essential to consider when designing a structure that will be occupied by people. A cold sensation will be pleasing when the body is overheated, but unpleasant when the core is already cold. At the same time, the temperature of the skin is not uniform on all areas of the body. There are variations in different parts of the body which reflect the variations in blood flow and subcutaneous fat. The insulative quality of clothing also has a marked effect on the level and distribution of skin temperature. Thus, sensation from any particular part of the skin will depend on time, location and clothing, as well as the temperature of the surroundings.[10]

[10] http://sustainabilityworkshop.autodesk.com/buildings/human-thermal-comfort#sthash.5Fuwt01U.dpuf

2.3.1 Factors in Human Comfort

There are six factors to take into consideration when designing for thermal comfort. Its determining factors include the following:

a. Metabolic rate: The energy generated from the human body
b. Clothing insulation: The amount of thermal insulation the person is wearing
c. Air temperature: Temperature of the air surrounding the occupant
d. Radiant temperature: The weighted average of all the temperatures from surfaces surrounding an occupant
e. Air velocity: Rate of air movement given distance over time
f. Relative humidity: Percentage of water vapor in the air

Thermal comfort is calculated as a heat transfer energy balance. Heat transfer through radiation, convection, and conduction are balanced against the occupant's metabolic rate. The heat transfer occurs between the environment and the human body, which has an area of 19 ft^2. If the heat leaving the occupant is greater than the heat entering the occupant, the thermal perception is "cold." If the heat entering the occupant is greater than the heat leaving the occupant, the thermal perception is "warm" or "hot."

A method of describing thermal comfort was developed by Ole Fanger and is referred to as Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD).[11]

[11] http://sustainabilityworkshop.autodesk.com/buildings/human-thermal-comfort#sthash.A8fzjfLs.dpuf

2.3.2 Factors Affecting Thermal Performance of Commercial Buildings

Site Planning and Built Form

Orientation of the building on site is important and the plan of the building should be narrow to allow for cross ventilation and natural day lighting all through the day. If the building has a wide plan, then the interior spaces six meters away from an openable window will require artificial lighting and this is not ideal in a building in the tropics. Orientation of the building should always be along the north south axis to avoid the sun's path.

Solar Control Strategies

Nairobi has tropical upland climate with harsh sunny days. Therefore, climate responsive architecture in the city requires sun shading devices to be used to ensure that the harsh sun does not penetrate the buildings envelope and make the interior spaces of the commercial buildings uncomfortable.

External Spaces

External spaces such as courtyards, balconies or atriums in office buildings, increase the chances of catching natural ventilation, although unpredictable when it comes to direction but cools the external spaces which in turn cool the internal spaces and enhance human thermal comfort levels. Besides functioning as shaded outdoor spaces, these spaces also perform highly important functions like shielding the walls and openings from direct sun and other harsh weather elements and also sky glare will be eliminated due to having these external spaces.[12]

Construction Materials

Materials, energy and water are the three main resources required to construct and run buildings. A sustainable building design approach has to consider these three resources in terms of their depletion and the environmental and social impacts associated with their use. The constructional materials used need to have a minimum of 200mm thick walls. For low embodied energy, local available materials are encouraged to be used for construction.

External Façade

With reference to passive design strategies mentioned above, the external façade should be smooth and light colored to reduce solar heat absorption.

Human Thermal Comfort

Energy-efficient buildings are only effective when the occupants of the buildings are comfortable. If they are not comfortable, then they will take alternative means of heating or cooling a space such as space heaters or window-mounted air conditioners that could be substantially worse than typical Heating, Ventilation and Air Conditioning (HVAC) systems.

[12] Hooper, C. (1975), Design for climates: a guideline for the low-cost houses for the climates of Kenya, Nairobi, University of Nairobi

Thermal comfort is difficult to measure because it is highly subjective. It depends on the air temperature, humidity, radiant temperature, air velocity, metabolic rates, and clothing levels and each individual experiences these sensations a bit differently based on his or her physiology and state.

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2.4 Retrofitting for Environmental Suitability of Commercial Buildings

Most of the world's scientific community believe that the apparent climate change is manmade, being largely caused by emissions from the use of fossil fuels, and we know that around 40 per cent of this energy is used in buildings[13]. Reducing energy use in our building stock is a major concern.

Whilst there is increasing recognition that green buildings outperform conventional buildings in terms of a variety of environmental, economic and social indicators, much less is known about how green-building initiatives might be incorporated into existing buildings, which make up the bulk of the market. If the challenge of climate change is to be successfully addressed, therefore, this vast stock of older buildings (developed decades ago when sustainability was not a consideration) needs to be retrofitted. Unfortunately, retrofitting existing buildings is significantly more difficult than creating a new green building from scratch. For example, in existing multi-tenant commercial buildings, any sustainable retrofit or technology upgrade requires the cooperation and participation of a wide range of stakeholders (i.e., owners, managers, occupants and contractors) who often must reside in the building during the potentially disruptive retrofitting process.

Moreover, whilst there is the technological capacity, issues such as cost and tangible demand from consumers, organizations and policy-makers will determine the priority that industry places on retrofitting existing buildings for sustainability[14].

[13] Burton, S. (2014) Sustainable retrofitting of commercial buildings: Cool Climates, London and New York, Routledge

[14] Miller E., Buys L., (2008), Retrofitting Commercial Office Buildings for Sustainability: Tenants' Perspectives. Journal of Property Investment & Finance, Retrieved from: http://eprints.qut.edu.au/

2.4.0 Retrofitting

Retrofitting means 'providing something with a component or feature not fitted during manufacture or adding something that it did not have when first constructed' (Ref: Retrofit 2050: Critical challenges for urban transitions). It is often used in relation to the installation of new building systems, such as heating systems, but it might also refer to the fabric of a building, for example, retrofitting insulation or double glazing.

Fig 2-8: A building envelope which is existing can be improved by changing the building envelope so that the thermal; performance of the building can increase. Source: Arch Laura Pedata, Tirana, Polis University (2011)

Retrofitting has come to prominence in recent years as part of the drive to make buildings more thermal efficient and sustainable. This can help reduce carbon emissions, reduce the running costs of the building and mitigating poor ventilation and heat problems thereby improving the health of occupants.

But why is there an interest in sustainable retrofitting of commercial buildings? Buildings can be easily built to be environmentally friendly, and legislation inexorably moves in that direction. Nevertheless, in most countries, numerous buildings are certainly not efficient to run nor necessarily comfortable to work in, so their future must be to either demolish them or refurbish them. There are at least three valid reasons for refurbishment rather than demolition: the building may be an important historic building; it may be capable of refurbishment at lower cost than demolition and new build; or it may be considered that the environmental impact is less if it is refurbished rather than demolished. (Burton 2014).

The architectural profession, often as the project managers as well as designers, are the major players in driving a sustainable refurbishment. Whilst designing to reduce the emissions that drive climate change, the architect must also focus on adaptation, designing maybe in a different way to take proper account of the changes underway and make the building resilient to climate change.

The case studies examined below in regards to the history of retrofitting will investigate buildings which were initially constructed without employing passive design strategies that led the buildings to have high running costs, high carbon emissions and low thermal performance. These buildings will showcase the outcome of the building's thermal performance and energy efficiency when sustainable retrofitting strategies are applied.

2.4.1 History of energy efficient retrofitting

Energy efficient retrofitting resulted to reduce greenhouse gases within a building and minimize on the cost the building was accumulating. The high costs consumed in the buildings can be from equipment and/or the design of the building’s envelope. Retrofitting for environmental suitability can be looked back to about 2005 when the

Empire State Building in the United States of America was retrofitted to reduce greenhouse gases and carbon emissions as well as lower the buildings costs. The author hasn't come across any information before 2005. A brief look at the history of retrofitting in the major continents, namely, United States of America, Australia, Asia and Africa.

<u>United States of America</u>

The first case documented on sustainable retrofitting was for the Empire State Building a complex and famous office building in New York. The retrofitting begun in 2005, where almost all the changes were unnoticeable from the outside and by visitors to the 86th floor Observatory.

The agenda towards the sustainable retrofit of the Empire State Building was to prove or disprove the economic viability of whole-building energy efficiency retrofitting, create a replicable model for whole-building retrofits and to reduce the greenhouse gases it emitted and reducing the carbon emissions produced within the building therefore lowering the building's running costs tenfold. The project saves up to 38 percent of the building's energy and $4.4 million annually.

Some of the whole-building retrofits done for the Empire State Building are listed below:

a. Windows: The remanufacture of the existing insulated glass units within the Empire State Building's, approximately six thousand five hundred double-hung windows was to include suspended coated film and gas fill.

b. Radiative barrier: The installation of more than six thousand insulated reflective barriers behind the radiator units were to be located on the perimeter of the building.

c. Tenant daylighting/lighting/plugs: This measure involved reducing lighting power density in tenant spaces, installation of dimmable ballasts and photo sensors for perimeter spaces, and providing occupants with a plug load occupancy sensor for their personal workstation.

d. Chiller plant retrofit: The chiller plant retrofit project included the retrofit of four industrial electric chillers in addition to upgrades to controls, variable speed drives, and primary loop bypasses.

e. VAV air handling units: The replacement of existing constant volume units with variable air volume units using a new air handling layout (two floor-mounted units per floor instead of four ceiling-hung units).

f. DDC controls: The measure involved upgrading the existing control systems at the Empire State Building.

g. Demand control ventilation: This project involved the installation of carbon dioxide sensors for control of outside air introduction to chiller water and DX Air Handling Units.

h. Tenant energy management: This project provides tenants with access to online energy and benchmarking information as well as sustainability tips and updates. [15]

[15] Empire State Building Case Study - Cost-Effective Greenhouse Gas Reductions via Whole-Building Retrofits: Process, Outcomes, and What is Needed Next, Retrieved from: http://www.esbsustainability.com/

Australia

Located in the heart of the CBD, 215 Adelaide Street has been a prominent commercial tower in Brisbane's landscape for 30 years. In 2008, Norman Disney & Young (NDY) recommended a plan to improve tenant services and slash energy consumption. The main innovations and challenges in the delivery of the retrofit included pre-order of the chillers, fan speed modulation and chilled water thermal energy exclusion.

215 Adelaide Street stands apart from these buildings as an example where attention to detail and getting the basics right in an older building can deliver excellence in energy efficiency. By maintaining full occupancy, we avoid disruption to lessor's cash flow but also disruption to tenant business's and their employees. By refurbishing rather than rebuilding we can deliver 5 Star operational efficiency with the smallest initial carbon footprint and avoid large quantities of waste to landfill. [16]

Asia

When the Building and Construction Authority (BCA) in Singapore needed to retrofit its three-story building on the BCA Academy campus, it decided to try to make it a net zero energy building despite the challenge of doing so in a hot and humid tropical climate. After five years of operation, the net zero energy targets are being met and occupants are benefitting from the increased visual and thermal comfort. Before the

[16] NDY (2013) Award for sustainable building retrofit, Engineers Australia, Retrieved from: http://www.ndy.com/sites/default/files/Retrofit.pdf

retrofit, the building was used as a training center for craft workers for the rapidly growing construction industry in Singapore.

The planning began in 2007 as a public-private partnership project with the building owner (BCA), local designers/consultants and builders partnering with researchers from the National University of Singapore (NUS) and the Solar Energy Research Institute of Singapore (SERIS) to retrofit an existing building into a net zero energy building.

The BCA retrofit project was intended to demonstrate efficient use of energy in a retrofit building. Shading devices, light shelves, vertical green walls, high-performance glazing, and lightweight wall systems are integrated in the west facade. Light pipes and ducts are installed on the roof and east facade. The roofs are covered with large permanent ventilation systems to generate enough electricity for the building to become net zero. Parts of the roof have solar chimneys for improving the air movement within the naturally ventilated spaces. [17]

[17] ASHRAE (2009). Standard 189.1 – Standard for the Design of High-Performance, Green Buildings Except Low- Rise Residential Buildings. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc

Africa

In Africa, the retrofits documented emanate in South Africa. Some of these buildings are highlighted below.

Cape Town's mixed-use development, the Victoria & Alfred (V&A) Waterfront, embarked on a retrofit project to the tune of R22 million. The project involved changing light fittings, installing air conditioner control measures, waste water management and less water used on its irrigation system. Over a three-year period, the V&A Waterfront recorded a consumption saving of R15.5 million.

In Johannesburg, the 'The FirstRand Group' undertook a major retrofit of its premises in 2008. FirstRand's overall major retrofits included and upgrade of its chiller system, solar geyser, light fittings and purchasing energy efficient equipment totaling R30 million. Over three years retrofitting efforts saved the group R19 million.

In 2008, in another part of South Africa, the Old Mutual Property retrofitted its Cape Town-based Cavendish Square Shopping Centre and Pretoria's Menlyn Park Shopping Centre to improve heating and air conditioning systems at the respective centers.

2.4.2 Benefits of energy efficient retrofitting of buildings

An energy efficiency building effectively controls the flow of air, heat and moisture through the building.

People spend 80 - 90% of their time indoors - at work, school and home. An efficient building maintains moderate temperatures, low humidity and increased air quality. When buildings are built efficiently, they tend to produce less energy and cost less to operate and maintain as well as emit less greenhouse gases which is generally good for you and the environment by enlarge. Some of these benefits can be summarized as below:

i. Improve indoor comfort
ii. Save money on energy bills
iii. Breathe healthy, fresh, clean air
iv. Reduce moisture issues (mold, leaks, condensation)
v. Increase building resale value
vi. Reduce fossil fuel use and greenhouse gas emissions

Improve indoor comfort

Natural ventilation and natural lighting are ideal in the tropical climate. Being comfortable throughout the work day is ideal without having to sit in a space that requires full artificial lighting to operate and air-conditioning to cool or heat the space. Reduction of the sun's glare or direct sunlight into spaces causing heat into the room should be avoided therefore if having a fully glazed façade is required, then thermal glass should be used or photovoltaic curtain walls. Otherwise well shaded openings along the east west facades should be maintained.

Sun shaded facades can be incorporated to ensure views are not compromised and still maintain indoor thermal comfort. Many designers do not incorporate sun shading elements to the facades as they view the building will be archaic and not have the model feel as the buildings we see in First World Societies.

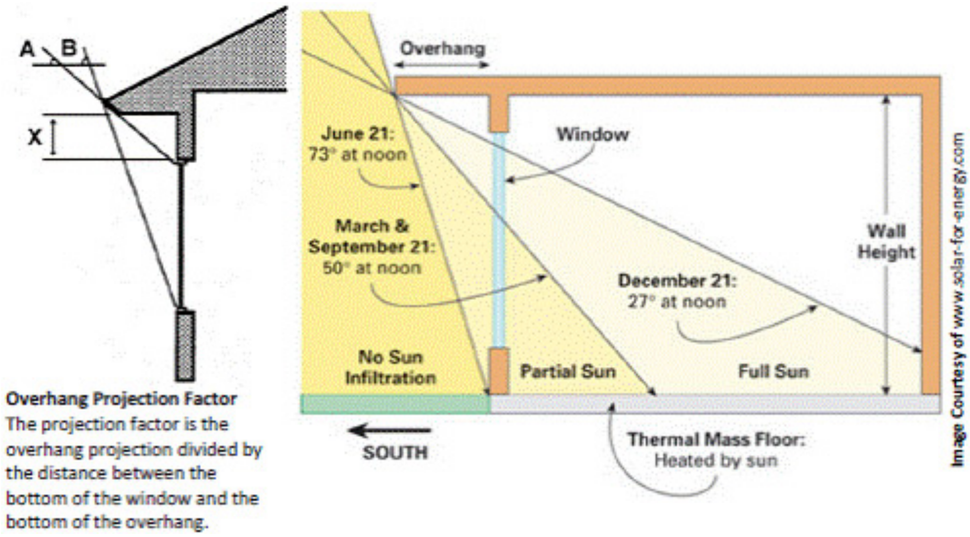


Fig 2-9: Image illustrates how sun shading overhangs can be calculated for maximum efficiency. Source: National institute of Building Science, 2016

<u>Save money on energy bills</u>

Improving the building's energy efficiency will definitely save you money. This means, for example, elimination of air-conditioning in the building, using renewable energy for running the buildings electricity and lighting, bio-digesters for the waste management etc. Air conditioning in the building may cause the buildings thermal performance to be low and with the same breath cause high electricity bills as air conditioning is left on throughout the day and sometimes at night and contributes to the emission of greenhouse gases to the atmosphere.

Compared to traditional incandescents, energy efficient lightbulbs such as halogen incandescents, compact fluorescent lamps and light emitting diodes have been known to typically use about 25%-80% less energy than traditional incandescents, saving you money and they can last up to twenty-five times longer.

Today's energy efficient bulbs are available in the wide range of colors and light levels as expected by the users. While the initial price of energy efficient bulbs is typically higher than traditional incandescents, the saving will be appreciated during the life span of the bulb. Energy efficient bulbs tend to last longer than traditional incandescent light bulbs therefore the replacement cost has been reduced[18].

[18] http://energy.gov/energysaver/how-energy-efficient-light-bulbs-compare-traditional-incandescents

The table below compares a 60 watt (W) traditional incandescent with energy efficient bulbs that provide similar light levels.

Comparisons between Traditional Incandescents, Halogen Incandescents, CFLs, and LEDs						
	60W Traditional Incandescent	43W Energy-Saving Incandescent	15W CFL		12W LED	
			60W Traditional	43W Halogen	60W Traditional	43W Halogen
Energy $ Saved (%)	–	~25%	~75%	~65%	~75%-80%	~72%
Annual Energy Cost*	$4.80	$3.50	$1.20		$1.00	
Bulb Life	1000 hours	1000 to 3000 hours	10,000 hours		25,000 hours	
*Based on 2 hours/day of usage, an electricity rate of 11 cents per kilowatt-hour, shown in U.S. dollars						

Table 2-2: Table illustrates how energy efficient light bulbs compare to the traditional incandescent. Source: Author redrawn

Other reasons why electricity bills are left on are some appliances as well as lights are left plugged in or on all day and night in without turning them off. To save on electricity bills if appliances or equipment in the commercial space are not in use they should be unplugged or turned off to save on energy.

Retrofitting to ensure natural lighting may help in the reduction of energy bills. This also does not mean designing fully glazed facades especially for tropical climates as it will then be an inappropriate building for that climate.

Breathe healthy, fresh, clean air

Just think of all the kettles, fish tanks, plants and even people who are expelling moisture into the air. Plus, microwaves, photocopiers, printers and even carpet and paint fumes all pollute indoor areas where we work. Having natural ventilation allows for the free air flow into the spaces where we work therefore being enclosed in a space that requires air-conditioning or has no access to free-flowing air causes low thermal comfort levels in a building which can lead to building sickness syndrome which is used to describe a situation in which the occupants of a building experience acute health- or comfort-related effects that seem to be linked directly to the time spent in the building. No specific illness or cause can be identified.

Reduce Moisture Issues

10 to 50 litres of moisture are released inside a building each day[19]. Humidity levels over 40% can create air quality problems. When humidity is above 50%, airborne

[19] http://www.citygreen.ca/benefits-energy-efficiency

diseases become more difficult to control. To protect health, all moist, stale air should be replaced with fresh air every 3 to 4 hours. This drives the point to the importance on the prerequisite to have natural ventilation in a building.

Increase resale value

Energy efficient buildings typically have longer lifecycles, lower maintenance fees, and cost less to operate. The natural light, comfortable temperatures and increased indoor air quality of energy efficient commercial buildings results in increased staff productivity. And, building owners benefit from increased control over their energy bills while leasing out spaces that support the needs of the tenants.

Reduce greenhouse gas emissions and contribute to a healthier planet

Through energy efficiency retrofits, commercial buildings that were built which are environmentally unsuitable can have the potential to lower their energy bills and to reduce the amount of greenhouse gasses the building produces. Lowering the total amount of greenhouse gasses in the atmosphere is an important step to reducing the impacts of climate change, both locally and globally.

2.4.3 Sustainable and energy efficient retrofitting strategies

Today, most designers, developers and/or contractors are not using the guidelines for sustainable building as they are required to do thus having many buildings being erected with no connection to the climate it belongs to. In order to reduce the greenhouse gases created in a building and the carbon dioxide emissions that lead to global warming, sustainable retrofit needs to be employed. Some strategies are listed below:

i. Recommission all energy and water systems to determine they are operating at optimum performance; then upgrade energy and water systems to minimize consumption.
ii. Develop a plan to optimize the recycling and reuse of demolition debris and construction waste to minimize waste sent to landfills.
iii. Evaluate occupancy patterns, and then apply daylight and lighting sensors in appropriate locations. Incorporate energy efficient lighting into the project as appropriate for the tasks and functions of the spaces.
iv. Determine if natural ventilation and fresh air intake are feasible alternatives to reduce heating and cooling loads.
v. Investigate renewable energy options that can offset the purchase of fossil fuel-based energy.
vi. Consider solar shading devices for windows and doors, including those that generate electricity by photovoltaic (PV) devices.
vii. Replace existing windows with high-performance windows appropriate for climate and exposure. If building requires security upgrade, evaluate blast resistant windows and films. If building is located in a high noise area, evaluate windows that also include adequate exterior to interior noise reduction.
viii. Balance the project's sustainable goals with its security goals including protecting the building and its occupants from natural and man-caused disasters.
ix. Certain site renovations can improve the energy performance of the building including reducing the heat island effect.
x. Determine if a cool roof or green roof is cost-effective ways to reduce heat island effect and storm water runoff.

xi. To ensure a newly renovated building continues to perform as designed, measure the performance of the building regularly.

xii. If not already metered, plan on installing meters for electric, gas, water and other utilities. Smart meters and sub-meters are preferable to monitor real-time consumption, control demand and increase tenant accountability (cost control).[20]

Retrofitting in this context should involve applying an integrated, whole-building process; however, there are a number of basic techniques that can be used for key elements of a building:

a. Walls: Cavity wall insulation, internal or external insulation, and cladding of external and internal surfaces.
b. Roofs: Insulation and ventilation systems or green roofs (roof gardens).
c. Doors: Draught proofing or replacement high-performance doors.
d. Windows: Installation of double or triple glazing, draught proofing of existing glazing.
e. Floors: Installation of insulation.
f. Tanks and pipes: Lagging.
g. Lighting: New controls, occupancy sensors, Light-Emitting Diode (LED) lighting and other low energy technologies.
h. Controls: Installation of smart controls and building management systems.

[20] https://www.wbdg.org/resources/retro_sustperf.php

i. Renewable energy systems: Installation of photovoltaics, solar thermal heating, passive solar heating, wind energy, wood and organic waste power sourced heating or power plant, micro-hydro power, and so on.
j. Water conservation: Installation of low-flow equipment such as water fittings, shower heads, dual flush WC's, rainwater harvesting, and so on.
k. Electricity: Peak saving through thermal energy storage, onsite electricity generation, combined heat and power, and so on.
l. Advanced metering systems: Smart meters.

Did you know that energy efficiency is about five times less expensive per watt than alternative energy sources…that energy efficiency is, in fact, the cheapest source of alternative energy out there? Buildings consume over 50% of the world's energy. Making them more efficient through retrofitting will have a greater impact than any alternative energy source. Investing in retrofitting for environmental suitability will generally create jobs, save a lot of money in the long run, allowing for greater competitiveness, productivity, and ultimately profits.

Retrofitting for environmental suitable has proven that sustainability does not have to be a compromise.

2.5 Energy Efficient Principles and Technologies for Retrofitting

The most important part of environmental sustainability in a refurbishment project is minimizing the use of energy, particularly energy from non-renewable sources, to reduce the contribution to climate change. There are two aspects: embodied energy in the refurbishment process and energy in use in the subsequent lifetime of the building.

Reducing lifetime energy use is usually by far the larger component and the area in which the largest impact can be made in refurbishment, even reducing it to zero in some cases with the judicious use of renewable energy sources.

Design for energy efficiency in a new building needs to start as early in the project as possible, at the briefing and concept stages, so that efficiency can influence the location, layout and basic design concepts and lead to the optimal solution. With a refurbishment project, the design needs to start with the existing building, what level of refurbishment is being considered, the energy efficiency of all elements or of those elements which will be retained and, where available and relevant, historical data on comfort and energy use in the building. The principles of energy efficiency and the technologies available will be virtually identical to those for new build, the challenge for the refurbishment designer is to select those technologies that maximize the use of what already exists, exploit the potential of the building and integrate new technologies that complement these and make the building as energy efficient as possible.

Below is a general outline of typical approaches to optimizing energy use in the different areas, which are available to designers involved in retrofitting:

2.5.0 Energy use in buildings

In buildings, the sources of energy are commonly used for lighting, that is, a supplement for daylighting, air-conditioning, mechanical ventilation in the basements or bathrooms where natural ventilation was not possible, equipment, that is, computers, lifts, security equipment, kitchens in restaurants and plants running factories.

Renewable energy can be retrofitted into the buildings to reduce the amount of fossil fuels in use. Such renewable energy can be used to light and generate electricity in the building, manage waste and be a solution for sanitation amongst other things.

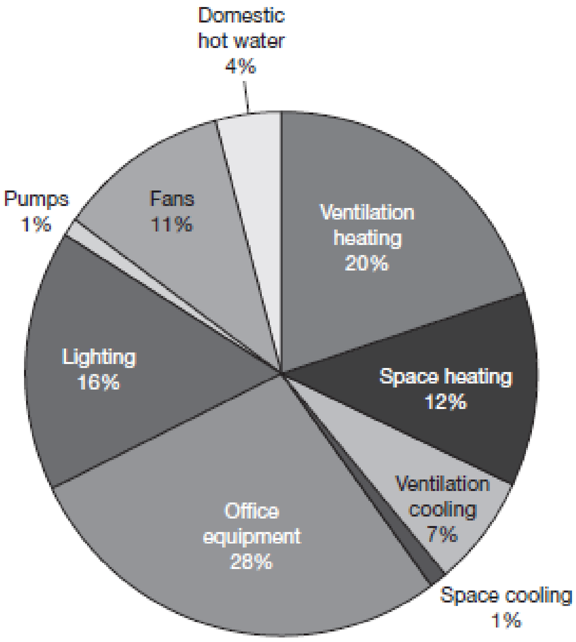


Fig 2-10: Breakdown of Building energy use. Source: Simon Burton

2.5.1 Natural Lighting

Lighting can be one of the main sources of high energy consumptions in a building especially when it comes to having conventional lighting and using artificial lighting all through the day.

'Modern' buildings being designed today have full glazed curtain walling as their external building envelope yet has little to no contribution to proper daylighting in the interiors as the 'open plan' spaces initially designed have to be partitioned and therefore interior spaces lose the access to direct sunlight into these spaces.

Natural lighting is significant for comfort by the users of a building. The ratio of window openings vis a vis the floor area is calculated to perceive how much natural lighting can get into a space without any obscurities. For instance, in retrofitting, the physical audit of bulbs, as well as, wattage output of bulbs is taken and calculations made on how changing of the bulbs simply to LED bulbs can reduce the energy consumption from lights in the building. Companies like Phillips are experts on this sort of retrofitting.

Carefully designed 'light shelves' can be retrofitted to window openings to reflect natural light further into a room while reducing intensity adjacent to the window. Roof lights and sun pipes can be added to corridors and internal rooms if located on the top floor and borrowed light brought in from adjacent spaces using glazed partitions, with high-level windows if privacy is required.

Natural light can add value to the thermal performance of the building which in conclusion leads to thermal comfort of the user.

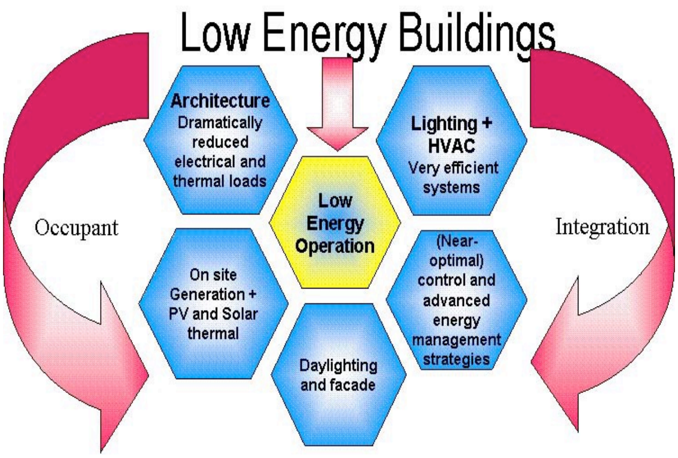


Fig 2-11: Diagrammatic explanation on low energy buildings Source: Simon Burton

Similarly, there can be smart lighting (automated lighting) incorporated when retrofitting. The control system for the artificial lighting must be designed to optimize the use of daylighting and minimize electricity use. Lighting control systems typically provide the ability to automatically adjust a lighting device's output based on:

a. Chronological time - Chronological time schedules incorporate specific times of the day, week, month, or year.
b. Astronomical time - Astronomical time schedules incorporate sunrise and sunset times, often used to switch outdoor lighting. Astronomical time scheduling requires that the location of the building be set. This is accomplished using the building's geographic location via either latitude or longitude or by picking the nearest city in a given database giving the approximate location and corresponding astronomical times.
c. Occupancy - Space occupancy is primarily determined with occupancy sensors.
d. Daylight availability – Daylight availability electric lighting energy use can be adjusted by automatically dimming and/or switching electric lights in response to the level of available daylight. Reducing the amount of electric lighting used when daylight is available is known as daylight harvesting.
e. Alarm conditions - Alarm conditions typically include inputs from other building systems such as the fire alarm or HVAC system, which may trigger an emergency 'all lights on' command for example.
f. Program logic - Program logic can tie all of the above elements together using constructs such as if-then-else statements and logical operators.

2.5.2 Natural Ventilation

Because global warming brings about new climatic conditions, the impact of climate change on our built environment will be significant whether through high temperatures, increase in flooding risks, strain on water resources or less stable ground conditions among others. It is expected that climate change will have a significant impact on the design, construction and performance of buildings, as well as the health and productivity of people living and working inside them (Guan.L, 2009).

Narrow-plan buildings with the ability for cross ventilation may be able to be comfortable with natural ventilation and this will provide the best energy efficiency where usable. Natural ventilation needs careful design to enable wind and stack-driven air movement to provide enough fresh air for a healthy internal environment and to remove excess in the heat gain in summer. Draught free controllable openings in the facades can be windows or low- or high-level vents and these latter can be wind pressure controlled to control the amount of wind-driven ventilation (Burton.S, 2015).

2.5.3 Low electricity outputs for equipment

Retrofitting should be the opportunity to install the most efficient equipment which will both reduce energy consumption. Mechanical services equipment, fans and pumps, are available which use a fraction of the energy of older models and can frequently replace older components without difficulty. Office equipment, servers, computers and printers are major energy users in offices and should be chosen for maximum energy efficiency and programmed to ensure that they are turned off when not in use. Replacement lifts can all be chosen to be low-energy versions. Kitchen equipment for food storage, cooking, serving and washing up can all be chosen, and systems designed, to minimize energy use (Burton.S, 2015).

2.5.4 Renewable energy

Renewable energy is energy which can be obtained from natural resources that can be constantly replenished. Renewable energy technologies include technologies that use—or enable the use of—one or more renewable energy sources.

bioenergy	geothermal energy	hydropower
ocean energy	solar energy	wind energy

Table 2-3: Illustrated above are the different types of renewable energy available. Source: http://arena.gov.au/about-renewable-energy/

Renewable energy technologies also include hybrid and related technologies. For example, technologies that:

a) store energy generated using renewable energy
b) predict renewable energy supply
c) assist in the delivery of energy generated using renewable energy technologies to energy consumers.

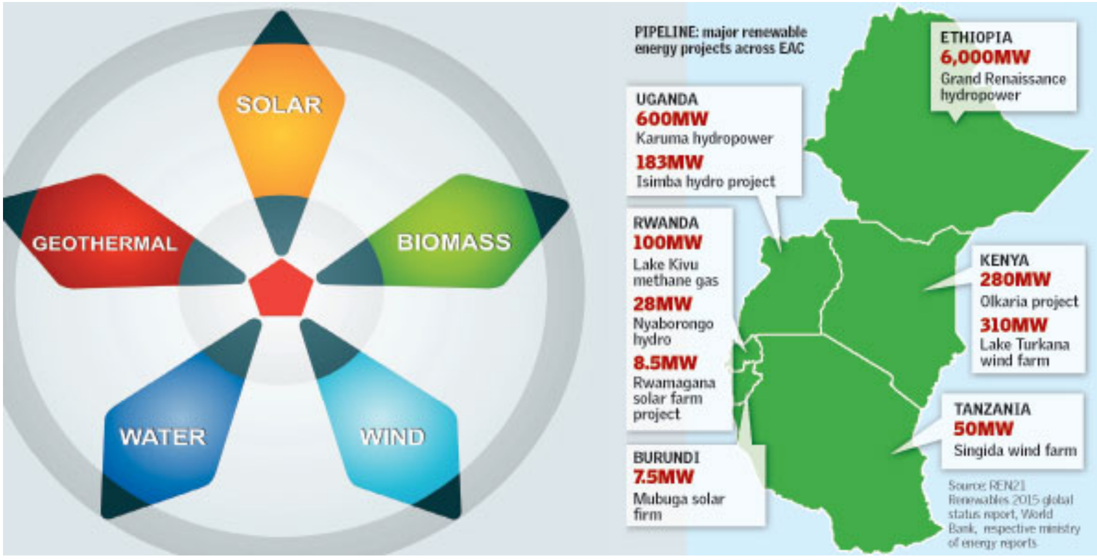


Fig 2-12: East Africa is emerging as a global renewable energy hub thanks to completed and ongoing projects to exploit clean power sources such as geothermal, hydro, wind, solar and biofuels. Source: Tea Graphic | Nation Media Group

2.5.5 Smart buildings

The first buildings ever constructed were primitive shelters made from stones, sticks, animal skins and other natural materials. While they hardly resembled the steel and glass that make up a modern city skyline, these early structures had the same purpose to provide a comfortable space for the people inside.

Buildings today are designed using different systems, technologies and different structures that are available in the industry today. Over time, each of the components inside a building has been developed and improved.

Building owners are willing today to think outside the box (four walls of the building) and come up with designs that are economical and functional at the same time beneficial to the impact of the environment with the help of Architects and Designers in the relative fields. To meet these objectives, it is not enough for a building to simply contain the systems that provide comfort, light and safety. Buildings of the future must connect the various pieces in an integrated, dynamic and functional way. This vision is a building that seamlessly fulfils its mission while minimizing energy cost, supporting a robust electric grid and mitigating environmental impact.

At the most fundamental level, smart buildings deliver useful building services that make occupants productive (e.g. illumination, thermal comfort, air quality, physical security, sanitation, and many more) at the lowest cost and environmental impact over the building lifecycle. Reaching this vision requires adding intelligence from the beginning of design phase through to the end of the building's useful life. Smart buildings use information technology during operation to connect a variety of subsystems, which typically operate independently, so that these systems can share information to optimize total building performance. Smart buildings look beyond the building equipment within their four walls. They are connected and responsive to the smart power grid, and they interact with building operators and occupants to empower them with new levels of visibility and actionable information.

2.5.6 Materials

As earlier mentioned, passive design strategies consider materials at concept stage. When retrofitting a building materials also comes into discussions as these are what will be employed to ensure the building improves in terms of thermal performance. Therefore, designer must ensure the use of external finishes that are smooth and light colored to reduce solar heat absorption.

If alternative construction materials can be considered then there are many choices in today's modern world. In addition to using alternative construction materials, locally available materials, with low embodied energy, with little to no maintenance, materials that are sustainably harvested, non-toxic, those with minimal internal pollution and damage to health and those which are easy to re-cycle or to re-use.

2.6 Importance of The Building Envelope

2.6.0 Façade design

Often retrofit involves modifications to existing commercial buildings that may improve energy efficiency or decrease energy demand. This building retrofitting leads to improving the thermal performance of the building and also leads to the efficiency of running the building. Therefore, a building that was once 'tired' may be rejuvenated into an active and useful building.

The facade is an essential element of the building's performance and of its essential value. Aesthetically the facade gives a building image, responding to and creating context, and giving the lasting impression of value. In this way, it defines the longevity of a building.

Heat, light, air, sound and views all pass through the façade and the faced is a key environmental filter. Not only does the building envelope impact the performance of the building in embodied and operational carbon terms but it also influences the performance of the people working in the building. Their comfort and concentration are fundamentally related to the facade.[21]

Retrofitting the building envelope may vary from project to project and often involves a mixture of approaches depending on the different facade types involved. For simplicity, envelope refurbishment can be considered in four generic typologies:

a. over-cladding – installing a new envelope directly over the existing
b. re-cladding – removing the existing facade and installing a new system
c. refurbishment – repairing an existing facade
d. retained facades – keeping and repairing an existing facade whilst replacing the building behind it.

2.6.1 Over-cladding

As the name suggests, this includes retaining the existing façade of the building and creating a new façade over it. There may be a number of reasons to choose over-cladding:

i. It could be a low-cost option for the developer/owner of the building as demolition costs are eliminated. A point to note is if the existing façade is affecting the thermal performance of the building, it may still affect the building even with over-cladding done.
ii. Internal work should be at a minimum as the new facade can often be installed without the building's tenants vacating the premises. This may be good for the

[21] Burton, S. (2014) Sustainable retrofitting of commercial buildings: Cool Climates, London and New York, Routledge

developers or owners of the buildings as they can maintain making money from the existing occupants of the building. A disadvantage to be noted though, would be noise pollution during the over-cladding process.

iii. With savings on demolitions, this option is a low embodied carbon emission option meaning reduction in material use and waste, reliance on energy-intensive manufacturing and thus leading to being environmentally friendly.

iv. The building's overall look remains similar so it may offer a smooth ride through the local planning process.

Although it may be a cost saving typology, it is not straight forward and may have many disadvantages that may affect this to be the optimal choice.

2.6.2 Re-cladding

Examples of re-cladding has been used in Kenya. Examples below are the examples found in Nairobi, Kenya which is in the tropics and is argued by environmental specialists as being unsuitable for Kenya's climate.

Fig 2- 13: Victor house as originally built on the left and glass cladded (2014) on the right. Source: Musau Kimeu, July 2015

Fig 2- 14: Family bank headquarters on Muindi Mbingu street, Nairobi currently being glass cladded (2014 - 2015) Source: Musau Kimeu, July 2015

The existing building envelope is completely removed and replaced by a new system. Within the geometric constraints of the existing building, re-cladding can reinvent a building's image and value. It also gives the opportunity to redefine its environmental performance. Re-cladding may be chosen for a number of reasons:

a. It allows a complete rebranding and repositioning of a building's value in its market.
b. The use of daylight and thermal performance of the building can be redefined.
c. Re-cladding can improve the thermal performance by using sustainable and efficient materials. An opportunity for natural lighting and natural ventilation may be introduced in the new façade.

Re-cladding has its own disadvantages just like over-cladding. Such include, surveying the existing structure to structurally allow such changes, high embodied carbon emissions as a new façade is being manufactured a fresh, noise pollution affecting occupants and loss of income for the developers or owners as the tenants/ occupants have to vacate the premises as this will be a construction zone.

This typology of façade design may be the best option as the best environmental strategies can be employed to the building although may not be a cost-efficient choice for the developer/owner.

2.6.3 Refurbishment

There are ways to repair an existing façade. In the tropical climate where a faced has 100% glass façade, there may be ways to change the façade without going deep into construction.

Sun shading elements may be added to the façade (vertical, horizontal or egg-crate sun shading elements) this may improve the thermal performance of the building but a disadvantage may be the views may be compromised and the installation of these elements may be high in embodied carbon emission as it is manufacturing elements to add to the façade.

Window upgrading may be another option of refurbishment. This may include adding double glazing for example to a single glazed building. This may not be optimal for the people working in the building but it may improve the thermal performance of the building as well as not compromise the view of the internal space. Using thermal glass for the window upgrading may also be an option for improving the thermal performance of the building as well as not compromise the views.

Although refurbishment may be a viable option, it is mostly to improve the internal spaces than change the façade design.

2.6.4 Retained façades

Some buildings have such huge heritage value in their facades that they need to be preserved because it is their appearance and cultural history that gives the buildings their value. It is worth mentioning in passing an extension of facade retention – dismantling and rebuilding historic facades, for example below, Leven house in Old Town Mombasa.

Fig 2- 15: Leven House is an example of a retained facade as it is protected under the conservation act in Kenya. The new facade mimics exactly the original building. Although the original building was almost a ruin, it was restored. Source: Author

Working on heritage facades is a skilled and somewhat specialized practice. Heritage buildings often establish a specific and positive brand.

2.7 Summary

In summary, façade design has its positives and its negatives. Some of the typologies are low cost and others may cost the developer or owner plenty especially capital cost or rental income from occupants.

Introduction of environmental retrofitting strategies to the building using re-cladding and refurbishment typologies. Such examples like natural ventilation and natural lighting may be achieved and overall, improving thermal performance of the commercial buildings.

In chapter three, a scientific study will be undertaken to determine which is the best typology to be used after determining which of the parameters investigated affect the building under study.

CHAPTER THREE: RESEARCH METHOD

3.1 Introduction

This chapter seeks to lay out the method used to satisfy aims and objectives of the study defined in chapter one. It identifies and catalogues all the instruments used during field work and outlines methods used for presentation, data collection and analysis. Simulation software will be introduced and basics interpreted.

3.2 Study Sampling

Time and restriction of number of words being genuine constraints in this study, the scope of this research is limited, and will focus on following areas:

a. Building components: The analysis has concentrated on the building envelope components above ground and are limited to: the roof, external walls, external windows, external doors and shading systems if any exist.
b. Building typology: The findings of this study is restricted to commercial buildings in Nairobi Central Business District and within the topical upland climate of Nairobi. The study focuses on climate non-responsive commercial buildings where the external façade is fully glazed and internal temperatures are considered to be not comfortable for the user.
c. Weather scenarios: Climatic data from the nearest meteorological stations, notably Dagoretti Corner.
d. Geographical locations: Nairobi, Kenya.

e. Thermal and energy performance: INKBIRD data loggers will be placed strategically in the building to log the temperature and relative humidity of the internal and external spaces of the building under study.

f. Others: Software – IES VE is an architectural analysis software package is specifically designed to meet the needs of Architects for sustainable analysis. The software will be used to employ retrofitting strategies to the building under study once it has been drafted as is with the data collected from the ground.

3.2.1 Mapping

This research as much as it focuses on one building in Nairobi's Central Business District, there is need to look at other similar buildings with the same Architecture of commercial buildings which have transformed since colonial days to the present.

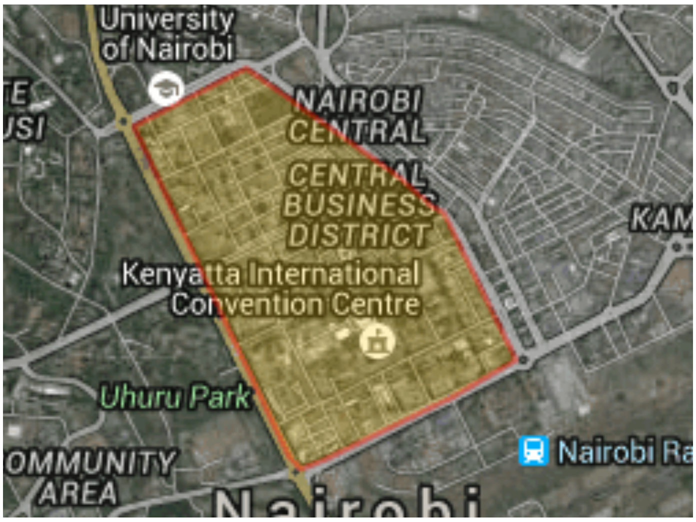
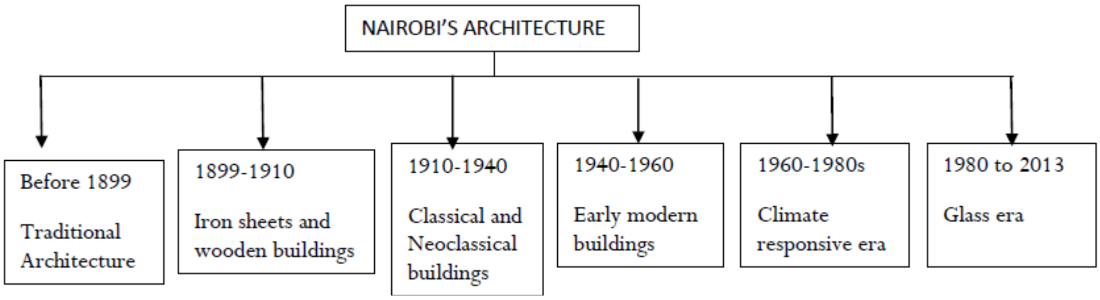


Fig 3-1: Nairobi CBD boundaries. Building under study is within these boundaries. Source: Author

Fig 3-2: Nairobi's skyline taken from a high-level building in upper hill. This image shows the different skyscrapers (some are deemed environmentally friendly others not). Visibly clear are the glass facades that are a fad in Nairobi's skyline today. Source: Internet

The Nairobi skyline is among the most recognizable cityscapes in the world. Nairobi's history of towers began with the 20-storey Hilton Nairobi in 1969, the 20-storey National Social Security Fund building in 1973, and the 30-storey KICC in 1974. Buildings in the city had remained relatively short until the late 1960s as well as suitable for Nairobi's climate, when the city experienced its first skyscraper boom. From 1960 to 1980, Nairobi witnessed a major expansion of skyscraper and high-rise construction, with many of the city's office towers completed during this period. A near 20-year lull in building construction followed, before picking up again in the late 1990s and early 2000s. Over the last 10 years, the city has experienced something of a renaissance in construction. As at the end of 2013, there were over 20 buildings either topped out, under construction, approved, or on-hold or proposed in Nairobi. At least 85 percent of those stand as tall as 65 meters (15 floors) or more.[22]

[22] Ventures Africa (2014), Nairobi's Changing Skyline: Commercial Real Estate on The Rise, Retrieved from: http://venturesafrica.com/nairobis-changing-skyline-commercial-real-estate-on-the-rise/



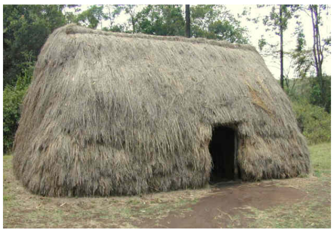
Mijikenda Kaya	Stanley Hotel	City Hall
		
City Market	IPS building	View Park Towers
		

Table 3-1: Images showing Nairobi's architecture evolving from the traditional Kaya to the case study being studied by the author which is a fully glazed façade skyscraper, View park Towers (this is amongst the first glass buildings in Nairobi and also the most criticized building in terms of environmental suitably).

3.2.2 Sampling

Building selected is View Park Towers which was constructed during the emergence of glass as a main facade material in 1989. It is considered to be one of the first glass skyscrapers during this era. The building is an office block with 22 floors above ground and 2 basement levels for 116 vehicles. Located on Uhuru Highway and Utalii lane in the CBD of Nairobi, it stands tall as a fully glazed building. Glazed facades located within Nairobi, which experiences tropical upland climate, are said to be unsuitable for the climate. Therefore, the author selected this building amongst the cluster of the other 'firsts' in the same area. In an article written by construction review in September/October 1990 edition, the building was covered as "transforming the dullness of the north-west end of town with its shimmering glass façade.

The building is only 75% occupied and the general floor finishes is wall to wall carpet and in some offices, floor tiles. The offices are partitioned with timber partitions. Not all of the offices use air-conditioning but because the building is oriented East-West the office spaces get really hot in the morning when the sun is rising and in the afternoons when the sun is setting. Another reason for the interior getting really hot is that the external wall is a glazed curtain wall allowing heat to penetrate easily and with no sun shading devices allowing direct sun rays into the building.

Fig 3-3: View Park towers view from Central Park at sunset. This skyscraper was amongst the first to be built in Kenya. It is surrounded by Hazina Towers on the left, Ambank house at the back and Utalii House on the right. Source: Author

The floor plan is anything but narrow and the services and circulation spaces are located in the middle of the building. There are dead spaces in the corner that aren't in use today which were a cause of the shape of the building floor plan.

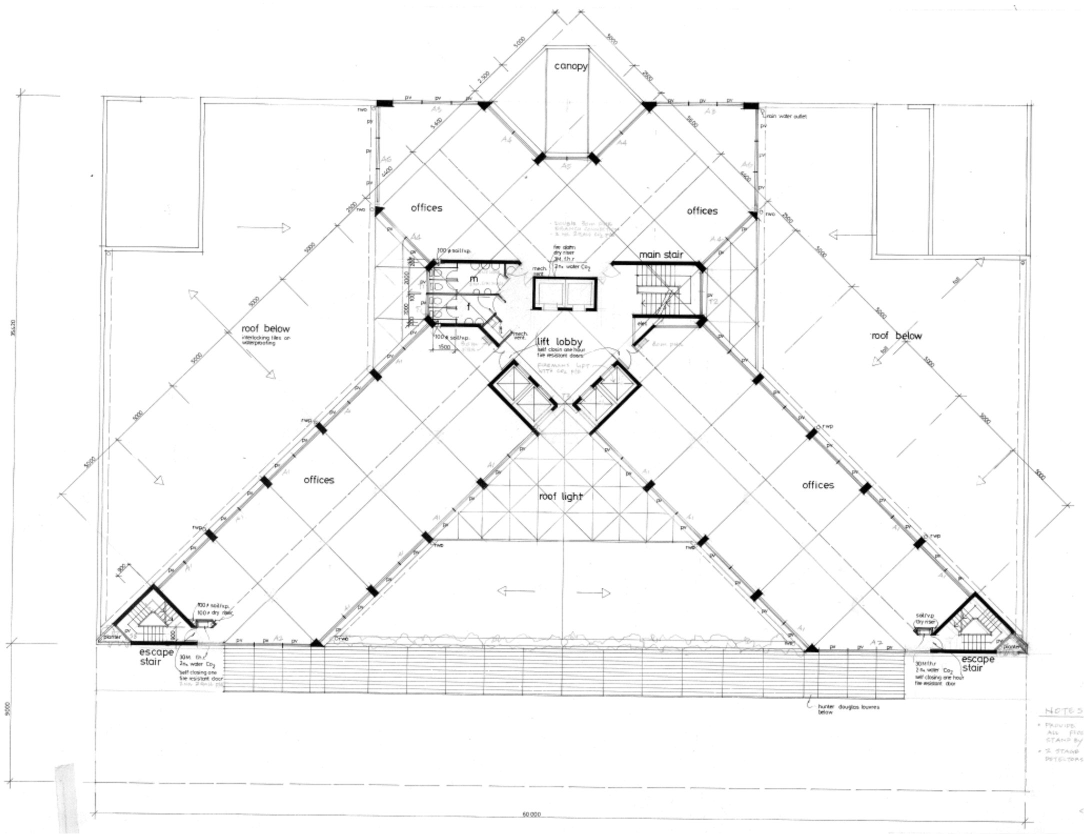


Fig 3- 4 Floor plan of View Park Towers drafted in the late 1980s. Source: Harbans Singh Associates

<u>3.3 Data Collection</u>

Quantitative thermal modeling of the case study building defined above was undertaken to present the indoor thermal levels for both the present-day climate (April – May 2016).

Computer simulations were undertaken using IES VE software to investigate the indoor temperature implications as a result of the dynamic interaction of the different building envelopes of the case study buildings in the context of Nairobi's changing weather.

IES VE helps the design team integrate performance analysis for sustainable building design early in the design process, where it belongs. The software works from master planning to conceptual and schematic design through detailed design and completion. The company's foundation lies in the main concept that "fossil fuels are finite and as buildings account for 40% of the world's carbon emissions they must be made more efficient". IES even offers software tools for tracking operating performance including thermal comfort, sustainability compliance, building metrics, carbon footprint and energy use.

There was no need to draft the whole building, only the office on the first floor where data logger was placed was drafted as shown in Fig 3-5 below.

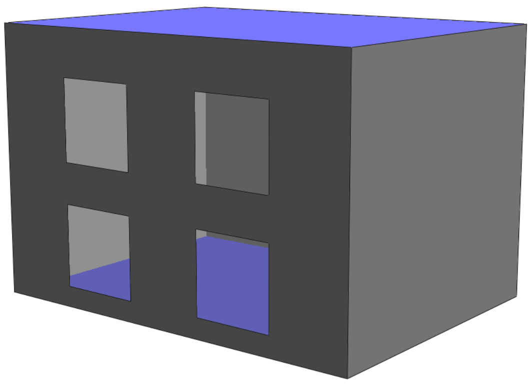


Fig 3-5: Three-dimensional drawing of View Park (one wing where office is located). The author illustrates how the simulation is done and applies the parameters to the model to analyze how the building will perform.

Source: Author

The field survey carried out in Nairobi Central Business District in Kenya, View Park Towers involved recording internal temperature over a period of 10 days from 4th April 2016 to 11th April 2016 and again from 28th April 2016 to 5th May 2016 using INKBIRD THC-4 data logger shown in Fig 3-6.

Fig 3-6: INKBIRD Data Logger used for collecting the temperature and relative humidity of View Park Towers. Source: Author

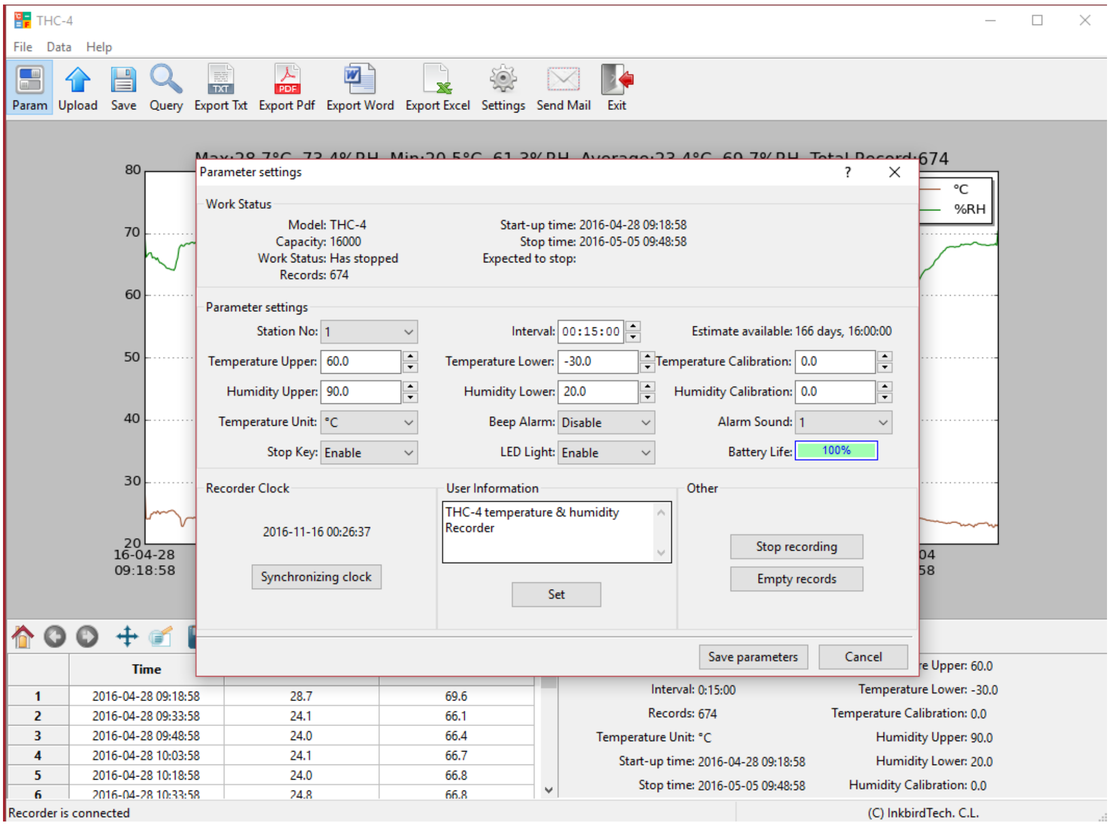
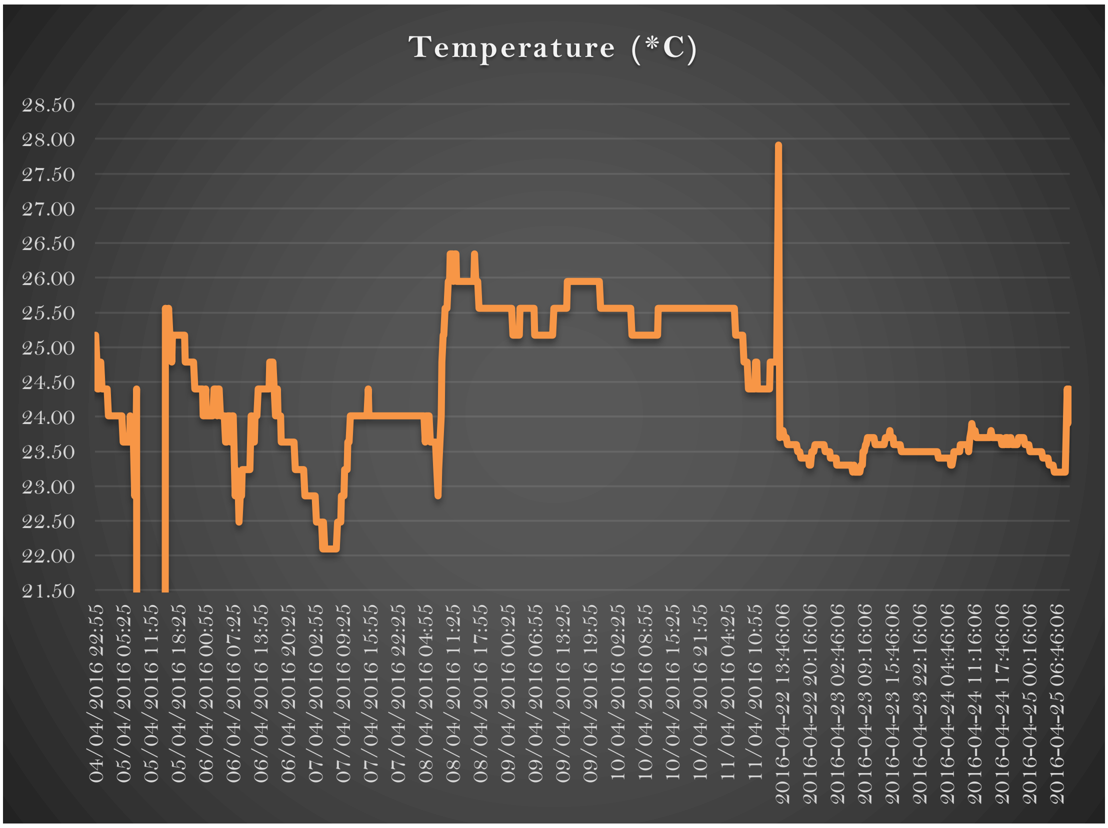


Fig 3-7: Interface for extracting the information of the INKBIRD data logger. From this software, you can export data in excel or PDF or word. Source: Author

The Psychometric chart derived by Givoni shows us that the comfortable climate for Nairobi is between 20 and 24 degree Celsius. The month of April is usually the beginning of the raining season in Nairobi, therefore temperatures are not as high. This explains why we do not see temperatures above 30 degrees during the day and low temperatures of below 16 degrees at night. The highest temperature recorded was 27.91 degrees Celsius and a low of -13.49 degrees Celsius where the author recorded that the logger was moved near the AC duct and lowered the temperatures exponentially. Other low temperatures recorded was 22.86 degree Celsius. The graph illustrated below shows the temperatures of the building are on the higher side of the comfort zone as temperatures range between 22.86 and 27.91 degree Celsius.



Graph 3-1: Data logger data for temperature and relative humidity for the days the author put the data logger in the office at View Park Towers. The information was taken for a period of five days. Source: Author

After collecting the temperature on the ground, this is again fed into the IES VE software so as to aid in the simulations. SimLab was used for generation of the number of simulations to be undertaken in IES VE software. SimLab is a didactical software designed for global uncertainty and sensitivity analysis. These analyses are based on performing multiple model evaluations with probabilistically selected input factors, and then using the results of these evaluations to determine the uncertainty or sensitivity in model predictions and the input factors that gave rise to this uncertainty. Saltelli et al (2004) notes that to use SimLab the user performs the following operations: Select a range and distribution for each input factor. These selections will be used in the next step for the generation of a sample of elements from the distribution of the inputs previously specified. The result of this step is a sequence of sample elements. Then, feed the model with the sample elements and produce a set of model outputs. In essence, these model evaluations create a mapping from the space of the inputs to the space of the results. This mapping is the basis for subsequent uncertainty and sensitivity analysis. Lastly, use the results of model evaluations as the basis for Sensitivity Analysis[23.]

[23] Saltelli A., Chan K., Stott EM (2004) Sensitivity Analysis in practice, West Sussex, England, John Wiley and Sons.

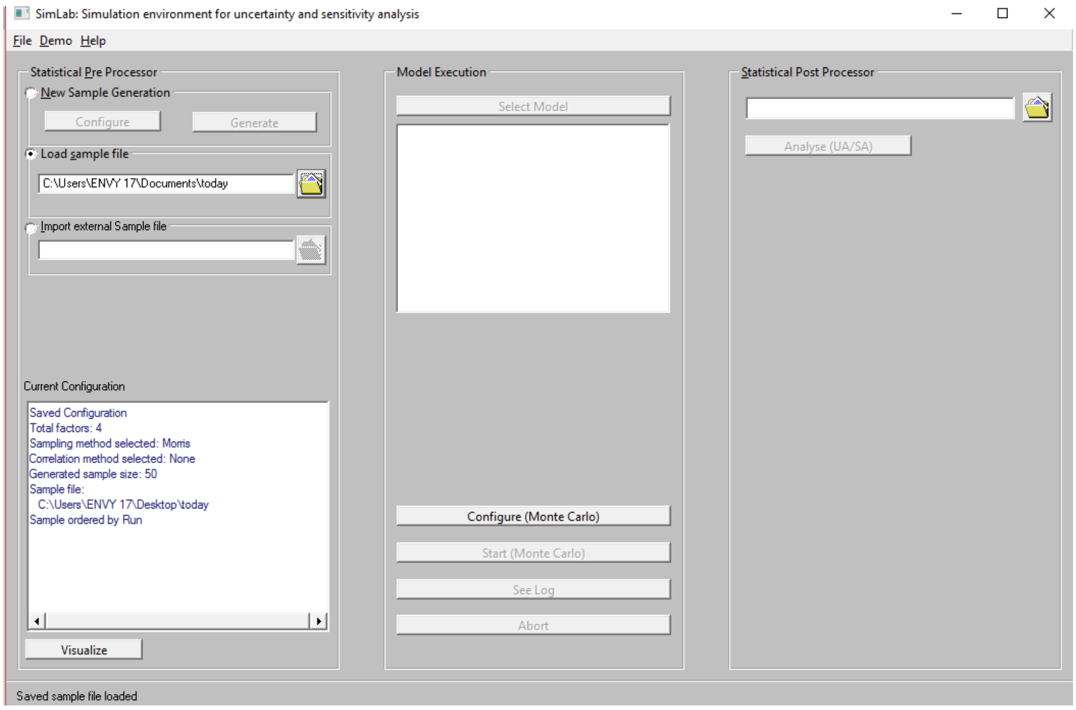


Fig 3-8: SimLab software platform where you generate the different scenarios used for simulation. You can either load data from a previously saved document or create the simulations by pressing on New. As viewed above with the four parameters inputted there are 50 scenarios needed to be simulated to improve the thermal performance of View Park Towers. Source: Author

As mentioned in Literature review, four parameters will be analyzed for the simulation of View Park Towers; Wall thickness, Window to wall ratio, glazing and sun shading devices.

After identifying the parameters to investigate, using SimLab, the next step is to define the list of factors that represents the input of the model and to specify the parameter assumptions on each factor.

All parameters assume a discrete probability distribution to illustrate the equal possibility of each option to materialize in the case study building at any given opportunity. Variability analysis was mostly informed by the case building design and the existing modes in Nairobi.

Below is a summary from SimLab showing the parameters.

PARAMETERS	DISTRIBUTION	RANGE	KEY
Window ratios	Discrete	25% or 75%	0 means 25% or 1 means 75%
Sun shading	Discrete	With or without	0 means With or 1 means without
Glazing	Discrete	Single or double glazing	0 means single glazing or 1 means double glazing
Wall thickness	Discrete	200mm or 450mm	0 means 200mm or 1 means 450mm

Table 3-2: Parameters defined. Source: Author

The next step to implement is the sample generation. Different choices are available in SimLab: Random Sampling, Quasi- Random, Replicated Latin Hypercube, Latin Hypercube, classic and extended FAST (Fourier Amplitude Sensitivity Test), Morris and fixed sample.

This step-in pre-simulation involves the generation of sample scenario spaces, from the options listed in table above, to act as input data during the simulation stage. A total of 50 different scenarios were generated using the Morris method.

The guiding philosophy of the Morris method is to determine which factors may be considered to have effects, which are negligible, linear and additive, or non-linear or involved in interaction with other parameters. Saltelli (2004) further notes that the general experimental plan for Morris method is composed of individual randomized 'one-factor-at-a-time' experiments, in which the impact of changing the value of each of the chosen factors is evaluated in turn. As such, the Morris method is relevant for generation of inputs for this study.[24]

3.4 Data Analysis

For the building under study, the envelope component materials were identified and areas calculated. The material layer combinations for each of these materials were input in IES VE software for simulation. Their net u-values are an output from IES VE software.

To perform a multi-scenario climatic analysis using IES VE building environmental simulation software, the provision of suitable weather data was critical. Closest meteorological station to Nairobi CBD is Dagoretti station and therefore this file data was loaded into IES VE software for the simulation.

[24] Saltelli A., Tarantola S., Campolongo F., Ratto M., (2004), Sensitivity analysis in practice: a guide to assessing scientific models, New Jersey, Wiley-Blackwell.

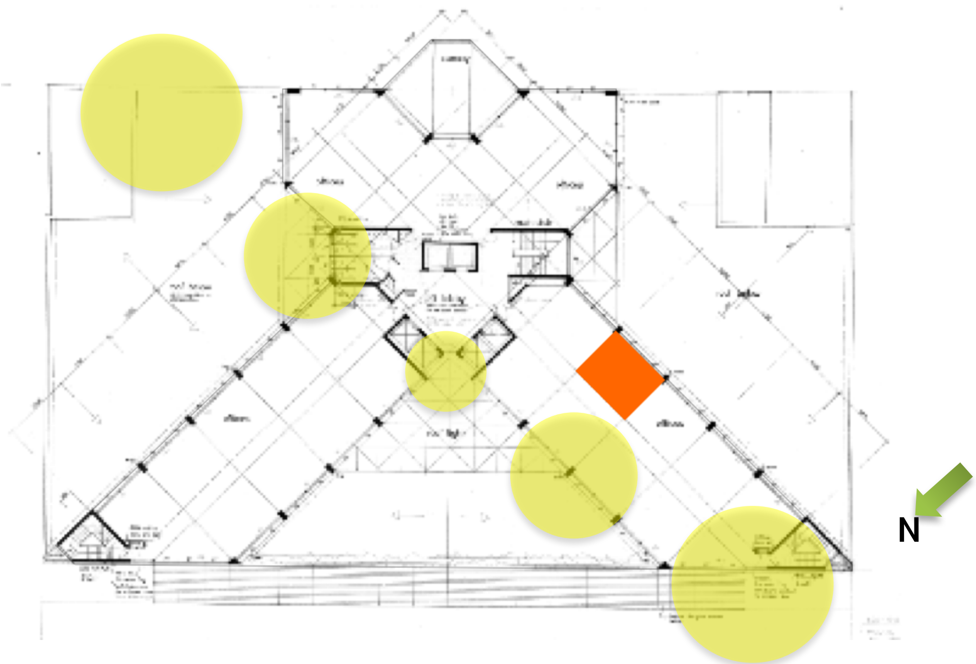


Fig 3-9: First Floor Plan of View Park Towers. In orange is the office which author is studying and is where the data logger was place. The office is directly in the sun's path has been illustrated. Source: Author

After the scenarios have been achieved from SimLab, the author then puts all this data into IES VE simulating 50 different models adjusting the different scenarios achieved. First step is to model the building/ office as it is exactly on the ground and compute the climatic data. Second step is to compute the different scenarios into the model and output data collected.

Table 3-1 illustrates the different parameters inputted into the simulation model no.10 to achieve the desirable retrofit in IES VE and together with using Humphrey's formula, the percentage of thermal comfort is calculated. The following retrofit was done:

i. Window ratio reduced to 25% from 100% fully glazed façade.
ii. The intervention shows that no sun shading elements were to be added to the façade.

iii. Building was to retain its single glazing façade

iv. Finally, façade design of over-cladding or re-cladding is to be done and wall thickness to be made 450mm.

Scenario	Parameters				Results
	Window ratios	Sun shading	Glazing	Wall thickness	% above comfort zone
10	0	1	0	1	0.776

Table 3-3: The results above shows that the improvement of the building only happened to 77.6%. In order for the building to drastically improve its thermal performance an ideal scenario would lead to 50% or below. Source: Author

3.5 Summary

The final stage involves performing a sensitivity analysis in order to determine which amongst the individual four parameters is the most important and which one is the least important to create an environmentally suitable building.

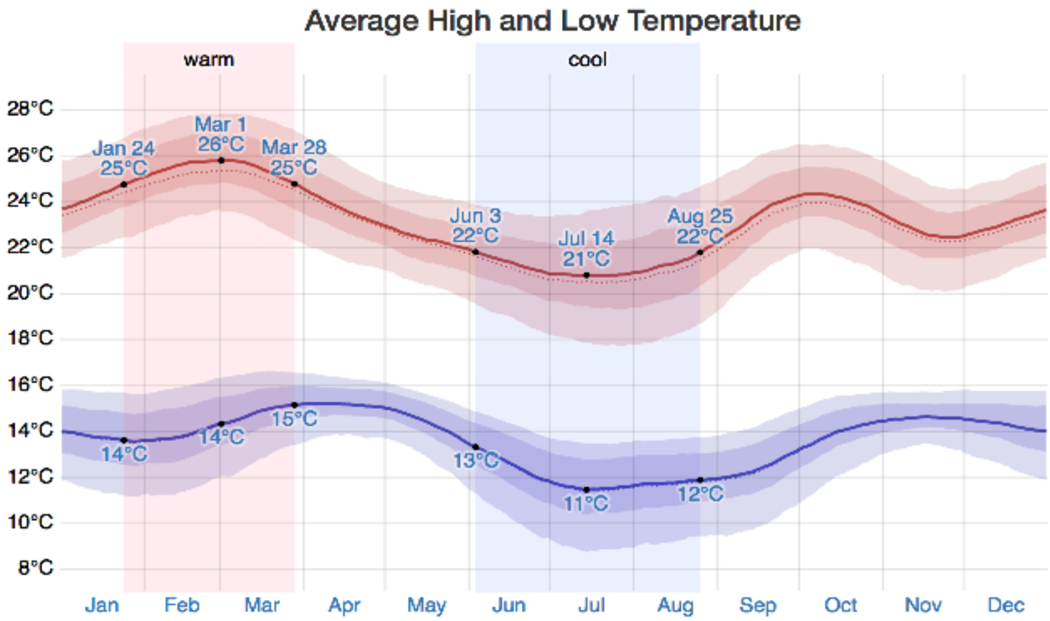
CHAPTER FOUR: DISCUSSIONS OF RESULTS

4.1 Introduction

In this chapter, the scientific study results will be discussed. Simulations which were done in previous chapter, will be analyzed and conclusions shared.

In the city of Nairobi, over the course of a year, the temperature typically varies from 11ºC to 26ºC and is rarely below 9ºC or above 28ºC. The warm season lasts from January 24th to March 28th with an average daily high temperature above 25ºC. The hottest day of the year is March 1st, with an average high of 26ºC and low of 14ºC. The cold season lasts from June 3rd to August 25th with an average daily high temperature below 22ºC. The coldest day of the year is July 14th, with an average low of 11ºC and high of 21ºC as shown Fig 4-1. [25]

[25] Kenya Meteorological Department (1984) Climatological Statistics for Kenya.



Graph 4- 1: The daily average high (red line) and low (blue line) temperature with percentile bands, with 25th to 75th and 10th to 90th percentile bands. The thin dotted lines are the corresponding average perceived temperatures. Source: www.weatherspark.com

In consideration of this, the author decided to investigate the sensitivity of the passive design strategies with overheating as the selected performance indicator using the Humphreys thermal neutral formulae for free running buildings ($11.9+0.534T_{me}$ (ºC)). An average of thirty-minute interval values of indoor temperature above the thermal comfort levels are calculated for each scenario calculating the net value of thermal discomfort in ºC in a typical year (T_0=21.97ºC).

4.2 Results

Climatic data from IES-VE software was used together with Humphreys formula ($11.9+0.534T_{me}$(°C)) to get the temperature that is above the comfort zone temperature. Using the formula, the optimal temperature is 21.97°C.

A sensitivity analysis was performed to identify the most important passive design parameters in improving the thermal performance of View Park Towers. Four passive thermal design strategies used on the View Park Towers were identified, namely, window ratio, sun shading devices, glazing and wall thicknesses. In the analysis, different design scenarios generated by SimLab were modelled in IES VE for the ten days the data loggers were in the building in addition to the indoor temperature above the thermal comfort recorded and evaluated by a different software package for sensitivity analysis results.

When each of the simulations are done, the temperature after the retrofit strategies are applied are then compared against optimum temperature deduced using Humphrey's formula to view by what percentage has the building's thermal performance improved.

Below are the scenarios generated by SimLab and the last column is the results on the improvement of thermal performance of the building.

Scenario	Parameters				Results
	Window ratios	Sun shading	Glazing	Wall thickness	% above comfort zone
1	0	1	1	0	0.688
2	0	1	0	0	0.786
3	0	1	0	1	0.776
4	1	1	0	1	0.557
5	1	0	0	1	0.422
6	1	0	1	0	0.417

7	1	1	1	0	0.579
8	1	1	1	1	0.557
9	1	1	0	1	0.557
10	0	1	0	1	0.776
11	1	0	0	0	0.422
12	1	1	0	0	0.557
13	0	1	0	0	0.776
14	0	1	0	1	0.776
15	0	1	1	1	0.771
16	1	1	1	1	0.724
17	1	0	1	1	0.703
18	1	0	0	1	0.724
19	1	0	0	0	0.682
20	0	0	0	0	0.682
21	1	0	1	1	0.667
22	1	0	1	0	0.667
23	1	0	0	0	0.667
24	0	0	0	0	0.682
25	0	1	0	0	0.682
26	0	1	0	0	0.682
27	0	0	0	0	0.682
28	1	0	0	0	0.667
29	1	0	0	1	0.703

30	1	0	1	1	0.667
31	0	1	0	0	0.682
32	0	1	0	1	0.776
33	1	1	0	1	0.557
34	1	0	0	1	0.703
35	1	0	1	1	0.667
36	0	0	1	1	0.672
37	0	0	0	1	0.724
38	0	1	0	1	0.776
39	0	1	0	0	0.776
40	1	1	0	0	0.557
41	1	0	1	1	0.667
42	0	0	1	1	0.672
43	0	0	0	1	0.724
44	0	1	0	1	0.776
45	0	1	0	0	0.682
46	1	1	0	1	0.557
47	0	1	0	1	0.776
48	0	0	0	1	0.724
49	0	0	1	1	0.672
50	0	0	1	0	0.729

Table 4- 1: Summary of results from SimLab and IES-VE simulation Source: Author.

4.3 Discussion of Results

To generate the sensitivity values shown in Table 4-2, the author used SALib - Sensitivity Analysis Library in Python. The script morris.py takes in the inputs, output data and parameters of input data in a text files.

Parameters	Mu_star	Mu	Mu_star_Config	sigma
X1	0.134	-0.094	0.064	0.150
X2	0.088	-0.056	0.060	0.125
X3	0.114	-0.009	0.113	0.225
X4	0.128	0.025	0.086	0.194

Table 4- 2: Chart of sensitivity analysis for the April and May. Source: Author.

Morris Method is an elementary effect method introduced by Morris in 1991 which proposed two sensitivity that determine the effect of input factor. The sensitivity measures are mean and standard deviation of the distribution of input data. Mean asses the overall influence of the factor on the output while standard deviation estimates the ensemble of the factors order effects. High values of sigma imply that the given factor depend highly on other factor will low value of sigma implies that the given factor is almost independent of the values taken by the other factors. Campolongo (2007) in this work proposed change of mean in Morris to mean star which defined total sensitivity.

Method of Morris Implementation Strategy[26]

i. Derives measures of global sensitivity from a set of local derivatives, or elementary effects (EE)

ii. Each factor xi is perturbed along a grid of size Δi to create a trajectory through the factor space, where f(x) is the baseline

iii. Each trajectory yields one estimate of the elementary effect for each factor, i.e., the ratio of the change in model output to the change in that parameter

$$EE_i = \frac{f(x_1,\ldots,x_i+\Delta_i,\ldots,x_p) - f(\mathbf{x})}{\Delta_i}$$

iv. The computational cost is r(k+1) model runs, where k is the no. of parameters and r=4 to 10

v. We repeat this for N trajectories in the parameter space to avoid the dependence on a baseline

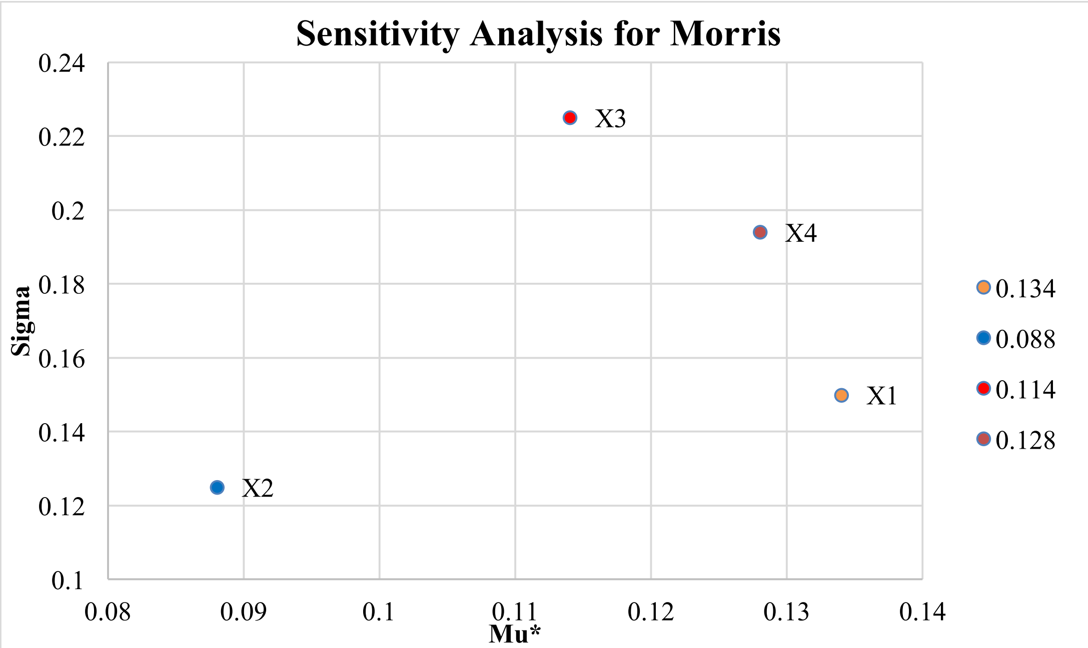
vi. We can then estimate the mean elementary effects μ (first order effects) and their standard deviation σ (interactions)

vii. Campolongo et al. (2007, EM&S) suggested calculating the absolute values of the mean

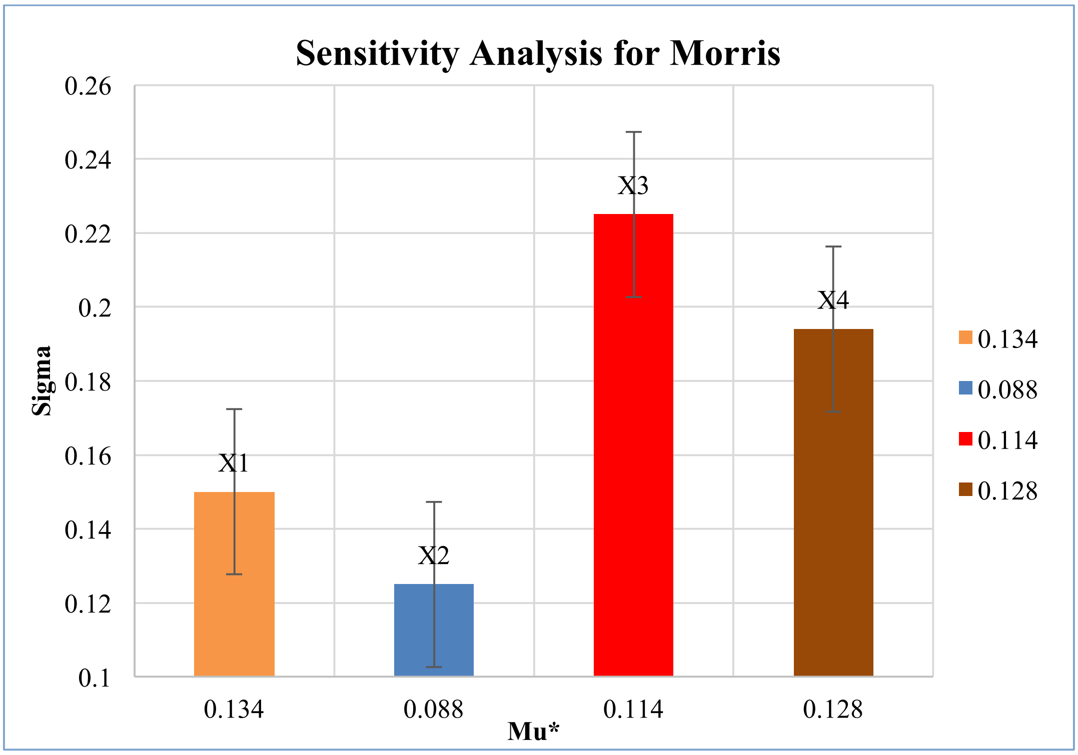
$$\mu_i^* = \frac{1}{N}\sum_{j=1}^{N}|EE_i^j|$$

[26] Kucherenko S., Rodriguez-Fernandez M., Pantelides C., Shah N., (2009) Monte Carlo evaluation of derivative-based global sensitivity measures, Retrieved from: https://www.repository.cam.ac.uk/bitstream/handle/1810/261584/Menberg_et_al-2016-

The results of the sensitivity analysis are shown in Graph 4-2. The figure shows the mean value (measure of importance) and the standard deviation (measure of interaction) in addition to Table 4-1 showing the ranking of the parameters for the entire year.



Graph 4-2: Chart of sensitivity analysis. Source: Author



Graph 4-3: Chart of sensitivity analysis. Source: Author

Legend
X1 – Window ratios
X2 – Sun shading devices
X3 - Glazing
X4 – Wall thickness

Table 4- 3: Legend. Source: Author

RANK	PARAMETER	M_u Star	Sigma
1	Glazing	0.128	0.194
2	Wall thickness	0.114	0.225
3	Window ratios	0.134	0.15
4	Sun shading devices	0.088	0.125

Table 4-4: Parameter ranking. Table of sensitivity analysis showing that glazing is the most important parameter in the design albeit the most dependent on other/certain parameters to perform well. The window to wall ratio and façade design of either over cladding or recladding to change the wall thickness are the two other important factors that are dependent on the glazing of the building. Adding sun shading devices was the parameter that was least dependent on other parameters to provide for comfortable indoor environments. Source: Author.

The sensitivity analysis determines which is the most important parameter to ensure View Park Towers improves its thermal performance to make it suitable for Nairobi's tropical upland climate. The window to wall ratio and façade design of either over cladding or recladding to change the wall thickness are the two other important factors that are dependent on the glazing of the building. Adding sun shading devices was the parameter that was least important to improve the thermal performance of View Park Towers.

For the period investigated, the sensitivity analysis results show that the glazing was the most sensitive/ most important parameter to be used in retrofitting of View Park Towers to improve the thermal performance and the environmental suitability. To carry out the research, two discrete values were analyzed, single glazing (as is existing in View Park Towers) or double glazing. The glass type employed, as existing on site, was 4mm clear glass. From the IES VE analysis, the results show that single glazing with no thermal properties whatsoever would increase the indoor space temperature to levels higher than all other scenarios investigated. Scenario number 2 (where the glass used was single glazing), for instance, had the highest levels above the comfort zone (see Table 4-5). Adding sun shading devises to this building while all other factors remain 'constant' has little significance because sun shading devices from the sensitivity analysis has the least impact on the retrofitting of the building to improve the thermal performance and make it more suitable to Nairobi Climate. This, in addition to other factors, can be attributed to the argument by Givoni (1994) when he noted that that heat gain through windows per unit area is much higher than through solid walls or roofs.

Scenario	Parameters				Results % above comfort zone
	Window ratios	Sun shading	Glazing	Wall thickness	
2	0	1	0	0	0.786

Table 4- 5: Extract from the summary of results from SimLab and IES VE simulation showing the highest possible indoor temperature. Source: Author.

To investigate the effect of the façade design, two parameters with two discrete values were analyzed; the wall thickness and the glazing of the building. Currently the building is 100% glazed with the wall thickness being the thickness of glass which 4mm. In

Scenario 5 and 11, retrofitting of the building reduced the window to wall ratio to 75%, with no sun shading, single glazing was maintained but recladding/ over cladding was done with a wall thickness of either 200mm or 450mm. The results show these combinations of parameters will improve comfort levels, leading to the assumption that having a wall thickness and not a glazed curtain wall as is the case of View Park Towers would have improved the thermal performance notwithstanding that it ranks second in regard to sensitivity analysis. The reason behind this finding would be in regards to the position of Nairobi near the equator meaning that wall thickness plays an important role in the passive design strategies for environmental suitability.

In Scenario 6, retrofitting by reducing window to wall ratio to 75%, with no sun shading, recladding/ over cladding was done with a wall thickness of 200mm and use of double glazing instead of single glazing. The results show these combinations of parameters improved the indoor thermal comfort the best. Table 4- 6 below confirms that the glazing and wall thickness have a huge impact on improving the thermal performance of View Park Towers.

Scenario	Parameters				Results % above comfort zone
	Window ratios	Sun shading	Glazing	Wall thickness	
5	1	0	0	1	0.422
6	1	0	1	0	0.417
11	1	0	0	0	0.422

Table 4- 6: Extract from the summary of results from SimLab and IES-VE simulation showing the lowest indoor temperatures achieved in the study. Source: Author.

To investigate the thermal performance of View Park Towers by adding sun shading devices in regards to retrofitting for environmental suitability, three scenarios were analyzed. According to the sensitivity analysis result, retrofitting strategy of adding sun shading devices is the least important strategy to be employed to the building. With assessment of Table 4-6, adding sun shading to each of those scenarios did not improve the thermal performance of the building but instead increased the temperatures slightly.

Adding external shading devices may affect the natural ventilation needed for passive cooling and thermal comfort thus increasing the indoor temperatures. Another factor to consider would be the author merely stated that the sun shading devices would be added or would not be added not taking into account that adding sun shading devices requires calculations in order to make them appropriate for the building requirements. A point to note, Scenario 4, 9, 33 and 46 have the same parameter combination and will give the same result as analyzed above.

Scenario	Parameters				Results % above comfort zone
	Window ratios	Sun shading	Glazing	Wall thickness	
4	1	1	0	1	0.557
8	1	1	1	1	0.557
12	1	1	0	0	0.557

Table 4- 7: Extract from the summary of results from SimLab and IES-VE simulation showing the second highest indoor temperatures achieved in the study. Source: Author.

Window ratios, ranked third in the sensitivity analysis although from the graph, the glazing type of the glass, the wall thickness and window ratios rely on one another to improve the thermal performance of the building. This can be attributed to factors like proportions and dimensions based on geographical latitude, need of having a minimum wall thickness of 200mmm in the tropics and the extent of solar energy absorption relatively and so much more.

All things considered, retrofitting the façade to reduce 100% glazed elevation to either 25% and 75% window to wall ratio impacted the thermal performance. Considering Table 4-8, where all the other parameters are kept 'constant' but only tweaking the window to wall ratio, improved the comfort levels. This analysis concludes that by only retrofitting the windows, the thermal performance of the building will improve but does not achieve the best percentage in the study.

Scenario	Parameters				Results % above comfort zone
	Window ratios	Sun shading	Glazing	Wall thickness	
35	1	0	1	1	0.667
36	0	0	1	1	0.672

Table 4- 8: Extract from the summary of results from SimLab and IES-VE simulation showing the third and fourth highest indoor temperatures achieved in the study. Source: Author.

4.4 Summary

Table 4-9 below illustrates the overall ranking of the four sustainable retrofitting strategies used in View Park Towers to improve the thermal performance. 50 scenarios generated by SimLab, didactical software designed for global uncertainty and sensitivity analysis, where each modelled and the percentage above the comfort level recorded. The results were fed back as inputs to Python library code SALib and a sensitivity analysis by Morris method performed.

It is evident from the results that the most important parameter was glazing, therefore in terms of sustainable retrofitting, the façade would have to be over cladded or re-cladded using glass with favorable thermal properties to improve the thermal performance of View Park Towers.

In conclusion, to generally improve View Park Towers to be climate responsive in Nairobi, all the parameters need to be applied in the retrofitting to improve the thermal performance of the building.

RANK	PARAMETER
1	Glazing
2	Wall thickness
3	Window to wall ratios
4	Sun shading devices

Table 4- 9: Overall ranking of the four parameters investigated in order of their importance to reducing overheating. Source: Author

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

View Park towers is located in Nairobi's Central Business District which experiences Tropical Upland Climate meaning it has very high temperatures. Glass buildings have become very popular in Nairobi's skyline as discussed in Chapter 2 not because they compromise views and do not allow maximum light into the building but because the layman feels that they have that modern feel like buildings in the West. Most designers argue that the glass skyscrapers reflect architecture in the present and most clients feel relevant with current trends if they perceive their buildings with the use of glass. With global warming becoming a major concern in the world, the glass structure is not ideal for the Nairobi climate. Most glazed buildings have not applied simple passive design strategies and therefore have led the buildings to have high carbon footprints, high running costs due to cooling of the building using air conditioning and primarily have low thermal performance and energy efficiency.

The research first and foremost highlighted how there are past studies taken with emphasis and focus on sustainable design for buildings from concept stages except some of these buildings end up being constructed without bringing into play the passive design strategies discussed in Literature review of this thesis and end up insensitive to their climate.

Thereafter, retrofitting was defined and the basic understanding illustrated as well as relaying the importance of retrofitting for environmental suitability. Retrofitting an existing building can in most cases be more cost-effective than demolishing and building a new facility. Buildings consume a considerable amount of energy especially in regards to cooling of commercial buildings in the tropics where the temperatures are exceedingly high. It would be important to instigate retrofits for environmental suitability that improve the thermal performance and energy efficiency of the building. Designing retrofits for existing buildings to include sustainability initiatives will reduce operation costs and negative environmental impacts.

The author divulged into retrofitting by looking at the history of it and highlighting at least one building that was retrofitted for sustainable purposes in the major continents. The buildings identified for the case studies were the first of their kind, in terms of sustainable retrofitting, and essentially buildings that were not environmentally conscious from inception stage. These buildings were retrofitted to reduce the greenhouse gases it emitted and reduce the carbon emissions produced within the building therefore lowering the building's running costs tenfold.

The complexity of identifying the most constructive sustainable retrofitting strategies was one of the major challenges. Retrofitting for environmental suitability can be done for the external properties of the building or the internal or both. The author focused on the external characteristics of the building, how they can be retrofitted to improve the thermal performance of the building, all in all, improving thermal comfort of the interior and its occupant. The external properties of View Park Towers to be analyzed were curtain waling, the lack of wall thickness, the use of single glazing and the lack thereof of external sun shading devices.

To meet the objectives of this research, View Park Towers was singled out as the case study building. The next step involved the identification of the sustainable retrofitting strategies to be employed to the building. From Chapter 2, four sustainable retrofitting strategies were identified, namely, widow to wall ratios, sun shading devices, glazing and wall thickness. Using the IES VE building simulation software, a model of the office under study in View Park Towers was built with all it attributes, both physically and thermally. SimLab software designed for global uncertainty and sensitivity analysis was used to generate fifty scenarios for the study and later Python library code SALib was used for sensitivity analysis using the Morris method.

Morris method is sometimes referenced to as a qualitative method where it gives a rough estimation with a limited number of calculations. The author determines which amongst the four parameters is the most important parameter to be retrofitted in order to improve the thermal performance of View Park Towers. The author firstly inputs all details pertaining to the building into a software called IES VE. These details constitute -building materials (exterior), internal finishes in the office under study, orientation of the building, climatic data of the closest meteorological station- which are used to inform the thermal performance of the building as is before any retrofitting parameters are applied. Secondly, the office space in View Park Towers building is drafted as it - 100% glazing, no sun shading and single glazing used for the glass façade. Thirdly, the author inputs the retrofitting parameters into another software called SimLab where it generates fifty scenarios. Thereafter each scenario is modelled applying the different combination of parameters derived from SimLab and each scenario is simulated to give output data. Lastly, using Humphreys' formula for free running buildings to identify the comfort temperature to be used for the analysis, in comparison to the thermal environment was assessed using the overheating index performance indicator. This is a cumulative indexing of the percentage above the comfort temperature (21.97ºC)) which in turn shows how much in terms of percentage does each combination of parameters improve the thermal performance of the building.

The value of sensitivity analysis lies in the fact that it helps in identifying the most important parameters in a set of alternatives. Sensitivity analysis for sustainable retrofitting can aid designers and developer (to some extent owners of buildings) some insights on how they can improve the thermal performance of building thus reducing overall costs, carbon emissions and greenhouse gases that contribute to global warming. Within the limited scope of this study, the results suggest that some interventions cause a greater variation to thermal performance than others. Out of the four parameters investigated, the glazing was the most important factor needed to be retrofitted to improve the thermal performance of View Park Towers. The least significant retrofitting strategy identified was the external sun shading devices.

In a broader sense, the results showed that the four parameters needed for retrofitting affected each other and it would be useful that all the strategies be employed to the building to get the best thermal performance. This is highlighted in Table 4-1 showing which combination of parameters improve the building's thermal performance.

5.2 Recommendations

The overall recommendation arising from this work, shows that a sustainable retrofit is a viable option as compared to demolishing the building and replacing it with a new build.

This thesis focused on View Park Towers as the primary case study. If sustainable retrofitting is to be carried out on another commercial building, it is recommended that retrofits are assessed on a site-specific basis

A sensitivity analysis should be carried out following the process outlined in this research as every building has a unique design and the microclimate of each building plays a very important role in its performance, there would be limits to the generalization of the results.

Owners and developers of commercial buildings within Nairobi's should consider retrofitting for environmental suitability. This will reduce the carbon emissions that contribute to global warming, reduce their running costs and electricity bills which are accumulated by cooling their buildings. By carrying out the sustainable retrofit, it ensures improvement of thermal performance of their buildings thus making them energy efficient.

Architects in Nairobi and by and large Kenya and Africa, should borrow from the other countries taking up retrofitting. From the case studies, it has shown that the consumption of a buildings energy can be reduced by up to 40%.

Recommendations for future work

Retrofitting and upgrading existing commercial buildings to energy efficiency through testing different retrofitting strategies is of utmost importance but their long-term viability depends on the sustainable, holistic approach where energy related measures are closely linked with functional, construction, and economic demands.

The implementation of the preliminary architectural and energy efficiency improvements in commercial buildings would have the additional benefits of increasing the commercial space market value and positive social effects, and incentivizing building owners and developers on awareness of energy consumption. At the same time, energy efficiency implementations targeted at the selected case study building can also improve indoor air and indoor environmental quality, with corresponding to reducing overheating risk assessment of a building.

In addition to direct energy consumption reduction, energy use potentialities of retrofitting measures can provide indirect economic benefits to both clients and developers, particularly in this research context.

Introducing subsidies/implications improves the feasibility of undertaken energy conscious retrofitting strategies, but they become sustainable on their own aspects and design parameters. Undertaken energy performance analysis of prototype models shows clearly that the proposed energy efficient strategies must be feasible. Obtained results must be valid and reliable justification of the significance of the proposed retrofitting to bring significant potentialities for energy savings.

To conclude, optimizing energy efficient retrofitting measures for mass and large scale commercial developments are of crucial importance, thus the existing commercial standard can be treated in a methodical manner to attain similar energy saving potentials.

Undoubtedly, as consumption patterns change and social standards shift, the adjustment of eco-e will need to adjust our eco-retrofit priorities.

REFERENCES

1. ASHRAE (2004). Standard 55 - Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
2. ASHRAE (2007). ASHRAE Handbook – HVAC Applications. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
3. ASHRAE (2008). ASHRAE Handbook – HVAC Systems and Equipment. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
4. ASHRAE (2009). Standard 189.1 – Standard for the Design of High-Performance, Green Buildings Except Low- Rise Residential Buildings. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc
5. ASHRAE (2011). Advanced Energy Design Guide for Small and Medium Office Buildings. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
6. Building and Construction Authority of Singapore (2014), Leading the Way to Net Zero, 2009-2014: Inside SE Asia's First Retrofitted Zero Energy Building, Retrieved from: http://www.csb.sg.
7. Builtr (2015), Eight Myths About Green Design, Retrieved from: http://www.builtr.io/eight-myths-about-green-design/
8. Burton, S. (2014) Sustainable retrofitting of commercial buildings: Cool Climates, London and New York, Routledge
9. Campolongo F., Cariboni J., Saltelli A., (2007), An effective screening design for sensitivity analysis of large models, Italy, European Commission

10. Cetinera I., Ozkan E., (2005) An approach for the evaluation of energy and cost efficiency of glass facades, retrieved from: Energy and Buildings 37, p673–684
11. Corrado V., Mechri H.E., (2009), Uncertainty and sensitivity analysis for building energy rating
12. Dixon D., Eames M., Lannon S., Hunt M. (2014), Urban Retrofitting for Sustainability: Mapping the transition to 2050, London and New York, Routledge
13. ECON 19 (2003) Energy Consumption Guide 19, Energy Consumption in Offices. Available from: www.actionenergy.org.uk (accessed 27 May 2014).
14. Empire State Building Case Study - Cost-Effective Greenhouse Gas Reductions via Whole-Building Retrofits: Process, Outcomes, and What is Needed Next, Retrieved from: http://www.esbsustainability.com/
15. Gichuyia L. N., (2012) Impact of Climate Change on buildings, MPhil Essay 3 and 4, Department of Architecture, University of Cambridge, Unpublished
16. Giglioli N, Saltelli A (2011). Simlab - Software package for uncertainty and sensitivity analysis. Ispra, Italy: Institute for Systems Informatics and Safety (Joint Research Centre, European Commission)
17. Givoni, B. (1994) Passive Low Energy Cooling of Buildings, London and New York, John Wiley And Sons
18. Givoni, B. (1997) Climate Considerations in Building and Urban Design, New York, Van Nostrand Reinhold
19. Green Building Council of South Africa (2012), Improving lives by greening low-cost housing. Pretoria: British High Commission.
20. Grobe, L.O., Wittkopf S. Pandey A. R., Xiaoming Y., Jean-Louis Scartezzini J.L., Selkowitz S., (2010), Singapore's Zero Energy Building's daylight monitoring

system, International Conference on Applied Energy, Retrieved from: http://www.hpbmagazine.org/

21. Heiselberg P., Brohus H., Hesselholt A., Rasmussen H., Seinre E., Thomas S., (2009), Application of sensitivity analysis in design of sustainable buildings, Retrieved from: http://vbn.aau.dk/files/13735553/Application_of_Sensitivity_Analysis_in_Design_of_Sustainable_Buildings
22. Hien W.N., Tan E., Seng A. K., Mok S., (2011), Performance of greenery systems in Zero Energy Building of Singapore, International Conference on Sustainable Design and Construction, Retrieved from: http://ascelibrary.org/doi/abs/10.1061/41204%28426%2910
23. Hooper, C. (1975), Design for climates: a guideline for the low-cost houses for the climates of Kenya, Nairobi, University of Nairobi
24. Hosey, J. (2015), Six Myths of Sustainable Design: A half-dozen misperceptions help explain why green building hasn't gained more traction, Retrieved from: http://www.greenbuildingadvisor.com/blogs/dept/guest-blogs/six-myths-sustainable-design
25. Humphreys, M.A. (1976), Outdoor temperature and comfort indoors, Building research and practice (journal of CIB)
26. Kenya Meteorological Department (1984) Climatological Statistics for Kenya.
27. Kimeu, M (2015), Environmental Building Design Guidelines for Practitioners, Financiers & Developers in East Africa: A paper presented at The Eastern Africa Real Estate Infrastructure Development & Finance Conference, Nairobi

28. Kishnani N, (2012), Greening Asia: Emerging Principles for Sustainable Architecture, BCA Asia.
29. Koenigsberger, Ingersoll, Mayhew and Szokolay, (1974). Manual of Tropical Housing and Building – Part 1 Climatic Design, London, Longman.
30. Kok N., Miller N.G., Morris P., (2011) The Economics of Green Retrofits, Retrieved from: http://www.normmiller.net/wp-content/uploads/2012/08/Economics-of-Green-Retrofits-Draft-212-1-2011.pdf
31. Kristensen M.H., Petersen S., (2016), Choosing the appropriate sensitivity analysis method for building energy model-based investigations, Retrieved from: https://www.repository.cam.ac.uk/bitstream/handle/1810/261584/Menberg_et_al-2016-Energy_and_Buildings-VoR.pdf?sequence=1
32. Kucherenko S., Rodriguez-Fernandez M., Pantelides C., Shah N., (2009) Monte Carlo evaluation of derivative-based global sensitivity measures, Retrieved from: https://www.repository.cam.ac.uk/bitstream/handle/1810/261584/Menberg_et_al-2016-Energy_and_Buildings-VoR.pdf?sequence=1
33. Mara T.A., Tarantola S., (2008), Application of global sensitivity analysis of model output to building thermal simulations, Building Simulation, Volume 1, Issue 4, pp 290–302
34. Mariaan, W (2014), The case for green retrofitting in South Africa, Retrieved from: http://www.engineeringnews.co.za/article/mittal-pulls-back-from-bee-deal-confirms-r11bn-newcastle-loss-2011-10-07
35. Miller E., Buys L., (2008), Retrofitting Commercial Office Buildings for Sustainability: Tenants' Perspectives. Journal of Property Investment & Finance, Retrieved from: http://eprints.qut.edu.au/

36. Mtamu, Kililo (2015), Africa Needs Glass Architecture; Or Does It? ArchiDatum: Architecture in Africa. Retrieved from: http://www.archidatum.com/articles/africa-needs-glass-architecture-or-does-it/
37. Mwangi, M.N, (2008), Transformation of Nairobi Post-Independence Architecture: Climate Responsive Architecture, Nairobi, university of Nairobi, Unpublished
38. NDY (2013) Award for sustainable building retrofit, Engineers Australia, Retrieved from: http://www.ndy.com/sites/default/files/Retrofit.pdf
39. Njoroge, B. (2015), Towards a Climate-Responsive Architecture: A sensitivity analysis of passive design strategies for a free-running building in the Tropical climate of Nairobi, Department of Architecture, University of Cambridge, Unpublished
40. Nock L., Wheelock C., (2010), Energy Efficiency Retrofits for Commercial and Public Buildings Energy Savings Potential, Retrofit Business Cases, Financing Structures, Policy and Regulatory Factors, Demand Drivers by Segment, and Market Forecasts, Research Report, Pike Research
41. Perspectives. Journal of Property Investment & Finance,26(6), 552-561.
42. Saltelli A., Ratto M., Andres T., Campolongo F., Cariboni J., Gatelli D., Saisana M., (2008), Global Sensitivity Analysis, New Jersey, Wiley-Blackwell.
43. Saltelli A., Tarantola S., Campolongo F., Ratto M., (2004), Sensitivity analysis in practice: a guide to assessing scientific models, New Jersey, Wiley-Blackwell.
44. Siew L., Eang L.S., (2014), The design, development and performance of a retrofitted net zero energy building in Singapore, High Energy Performance Buildings.

45. Silveira M., Lumsdaine A., White J., (1994) SIMLAB User's Guide. The Research Laboratory of Electronics MIT. Cambridge, Massachusetts.
46. SIMLAB, (2004), Version 2.2 simulation environment for uncertainty and sensitivity analysis. Developed by the Joint Research Center of the European Commission
47. Tian W., (2013), A review of sensitivity analysis methods in building energy analysis, Retrieved from: http://econpapers.repec.org/article/eeerensus/v_3a20_3ay_3a2013_3ai_3ac_3ap_3a411-419.htm
48. Ventures Africa (2014), Nairobi's Changing Skyline: Commercial Real Estate on The Rise, Retrieved from: http://venturesafrica.com/nairobis-changing-skyline-commercial-real-estate-on-the-rise/
49. WBCSD (2008) Energy Efficiency in Buildings. World Business Council for Sustainable Development