THE IMPACT OF GREEN ARCHITECTURE ON ENERGY CONSUMPTION IN HIGHRISE OFFICE BUILDINGS IN NAIROBI

BY
MOSES NYAKWEBA OKEMWA
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DECLARATION

This Research Project is my original work and has never been presented for a approval in any other University

Okemwa Nyakweba Moses
(C50/64270/2013)

This Research Project has been submitted for examination with our approval as the University Supervisors

Dr. Isaiah A. Nyandega	Mr. I. J. Ndolo
Department of Geography & Environmental Studies,	Department of Geography & Environmental Studies,
University of Nairobi	University of Nairobi

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DEDICATION

To my wife Ng'endo
and
To my parents Jane and Humphrey

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LIST OF ACRONYMS

ASHRAE - American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BIM - Building Information Modelling
BREEAM - Building Research Establishment Environmental Assessment Method
BTU - British Thermal Unit
CASBEE - Comprehensive Assessment System for Building Environmental Efficiency
CO_2 - Carbon Dioxide
CBD - Central Business District
CCN - City County of Nairobi
EPA - Environmental Protection Agency
GBCA - Green Building Council of Australia
GBCSA - Green Building Council of South Africa
GBI - Green Building Initiative
GDP - Gross Domestic Product
GEF - Global Environment Facility
GHGS - Green House Gas Emissions
GOK - Government of Kenya
HQE - Haute Qualité Environmentale
HVAC - Heating Ventilating and Air-Conditioning
IEA - International Energy Agency
IPCC - Inter-governmental Panel Climate
JICA - Japan International Cooperation Agency
KMS - Kenya Meteorological Station
KNBS - Kenya National Bureau of Statistics
LEED - Leadership in Energy and Environmental Design
OECD - Organization for Economic Cooperation and Development
OFEE - Office of the Federal Environmental Executive
UNEP - United Nations Environmental Programme
WBDG - Whole Building Design Guide

ABSTRACT

Based on the available scientific evidence, it is now more certain than ever that people are altering the climate. The temperatures in the atmosphere and even the in the oceans are rising, sea-levels are going up and the Arctic sea ice is waning. One of the major contributors of these climatic changes is the increased energy consumption due to rapid urbanization and growth in the building and construction industry both internationally and locally. The building and construction industry is one of the largest consumers of energy and also one the largest emitters of greenhouse gases in the world today. Urgent measures are therefore required to reduce energy consumption, control emissions during manufacturing, transportation and installation of building materials.

The main objectives of this research was to establish if there are green buildings in the area of study, determine the impact of building services on energy consumption and subsequently establish the variations in energy consumption by building architecture. The study covered 42 buildings which formed 20% of all the tall office buildings within the study area.

The research established that there exists green buildings within the study area with the best performing building being the Coca Cola headquarters in Upperhill attaining a 5 star rating based on the Green Star rating criteria; this building offers the best case study of how buildings within the tropics can be designed, constructed and operated to meet the requirements of a green building.

This research recommends for formulation of a policy framework that will ensure that developers and existing office building owners incorporate renewable energy sources in their brief to supplement the energy from the national grid; the research further recommends for the formation of a national body that will ensure that new buildings are designed to meet the green building requirements that will subsequently lead to efficient use of energy within the building and construction industry

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

One of the biggest challenges facing mankind today is mitigating climate change (Godwin *et al*, 2007) mainly due to rapidly growing world energy consumption which is considered as one of the main elements in climate change. The energy consumption role in climate change is viewed in terms of its damage on the environment in the form of ozone layer depletion and global warming. In terms of global warming, the increase in energy consumption has resulted in corresponding increase in carbon dioxide (hereafter referred to as CO_2) which contributes a substantial 80% of global anthropogenic greenhouse gas emissions (IEA, 2006). According to the International Energy Agency (2006), during the last two decades (1984–2007) energy consumption went up by 49% and CO_2 emissions by 43%, with an average annual increase of 2% and 1.8% respectively and this trend is predicted to continue. The increase on the energy consumption and corresponding increase CO_2 emission is predicted to increase more in the emerging economies especially in Africa with an estimated average growth of 3.2% and expected to exceed by 2020 for the developed countries.

The International Panel on Climate Change (IPCC, 2004), notes that CO_2 emissions from the building and construction industry could increase from 8.6 billion tonnes in 2004 to 15.6 billion by 2030 under a high growth scenario (Levine *et al*., 2007). The high growth scenario of CO_2 emissions from buildings was also reported in the IEA (2009) estimates where it was indicated that buildings could be responsible of 33% of the globe's total final energy usage. The energy consumption in buildings can be attributed to production of raw materials, operations during construction, operation during use and the demolition phases of buildings. The rise in energy consumption in office buildings is due to the growth in information technology use in office buildings, air-conditioning, density of use, and comfort in the workplace. The energy consumption in office buildings is largely in the form of electricity where IEA (2009) estimated that two thirds of all energy consumed in an average office building to be electricity. It will therefore be logical to measure energy consumption in buildings as an indicator of green Architecture in terms of the key office buildings energy requirements.

For an office block to qualify as a green building, there should be significant reduction in the overall green-house gas emissions and energy demand. Green buildings should therefore be designed to save on energy in a more sustainable manner. In Architecture, sustainability entails integrating energy conservation strategies in all phases of building lifespan and it is this holistic design that comprises the green Architecture. OECD (2005) describes green buildings as those that have minimum adverse impacts on the built and natural environment while sustainable building is defined as the building which practices integral quality in a very broad way. The efficient use of natural resources thus contributes to saving limited resources, cutting down on energy consumption and thus good environmental quality. Policies that advocate for sustainable building practices should be encouraged and implemented taking into account the existing conditions since both the environmental practices of the construction sector and the demands of users are key factors in sustainability.

Improved efficiency in the building sector and de-carbonising the energy sector could offer significant potential emissions reduction. In Kenya, the construction industry has been on a steady and tremendous growth where the Kenya National Bureau of Statistics (KNBS, 2011) reported a contribution of KSh12.6 Billion from the construction industry to the country’s GDP in first quarter of 2011. This growth in construction was also reflected in cement consumption which rose to 779.3 million tonnes up from 667.1 million tonnes consumed in first quarter of 2010 (KNBS, 2011). A big percentage of this building construction projects in the country are taking place in Nairobi. In light of this, Green Architectural design concepts throughout the project cycle could have a significant impact on energy consumption. Buildings can be constructed and operated to meet user’s need for thermal and visual comfort with minimal levels of energy and resource utilization. Thus this study analysed the impact of Green building design in reducing the energy consumed in office buildings in Nairobi.

1.2 Statement of the Problem

This study attempted to address the problem of energy consumption in high-rise office buildings in Nairobi in terms of what constitutes a green building, amounts of energy consumptions, differences in energy consumptions and occupants behaviour. Buildings are classified as some of the largest consumers of natural resources with significant contributions to greenhouse gas emissions (Yi Kai *et al,* 2010). Urbanization in Kenya, like any other growing economy have largely followed conventional building design relating to those in Europe and Western world without consideration of climatic variation and this has resulted in energy consumption for up to 35% of the country's total energy consumption with carbon emissions exceeding those in the transport and industrial sectors (GEF, 2009). The immediate effect in Nairobi is manifested by the formation of an urban micro climate and gradual transformation of the city into a heat island. In this sense, rapid urbanization of Nairobi city under conventional building designs is contributing immensely towards intensifying change in climate that could affect the weather patterns and other life supporting systems. Notably, no attention has been paid to ensuring energy efficiency in the construction industry despite the impact buildings have on the environment.

Energy efficiency in the construction industry particularly in the high-rise buildings can be enhanced through adoption of an integrated approach to building design, a concept known as green Architecture. A number of private corporations in the building sector in Kenya have started to embrace green Architecture in their building designs in a bid to save on resources alongside reducing environmental impacts. Recent Studies on the effects of green Architecture on energy saving have not been conclusive with some indicating significant effect (Scofield 2009; Chang *et al,* 2011) while others (Kneifel 2009; Fay *et al.,* 2000) have indicated no effective savings in energy. Besides methodological differences, most comprehensive studies on energy consumption and green architecture have been conducted in western world where climate, being a key external influence of energy consumption, differs significantly with that of tropical countries and Kenya in particular. In bridging this gap this study will aim at investigating the levels of energy consumption in green and non-green office buildings in Nairobi, assess comprehensive studies on energy consumption and green architecture have been conducted in western world where climate, being a key external influence of energy consumption, differs significantly with that of tropical countries and Kenya in particular. In bridging this gap this study will aim at investigating the levels of energy consumption in green and non-green office buildings in Nairobi, assess occupants behaviour and recommend architectural design strategies of coming up with more energy efficient buildings. The specific questions that were addressed in this study were as follows:

1.3 Research Questions

1. Are there high-rise green buildings in Nairobi?
2. Which services in high-rise office buildings consume the highest amounts of energy?
3. What is the difference between energy consumption in green and non green high-rise buildings in Nairobi?
4. What is the role of occupant behaviour in energy consumption in green and non-green high-rise buildings in Nairobi?

The solutions to the four questions above were aimed at achieving the objectives of the study as specified below.

1.4 Objectives of the Study

1.4.1 General Objective

The general objective of this study was to determine the impact of green Architecture on energy consumption in high-rise office buildings in Nairobi

1.4.2 Specific Objectives

The specific objectives sought to:

1. Assess the prevalence of green buildings in Nairobi
2. Analyse the impact of buildings services on energy consumption
3. Analyse the variations in energy consumptions by building Architecture

H_1: There is a significant presence of green high-rise office buildings in Nairobi

H_0: The building services in high-rise office buildings in Nairobi do not affect variations in energy consumptions

H_1: Building services significantly affect energy variations in high-rise office buildings in Nairobi.

H_0: There is no difference in energy consumption by building Architecture

H_1: There is significant difference in energy consumption by building Architecture

1.6 Study Justification

The journey of greening buildings has taken root in Kenya with an ultimate aim of saving on resources and energy consumption. While doing this, various designs and material combination are used to provide the most efficient building designs. Studies in this area have mostly been conducted in developed countries where green Architecture has advanced over the past decades. The energy consumption of buildings, however, varies with designs and most importantly, geographic locations and climatic conditions of which extreme characteristics of climate in these countries makes it erroneous to generalize their findings in Kenya. Secondly, most of green building technologies in use especially in Africa are still at the test level and subject to more improvement to attain optimum efficiency. Improvement of the building designs will require more information on the performance of these buildings. This study, being among first in evaluating energy consumption in green buildings in Kenya was timely in informing the effectiveness of already implemented designs in reducing energy consumption and enhancing efficiency in green building.

The procedures, methodology and results of this study will make significant contribution to theory and practice of green technologies in general and green architecture in particular. Results of this study will provide useful insight and review of energy consumption of green buildings to owners, government and stakeholders in the green technologies. The results of the study will be useful in informing policy decisions, adjustment of building designs and materials alongside scoring the contribution of green buildings in energy conservation.

The study approach will make theoretical and methodological contribution to researchers, consultants and practitioners in the areas of green technologies. Further, this study will give valuable inputs into the scholarly debate on effectiveness of green buildings alongside offering a useful source of literature on green architecture.

1.7 Scope and Limitation of the Study

The study focused on only high-rise buildings of office type; therefore the investigation was carried out in Nairobi's business districts with the highest concentration of high-rise buildings of office type and these are found in Westlands, Upperhill and the Central Business District (CBD). The research was restricted to measuring operational energy assuming embodied (energy used in extracting, transportation and construction of building) to be constant across the green and non-green buildings. It was also assumed that the occupants in all buildings studied had similar behavioural patterns with regard to energy use. Information on energy consumption and materials used was gathered from building owners, property managers, designers and occupants.

The limitations of the study were access to these buildings which was dealt with through presenting introduction letters describing the study and aim of the research.

1.8 Operational Definitions of Terms

Green Architecture: The design, construction, operation, maintenance, and demolition of buildings in ways that minimize energy use

Green building: Building design and construction practices that encourage people to be more responsible with energy, natural resources and the environment.

Energy Consumption: The total energy used in a building during operation and its measurable.

Energy Efficiency: The use of energy in such a way that there is minimal wastage without compromising the performance of a building.

Green House Gas: A gas that can absorb and emit long-wave radiation in the atmosphere.

High-rise office building - A building with five or more floors above the ground level with most spaces used as offices.

Climate Change: The gradual change in average temperature and precipitation of region over a long period of time mainly because of human induced effects.

Curtain Walling: A metal-framed wall made of glass, metal panels, or stone that is attached to a building and does not carry any building loads.

Renewable Energy: Energy that comes from resources whose regeneration rate is faster than extraction rate.

CHAPTER TWO

2.0 LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1 Introduction to the Literature Review

The objectives of this review were to define green buildings and their historical background, identify and analyze the various green building rating systems, extract the major characteristics of green buildings, identify gaps in existing literature and generate a conceptual framework that was adopted in the study.

This literature review is structured to draw the relationship between green buildings and their energy consumption. It begins by introducing green buildings, their characteristics and their historical background. The next section reviews empirical literature on green building identifying the gaps that need to be filled, theoretical and conceptual frameworks showing the relationships between green buildings and energy consumption.

2.2 The Review

2.2.1 Green Architecture

Green architecture is a multi-faceted concept that attracts numerous definitions from different authorities. According to EPA (2013), green building or architecture is the practice of creating and using healthier and more efficient-resource models of construction, renovation, operation, maintenance and deconstruction. Vale and Vale (1992) defines a green building as that approach to the built environment that involves a holistic approach to the design of building; that all the resources that go into a building, be they materials, fuels or the contribution of the users need to be considered if sustainable architecture is to be produced. The Office of the Federal Environmental Executive (OFEE, 2012) describes green architecture as sustainable building - the practice of designing, constructing, operating, maintaining, and removing buildings in ways that conserve natural resources and reduce pollution.

The definitions above indicate lack of a universally accepted definition to green Architecture, the common denominator on all of them is that, they are structures intended to improve the practices in the construction industry so that buildings can last, costs reduce, easy to operate, save on natural resources and enable enhanced productive and better working environments for the users thus for the purpose of this research adopted the definition by Vale *et al.* (1992).

2.3 Characteristics of Green Buildings

Both the LEED and Green Point rating systems (2010) identify efficient use of energy, water, natural resources, good indoor environmental standards and community design as the main key features of green buildings.

EPA (2004) notes that energy efficiency is the foundation of green building. It important since improved efficient use of energy cuts costs of utility bills and improve the indoor environment for the building users.

2.3.1 Energy Efficiency

World Business Council for Sustainable Development (WBCSD, 2007) notes that there are three main approaches to energy efficiency:

i. Reduction of the buildings' energy need by for example using energy efficient machines and equipment.

ii. Local production of energy from renewable and other green energy resources

iii. Sharing energy – Building to generate their own energy and even supply the surplus to the national grid.

Meier and Olofsson (2002) note that an energy-efficient office buildings must contain elements from three categories:

i. The building must contain energy-efficient technologies that, when operating as designed, will effectively reduce energy use.

ii. The building must supply the amenities and features appropriate for that kind of building. Thus, an office must provide around 60 hours/week of suitably conditioned air, lighting, and equipment.

iii. The building must be operated in such a manner as to be efficient. The evidence of this operation is low energy use relative to other, similar, buildings.

The two approaches to energy efficiency above fail to address the impact of human (users) behaviour in buildings' energy use which could have significant effects on the overall energy consumed in the buildings. This research examined this gap and gave recommendations that can help efficient energy use behaviours for the users of the buildings.

2.3.2 Water Efficiency

Water usage is responsible for about a quarter of energy use. Humanity's prosperity depends on having adequate supplies of fresh, clean water. Buildings can be designed and built to use water wisely both inside and out while reducing expenses. High efficiency appliances do not have to be more expensive, and landscape water management systems are cost-effective. Water harvesting systems offering integrated alternative for green buildings typically combines; rainwater catchment, storage filtering and recycling to adequately supply the water needs to the building (Fowler and Rauc 2006). Additionally, green building designs integrate dual flush toilets, which allow users to choose small flush (0.8 gallon per flush) or a larger flush (1.6 gallon per flush) based on need. The garden landscape relies on indigenous species of plant that are more tolerant to low precipitation and high temperatures, thus saving on water for irrigation.

The other factor considered under water efficiency in green buildings is management of waste and storm water. Green buildings incorporate provisions for on-site water treatment system, for; grey water and black water, which can be used for garden irrigation, landscaping or toilet flushing (Yoders, 2008).

2.3.3 Material Resources Conservation

Careful planning and management of the construction process can prevent waste. Advanced framing techniques have become well-established homebuilding practices, along with making maximum use of engineered lumber. Using more durable products makes buildings and their components last longer. Specifying recycled materials and products make use of waste that would otherwise end up in landfills.

2.2.2 Indoor Environmental Quality

Indoor air is often more polluted than outdoor air; children are particularly vulnerable to the effects of air pollution. Many building materials give off chemicals that produce air pollution, particularly during construction and for a period afterwards. Green building procedures use safer building materials that do not cause problems from these chemicals cause, and the costs and performance are comparable to conventional products. Biological contaminants such as mould that can grow if conditions are right, and dust from outdoor air infiltrating into the house, are also contributors to poor indoor air quality. Green building prevents or minimizes these conditions.

2.2.3 Community Design

Developments that are designed to infill already developed areas instead of converting farmland or forests can revitalize older areas and reduce transportation needs. New developments that cluster homes together can make more efficient use of the land to preserve natural areas for wildlife habitat as well as recreation. Homes should be oriented on lots to take advantage of the sun. Mixed-use developments encourage economic vitality and diversify the tax base.

2.3 Green Building Rating Systems

Worldwide, a variety of assessment programs have been developed around environmental and energy impacts of buildings. The first environmental certification system was created in 1990 in the UK, The Building Research Environmental Assessment Method (BREEAM). In 1998 the Leadership in Energy and Environmental Design (LEED) Green Building Rating System was introduced based quite substantially on the BREEAM system. In turn, in 2005, the Green Building Initiative (GBI) launched Green Globes by adapting the Canadian version of BREEAM and distributing it in the U.S. market. The most common green building systems in the world include:

i. Building Research Establishment Environmental Assessment Method (BREEAM)
ii. Leadership in Energy & Environmental Design (LEED)
iii. Green Star
iv. Haute Qualité Environnementale (HQE)
v. Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)
vi. Green Globes

2.3.1 Building Research Establishment Environmental Assessment Method (BREEAM)

BREEAM was developed in the United Kingdom in 1990 and is the building environmental assessment method with the longest track record. BREEAM covers a range of building types including: offices, homes, industrial units, retail units, and schools. Other building types can be assessed using Bespoke BREEAM ("bespoke" - custom-made). When a building is assessed, points are awarded for each criterion and the points are added for a total score. The overall building performance is awarded a "Pass", "Good", "Very Good" or "Excellent" rating based on the score. BREEAM major categories of criteria for Design and Procurement include the following:

i. Management (commissioning, monitoring, waste recycling, pollution minimization, materials minimization)
ii. Health & Wellbeing (adequate ventilation, humidification, lighting, thermal comfort)
iii. Energy (sub-metering, efficiency and CO_2 impact of systems)
iv. Transport (emissions, alternate transport facilities)
v. Water (consumption reduction, metering, leak detection)
vi. Materials (asbestos mitigation, recycling facilities, reuse of structures, facade or materials, use of crushed aggregate and sustainable timber)
vii. Land Use (previously used land, use of remediated contaminated land)

viii. Ecology (land with low ecological value or minimal change in value, maintaining major ecological systems on the land, minimization of biodiversity impacts)

ix. Pollution (leak detection systems, on-site treatment, local or renewable energy sources, light pollution design, avoid use of ozone depleting and global warming substances

This rating system is designed mainly to measure in the UK therefore might not be accurate in measuring buildings in Kenya

2.3.2 Leadership in Energy and Environmental Design

LEED was developed and piloted in the U.S. in 1998 as a consensus-based building rating system based on the use of existing building technology. The development of LEED has been through the U.S. Green Building Council member committees. The rating system addresses specific environmental building related impacts using a whole building environmental performance approach. In addition to LEED-NC (for new construction and major renovations), there are versions for existing buildings, commercial interiors, core and shell, homes, and neighbourhood development. There are also application guides that can be used to increase the applicability and flexibility of LEED (e.g., multiple buildings and campuses, schools, health care, laboratories, lodging, and retail (pilot)). The LEED Reference Guide presents detailed information on how to achieve the credits within the following major categories:

i. Sustainable Sites (construction related pollution prevention, site development impacts, transportation alternatives, storm water management, heat island effect, and light pollution)

ii. Water Efficiency (landscaping water use reduction, indoor water use reduction, and wastewater strategies)

iii. Energy and Atmosphere (commissioning, whole building energy performance optimization, refrigerant management, renewable energy use, and measurement and verification)

iv. Materials and Resources (recycling collection locations, building reuse, construction waste management, and the purchase of regionally manufactured materials, materials with recycled content, rapidly renewable materials, salvaged materials, and sustainably forested wood products)

v. Indoor Environmental Quality (environmental tobacco smoke control, outdoor air delivery monitoring, increased ventilation, construction indoor air quality, use low emitting materials, source control, and controllability of thermal and lighting systems)

vi. Innovation and Design Process (LEED accredited professional, and innovative strategies for sustainable design)

LEED, however, has not been created with some level of adaptability to other regions in the world and it is not run that way. Instead it is fixed to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standards and the US way of thinking (for example, credits are awarded for having enough car parking spaces, rather than minimizing them).

2.3.3 Green Star

The Green Star rating system was launched in 2003 by the Green Building Council of Australia (GBCA). It can be used to register and potentially certify a broad range of building types, including new building design and construction, interior fit outs, and existing building retrofits. It is a green building rating system that assesses key attributes by predicting building performance. As of August 2013, Green Star has been used to rate 615 projects with over 7.2 million m2 (78 million ft2) of certified space and an additional 8 million m2 (86 million ft2) of registered space.2,3 Currently there are three active rating systems for commercial buildings in the Green Star family of green building rating tools:

a) Green Star Office Design and As-Built Offices V3
b) Green Star Office Interiors

Green Star Performance measures green building performance using criteria related to:

i. Management (9%)
ii. Indoor Environmental Quality (15%)
iii. Energy (25%)
iv. Transport (9%)

iv. Transport (9%)
v. Water (14%)
vi. Materials (13%)
vii. Land Use and Ecology (7%)
viii. Emissions (8%)
ix. Innovation

This rating system has been adopted in measuring buildings in Australia and South Africa. The system is flexible can be adopted in measuring buildings in other regions (GBCA 2010) and therefore it was adopted in rating the high-rise office buildings in this study.

2.3.4 Haute Qualité Environnementale

The HQE (Haute Qualité Environnementale) is a voluntary approach aiming to limit the short and long-term environmental impact of a new build or refurbishment, while guaranteeing healthy and comfortable living conditions for the occupants. It is the most frequently applied certification scheme in France.

The HQE association was founded in 1995 and recognized as a non-profit organisation in 2004. The HQE certification system was developed by the subsidiaries of QUALITEL (for residential) and CSTB (for non-residential) and has been operating since 2005. The HQE parameters cover a broad range of site, construction process, operational, user comfort and user health sub-issues, but does not extend to socio-economic issues. Considerable emphasis is placed on the quality of the, process and inclusion of relevant local issues. The HQE system expresses the building's Environmental Profile. The Building is rated according to 14 targets, each one achieving one of the following levels: 1) BASIC, 2) PERFORMING, 3) HIGH PERFORMING. The 14 specific targets of the HQE certification have been defined to cover all the links between the building and its environment, and are divided into four categories as follows

a) Eco-construction
    i. Harmonious relationship of the building with its immediate environment
    ii. Integrated choice of construction processes and products
    iii. Low-nuisance construction sites
b) Eco-management

    i. Energy management
    ii. Water management
    iii. Process waste management
    iv. Management of maintenance
c) Comfort
    i. Hydrothermal comfort
    ii. Acoustic comfort
    iii. Visual comfort
    iv. Olfactory comfort
d) Health
    i. Cleanliness of the internal environment
    ii. Air quality
    iii. Water quality

The recently developed International passport (for non-residential buildings) also rates the building's performance in four fields: energy, environment, health, and comfort. Stars are awarded in each category (between 1 and 4 stars) and then added up to obtain a final score:

Table 2.1: Table showing Haute Qualité Environnementale scoring system

RATING	NUMBER OF STARS
HQE - good	1-4
HQE - very good	5-8
HQE - excellent	9-11
HQE - outstanding	12+

Source: HQE 2005

2.3.5 Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)

CASBEE is a rating tool used for evaluating environmental building performance in Japan, developed under the guidance of the Ministry of Land, Infrastructure and Transport. CASBEE is used to assess buildings based on interior comfort, scenery consideration and environmental awareness (utilize energy saving materials and equipment, or those that cause smaller environmental loads). Comprehensive assessments are ranked in five grades:

Poor (C) - Fairly Poor (B-) - Good (B+) - Very Good (A) - Excellent (S)

CASBEE comprises the following assessment tools:

i. The Pre-design Assessment Tool (Tool-0), which supports owners and planners in identifying the basic context of the project. This may suggest proper site selection and the primal impact of the project.

ii. The DfE (Design for Environment) Tool (Tool-1), which is a simple self-evaluation check system for designers and engineers to improve the BEE of relevant buildings during the design process

iii. The Eco-labelling Tool (Tool-2), with which buildings are rated in terms of BEE after completion. This could be used to determine the basic property value of the labelled building in the market.

iv. The Sustainable Operation and Renovation Tool (Tool-3), which provides building owners and managers with information concerning how to improve the BEE of their own building property during the post-design process

2.3.6 Green Globes

Green Globes is an online tool that offers a comprehensive and interactive experience. Once the user completes an online questionnaire, the system generates a point score and offers project design suggestions aimed at reducing the building's overall environmental impact. Suggestions are supported by links to other resources that provide best design practices, standards and information on building systems and materials. They are designed to help users achieve a higher Green Globes score and, ultimately, a better performing building. Projects are awarded up to 1,000 points based on their performance in seven areas of assessment:

i. Project Management - 50 Points. Points are awarded for: integrated design, environmental purchasing, commissioning, documentation and emergency response planning.

ii. Site – 115 Points. Points are awarded for: site development, reducing ecological impacts, the enhancement of watershed features and site ecology improvement

iii. Energy – 360 Points. Points are awarded for: energy consumption, energy demand minimization, "right sized" energy efficient systems, renewable sources of energy and energy efficient transportation

iv. Water – 100 Points. Points are awarded for: water consumption, water conserving features and the reduction of offsite water treatment

v. Resources – 100 Points. Points are awarded for: materials with low environmental impact, minimized consumption and depletion of material resources, reuse of existing structures, building durability, adaptability, and disassembly and the reduction, reuse and recycling of waste

vi. Emissions, Effluents and Other Impacts – 75 Points. Points are awarded for: air emissions, ozone depletion and global warming, contamination of sewers or waterways, land and water pollution, integrated pest management, storage of hazardous materials

vii. Indoor Environment – 200 Points. Points are awarded for: effective ventilation system, source control of indoor pollutants, lighting design and integration of lighting systems, thermal comfort and acoustic comfort

Green Globes Scoring

Projects that achieve a score of 35% or more become eligible for a Green Globes rating of one, two, three or four globes, as follows:

i. One Globe: 35-54%

ii. Two Globes: 55-69%

iii. Three Globes: 70-84%

iv. Four Globes: 85-100%

There is no established green rating system for Kenya and other African Countries except South Africa; however, in the year 2010 UN-Habitat organised a

Conference on Promoting Green Building Rating in Africa as part of its Cities and Climate Change Initiative which took place in Nairobi.

The Green Building Council of South Africa (GBCSA) is currently licensed by the Green Building Council of Australia (GBCA, 2010) to allow certification using the Green Star SA v1 rating tools only in South Africa (Office, Retail Centre, Multi-unit Residential, Public and Education Building), Ghana (Office), Namibia (Office) and Mauritius (Office). Through this local context assessment, the GBCSA aims to apply for approval from the GBCA to allow for certification in Kenya using the all the Green Star SA v1 Design/As Built rating tools – this includes the following Green Star SA rating tools: Office, Retail Centre, Multi Unit Residential and Public & Education Building. For this study we will therefore adopt the South African Green Star rating components in rating green buildings in Kenya

2.4 Energy use in office buildings

The global consumption of electricity has been increasing faster than the overall energy consumption because of the versatile nature of the production of electricity, as well as its consumption (EIA 2006). Worldwide electricity consumption in 2006 was 16378 TWh, which was 11.8% of the total primary energy consumption (EIA 2006). Because of losses in the generation process, the amount of input energy for electricity generation is much higher than the amount of electricity at its point of use. Worldwide electricity generation uses 40% of the world's primary energy supply (Hore-Lacy 2003). According to the International Energy Outlook 2009 (EIA 2009), the world's total net electricity generation in 2030 is expected to be increased by 77% from the 2006 level. The growth of the primary energy consumption for the same period will be 44%, expanding from 472 quadrillion BTU in 2006 to 678 quadrillion BTU in 2030.

The largest users of energy in an office building are:

i. Lighting
ii. Heating and cooling
iii. Ventilation, and

iv. Air-conditioning (HVAC) systems.

Properly designed buildings adopt the most energy efficient strategies of ensuring an overall reduction of energy use by all building services; for instance, HVAC systems can reduce the amount of energy used for heating and cooling a building. A HVAC system includes a heater, air conditioner, and fan in one system and operates at a partial load nearly all the time. The design of the HVAC system as a whole-system mechanism saves energy by monitoring airflow and keeping the indoor temperature fairly constant. A HVAC system must have a correctly designed distribution system to minimize the amount of airflow (and thus energy) necessary to heat and cool the building. In addition, allowing building occupants to individually control heating and cooling in their living or working spaces is an effective way to reduce energy use.

Electric lighting consumes about one-quarter to one-third of the energy in a typical commercial building. Lighting also generates heat, so reducing the amount of energy consumed for lighting through effective and efficient lighting also reduces the size of a building's air-conditioning plant. Building Information Modelling (BIM) enables building design and construction teams to draw and test the building's operating systems, such as electricity or hot water, in one computer model. Modelling buildings with BIM can aid in quantitative energy analysis, connecting complex systems and allowing more precise analysis for better energy use.

Insulations are also alternative approaches and designs for controlling energy use and emission in green buildings. Effective insulation is considered an important parameter in enhancing energy consumption in green buildings. Fay *et al* (2000) examined the effects of insulation in alternative building designs on energy consumption in residential buildings in Australia. They used life-cycle assessment approachin evaluating the marginal change in insulation and payback period of the savings embodied in the energy efficient designs. The study established that the initial embodied energy in life cycle terms for residential buildings is around 12years. This, according to Fay *et al.* (2000), represented less than 6% of the total embodied energy and operational energy of the building over 100-year life cycle. From the study, other strategies may be considered worth pursuing before emphasizing on additional insulation.

2.2.2 Energy use for lighting

Lighting was the first service offered by electric utilities and it continues to be a major source of electricity consumption (IEA 2006). Globally, almost one fifth of the total amount of electricity generated is consumed by the lighting sector. The total electricity consumption of lighting is more than the global electricity produced by hydro or nuclear power plants, and almost the same as the electricity produced with natural gas. Almost half of the global lighting electricity (48%) is consumed by the service sector. The rest is distributed between the residential sector (28%), industrial sector (16%), and street and other lighting (8%). The share of electricity consumption of lighting of total electricity consumption varies from 5% to 15% in the industrialized countries, whereas the share is up to 86% in developing countries (Mills 2002).

The environmental impacts of lighting are caused by the energy consumption of lighting, the material used to produce lighting equipment, and the disposal of used equipment. Emissions during the production of electricity and also as a result of the burning of fuel in vehicle lighting and in fuel-based lighting are responsible for most of the lighting-related greenhouse gas emissions. Hazardous materials (e.g. lead mercury etc.) used in the lamps and ballasts, if not disposed properly, can cause harmful impacts on the environment. Lighting also affects the environment due to wastefully escaped light into the night sky (light pollution).

The environmental impacts of electric lighting depend on the electricity generation method. Thermal power generation system has the highest impact on the environment due to combustion fuel, gas emissions, solid waste production, water consumption, and thermal pollution. Electricity generated from renewable energy sources has the lowest effect on the environment. Lighting is one of the biggest causes of energy-related greenhouse gas emissions. The total lighting-related CO_2 emissions were estimated to be 1900 million tons (Mt) in

2005, which was about 7% of the total global CO_2 emissions from the consumption and flaring of fossil fuels (EIA 2007, IEA 2006).

Energy efficient lighting reduces the lighting energy consumption and is thus a means to reduce CO_2 emissions. Fuel based lighting used in developing countries is not only inefficient and expensive, but also results in the release of 244 million tons of CO_2 to the atmosphere every year, which is 58% of the CO_2 emissions from residential electric lighting globally (Mills 2002). Replacing fuel based lighting with energy efficient electric lighting (e.g. on LEDs) will provide means to reduce greenhouse gas emissions associated with lighting energy consumption.

2.3 Green Buildings and Energy Consumption

Energy performance of green buildings has significant bearing on the built environment and sustainable development. The concept of green buildings is founded on designs that promote efficient energy use alongside integrated designs that cut energy demand and consumption by applying on-site renewable energy sources (Hosseini *et al*., 2013). Green buildings apply different combinations of technologies, materials and designs to achieve energy efficiency. Green buildings have largely been viewed as the solution to sustainable urban building architecture. Their design, construction, operation and demolition are meant to conserve resources such as energy. However, questions as to its economic and environmental costs including energy saving have been lingering on in empirical literature especially when compared to the conventional architectural designs. In Israel, Gabay *et al* (2013) carried out a study on the cost benefit analysis of green office buildings focusing on office buildings of different sizes and finished standards based on the voluntary Green Building Standards; Israel Standards IS 5281. The study captured benefits for the entrepreneur and the public for 20 years alongside costs of compliance to standards and found out that, even though the operations of green buildings have significantly reduced energy consumptions, the discounted costs exceeded benefits over the considered period.

Heating, ventilation, and air-conditioning (HVAC) systems for office buildings are responsible for monitoring humidity and temperature as well as enable flowing of fresh air throughout a building. These systems have a very high energy demand and consume a significant amount of power in a building.

These features of green architecture that include day-lighting, indoor lighting technologies and controls are combined to ensure that the buildings remain energy and resource efficient. Against this, Kneifel (2009) carried out a study aimed at evaluating cost analysis of energy efficiency measures in green buildings in the United States. The study was conducted across 16 cities in 576 buildings with simulated energy consumption and building costs being the key variables in determining life-cycle cost effectiveness of the improved energy efficient building designs. The study established that an energy efficient technology that comprises good insulation, reduced emissivity of windows, window shades and day-lighting strategies can be used to decrease energy consumption by approximately 25% on average and up to over 35% for some buildings. Even though improved designs typically increase the cost of building compared to conventional designs energy saving over the service life of the building often offset the initial higher costs (Kneifel, 2009; Chang *et al*, 2011).

The results of the study by Kneifel (2009) agree with those of previous New Buildings Institute (NBI, 2008) that indicated on average, green buildings in the U.S use 25-30% energy lower than the national energy consumption for buildings and 18-39% of energy consumption lower than conventional designs. However, Scofield (2009) faulted the methodology used in assessing building by NBI citing voluntary submissions by building owner alongside biased data gathering and sampling techniques. Consequently, Scofield expanded the methodology by considering energy used on-site and off-site losses associated with the generation and distribution of electric energy. The study was conducted in green and non-green buildings and established that there is no significant primary energy savings in green comparable to non-green buildings.

From the above studies, energy consumption and conservation in green building is still contested. However, the scenario in tropical zones is different based on the variation in climate and the bearing it has on the energy consumption.

In achieving the design for green building some technologies are vital and are discussed in the next section.

1.8.1 Day-lighting

Day-lighting entails using natural passive solar energy to bring day light into the home through highly efficient windows and advances in lighting design that allow efficient use of windows to reduce the need for artificial lighting during daylight hours without causing heating or cooling problems. The sizes and locations of windows should be based on the cardinal directions rather than their effect on the street-side appearance of the house, for example, south-facing windows are most advantageous for day-lighting and for moderating seasonal temperatures because they allow most winter sunlight into the home but little direct sun during the summer, especially when properly shaded (Monroe *et al.* 2003). North-facing windows are also advantageous for day-lighting because they admit even, natural light, with little or no glare. East- and west-facing fenestrations give controlled daylight in the morning and evening, respectively, they should be limited because they may cause glare, admit a lot of heat during the summer when it is usually not wanted, and contribute little to solar heating during the winter (LEED 2002).

1.8.2 Indoor lighting strategies

These have traditionally delivered about 80 percent of building lighting. Incandescents operate without ballast, are dimmable and instantly controllable, and light up instantly (Hopkinson 1966). Most familiar are the standard pear-shaped, screw-in “A”-type incandescent light bulbs. They produce a warm light and provide excellent colour rendition. They have a low efficacy compared to all other lighting options (10 to 17 lumens per watt) and a short average operating life (750 to 2500 hours).

Incandescent lamps can be made in other shapes and variations. Tungsten halogen lamps provide excellent colour rendition. Reflector (R) and parabolic aluminized reflector (PAR) lamps direct light in a desired direction. All three are slightly more efficient than standard bulbs, have longer operating lives (2000 to 4000 hours), and are often used for accent lighting.

Fluorescent lamps - use 25 to 35 percent of the energy used by incandescent lamps to provide the same amount of illumination (efficacy of 30 to 110 lumens per watt) and last about 10 times longer (7,000 to 24,000 hours). Improvements in technology have resulted in fluorescent lamps with colour temperature and colour rendition that are comparable to incandescent lamps (O'Connor *et al.* 21997).

Fluorescent lamps require a ballast to regulate operating current and provide a high start-up voltage. Electronic ballasts outperform standard and improved electromagnetic ballasts by operating at a very high frequency that eliminates flicker and noise. They are also more energy-efficient. Special ballasts are needed to allow dimming of fluorescent lamps.

2.2.4 Indoor lighting controls

The traditional **on-off toggle** switch has long been the lighting control of choice in buildings. For rooms with two entrances, two-way switches make it more convenient to turn off lights when leaving the room. However, research shows that even with convenient light switch locations, lights are often left on when rooms are unoccupied (Baker et al. 1993).

Dimmer controls - provide variable lighting for fixtures. Off-the-shelf switches for incandescent fixtures are inexpensive and provide some energy savings when lights are used at a reduced level. Fluorescent dimmers are dedicated fixtures and bulbs that provide even greater energy savings than a regular fluorescent bulb.

Photo sensors have little utility in controlling lights inside the home because lighting needs vary with occupant activity rather than ambient lighting levels.

Occupancy sensor: Home automation can be achieved on a small scale through smart switches. Occupancy sensors provide individual switching and timing for room lights and other fixtures. They detect activity within a certain area and provide convenience by turning lights on automatically when someone enters a room. They reduce lighting energy use by turning lights off soon after the last occupant has left the room.

Occupancy sensors must be located where they will detect occupants or occupant activity in all parts of the room. There are two types of occupancy sensors: ultrasonic and infrared. Ultrasonic sensors detect sound, while infrared sensors detect heat and motion. In addition to controlling ambient lighting in a room, they are useful for task lighting applications, such as over work stations. In such applications, task lights are turned on by the motion of a person and automatically turn off a few minutes after the person stops (Hastings *et al.* 1994).

Timers: These are sometimes used to give unoccupied houses a lived-in look. However, they are an ineffective control for occupied buildings because they do not respond to changes in-occupant behaviour.

2.2.5 Green Roofs

Green architecture entails combining materials and designs that optimize energy alongside ensuring environmental sustainability. Such components such as green roof have attracted researchers' interest on their effectiveness in saving energy. According to Saiz *et al* (2006) and Wong *et al* (2003), green roof as a component of green architecture reduces annual house hold energy consumption by 1% owing to reduction in electricity used for cooling. Further, research has shown that green roofs have impacts in reducing Urban Heat Island (UHI) by providing a medium for evapo-transpiration and altering albedo. Experimentation studies carried out independently by Stovin (2009) and Bliss *et al* (2009) established that green roofs accounts to 6% reduction in summer cooling loads for multifamily building in Madrid, Spain. However, Blackhurst *et al* (2010) carried out a study on the cost effectiveness of green roofs in Pittsburgh using lifecycle assessments methods on buildings in an urban setting. They found out that green roof approaches may not the most effective energy conservation strategy; though insightful, these studies have focused on components of green buildings (green) roofs without considering the holistic effect of the entire green architecture on energy consumption especially in high-rise office buildings.

1.9 Occupants Behaviour/Perception and Building Energy Consumption

Energy performance of buildings is determined by an array of architectural features, climatic conditions alongside occupants' behaviour. Energy simulation models based on energy inflows and outflows have been used to measure energy consumption across different types of building. However, by using architectural design without consideration of the role of occupants in the building's energy consumption, these models often makes erroneous conclusion on the determinants of energy consumption in a building. In other words, these simulations are inadequate in precisely replicating the actual energy performance of buildings because they are based on basic assumptions that affect the results. Consequently, the calculated energy consumptions from these simulations may significantly differ from real energy performance of the buildings. Knowledge and better description of occupants' behaviour is crucial in better understanding energy performance of building with valid prediction (Fabi *et al*, 2011).

Effective operation, control and measurement of energy performance takes into consideration user control over lighting, blind, windows or heating and cooling set points. Review of studies on the role of user in building energy consumption indicates that user' behaviors, especially a 'don't care' attitude could increase energy consumption far and above the conventionally predicted levels. Masoso (2010) analyzed energy consumption in commercial buildings in different South Africa cities. The research factored user behaviors and found out that wastage of energy emanating from occupants' carefree attitudes affected to a great level, the amount of energy consumed in a building. Indeed, Haymaker *et al*, 2004 shows that, users' actions can affect energy consumption of a building up to 150% of the simulated amount. Lutzenhiser (2003) observed that energy use of different occupants in identical units can have a variation of between 200% and 300%.

1.10 Gaps in Literature

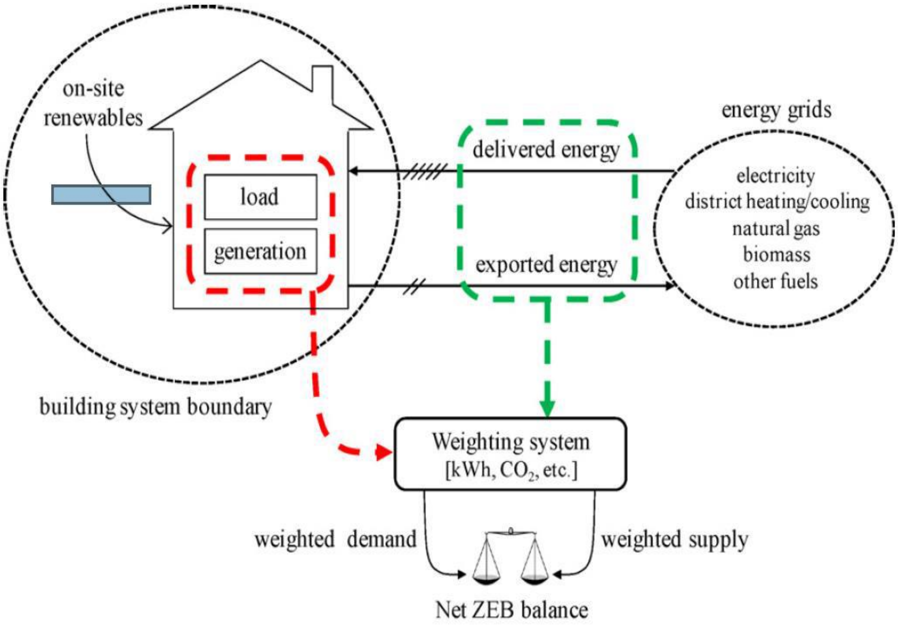
Most of the studies on energy performance of green building have been carried out in developed countries where these designs have existed for a longer period. However, green designs in these countries are different from those in Africa and Kenya in particular due to sharp variations in climate. This implies that results for these studies cannot be generalized to Kenyan context thus prompting the need for this study which investigated the energy performance of green buildings perform locally.

Secondly, studies conducted on energy consumption in green building have relied on simulating energy estimates across the entire life of the building. This approach lacks precision in approximating real energy performance of a building as most simulations rely on ideal situation of climate and usage. This study bridged this gap by computing energy performance from actual recorded energy consumption of the green buildings and compare to actual non-green buildings.

1.11 Theoretical Framework

The idea of 'greening' our building designs is intertwined by the concepts of reduction in energy consumption, gas emission, environmental impacts and efficiency in building performance. These targets for green buildings are represented in critical criteria defined and explained under Zero Emission Buildings (ZEB) model. Under the model, the power consumption processes and the relationship between the building and national power grids are expounded. Consequently, the analysis of energy consumption in a building and their levels of efficiency are undertaken by carefully reviewing the buildings' energy performance (Wang, 2012).

Figure 1.1: Zero Energy Balance Model



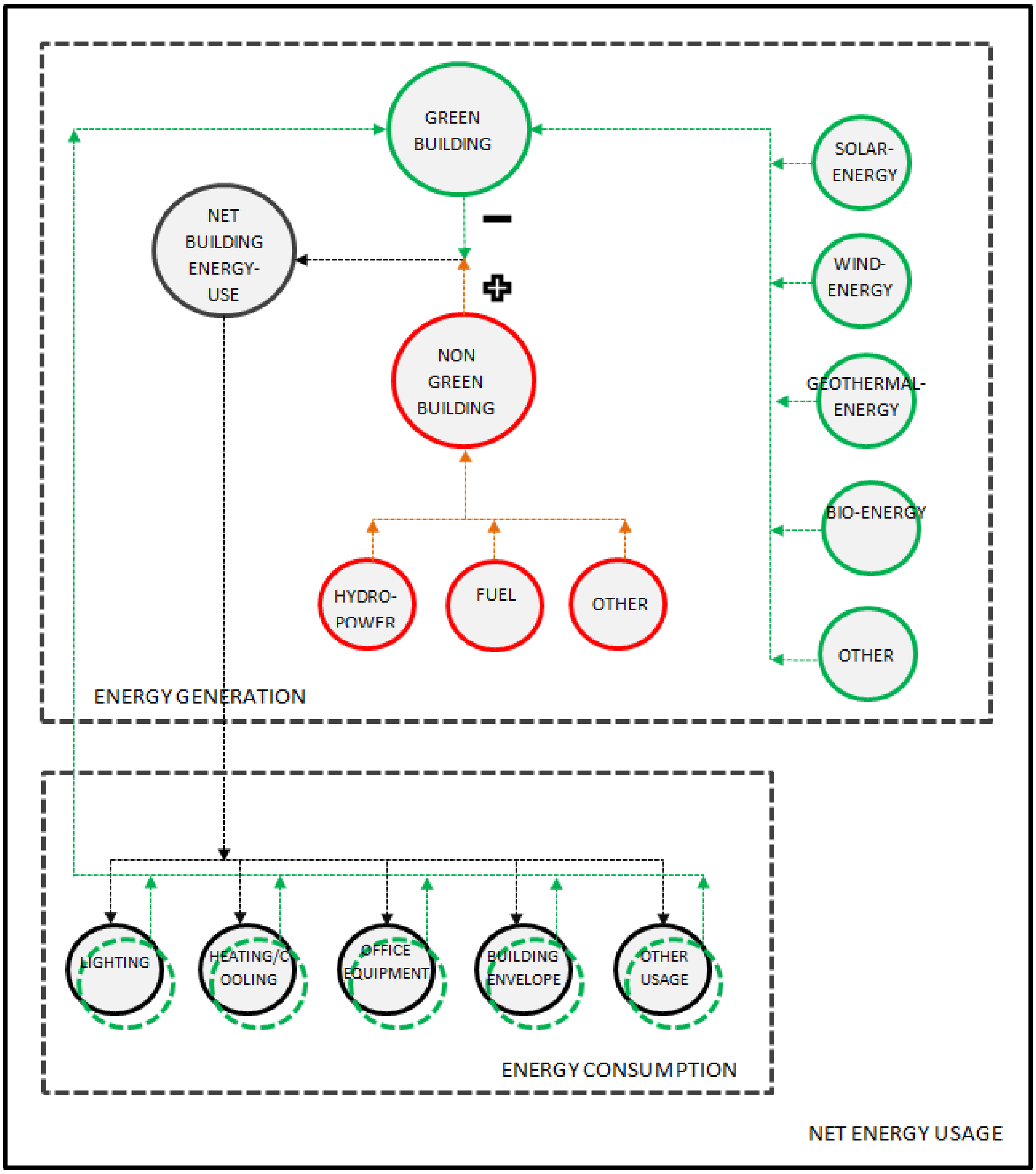
Source: Hosseini *et al* (2013)

The rationale for sustainability of buildings according to ZEB model (figure 3.1), is that, buildings should have acceptable energy performance and looking introspectively into the identified interrelated parameters, indoor environmental quality, cost efficiency and energy efficiency should enable the building to reach acceptable level of energy performance (Omer, 2008). In meeting sustainable energy performance under ZEB model, accurate balance between energy demand and energy supplies are fundamental factors to success. The weighted balance can be calculated in different ways but essentially the building should be able to export more energy to the grid and a net balance obtained for it to qualify under ZEB model.

The *export/import* balance takes into account the self consumption of generated energy, and afterwards creates a balance between the need for exported and imported energy this balance applies well in monitoring. The *load/generation* balance is a simpler approach where the interactions between the grids are overlooked. This is equivalent to assume that, per each carrier, the load is completely satisfied by delivered energy while generated energy is entirely fed into the grid. This balance is applicable in early stage design for compliance with green building standards.

1.12 Conceptual Framework

Figure 1.2: Conceptual framework



Source: Adopted and modified from Barley D. *et al*, (2005) According to Barley *et al* (2005), a net-zero energy building is a residential or commercial building with greatly reduced energy needs. In such a building, efficiency gains have been made such that the balance of energy needs can be supplied with renewable energy technologies. In the figure above, the green (renewable) energy sources cumulatively reduce the energy demand from other non-renewable sources (from outside the building). If the total energy demand for the building is equal to the total energy produced from the green sources, then the building is said to be a net zero energy building or an energy independent building (WBDG, 2013); when a building is at zero energy consumption, then non green energy sources remain as backup power.

Green buildings also install energy efficient equipment and lighting fixtures and in so doing they lower their energy demands significantly (EPA, 2004). This implies that the building will require less energy for day to day needs and therefore attaining the building’s energy independence level is possible using the energy sources from within the building (green sources). In a way, these eco-friendly appliances contribute to the lowering the building’s energy demand.

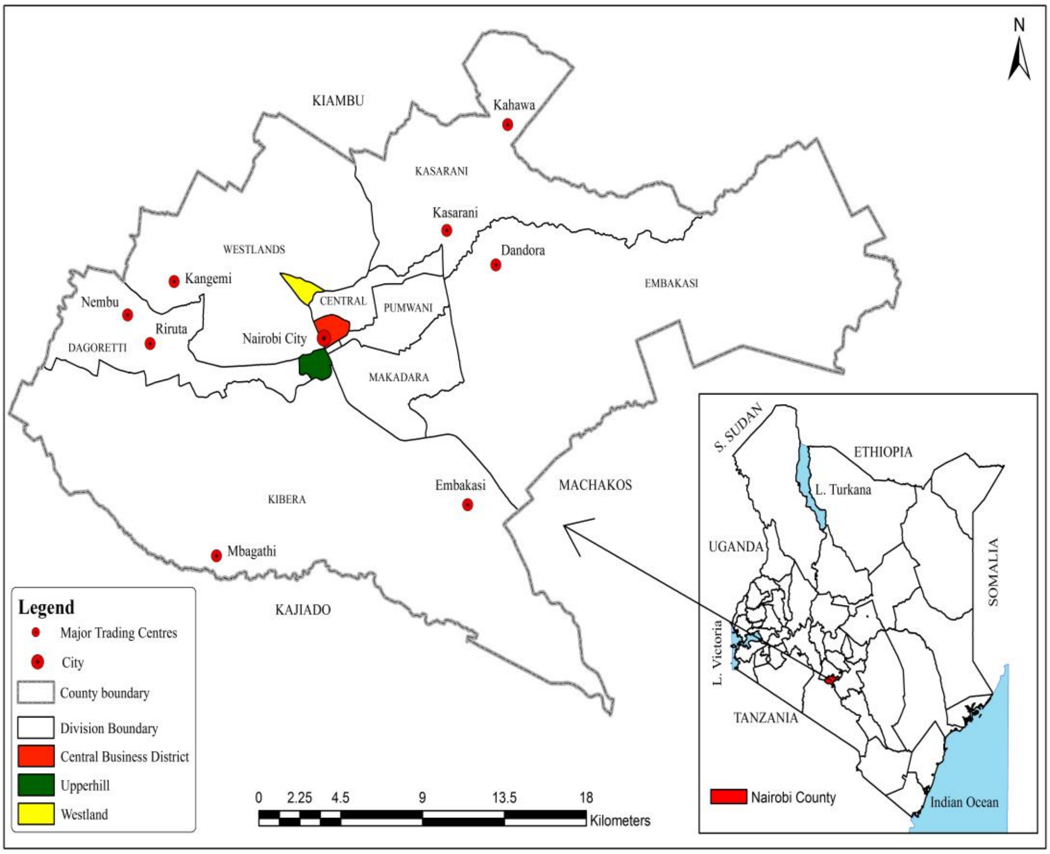
It is also important to note that greatest opportunities for energy efficiency exist at the design stage of the building (UNHABITAT, 2012). A green building with large windows can help in eliminating the need for artificial lighting during the day while a properly cross-ventilated building will eliminate the need for artificial cooling; in this way the structure helps in cutting down its overall energy demand.

1.13 Study Area

1.13.1 Location and Size

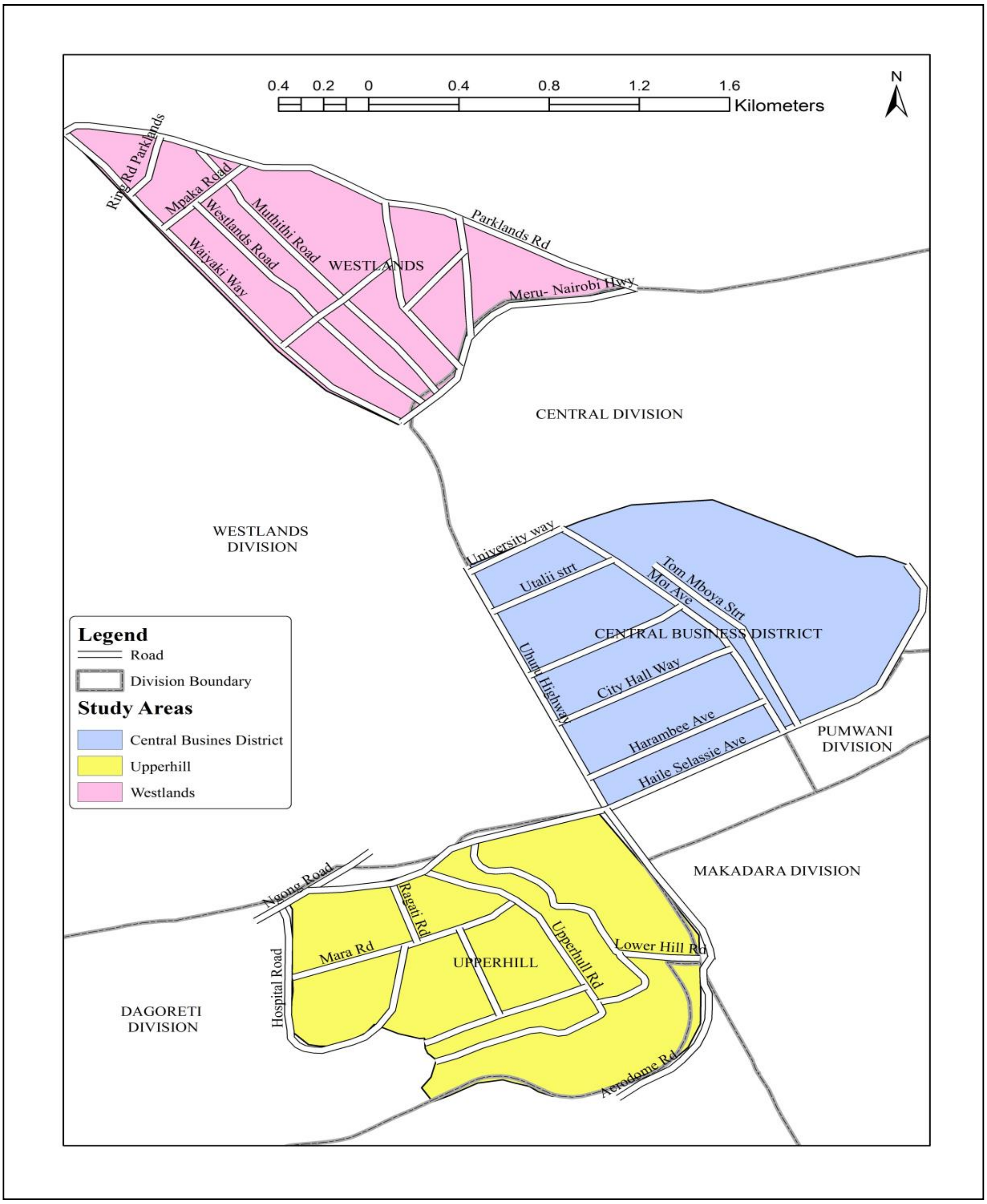
Nairobi is located at the south-eastern end of Kenya’s agricultural heartland, at approximately 1° 9’S, 1° 28’S and 36° 4’E, 37° 10’E. It occupies an area of about 696km^2 (CBS 2001) and the altitude varies between 1,600 and 1,850 metres above sea level (Mitullah 2003). The research was carried out in the areas with the highest concentration of highrise office buildings; Westlands, Upperhill and the Central Business District as indicated in figures 1.1 and 1.2.

Figure 1.3: Map of Nairobi showing the study area



Source: Modified from Survey maps of Kenya, (2015)

Figure 1.2: Map of Nairobi's Westlands, Upperhill and CBD (the study areas)



Source: Modified from Survey maps of Kenya, (2015)

2.7.1 Geology and Soils

The rocks in the Nairobi area mainly comprise a succession of lavas and Pyroclastics of the Cainozoic age and overlying the foundation of folded Precambrian schist's and gneisses of the Mozambique belt (Saggerson, 1991). The crystalline rocks are rarely exposed but occasionally fragments are found as agglomerates derived from former Ngong volcano. The soils of the Nairobi area are products of weathering of mainly volcanic rocks. Weathering has produced red soils that reach more than 50 feet (15m) in thickness (Saggerson, 1991). A number of subdivisions are recognized in the Nairobi area according to drainage, climatic regions and slopes, and other categories have been introduced for lithosols and regosols.

Nairobi City comprises several spots of sensitive soils and variable/inclined ground profiles. The surface is covered by any of the following soils: black cotton clays, red or brown clays, red-silt soils, laterites, decomposed tuffs, alluvium or swamp soils. Sikes (1934) indicates that existence of swamps made some parts of the city unsuitable for structural development. Many borings as well as trial pits beneath and around building sites show that the thickness of the soft and sensitive deposits varies from 0.8 to 21 meters (m) below the ground surface. Groundwater level varies considerably with surface topography and season and lies between 0.5 m to 18 m below the ground surface. The shallow groundwater is found to flow towards nearby rivers creating underground rivers that flood foundation excavations and in a few cases it is found to recharge from the nearby rivers. Most of the rivers draining the city join River Athi that discharges water to the Indian Ocean.

Building designers routinely use a variety of methods to minimize adverse effects on structures supported on sensitive and variable soils. The approach used is to minimize total settlement under footings to a range of 4 to 8 cm or by use of foundation types that are able to bridge over the soft spots such as strip footings or rafts. Floating rafts have rarely been utilized because of factors such as: the depth that the foundation should be placed to get full flotation, need for shoring to prevent heaving and cave-ins, the groundwater that might need lowering, and, the effect of deep excavation on adjacent foundations that cannot be adequately determined (Saggerson, 1964).

Variability of engineering properties of the subsurface materials in Nairobi calls for thorough geotechnical investigations before design of structures but generally the soils are stable enough to carry high-rise buildings without the need to use expensive foundation types like driving piles saving on materials used on construction.

2.7.2 Relief

The western part of Nairobi is on high ground (approximately 1700–1800 msl) with rugged topography, the eastern side is generally low (approximately 1600 msl) and flat (Saggerson 1991). Key physical features include the Nairobi, Ngong and Mathare rivers and the indigenous Karura forest in northern Nairobi.

The Ngong hills stand towards the west, Mount Kenya towards the north and Mount Kilimanjaro towards the south-east. As Nairobi is adjacent to the Rift Valley, minor earthquakes and tremors occasionally occur therefore the structural design of high-rise building must always consider there occurrence.

2.7.3 Climate

Nairobi has a temperate tropical climate with two rainy seasons. Highest rainfall is received between March and April and the short rainy season is between November and December. The mean annual rainfall ranges between 850- 1050mm. The mean daily temperature ranges between 12 and 26°C (Lakin, undated). It is usually dry and cold between July and August, but hot and dry in January and February (CBS 2003). The mean monthly relative humidity varies between 36 and 55 per cent. The mean daily sunshine hours varies between 3.4 and 9.5 hours (CBS 2003). The cloudiest part of the year is just after the first rainy season, when, until September, conditions are usually overcast with drizzle (KMA 2014).

Table 2.2: Precipitation, temperatures and sunlight hours experienced in Nairobi

Month	**Precipitation**		**Maximum**		**Minimum**		**Average Sunlight**
	in	**cm**	**F**	**°C**	**F**	**°C**	**Hours**
January	1.5	3.8	77	25	54	12	9
February	2.5	6.4	79	26	55	13	9
March	4.9	12.5	77	25	57	14	9
April	8.3	21.1	75	24	57	14	7
May	6.2	15.8	72	22	55	13	6
June	1.8	4.6	70	21	54	12	6
July	0.6	1.5	70	21	52	11	4
August	0.9	2.3	70	21	52	11	4
September	1.2	3.1	75	24	52	11	6
October	2.0	5.3	75	24	55	13	7
November	4.3	10.9	73	23	55	13	7
December	3.4	8.6	73	23	55	13	8

Source: KMA (2015)

Table shows that Nairobi experiences averagely 7 sunlight hours which adequate to provide daylight to office building almost throughout the day and throughout the year.

Nairobi temperatures are typically in the mid-20s Celsius therefore the buildings can use this benevolent climate to maximum effect by adoption of natural heating and cooling, abundant natural light, and solar energy. Under these conditions, the designs for green buildings are more ideal as incorporating extra insulations in the design to cover for extreme temperatures is not necessary. The constructions can use as many renewable and recycled materials as possible to minimize energy use and hazards to human health, and local materials can be selected when available in order to avoid excessive emissions caused by transporting them to construction sites.

2.7.1 Drainage

Nairobi's main drainage follows the regional slope of the volcanic rocks towards the east, while subsidiary internal drainage into the Rift region is confined to the western part. The lava plains east of the line Ruiru-Nairobi-Ngong are underlain by a succession of lava flows alternating with lakebeds, streams deposits, tuffs and volcanic ash. These plains, comprising mainly the Athi plains and the northern section of the Kapiti plain, extend westwards, rising from 4900 feet (1493 m) at the Athi River to 6000 feet (1829 m) in the faulted region near Ngong. The lava plains are crisscrossed with steep-walled gullies and canyon-like gorges, such as those along the Mbagathi valley. Further east this valley widens slightly where soft material is being actively eroded (Saggerson, 1991).

Water draining eastward from the hilly areas accumulates on the low-lying ground between Parklands in the north and Nairobi South estate, forming a perched water table above the Nairobi phonolite. The Kerichwa Valley Tuffs lying to the east of the highway function like a sponge and the contact between them and the underlying impermeable phonolite thus forms a perfect aquifer, so much so that a number of channels containing water occur beneath Nairobi.

These drainage pattern is critical in the design of buildings in Nairobi especially buildings with basements otherwise in cases of flooding it leads to high building maintenance costs needed pump out the water, replace any broken finishes and machinery.

2.7.2 Vegetation Cover

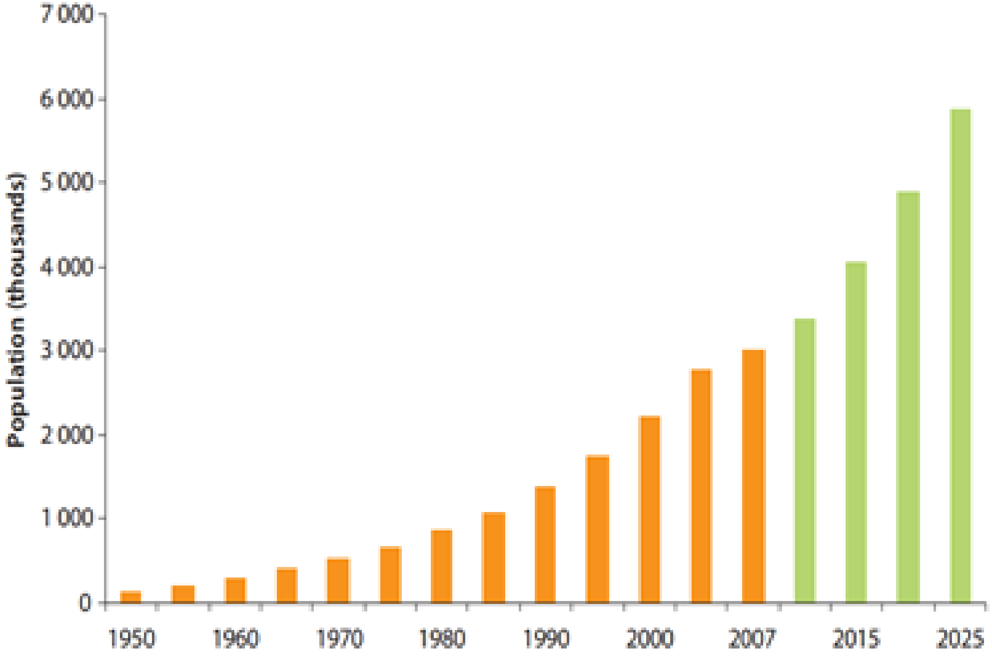
According to Mundia C. N. *et al* (2007), land cover statistics, extracted from Landsat Multi-spectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM+) images for 1976, 1988 and 2000 respectively, revealed that the built-up area has expanded by about 47 km^2. The road network has influenced the spatial patterns and structure of urban development, so that the expansion of the built-up areas has assumed an accretive as well as linear growth along the major roads. The urban expansion has been accompanied by loss of forests and urban sprawl. Integration of demographic and socio-economic data with land use/cover change reveal that economic growth and proximity to transportation routes have been the major factors promoting urban expansion and destruction of Nairobi's vegetation cover.

2.7.3 Human Environment

The population of Nairobi grew from 8,000 in 1901 to 118,579 in 1948 (Rakodi 1997). By 1962, the city had a population of 343,500 people, although some of this could be attributed to extension of the city's boundaries. Between the 1948 and 1962 censuses, the population grew at an average rate of 5.9 per cent per annum, compared with 7.6 per cent in the previous 12-year period. Taking the 1999 census figures as a baseline, it is projected that the city's population by the next census in 2009 will be about 3.1 million, and 3.8 million by 2015 (CBS 2001).

Nairobi is currently home to nearly four million people and represents about a quarter of Kenya's urban population. A growing economy and swelling population numbers from both in-migration and natural growth are continually increasing the city's size. A significant number of commuters from satellite towns such as Thika, Naivasha, Ngong, and Machakos come into Nairobi daily to work or bring goods and supplies. Daily commuters from such satellite towns contribute an estimated additional half-million people to the city's population (KNBS 2014). The chart below shows how the Nairobi population is likely to grow by 2025.

Fig 1.3: Nairobi's historical and projected population (1950-2025)



Source: KNBS (2008)

This increase will put even more pressure on the available resources. Although it covers only 0.1 per cent of Kenya's total surface area, Nairobi already has about 8 per cent of the country's total population (CBS 2001) and 25 per cent of Kenya's urban population (UN-Habitat 2001).

Nairobi is a major contributor to Kenya's economy: it generates over 45 per cent of GDP, employs 25 per cent of Kenyans and 43 per cent of the country's urban workers (UN-Habitat 2006). The paradox is that the financial capacity of the City Council of Nairobi is extremely limited, largely because of poor resource management and a weak revenue collection system. As a result, there is a 200 per cent shortfall between the revenue collected per capita ($7 on average) and per capita expenditure ($21) (UN Habitat 2006). Although foreign direct investment is small, it plays a key role in Kenya, particularly as a means for technology and knowledge transfer, such as in horticulture and floriculture.

The lower income group constitutes about 80 per cent of the population in Nairobi. For the middle and upper income group, the inflation rate rose from 8.0 in 2004 to

10.1 per cent in 2005. It is estimated that about 500,000 people join the labour force annually. Most of these are unable to secure employment and thus remain unemployed or end up in traditional agriculture and in the informal sector (Odhiambo and Manda 2003). The 1997–1998 labour force survey showed that 9 per cent of people in Nairobi were employed and 24 per cent were unemployed (CBS 2003b).

2.7.4 Political Structure and Governance

Nairobi is governed by the County Government of Nairobi (CGN) and is headed by a Governor. The County Government is mandated with the provision of services and these are delivered in various sectors which are in tandem with the Constitution of Kenya, 2010 (CGN, 2014).

The structures within the Nairobi City County include; the County Assembly, the County Executive Committee, the County Public Service Board, Advisors of the Governor and the Transitional Team from the Transitional Authority. The County Assembly consists of 85 elected members and 43 nominated members; adding to a total of 129 members.

The functions of the County Assembly include; making laws for the effective performance of the County Government, exercising oversight over the county executive committee, receiving and approving plans and policies for: managing and exploiting the county's resources and developing and managing the infrastructure and institutions.

CGN plays a very key role in approving all building development plan within the city of Nairobi and are also responsible for formulating building development policies which have to be complied with by the developers. This CGN function provides a window through which green building design concepts can be incorporated into the regulations in ensuring energy conservation.

CHAPTER THREE

2.0 METHODOLOGY

2.1 Research Design

2.1.1 Sampling Method

This research adopted purposive sampling method to get the target population of 210 high-rise office buildings in Nairobi. This data was obtained from the Nairobi City County Building Development Control Department Registry (Appendix II). Simple random sampling technique was then used in obtaining a sample of 42 high rise office buildings out of a target population of 210 high rise office buildings in Nairobi and this was done by writing the names of all the 210 buildings (139 building in the CBD zone, 34 buildings in Upperhill zone and 37 buildings in Westlands zone) in separate sheets of papers. The papers were then individually folded and put in three different huts ('CBD hut', 'Westlands hut' and 'Upperhill hut'), each of the huts was shaken and from the 'CBD hut' 28 buildings were picked, from the 'Westlands hut' 7 buildings were picked and from the 'Upperhill hut' 7 buildings were picked.

The 42 high rise office buildings were then assessed to qualify them as green or non green buildings using the Green Star rating system. This was informed by existing local and international best practices on green Architecture with emphasis on energy conservation in high-rise office buildings.

The study collected data on existing green and non-green buildings within the area of study to determine the building characteristics which have an impact on energy consumption and the amount of energy conservation per unit area per unit time. A comparative analysis was then done to determine the differences in energy consumption between the green and non-green buildings with the intention of formulating a guideline of realizing energy efficient buildings in Nairobi.

2.2 Data Types and Sources

Primary data was collected from the field by use of questionnaires and checklist for assessing building design and materials. The questionnaires were designed to collect information on user behaviour alongside key informants’ interviews to the management and owners of the buildings to provide technical information. User behaviour aimed at interrogating thermal and optical comfort of buildings and subsequent behavioural response. Use of photographs and personal observations was also be used in data collection. The checklists were designed to assess the building in line with the variables such as materials, designs and services offered. Data on energy consumption will be obtained from secondary sources recorded on monthly billing and electricity meter reading.

The key areas in the office buildings that formed the main variables of the study were:-

a) Characteristics of green office buildings
b) Material resource utilization
c) Building services and equipment that consume the buildings' energy
d) The energy conservation strategies in place

2.3 Data Collection Procedure

2.3.1 Reconnaissance survey

A preliminary investigation was done to establish the regions in Nairobi with the highest density of high-rise office buildings. The total number and the names of these buildings were obtained from the Nairobi City County Building Development Control Department (Appendix II). The actual buildings were also visited to ascertain whether the buildings were purely of office type as verification of the data provided by Nairobi City County.

The zones in Nairobi with the highest concentration of high rise office buildings were identified then structured questionnaires with open ended questions was used to collect data in the selected study areas.

2.3.2 Sampling Frame and Sample Size

The sampling frame for high-rise buildings comprised individual high-rise office buildings of not less than six floors in Nairobi (appendix II). Since there was more than one area of high-rise buildings concentrations in Nairobi, this study subdivided the Nairobi surface into zones of high concentration of high-rise buildings. These zones included the Central Business District, the Upper hill area, Westlands, Hurlingham area and Buruburu Centre. Only those areas with high concentration of high-rise office buildings were considered in the study resulting in three sampling areas of CBD, Westlands and Upper hill.

Within each of these sampling areas a list of buildings with not less than six floors was made and the total number of high-rise office buildings was 210 out of which 42 buildings were chosen using the formula,

$n = \left(\frac{zs}{d}\right)^2$, *assume a margin of error of 4 at 95% confidence level*

where

n = sample size

s = standard deviation

d = margin of error

Using the formula above and the frequency table below, the sample size for the high-rise buildings was arrived at as follows:

Determining the sample size (Refer to Appendix II for the target population)

Table 2.1: Table showing the number of high-rise office buildings in the study area

Class interval	CBD	Westlands	Upperhill	F
06 - 10	75	28	13	**116**
11 - 15	31	6	12	**49**
16 - 20	18	3	4	**25**
21 - 25	9	0	2	**11**
26 - 30	3	0	1	**4**
30 - 35	3	0	2	**5**

Total	**139**	**37**	**34**	**210**

Source: Research, (2015)

Table 2.2: Frequency table of high-rise office buildings from the study area

X	**F**	**FX**	**X^2**	**FX^2**
08	116	928	64	7424
13	49	637	169	8281
18	25	450	324	8100
23	11	253	529	5819
28	4	112	784	3136
33	5	165	1089	5445

Source: Research, (2015)

Mean = $\sum fx/N = 2545/210 = 12.12$

Variance = $\sum fx^2/N - \dot{x}^2 = (38205/210 - 2545/210) = 35660/210$

$\sigma^2 = 169.81$

Standard deviation = square roof of 169.81 = 13.03

$n = [(1.96 \times 13.03)/4]^2$

$n = [(25.5)/4]^2 = (6.4)^2$

$n = 40.96$

Approximate sample size, n = 42 buildings

For each area of study the following number of buildings will be investigated:

CBD

*(139/210)*42 = 27.79 = 28 buildings*

Westlands

*(37/210)*42 = 7.39 = 7 buildings*

Upperhill
*(34/210)*42 = 6.7 = 7 buildings*

2.3.3 Data Collection Instruments

Questionnaires formed the main instrument for data collection (Appendix I). The questionnaire used was structured and non-disguised. The respondents were guided by the open-ended questions categorized in ten main categories.

Property agents and property managers for respective buildings were used as the respondents. In cases where technical information was required and the respondents were not competent enough to respond, key informants like the project Architects were used to get the required information. Personal observations and photographs were also used to aid in data collection especially of materials and finishes used in the buildings.

Forty two questionnaires were administered during data collection with twenty eight administered in the CBD, seven in Upperhill and seven in Westlands. The number of questionnaires given was determined by the formula, $n = \left(\frac{zs}{d}\right)^2$, as indicated below.

2.3.4 Data Analysis Techniques

i. Prevalence of green buildings

All the building buildings studied were analysed and scored based on the Green star certification criteria under the following nine aspects:

i. Land use and ecology - 5%
ii. water efficiency - 10%
iii. Resource utilization - 14%
iv. Energy use - 20%
v. Indoor Environmental quality - 18%
vi. Emissions - 11%

vii. Innovation - 4%
viii. Transport - 9%
ix. Management - 9%

The buildings that scored a total of 0 - 19 percent were given 1 star rating, the buildings that scored 20 - 29 percent were given 2 star rating, the buildings that scored 30 - 44 percent were given 3 star rating, the buildings that scored 45 - 59 percent were given 4 star rating, the buildings that scored between 60 - 74 percent were given 5 star rating and the buildings that scored 75 percent and above were given 6 star rating.

The building that were rated 4 star and above in this study were considered to be green buildings while the buildings that were rated 3 star and below were considered as non-green office buildings.

ii. The impact of buildings services on energy consumption

All the building services that consume energy in high rise office buildings were identified and an assessment was done on each building service to determine the amount of energy it consumes. This was done by ranking all the building services identified from the highest consumer to the least consumer for each high-rise building under study.

iii. The variations in energy consumptions by building Architecture

A comparative analysis between green and non-green office buildings was undertaken to determine the differences in energy consumption per unit area per unit time. This was done by establishing the average energy consumed in 1 star rated buildings, 2 star rated buildings, 3 star rated buildings, 4 star rated buildings, 5 star rated buildings and 6 star rated buildings.

2.4 Data Processing

Data collected was organized and edited for the purpose of ensuring comprehensiveness, accuracy and consistence thereafter analyzed quantitatively using descriptive statistics to get frequencies, percentages, mean and standard deviations. Cross tabulation was done to compare energy performance variables of both green and non-green buildings in order to test significant difference. Further, data on energy was used to test hypothesis using chi-square. This helped the researcher obtain detailed information which facilitated useful conclusions and recommendations on energy performance in green buildings.

CHAPTER FOUR

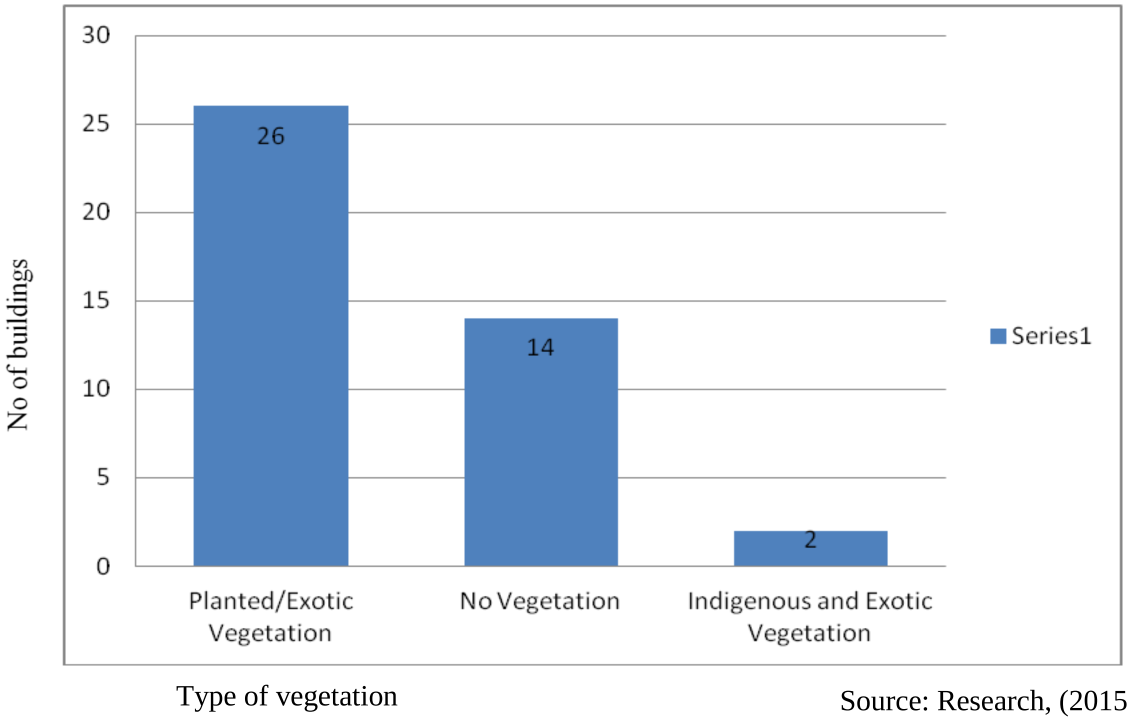
4.0 RESULTS AND DISCUSSION

4.1 Prevalence of green buildings in Nairobi

4.1.1 Land use and Urban ecology

All the respondents were asked if there was any vegetation and whether the vegetation consisted of exotic planted trees or indigenous trees. Out of the 42 buildings studied 14 buildings had exotic planted vegetation consisting of shrubs and mature trees, 26 buildings had no vegetation and 2 buildings had indigenous trees that existed even before the buildings were put up.

Figure 4.1: A graph showing the number of buildings with indigenous and exotic vegetation and the buildings without any vegetation.



Source: Research, (2015)

Trees and shrubs are an important part of urban environments. In addition to aesthetic values, they reduce the need for air-conditioning and the use of fossil fuels. Trees and shrubs also can absorb and concentrate pollutants and improve the air quality in a city. The stakeholders in the building industry should therefore be encouraged to retain existing vegetation as much as possible and also plant new vegetation after construction so as to reap the maximum benefits of having vegetation in our urban environments.

Plate 3.1: International life house at CBD with both exotic and indigenous vegetation on site.

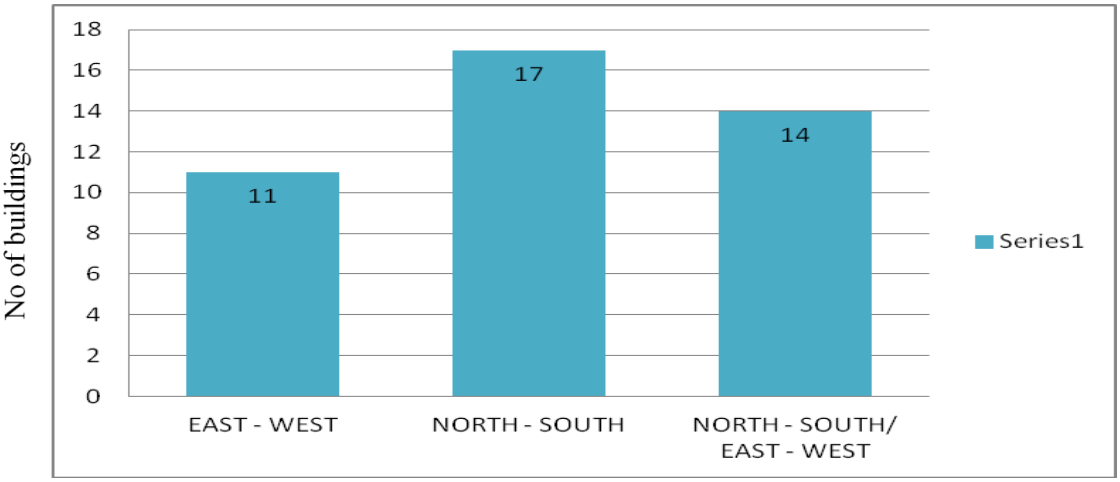
Source: Research, (2015)

Plate 4.2: Good man house along Waiyaki with all vegetation cleared from site.

Source: Research, (2015)

The survey also found out that 41 percent of the buildings had their fenestrations on the South facing and North facing facades with 33 percent of the buildings having their fenestrations on all sides of the building as shown in the graph below.

Figure 4.2**:** A graph showing the orientation of the building windows.



Source: Research, (2015)

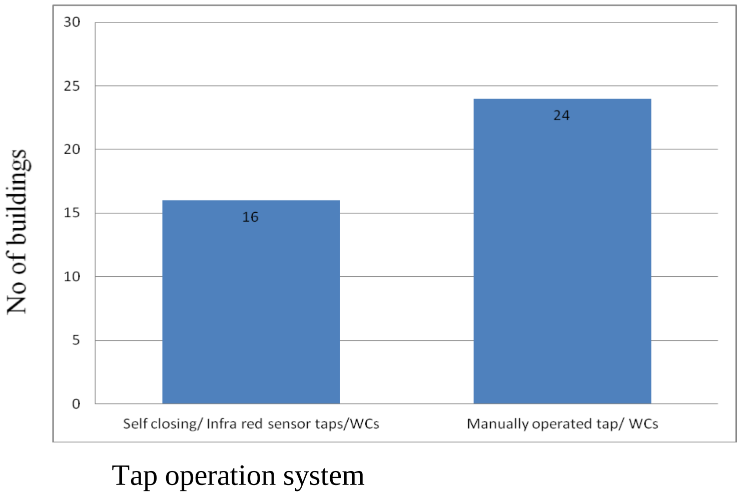
South and North facing windows are shielded against the direct sun glare therefore eliminating the need for building sun-shading devices; however, the winds have a high frequency easterly flow thus placing windows on East - West facades helps cross ventilation which eliminates the need for mechanical ventilation in buildings. The building Architects should give considerations of these building aspects and design buildings that are responsive to the various site specific issues and ecologically sound

4.1.2 Water efficiency

All the 42 buildings studied depend on water supply from Nairobi Water and Sewerage Company (NWSC) with 25 percent of them having a backup borehole. Only one building was found to recycle their waste water and also collect the surface run - off water to irrigate their vegetation.

On the aspect of adoption of water-waste reducing technologies, the respondents were asked to note the type of water taps and water closets that had been installed on their respective buildings, 60 percent of the buildings were found using the traditional manually operated taps while 40 percent had installed the water-waste reducing self-closing taps and water closets as shown on the graph below

Figure 4.3 A graph showing the number of buildings with self-closing taps and those with manually operated taps.



Source: Research, (2015)

The building owners should try as much as possible to install the more technologically advanced water-waste reducing sanitary fittings. Reducing water consumption and protecting water quality are key objectives of sustainable design. One critical issue of water consumption is that in urban areas, the demands on the supplying aquifer exceed its ability to replenish itself. To the maximum extent possible, urban buildings should decrease their need for water by increasing efficiency. Once efficiency has been optimized, facilities should maximize the use of water that is collected, used, purified, and reused on-site. Though the collect and treat strategy will do little to reduce total water volume used on-site, it will minimize treatment and transport losses as well as reduce the overall energy required for processing and conveyance.

3.1.3 Resource Conservation

Material resource conservation is one of the key aspects of green Architecture. In almost all buildings studied, it was found out that over 70 percent of the materials used in the building skeleton are locally obtained but also 0ver 70 percent the materials used to finish the buildings were imported as illustrated by the plates below.

Plate 4.4: Delta tower along Waiyaki way in Westlands, Nairobi
Source: Research, (2015)

Plate 4.3: Corner house in Kimathi Street at CBD
Source: Research, (2015)

Plate 4.4 shows the exterior view of Delta towers whose facade is almost fully clad in imported materials consisting of aluminium composite panels and glass curtain walls while plate 4.3 shows the exterior view of Corner house whose facade is done using plaster and paint that is locally available and framed curtain walls and windows that are partly imported and partly locally available

It is critical to achieve an integrated and intelligent use of materials that maximizes their value, prevents upstream pollution, and conserves resources. A green building is designed and operated to use and reuse materials in the most productive and sustainable way across its entire life cycle. The materials used in a sustainable building minimize life-cycle environmental impacts such as global warming, resource depletion, and human toxicity. Environmentally preferable materials have a reduced effect on human health and the environment and contribute to improved worker safety and health, reduced liabilities, reduced disposal costs, and achievement of environmental goals.

Extraction and consumption of natural resources as building materials or as raw materials for production of building materials and building materials production itself in implementing construction works has a direct impact on natural bio-diversity due to the fragmentation of natural areas and ecosystems caused by construction activities. In particular, large amount of minerals resources are consumed in the built environment and most of these mineral resources are non-renewable. Therefore, it is important to reduce the use of non-renewable materials. According to Abeysundara *et al* (2009) this should be incorporated for consideration at the project initiative and design phases, where the selection of materials is very important and the choice should be based on the materials' environmental impacts.

3.1.4 Energy Efficiency

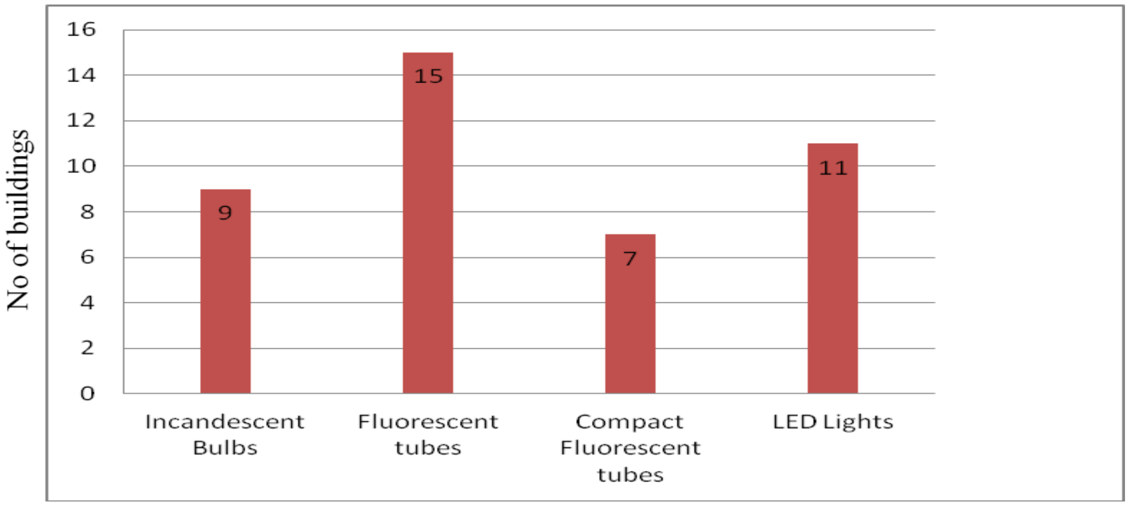
Energy use is one of the most important environmental issues and managing its use is inevitable in any functional society. Buildings are the dominant energy consumers. Buildings consume energy and other resources at each stage of building consumers. Buildings consume energy and other resources at each stage of building project from design and construction through operation and final demolition. According to Lenzen *et al* (2002), the kind and amount of energy use during the life cycle of a building material, right from the production process to handling of building materials after its end life can, for example, affect the flow of greenhouse gases (GHGs) to the atmosphere in different ways over different periods of time.

All the 42 buildings studied use power from the national grid as their main source of energy with 75 percent of them having generators as their backup power source. Only one building out of the 42 buildings studied had installed solar panels as their secondary source of power.

a) Type of lighting fittings

All the respondents were asked to identify the type of lighting fixtures that they had installed on their buildings and it was found out that 9 buildings were using incandescent bulbs, 15 buildings were using fluorescent tubes, 7 buildings were using compact fluorescent tubes and 11 buildings were using LED lights as summarized in the graph below.

Figure 4.4: A graph showing the type of light fittings installed in the buildings studied.



Lighting fitting type

Source: Research, (2015)

According to WBDG 2014, fluorescent lamps are about 3 to 5 times as efficient as standard incandescent lamps and can last about 10 to 20 times longer. To gain the most efficiency, use current and proven equipment technology and install fluorescent fittings in places where they can be integrated with the Architecture, available daylight, and switching or dimming controls. LED lamps are the newest addition to the list of energy efficient light sources. While LED lamps emit visible light in a very narrow spectral band, they can produce "white light". This is accomplished with either a red-blue-green array or a phosphor-coated blue LED lamp. LED lamps last up to between 40,000 and 100,000 hours depending on colour. The current challenges of the LED source are a poor colour Rendering Index (CRI) of 65 or lower and poor efficacy, often less than 30 lumens per watt. LED lamps have made their way into numerous lighting applications including exit signs, traffic signals, under-cabinet lights, and various decorative applications. Though still in their infancy, LED lamp technologies are rapidly progressing and show promise for the future therefore the building owners should install this type of light fittings since they are the most efficient.

b) Passive design strategies

All the 42 buildings studied had to some extent applied various passive design strategies so as to cut on their energy consumption.

Use of passive energy design such as natural ventilation, landscaping by vegetation, use of water bodies for evaporation and cooling and orientation of building can help achieve thermal and visual comfort inside the building, so that there is significant reduction in energy consumption by conventional air conditioning and artificial lightning in a building. Architects can achieve energy efficiency in buildings by studying the macro and micro climate of the site, applying solar-passive and bioclimatic design feature and taking advantage of the natural resources on site.

c) Design for climate

Good passive design ensures that the occupants remain thermally comfortable with minimal auxiliary heating or cooling in the climate where they are built. Building in the tropics, if well designed, the need for air conditioning, heating and cooling can completely eliminated since there are no extreme weather changes experienced.

d) Orientation

Orientation refers to the way the building is placed its site to take advantage of climatic features such as sun and wind breezes. 41 percent of the buildings studied face north-south, or as close to north as possible, allowing maximum exposure to the sun, and easy shading of walls and windows. Good orientation reduces the need for auxiliary heating and cooling and improves solar access to panels for solar photovoltaics and hot water. The building is thus more comfortable to work in and cheaper to run. It takes account of hot and cold seasonal variations in the sun's path as well as the direction and type of winds.

e) Day-lighting

All the 42 buildings studied use this passive design strategy however that interior partitions block the daylight from getting into the spaces at the centre therefore artificial lighting had to be used to light those spaces.

Daylight should be used as much as possible to light buildings, both for energy efficiency and for the health and comfort of occupants. Design requirements for day-lighting must be balanced with the user's requirements for views and privacy. Day-lighting must also be considered alongside building location, orientation and layout, in order to control solar access for passive heating and cooling.
Most of the building studied had used the following strategies for utilizing natural light:

- Use diffused light rather than direct sunlight, which requires careful placement and sizing of windows

- Avoidance over-glazing which may cause glare and heat gain in summer and heat loss in cold seasons.

f) Passive ventilation

All the buildings studied had applied passive ventilation strategies. Passive ventilation is when air is exchanged in a building through openings in the building envelope using the stack and wind pressures.

The following strategies were observed:

- Controlled through openings such as windows and doors or purpose-built small vents (such as trickle vents on some windows).
- Uncontrolled by infiltration through unintentional openings such as gaps around windows and doors and between building components.

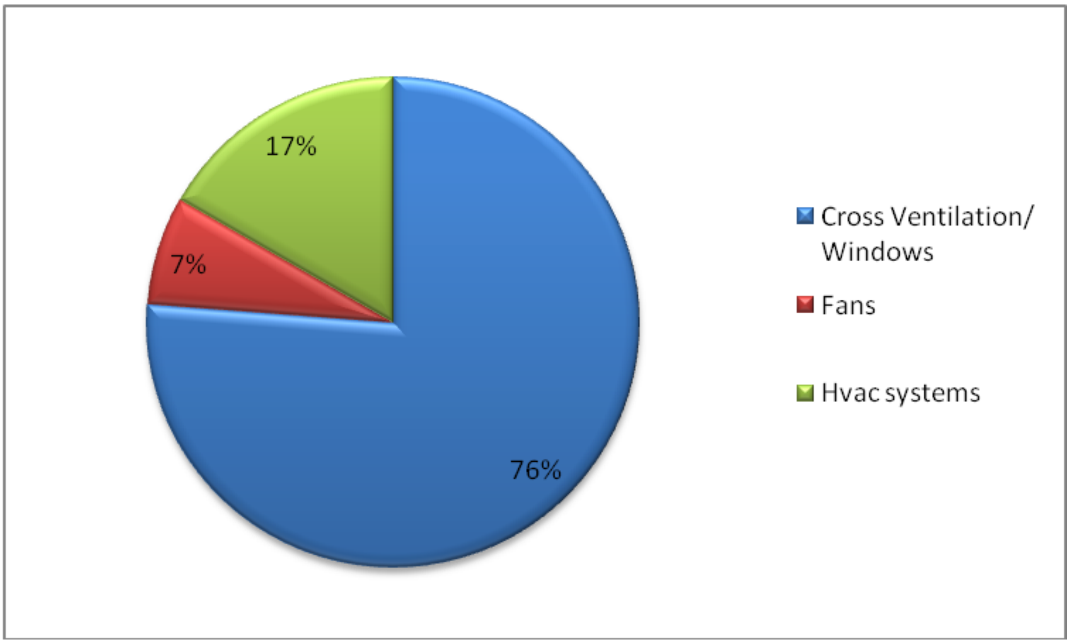
Passive ventilation is an essential component of passive design and is a free and environmentally friendly method of ventilation that is suitable for all buildings with the tropics.

3.1.5 Indoor Environmental Quality

a) Type of ventilation

32 buildings out of the 42 studied solely depend on natural or cross ventilation through the building fenestrations; this is the efficient and sustainable building design strategy that saves on the building's energy consumption. Most of the spaces that are mechanically ventilated are the boardrooms since they normally accommodate more users per square area as opposed to the other general office spaces

Figure 3.4: A Pie chart showing the type of ventilation used in the studied buildings

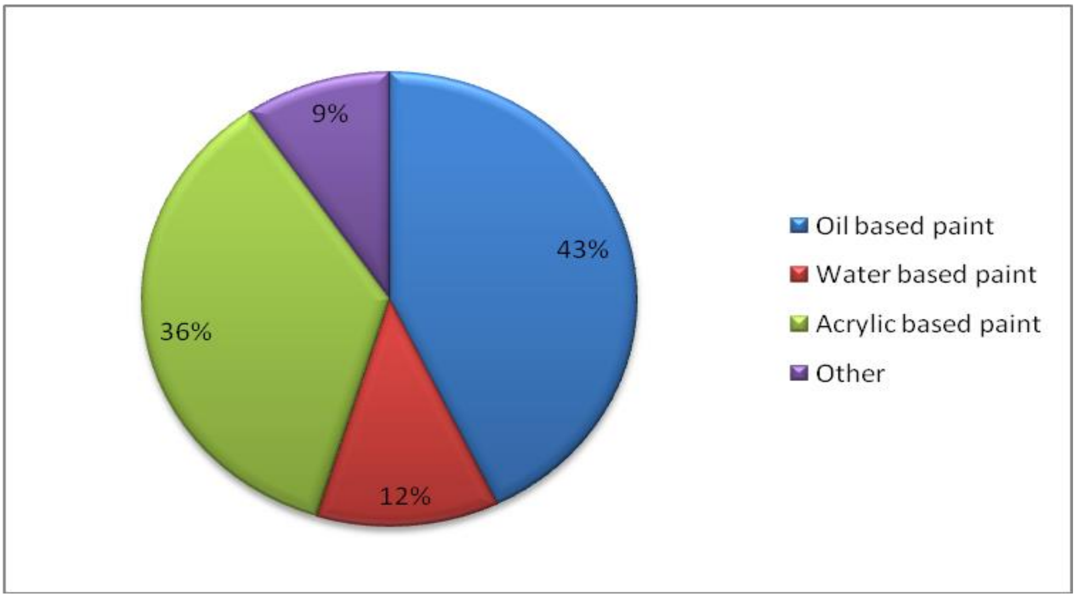


Source: Research, (2015)

a) Type of Paint

Almost 80 percent of the buildings had used oil based and acrylic paint wall finish internally while only 4 out of the 42 studied had used water based paints as indicated in the chart below.

Figure 3.5: A Pie chart showing the type of paint used internally in the studied buildings

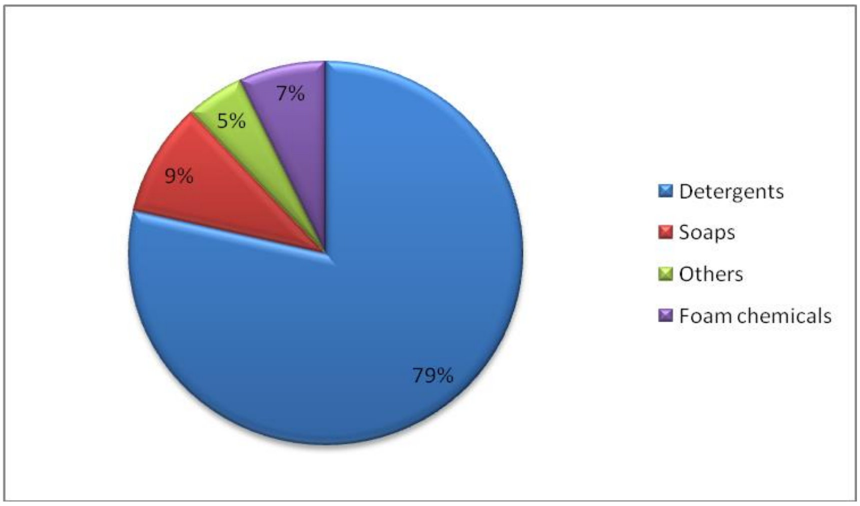


Source: Research, (2015)

b) Cleaning agents used

The study showed that 79 percent of the buildings investigated used detergents in cleaning their facilities with a small percentage using soaps and forms as shown in the chart below.

Figure 3.6: A Pie chart showing the type of cleaning agent used in the studied buildings.



Source: Research, (2015)

Well-being (health and comfort) is an important aspect determining the quality of life of an occupant. In a modern society, where individuals spend more than 90% of their time indoors and more than 70% of their time indoors (Adgate *et al*. 2002, Sev 2009) an essential role of architecture is to provide occupants' health, physiological comfort, physiological satisfaction and productivity. Buildings should therefore be designed and operated by use of materials that are not hazardous to their health and comfort. Application of water based paints, use of natural ventilation, thermal comfort; proper acoustical environment, proper day-lighting and reduction in use of detergents or any other form of harmful chemicals should be avoided as much as possible.

3.1.3 Emissions

All the buildings studied identified the following as the major wastes produced:

i. Toilet waste (both solid and liquid)
ii. Paper waste
iii. Electronic waste
iv. Gaseous emissions mainly from the backup generators
v. Food waste
vi. Clinical waste

None of the buildings had a proper strategy on waste management except that all of them had sub contracted a waste collection firm that picked up the waste twice a week.

Only 3 buildings out of all the buildings studied sorted their waste to either recycle or non-recyclable containers although no follow was being done to ensure that the collected recyclable waste was actually recycled to form any use products.

3.1.4 Innovation

The various innovative design concepts observed during the study were:

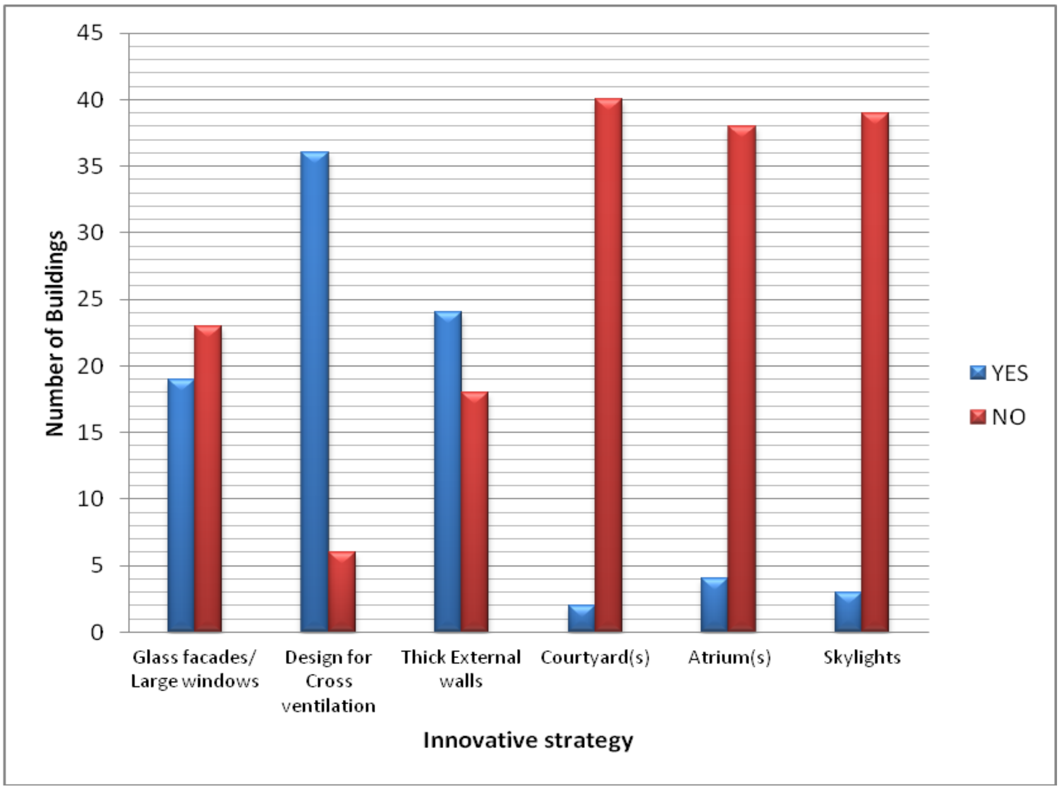
i. Use of courtyards
ii. Use atriums
iii. Use of thick external walls

iv. Orientation of windows in the direction of wind flow
v. Use of large windows and curtain walls to allow for day lighting
vi. Use of Sky-lights

Plate 3.5: Example of Innovative Green designs - Courtyard

Source: Research, (2015)

Figure 3.7: A graph showing the various innovative ideas applied in the studied buildings.



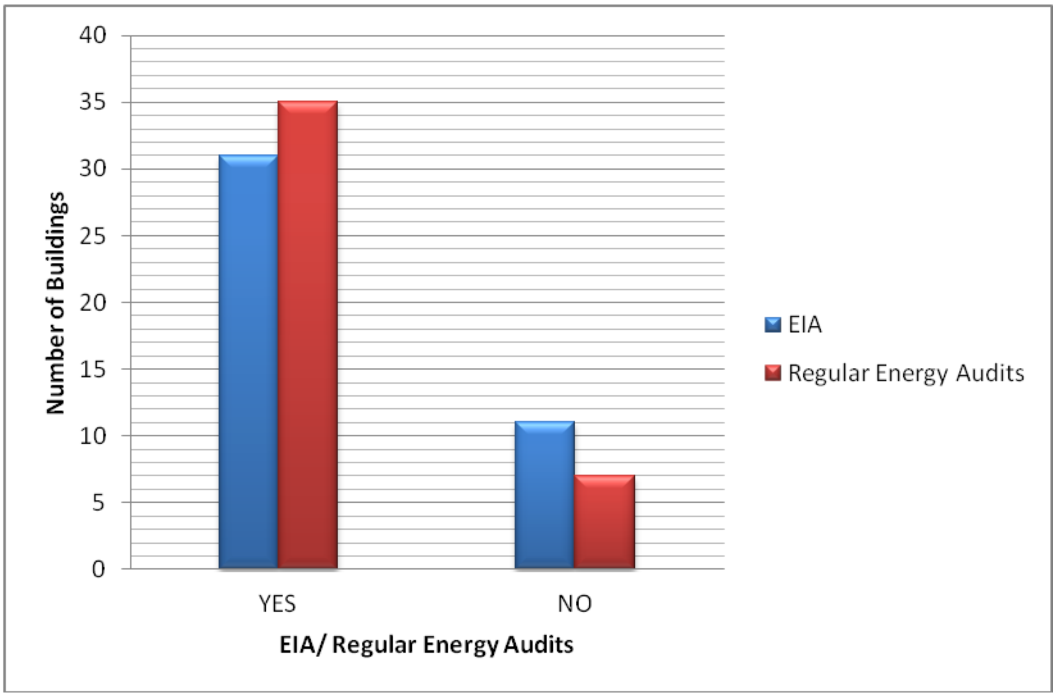
Source: Research, (2015)

A majority of the buildings had used large windows, thick external masonry walls and cross ventilation as the main innovative ideas towards attaining greening buildings. Architects should be continually encouraged to adopt as well as come with new ideas of ensuring that the buildings they designed are eco-friendly.

3.1.5 Management and Transport

All the respondents were asked if they had conducted an Environmental Impact Assessment (EIA) study before the building was put up; 76% percent noted that they had conducted an EIA study while 24% percent had not conducted the EIA study. Most of the buildings that had no prior EIA study were found to have been built before the year 1999 when the EIA law was enacted.

Figure 3.8: A graph showing the number of buildings where EIA was carried out and those that conduct regular energy audits.



Source: Research, (2015)

The study indicated that over 70 percent of the buildings studied conducted regular energy surveys however none indicated whether the recommended given in the surveys were implemented.

Property managers and building owners should try and implement the recommendations given in the energy audit report and those buildings that do not conduct these surveys should be encouraged to do so in order to minimise on the energy consumption by these buildings.

The study further showed that out of the 42 buildings studied, none of them provided mass transport services to and from work for their employees; the building occupants either use personal vehicles that cause a lot of pollution to the environment or public transport (*matatus*) which is a more sustainable means of transport.

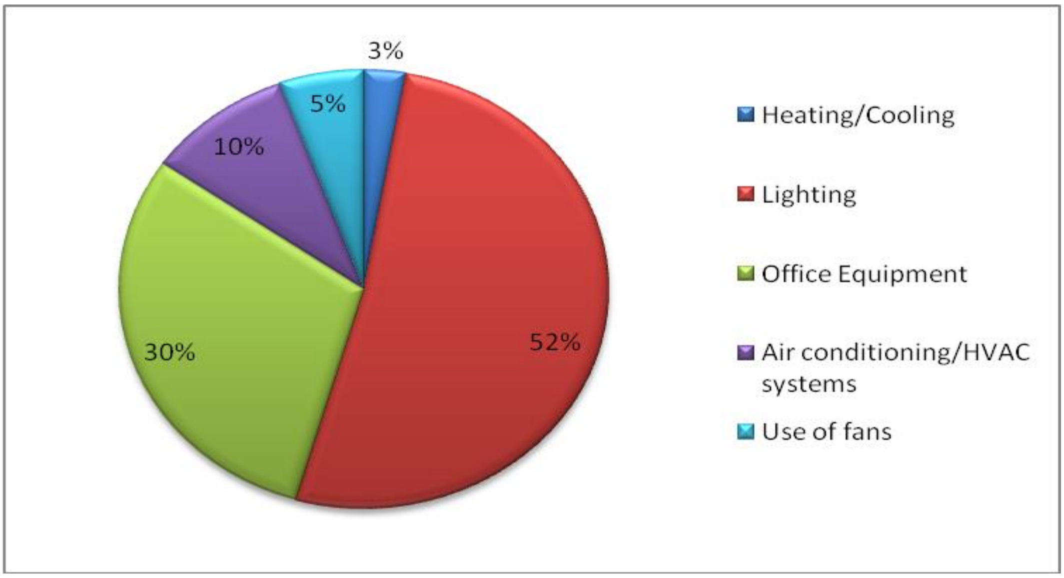
3.2 Building services that consume energy

The following building services were identified by the property managers as the main consumers of the supplied energy

i. Lighting
ii. Heating/cooling
iii. Office equipment
iv. Air conditioning
v. Ventilation/Use of fans

The study indicated that lighting was the biggest consumer of energy in the high-rise office building studied, followed by the energy consumed by the office equipment. The least energy consumers were the energy needs for air conditioning and ventilation as summarized in the pie chart below.

Figure 3.9: A Pie chart showing energy consumption by various building services



Source: Research, (2015)

The results above indicate that if more attention was given to adoption of day lighting passive design strategy and even use of efficient lighting fittings, then a significant amount of energy can be saved in office buildings in Nairobi.

3.3 Variations in energy consumption between green and non-green buildings

All the building buildings studied were analysed based on the Green star certification criteria under the following nine aspects:

x. Land use and ecology - 5%
xi. water efficiency - 10%
xii. Resource utilization - 14%
xiii. Energy use - 20%
xiv. Indoor Environmental quality - 18%
xv. Emissions - 11%
xvi. Innovation - 4%
xvii. Transport - 9%
xviii. Management - 9%

Each building was scored according to its performance on all the nine aspects and the rating was given based on the Green star rating indicated in the table below.

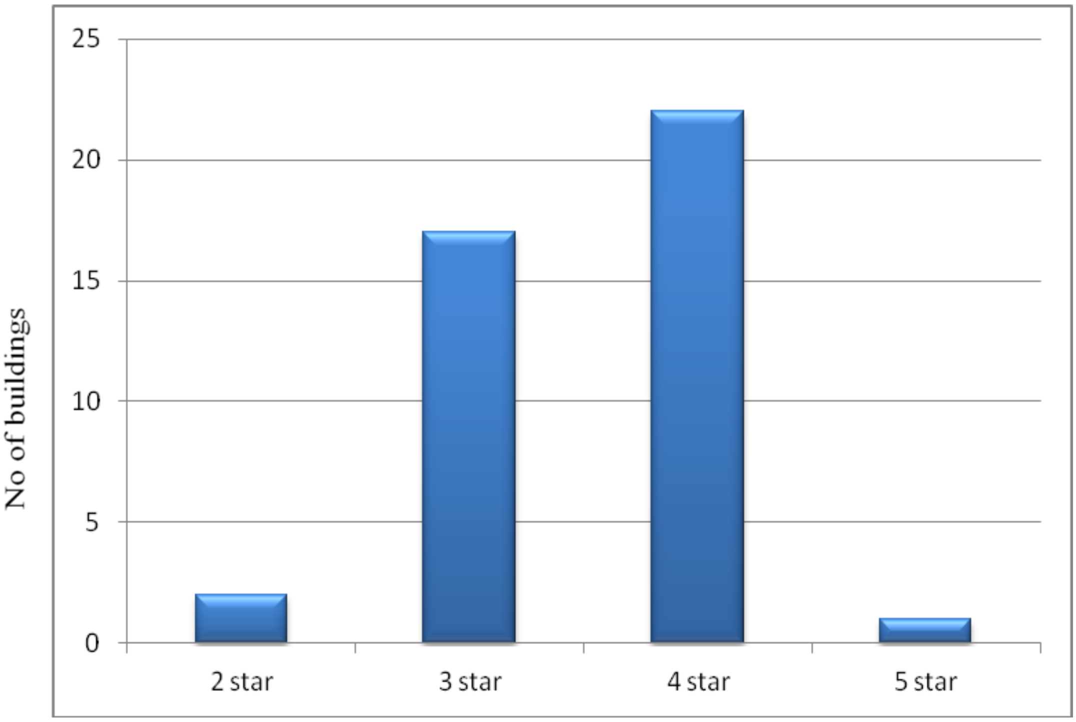
Table 3.1: Green star rating on various scores

Star rating	**Score**
One star (lowest/minimum practice)	10
Two star	20
Three star (good practice)	30
Four star	45
Five star	60
Six star (world leadership)	75

Source: Research, (2015)

Out of the 42 building assessed, only one building attained a 5 star rating, 22 buildings attained 4 star rating, 17 buildings attained 3 star rating and 2 buildings attained a 2 star rating as summarized in the graph below.

Figure 4.11: Number of buildings with the various star ratings



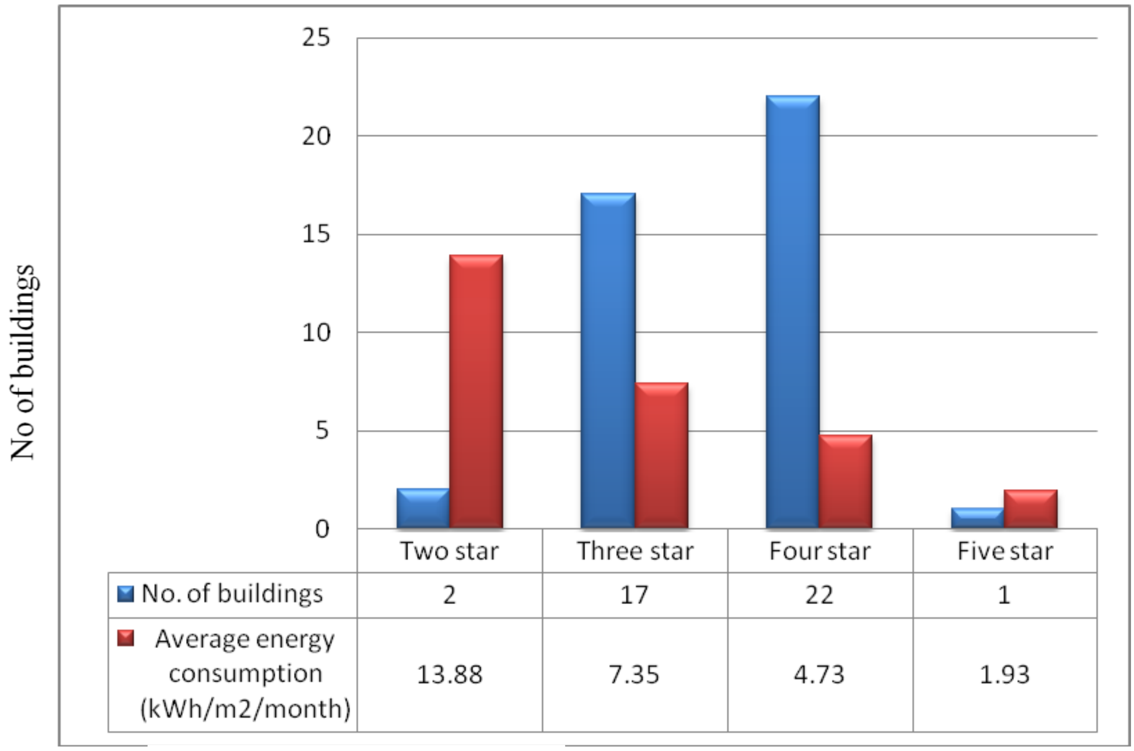
Star rating

Source: Research, (2015)

The buildings that attained 2 star and 3 star ratings were taken as non green buildings while the buildings that attained 4 scores and above were taken as the green office buildings. Only the Coca cola centre attained the highest performance as green building amongst all the buildings that were assessed.

Average energy consumption per square metre per month (kWh/M^2/month) was obtained for green buildings and non-green buildings and the results are as shown in the graph below.

Figure 4.12: A graph showing the average energy consumption for the various star rated buildings



	Two star	Three star	Four star	Five star
🟦 No. of buildings	2	17	22	1
🟥 Average energy consumption (kWh/m2/month)	13.88	7.35	4.73	1.93

Source: Research, (2015)

4.4 The role of building occupants in energy consumption

Occupant behaviour affects the building energy use directly and indirectly by opening/closing windows, turning on/off or dimming lights, turning on/off office equipment, turning on/off heating, ventilation, and air-conditioning (HVAC) systems, and setting indoor thermal, acoustic, and visual comfort criteria. During the study it was observed that despite the Architect's attempt to design energy efficient buildings, the users were on the contrary misusing the energy that was meant to be saved; in some instances the building was well day-lit but still the occupants had the lights switched on as indicated by plate 4.6 below.

Plate 3.6: Example of an office where the lights were on yet there was adequate day lighting

Source: Research, (2015)

In other cases the office equipment were left running even after work hours and therefore unnecessarily consuming a lot of energy. The property managers need to regularly sensitize the building users on appropriate behaviour with regard to efficient energy use in their respective work stations that this way, significant amounts of energy that is otherwise wasted can be saved.

3.5 Chi Square tests for hypothesis

a) Prevalence of green high-rise office buildings in Nairobi

Table 3.2 Table showing the frequency of green and non-green office buildings in the area of study

	Green building	Non Green buildings
0	23	19
E	12.6	29.4

Source: Research, (2015)

df = (K-1) = 1

At 95% confidence level

Reject H_o if $X^2 \geq 3.841$

$$X^2 = \sum \frac{(0-E)^2}{E}$$

$$X^2 = \frac{(23-12.6)^2}{12.6} + \frac{(19-29.4)^2}{29.4}$$

$X^2 = 12.26$

$12.26 \geq 3.841$

Therefore the study rejected H_0 that the number of green high-rise office buildings in Nairobi are insignificant.

b) Differences in energy consumption by building Architecture

Table 3.3 Table showing the energy consumption per unit floor area per unit time between green and non-green office buildings in the area of study

	Energy consumption in Green building (kWh/m$^{2/}$month)	Energy consumption in Non Green buildings (kWh/m$^{2/}$month)
O	3.33	10.62
E	1.5	6

Source: Research, (2015)

df=K-1=2-1=1

At 95%confidence level

Reject H_0 if $X^2 \geq 3.841$

$$X^2 = \sum \frac{(0-E)^2}{E}$$

$$X^2 = \frac{(3.33-1.5)^2}{1.5} + \frac{(10.62-6)^2}{6}$$

2.2326 + 3.5574

=5.79

5.79 ≥ 3.841

Therefore the study rejected H_0 that there is no difference in energy consumption by building Architecture.

This means that adopting daylighting or use of energy saving lighting fittings and office equipment significantly reduces energy consumption in high-rise office buildings

CHAPTER FIVE

4.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

4.1 SUMMARY

As earlier hypothesized, this study established that; first, there are a significant number of green buildings within the area of study. Secondly, building services significantly affect energy variations in high-rise office buildings in Nairobi. Thirdly, there is significant difference in energy consumption by building Architecture. Finally, Occupants behaviour in high-rise office buildings in Nairobi significantly affects the levels of energy consumption. Out of the 42 buildings studied, 2 buildings attained a two star rating, 17 buildings attained a 3 star rating, 22 buildings attained a 4 star rating and 1 building attained a five star rating with a total rating score of 66.1 points.

It was also established that the building services that consume energy in high-rise office building include; lighting, heating/cooling, office equipment, air conditioning and ventilation. Out of the five services identified, lighting it was established that lighting was the highest consumer of energy at 52% followed by office equipment that consumed 30% of the total energy consumption.

The study also showed a strongly relationship between green Architecture and energy consumption per square area with buildings at two star rating averaging 13.88 kWh/m^2/month, three star buildings averaging 7.35 kWh/m^2/month, 4 star buildings averaging 4.73 kWh/m^2/month and the only five star rated building consuming 1.93 kWh/m^2/month.

The building occupants were also found to have a significant impact on energy consumption in their respective buildings.

4.2 CONCLUSIONS

This research was guided by specific research questions and clear objectives. As earlier hypothesized, it can be concluded that;

a) Based on the key findings from the research, it was established that there is a significant presence of green high-rise office buildings in Nairobi.

b) The building services significantly affect energy variations in high-rise office buildings in Nairobi are lighting and energy use by office equipment.

c) Green buildings consume less energy per unit floor area as compared to non-green high-rise office buildings in Nairobi.

d) Occupants behaviour in high-rise office buildings in Nairobi significantly affect the levels of energy consumption

4.3 RECOMMENDATIONS

Based on key findings from this research, this study makes the following recommendations;

a) The national government together with the private sector should formulate a legal and policy framework that will ensure that developers and existing office building owners incorporate renewable energy sources in their design briefs to supplement the energy from the national grid.

b) Formation of a national body that will ensure that new buildings are designed to meet the green building requirements that will subsequently lead to efficient use of energy within the building and construction industry.

c) Educating the property managers and office space users on the need to use efficient LED lighting fixtures and use of energy efficient office equipment.

d) Training and regular sensitization of the occupants of the office buildings on energy use conscious behaviour so as to cut on this unnecessary wastage.

e) This study held an assumption of constant occupant behaviour leaving out a significant variable that affect energy consumption. Future studies should model ways of accurately measuring the building user's behaviour with regard energy consumption with a view of giving recommendations to property managers and owners on optimum user behaviour in their buildings.

REFERENCES

Abeysundara, U.G.Y.; Babel, S.; Gheewala, S.; (2009): A matrix in life cycle perspective for selecting sustainable materials for buildings in Sri Lanka. Build. Envrion. 44, 997–1004.

Adgate, J.L.; Ramachandran, G.; Pratt, G.C.; Waller, L.A.; Sexton, K.; (2002): Spatial and temporal variability in outdoor, indoor, and personal PM2.5 exposure. Atmos. Environ. 36, 3255–3265.

Azadeh, S.; Ehsan V.; Pradeep K. R.; (2014): The Role of Building Construction Materials on Global Warming, Lessons for Architects.

Barley D., Deru M..; Torcellini P.; (2005): 'Procedure for Measuring and Reporting Commercial Building Energy Performance: Innovation for our energy future' *Energy and Building,* 66, 341-356

CBS (2001). Population and Housing Census. Counting Our People for Development Vol.1. Central Bureau of Statistics, Nairobi.

Fabi, V., Anderson, R.V., Corgnati, S.P., OLesen, B.W. and Fillipi, M.; (2011): 'Description of Occupant Behaviour in Building Energy Simulations: State-of Art and Concepts for Improvements' *Proceedings of Building Simulation 2011:2th Conference of International Building Performance Simulation Association, Sydney, 14-16 November*

Fay, R., Treloar, G., and Iyer-Raniga, U.; (2000): Life-cycle Energy Analusis of Buildings; A Case Study' *Building Research and Information* 28 (1) 31-41.

Gabay, H., Meir, I.A., Schwartz, M., Werzberger, E.; (2014): 'Cost Benefit Analysis of Green Buildings: An Israeli Office Buildings Case Study' *Energy and Buildings* Vol 76, pp558-564

Godwin, E., Usenbong F.; (2012): The Contribution of Energy Consumption to Climate Change: *A Feasible Policy Direction*, pg 21

Haymaker, J., And Clevenger, C.M.; (2004): '*The impact of building occupants on Energy Modeling Simulations*' California; Stanford University Press

Hosseini, A.M.G., Dahlan, N.D., Berardi, U., Hoseini, A.G., Makaremi, N., Hoseini, M.G.; (2013): 'Sustainable Energy Performances of Green Buildings: A Review of Current Theories, Implementations and Challenges' *Renewable and Sustainable Energy Reviews* 25, 1-17

International Energy Agency, (2008): 'Promoting energy efficiency investments: case studies in the residential sector' IEA

Kilbert A.; Pohl J.; (2005): '*Building Science: Concepts and application'* New York. Wiley Blackwell

KNBS (2011), Economic survey 2011, Nairobi, Government Printer

Kneifel (2009): 'Life-cycle Carbon and Cost Analysis of energy Efficiency Measures in New Commercial Buildings' *Energy and Buildings* 42 (2010) 333–340

Lakin, D. (Undated): A Travel Guide and Manual. Association of Tour Operators (KATO). Nairobi, Kenya

Lenzen, M.; Treloar, G.J.; (2002): Embodied energy in buildings: Wood versus concrete-reply to Borjesson and Gustavsson. Energy Policy, 30, 249–244.

Lutzenhiser, L.; (2003): "Social and Behavioral Aspects of Energy Use." *Annual Review or Energy and the Environment*, 18, pp. 247-289.

Mills, E.; (2002): "Global Lighting Energy Savings Potential." *Light and Engineering*, 10(4):5-10.

Mitullah, Winnie. 2003. Understanding Slums: Case Studies for the Global Report on Human Settlements 2003: The Case of Nairobi, Kenya. UN-HABITAT, Nairobi.

Mwasha, A., Williams, R. G., Iwaro, J. (2011): “Modeling the performance of residential building envelope: The role of sustainable energy performance indicators”, *J. Energy and Buildings*, 35 (1) 330-337

Oginni, A., Adebamowo, M., and Adebayo, K.; (2012): ‘An Evaluation of the Lighting Energy Usage (Efficiency) of the Student Hostels in University of Lagos, Nigeria’ *ICIDA* (106)

Omer, A. M.; (2008): Energy, environment and sustainable development. Renewable and Sustainable Energy Reviews 2008;12(9):2265–300.

Scofield, J. H.; (2009): ‘Do LEED-certified Buildings Save Energy? Not really...’ *Energy and Buildings* 41, 1386–1390

Wang, S., Yan, C., Xiao F.; (2012): Quantitative Energy Performance Assessment Methods for Existing Buildings. Energy and Buildings;55:873–88.

Meier I. A. and Olofsson T.; (2002): What Is an Energy-Efficient Building? *Comparing energy efficiency in buildings in Brazil*: Vol. 10:5-26

Mundia, C. N., Aniya, M.; (2007): Analysis of land use/cover changes and urban expansion of Nairobi city using remote sensing and GIS

Saggerson, E. P., 1964. Geology of the Nairobi Area, Degree Sheet No. 51, Survey of Kenya.

Saggerson, E. P.; (1991): ‘Geology of the Nairobi Area, Degree Sheet No 51’ Survey of Kenya

Sev, A.; (2009): How can the construction industry contribute to sustainable development? A conceptual framework. Sustain. Dev., 17, 161–173.

Sikes, H. L.; (1934): ‘*Underground Water Resources of Kenya Colony*’ London: Crown Agents

Whole Building Design Guide (WBDG, 2013),

APPENDICES

Appendix I: Questionnaire

MOSES NYAKWEBA OKEMWA
UNIVERSITY OF NAIROBI
DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES
P.O. BOX 30197
NAIROBI

FIELD QUESTIONNAIRE FOR A M.A. ENVIRONMENTAL PLANNING AND MANAGEMENT STUDY PROGRAMME

Dear Sir/ Madam,

RE: FIELD DATA COLLECTION

I am a Masters student at the University of Nairobi, Department of Geography and Environmental studies and my contact address is as given above. My field study seeks to investigate the impact of green architecture on building energy consumption in high-rise office buildings in Nairobi. In this regard I would like to kindly request you to assist by answering the following questions.

Your views and opinion in this interview will be treated confidentially and strictly used for the purposes of the research work.

BUIDING GENERAL INFORMATION

Street/Road.................................	Property Agent...
Building Name......................................	No of Storeys and total floor area (m^2)..

Name of the Architect who designed and supervised the building.................................
.....

The year in which the building construction was completed...
....

The name of the contractor..

Building Characteristics (*Adopted from the Green Star building rating system*)

Land use and ecology

1. Physical/ geographical location of the building?

....
.....
....
.....

What is the type of soil on which the building stands on
....
....
....

2. Is there any vegetation within the building's compound?

Yes [1]
No [2]

3. If Yes in the question (2) above, describe the type of vegetation on site
....
....

4. On which side of the building are the windows facing?

East-West [1]
North-South [2]
Other (specify) ....

5. What is the predominant wind direction in the area? ....

Water Efficiency

1. Which is the primary source of water for your building?

   ....

   ....

   ....
2. Is there any other source(s) of water for your building?

   Yes [1]

   No [2]

   If yes in (2) above, specify

   ....

   ....

   ....
3. Approximately what amount of water is used per month in the building?

   ....(litres)

4. Is there any waste water produced from the building?

   Yes [1]

   No [2]

   If yes in (3) above, specify

   ....

   ....

   ....
5. Do you have a waste water recycling system on site?

   Yes [1]

   No [2]
6. If yes in (4) above, which system of recycling is used

   ....

....

....

7. What is use of the recycled water?

   ....

   ....

   ....

8. How is the storm water within the building compound managed ?

   ....

   ....

9. Is there any waste water produced from the building?

   Yes [1]

   No [2]

10. What type of mixer is used for the wash hand basin mixers
    a) Manual hand operated tap - turning the knob clock wise and anti clockwise
    b) Self-closing press type
    c) Single lever - manually operated type
    d) Infra-red sensor hands free type
    e) Piezo-eletronic hands free type
11. What type of water closets are used in the building?
    a) Manually operated - flush handle or press valve
    b) Sensor based flushing mechanism

Material/Resource Conservation

1. Describe the materials used in the construction of the following building elements
   a) Roof

      Trusses/Rafters/Purlins

      ....

      ... Roof-cover

      ....

      .

b) External walls

Main walls

....

Windows

....

Doors

....

Type of external wall finish(es)

....

.....

c) Internal walls

Partition walls

....

.....*Internal doors*

....

.....

Type of wall finish(es)

....

.....

d) Floor

Type of floor

....

.....*Type of floor finish(es)*

....

.....

ENERGY EFFICIENCY

1. What is the main source of energy in your building?

....

....

....

2. Is there any secondary source of energy in your building?

Yes	[1]
No	[2]

If yes in (2) above, specify

....

....

....

3. Are there any devices installed at the windows to protect the building users from direct sun glare?

Yes	[1]
No	[2]

If yes, Specify?

....

....

.....

4. What type of lighting fixtures do you use in your building?

Incandescent Bulbs	[1]
Fluorescent Tubes	[2]
Compact Fluorescent Tubes	[3]
LED Lights	[4]
Other	[5] specify..

5. What type of lighting switches do you use?

Wall switches	[1]
Light dependent resistor switches	[2]

Infra-red Sensors [3]

Other [4] specify..

6. If electricity, state the average consumption per month in kWh and Kshs

kWh...

Kshs...

7. In your own assessment, can you rank the following services according to the amount of energy they consume per month - (from the highest consumer to the lowest).

a) Lighting
b) Heating
c) Ventilation
d) Air-conditioning
e) Office equipment
f) Other

....

INDOOR ENVIRONMENTAL QUALITY

1. Does the building have any of the following features?

Thick Walls masonry (over 200mm) [1]

Windows oriented in the direction of wind-flow [2]

Courtyard [3]

Atrium [4]

2. How is your building ventilated?

Use of windows/openings on the wall [1]

Use of fans [2]

Use of HVAC system(s) [3]

Other [4]

specify...........................

Human/User Comfort

1. Are you able to work during the day with your lights off?

Yes [1]

No [2]

2. If no in (1) above, why ?

……

……

3. How can you describe the views through your windows?

Good [1]

Bad [2]

4. What type of paint have you used for interior finishes in your building?

Oil-based paint [1]

Acrylic-based paint [2]

Water-based paint [3]

Other [4] specify……………………………………

Emissions

1. List the types of wastes generated from your building

………

………

………

………

………

……………………

2. How do you dispose-off the waste generated in (1) above from your building?

Waste type	Disposal method

Innovation

1. Is there any innovative way(s) the building is designed to conserve energy

    Yes [1]

    No [2]

If Yes in (1) above, specify

……

……

……….

Transport

1. Is there any alternative means of transporting workers to and from work without using private cars

    Yes [1]

    No [2]

2. If Yes in (1) above, specify

……

……….

Management

1. Was an Environmental Impact Assessment (EIA) conducted before the building was constructed?

    Yes [1]

    No [2]

2. Do you conduct regular Environmental/Energy Audits for the building?

    Yes [1]

    No [2]

3. Are there any clauses in your lease agreement that are meant sensitize the building users on sustainable energy consumption practices?

   Yes [1]

   No [2]

4. If yes in (4) above, specify ....

USER BEHAVIOUR

OBSERVATION	YES(Y)	NO(N)
Lights on yet there is adequate daylight		
Power sockets on yet they are not is in use		
Equipment/machines on yet they are not in use		
Lights left on after-work hours		
Equipment left running after-work hours		
Air conditioning/Fans running while there is adequate cross ventilation		

Appendix II: High-rise Office Buildings in Nairobi

CBD HIGHRISE OFFICE BUILDINGS

NO.	Building	Height	Floors	Year
1.	Times Tower	140 m	38	1997
2.	Kenyatta International Conference Centre	105 m	32	1974
3.	I & M Bank Tower	99 m	18	2001
4.	Nyayo House	84 m	27	1982
5.	Cooperative Bank House	83 m	25	1981
6.	National Bank House	82 m	21	1976
7.	Anniversary Towers	80 m	26	1992
8.	Lonrho House	80 m	22	1990
9.	Reinsurance Plaza	77 m	20	1982
10.	Uchumi House	71 m	21	1972
11.	ICEA Building	69 m	19	1981
12.	International House	66 m	17	1971
13.	Electricity House	60 m	18	1974
14.	Treasury Building	48 m	15	1980
15.	Union Towers	48 m	14	1977
16.	Bima House	45 m	13	1973
17.	Office Of The President	43 m	14	1967
18.	NHC House	40 m	13	1975
19.	Harambee House	40 m	12	1962
20.	Development House, West Tower	39 m	12	1972
21.	KCS House	38 m	13	1975
22.	Central Bank Headquarters	≈170 m	50	1990
23.	Posta House GPO	≈92 m	27	1999
24.	Hazina Towers	≈81 m	24	-
25.	AmBank House	≈75 m	22	-
26.	Afya Center	≈71 m	21	-
27.	Fedha Towers	≈68 m	20	-
28.	View Park Towers	≈68 m	20	-
29.	Bazaar Plaza	≈64 m	19	-
30.	Loita House	≈61 m	18	-
31.	Chester House	≈61 m	18	-
32.	Corner House	≈61 m	18	-
33.	Finance House	≈58 m	17	-
34.	Nation Centre	≈58 m	17	1997
35.	Bruce House	≈51 m	15	-
36.	Barclays Plaza	≈51 m	15	-
37.	Ufundi Cooperative Plaza	≈47 m	14	-
38.	Utalii House	≈44 m	13	-
39.	Garden Plaza	≈44 m	13	-
40.	Rehani House	≈44 m	13	-
41.	City Hall Annex	≈44 m	13	1981
42.	Protection House	≈41 m	12	-
43.	Harambee Plaza	≈41 m	12	1987
44.	IPS Building	≈41 m	12	1967
45.	Transnational Plaza	≈34 m	10	-
46.	Sonalux House	≈34 m	10	-
47.	Kimathi House	≈34 m	10	-
48.	Maendeleo House	≈34 m	10	-

49.	Norwich Union Towers	≈31 m	9	-
50.	Kenya University Methodist Building	≈27 m	8	-
51.	Tembo Co-op House	≈27 m	8	-
52.	Cotts House	≈27 m	8	-
53.	Sasini House	≈24 m	7	-
54.	Ambassador house	≈24m	7	
55.	Ansh house	≈21m	6	
56.	Aqua house	22m	6	
57.	Baraka house	≈39m	12	
58.	Barclays house	46m	15	
59.	Bima house	≈42m	13	
60.	Cardinal Maurice Odinga Plaza	≈30m	10	
61.	Cargen house	≈18m	6	
62.	CFC Stanbic house	≈18m	6	
63.	Church house	≈39m	12	
64.	Cianda house	≈39m	12	
65.	City house	≈24m	7	
66.	Coffee plaza	≈39m	12	
67.	Commerce house	≈27m	8	
68.	Common wealth house	≈24m	7	
69.	Consolidated bank house	≈21m	6	
70.	Continental house	≈24m	7	
71.	Contrust house	≈33m	10	
72.	Development towers	≈51m	16	
73.	Eco bank chambers	≈21m	6	
74.	Eco bank towers	≈57m	18	
75.	El-roi plaza	≈24m	7	
76.	Embassy house	≈21m	6	
77.	Family bank towers	≈42m	13	
78.	Fourway towers	≈36m	11	
79.	Gatakani investment house	≈24m	7	
80.	Gilfillan house	≈27m	8	
81.	Guilders Centre	≈24m	7	
82.	Harambe coop house	≈36m	11	
83.	Impala house	≈30m	9	
84.	Intefina house	≈30m	9	
85.	International house	≈51m	16	
86.	Jamii bora house	≈21m	7	
87.	Jeeran bharati building	≈33m	9	
88.	Jethalal Chambers	26m	8	
89.	Jogoo house B	≈36m	12	
90.	Jubilee insurance plaza	≈22m	6	
91.	Kampus towers	16m	6	
92.	KCA	≈33m	10	
93.	Kemu Hub	≈27m	8	
94.	Kencom house	≈30m	9	
95.	Kenindia house	≈51m	16	
96.	Kenya comfort house	≈24m	7	
97.	Kenya Re plaza	74m	21	
98.	Kitamu house	≈21m	6	
99.	KPCU building	26m	6	
100.	KTDA plaza	≈33m	9	
101.	Lord’s house	≈21m	6	
102.	Lyric house	≈27m	8	
103.	Mageso chambers	≈24m	7	

104.	Meridian court	≈27m	8	
105.	Meru south house	21m	6	
106.	MKU towers	≈30m	9	
107.	Mwalimu coop house	≈30m	9	
108.	Namak house	≈18m	5	
109.	Nginyo towers	≈27m	8	
110.	Njengi House	≈27m	8	
111.	Nyati house	≈21m	6	
112.	Pension towers	≈54m	17	
113.	Pioneer house	≈24m	7	
114.	Post bank house	≈66m	21	
115.	Porter house	≈39m	12	
116.	Purshottam plaza	≈21m	6	
117.	Queensway house	≈24m	7	
118.	Rafiki house	≈21m	6	
119.	Rehema house	≈21m	6	
120.	Reli coop house	≈21m	6	
121.	Revlon professional plaza	≈21m	6	
122.	Rural –urban house	≈27m	8	
123.	Savoy towers	≈33m	10	
124.	Shelter house	≈21m	7	
125.	Southern house	≈21m	6	
126.	Stanbank house	≈39m	12	
127.	Standard house	≈24m	7	
128.	St. Ellis house	≈24m	7	
129.	Town house	≈30m	9	
130.	Tumaini house	≈24m	7	
131.	Ufungamano house	≈24m	7	
132.	Ufanisi house	≈24m	7	
133.	Ukulima coop house	≈42m	13	
134.	Uniafric house	≈15m	6	
135.	Vedic house	≈21m	6	
136.	Veteran house	≈30m	9	
137.	Victor house	≈24m	7	
138.	Yala towers	33m	10	
139.	Solar house	≈24m	7	

UPPERHIL HIGHRISE OFFICE BUILDINGS

NO.	Building	Height	Floors	Year
1.	Britam Tower	192 m	31	2015
2.	Social Security House	103 m	28	1973
3.	KCB Plaza	99 m	23	2013
4.	Ministry Of Works Building	43 m	14	1968
5.	CTDLT Towers	≈68 m	20	-
6.	Rahimtulla Tower	≈61 m	18	1999
7.	Landmark Plaza	≈47 m	14	2006
8.	Taj Towers	≈44 m	13	-
9.	Zep-Re Place	≈41 m	12	-
10.	Chancery Building	≈41 m	12	1992
11.	Victoria Towers	≈41 m	12	2000
12.	BSI Headquarters Building 1	≈37 m	11	2007
13.	Bishops Gate	≈27 m	8	2007
14.	Bishops Garden Towers	≈27 m	8	1992
15.	IKM Place	≈24 m	7	2007

16.	Mebank Tower	≈20 m	6	2000
17.	Kenya Re towers	42m	13	
18.	Afya house	37m	9	
19.	World bank offices/ Formerly delta centre	70m	21	
20.	Khushee Towers (ADB)	40m	14	
21.	Citi bank building	≈24m	7	
22.	Coca Cola Headquarters in Upperhill	≈21m	6	
23.	CBA Building	≈21m	6	
24.	NHIF building	≈24m	7	
25.	UAP towers upperhill	163m	33	uncomplete
26.	Shelter Afrique house	≈24m	7	
27.	Capital hill towers	≈51m	16	
28.	CIC plaza	≈24m	7	
29.	Corporate place	≈36m	11	
30.	Kasneb towers	≈45m	14	
31.	Kusco centre	30m	7	
32.	Maji house	≈27m	8	
33.	Nairobi hospice	≈57m	18	
34.	Nachu house	≈48m	15	

WESTLANDS HIGHRISE OFFICE BUILDINGS

	Building	**Height**	**Floors**	**Year**
1.	Delta Corner South Tower	≈61 m	18	2012
2.	Delta Corner North Tower	≈61 m	18	2012
3.	ABC Place	≈41 m	12	2013
4.	Purshottam Park	≈31 m	9	2007
5.	The Citadel	≈31 m	9	2007
6.	Unga house	≈27m	8	
7.	West end towers	≈33m	10	
8.	ICEA LION suites	25m	6	
9.	AACC building	25m	6	
10.	ABC bank house	≈27m	8	
11.	AIG Building	≈27m	8	
12.	Avocado towers	≈18m	5	
13.	Bandari plaza	≈42m	13	
14.	Capital west	≈24m	7	
15.	Centro house	≈21m	6	
16.	CFC centre	≈27m	8	
17.	Chiromo point	≈24m	7	
18.	Eden square	≈27m	8	
19.	Fedha plaza	≈33m	10	
20.	Fuji plaza	≈33m	10	
21.	Lions place	≈20m	6	
22.	Lion’s place annexe	20m	6	
23.	Mpaka plaza	≈24m	7	
24.	Office park	≈21m	6	
25.	Ojijo plaza	≈30m	9	
26.	Pan- Africa insurance	≈57m	18	
27.	Parklands office plaza	≈30m	9	
28.	Sky park	≈33m	10	
29.	The address	≈42m	13	
30.	Unga house	≈36m	11	

31.	Victoria towers	≈30m	9	
32.	Westlands commercial house	≈24m	7	
33.	9west	≈36m	11	
34.	Safaricom/Caribon LTD 01	28m	7	
35.	Safaricom/Caribon LTD 02	28m	7	
36.	Barclays Plaza westlands	28m	7	
37.	Westend towers	50m	12	

Appendix III: Data entry score sheet

BUILDING	ECOLOGY	WATER EFFICIENCY	MATERIAL RESOURCE CONSERVATION	ENERGY	INDOOR ENVIRONMENTAL AIR QUALITY	EMISSIONS	INNOVATION	TRANSPORT	MANAGEMENT	AGGREGATE	STAR RATING	ENERGY CONSUMPTION	NAME
NUMBER	5%	10%	14%	20%	18%	11%	4%	9%	9%	100%		(kWh/M^2/Month)	
CBD HIGHRISE OFFICE BUILDINGS													
1	3	4	9.5	8.6	10	5.5	0	0	6.75	**47.35**	4 Star	**3.64**	CARDINAL OTUNGA PLAZA
2	3.5	3.3	7.6	8.6	10	5.5	0	0	6.75	**45.25**	4 star	**5.42**	KEMU TOWERS
3	3	3.3	8.2	12.9	10	5.5	0	0	4.5	**47.4**	4 star	**4.56**	ELECTRICITY HOUSE
4	2	3.3	8.9	12.9	14	4.1	2	4.5	4.5	**56.2**		**3.13**	ECO BANK TOWERS
5	2.5	3.3	8.9	8.6	8	4.1	0	0	6.75	**42.15**	3 Star	**3.28**	CORNER HOUSE
6	3	3.7	8	8.6	10	5.5	0	0	4.5	**43.3**	3 Star	**4.19**	SONALAUX BUILDING
7	3.5	3.7	8.2	8.6	8	5.5	0	4.5	6.75	**49**	4 Star	**3.2**	DEVELOPMENT HOUSE
8	3.5	3.3	7.6	11.4	10	5.5	4	0	4.5	**49.8**	4 Star	**3.72**	REINSURANC PLAZA NRB
9	3.5	2.7	8.2	8.6	10	5.5	0	0	6.75	**45.25**	4 Star	**5.7**	ANNIVERSARY TOWERS
10	3	5.3	8.9	11.4	10	5.5	0	0	2.25	**46.35**	4 star	**5.9**	PRUDENTIAL BUILDING
11	3	4	8.9	8.6	8	5.5	0	0	4.5	**42.5**	3 Star	**9.61**	STANDARD BUILDING
12	3.5	4	8.9	8.6	10	5.5	0	9	2.25	**51.75**	4 Star	**6.2**	REHEMA HOUSE
13	3	3	9.8	8.6	6	5.5	0	9	6.75	**51.65**	4 Star	**4.95**	CHESTER HOUSE
14	3.5	3.7	8.9	8.6	8	5.5	0	0	6.75	**44.95**	4 Star	**4.49**	STANBANK HOUSE
15	3.5	3.3	8.9	8.6	8	4.1	0	0	6.75	**43.15**	3 Star	**8.33**	COMMERCE HOUSE
16	3.5	3.3	9.8	5.7	8	4.1	0	0	2.25	**36.65**	3 Star	**6.59**	HAZINA TOWERS
17	2	3.3	8.9	5.7	8	5.5	0	4.5	9	**46.9**	4 Star	**4.2**	REVLON PLAZA
18	2	4	7.6	8.6	10	4.1	0	0	6.75	**43.05**	3 Star	**5.56**	VETERAN HOUSE
19	2	3.7	8.9	5.7	10	4.1	0	0	2.25	**36.65**	3 Star	**13.8**	KITAMU HOUSE
20	2	3.3	8.2	5.7	10	5.5	0	0	6.75	**41.45**	3 Star	**8.21**	NORWICH UNION TOWERS
21	3.5	4	8.9	8.6	10	5.5	0	0	4.5	**45**	4 Star	**3.53**	PHOENIX HOUSE
22	2	3.7	8.2	11.4	10	5.5	0	0	6.75	**47.55**	4 Star	**6.05**	KCS BUILDING
23	2	3.3	8.2	8.6	2	5.5	2	0	6.75	**38.35**	3 Star	**7.91**	LONRHO HOUSE
24	2	4	8.2	5.6	4	1.5	0	0	1.5	**26.8**	2 Star	**12.25**	QUEENSWAY HOUSE
25	3.5	4	8.9	11.4	10	5.5	2	0	4.5	**49.8**	4 Star	**3.532**	UCHUMI HOUSE
26	2	3.3	9.2	11.4	10	5.5	0	0	4.5	**45.9**	4 Star	**2.53**	LYRIC HOUSE
27	2	4	8.2	8.6	8		0	0	6.75	**37.55**	3 Star	**5.18**	20TH CENTURY PLAZA
28	2	3.3	7.6	5.7	8	5.5	0	0	5.5	**36.6**	23 Star	**9.88**	CONTRUST HOUSE
WESTLANDS HIGHRISE OFFICE BUILDINGS													
1	3.5	3.7	8.9	8.6	10	5.5	2	4.5	4.5	**51.2**	4 Star	**5.2**	PROSPERITY HOUSE
2	2	4	8.9	8.6	10	5.5	0	0	6.75	**45.75**	4 Star	**5.32**	ROYAL OFFICES
3	3	3.7	9.5	8.6	10	5.5	2	0	4.5	**46.8**	4 Star	**4.8**	THE CITADEL
4	3	4	8.2	8.6	10	5.5	0	0	4.5	**43.8**	3 Star	**6.14**	KRISHNA CENTRE
5	3	3.7	9.2	8.6	12	4.1	0	0	4.5	**45.4**	4 Star	**5.43**	PARKLANDS PLAZA
6	1.5	3.3	8.2	5.7	6	5.5	2	4.5	4.5	**41.2**	3 Star	**6.75**	TRV PLAZA
7	2	3.3	8.6	8.6	6		0	0	4.5	**33.2**	3 Star	**9.32**	FORTIS TOWER
UPPERHILL HIGHRISE OFFICE BUILDINGS													
1	4	3.7	8.6	8.6	6	5.5	2	4.5	4.5	**47.5**	4 Star	**7.14**	NHIF
2	3.5	4	7.6	5.7	4	4.1	0	0	1.5	**29.8**	2 Star	**15.52**	BLUE SHIELD TOWERS
3	3.5	5.7	10.8	14.2	14	6.9	2	4.5	4.5	**66.1**	5 Star	**1.93**	COCA COLA HEADQUARTERS
4	2	4	8.9	-	12	5.5	0	9	6.75	**39.15**	3 Star	**9.7**	KMA CENTRE
5	3	4	8.9	7.1	10	5.5	0	0	6.75	**45.25**	4 Star	**5.06**	SHELTER AFRIQUE
6	3	4	9.2	7.1	8	5.5	0	0	6.75	**43.55**	3 Star	**10.5**	KENYA-RE

													TOWERS
7	3	4	8.9	8.6	9	5.5	4	0	9	**52**	4 Star	**3.663**	ACK GARDEN ANNEX