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ENERGY PERFORMANCE IN DEVELOPING SUSTAINABLE BUILDINGS: A CASE STUDY OF BUILDING IN KIGALI, RWANDA

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DECLARATION

I Jean d’ Amour MWONGEREZA, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

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ABSTRACT

Energy efficiency and conservation have been defined as the cheapest and fasted form of generation and also a key player for sustainable development in economies in the world. The practice of energy efficiency in all Rwandan sectors will increase the sustainable use of our natural resources and further contribute to national economic growth as well as sustainable development. The energy efficiency has the ability to stimulate economic development due to the fact that it will lead to saving of national income. In Rwanda, new buildings are being constructed to meet the ever increasing population and the accompanying socio-economic growth of the country. This thus implies increase in energy supply to meet the escalating energy demand.

This research was an investigation carried out in promoting energy performance in building in a bid to developing a new building model that will be efficient and also support a reduced energy utilization in buildings. The Kigali City Tower with 20 floors was selected as a case study in this work. Data including: (i) energy audit data of appliances in this building were captured, (ii) metered data obtained from facility management unit, and (iii) predicted data from eQUEST simulation tool were all considered in this study to measure energy consumption of the model building.

Energy audit result showed that among the electrical appliances, desktops computers and linear fluorescent lamps have the highest of the total energy consumption in the offices with 25% and 24% respectively. Furthermore, offices in the building were found to consume more energy, followed by the lifts and then the O-Zone (underground level) with 72%, 15% and 13% respectively. Comparison of the data obtained from energy audit (observed data) and simulated data from eQUEST (predicted data) were made. It was found that there was a good fit between the datasets (observed and predicted) with a correlation coefficient of 76 and 79% for the audited energy and metered data respectively at 95% confidence interval, thus calling for the adoption of eQUEST for energy simulation of buildings in Rwanda. The annual energy consumptions in the building, based on data obtained from energy audit exercise, metered (facility unit) and simulation results are 951,517kWh, 947,210.7kWh and 928,310kWh respectively. Energy performance in building was found to be affected by building envelop, occupancy behaviors and electrical/electronic appliances. Several Energy Management Opportunities were recommended to reduce energy being utilized in this building, based on the energy audit results. Replication of the same model of building (i.e. Kigali City Centre, with the envelopes and other appliances) in all the Provinces in Rwanda, showed that the lowest annual energy consumption was obtained in the Northern region when the building facing North direction and the highest in the Southern Province.

Key Words: Energy Efficiency and Conservation, Energy Audit, Building Energy Simulation Tools

Résumé

L'efficacité énergétique et la conservation ont été définies comme la forme de génération la moins coûteuse et la plus rapide et aussi un acteur clé pour le développement durable pour la croissance économique dans le monde. La pratique de l'efficacité énergétique dans tous les secteurs rwandais augmentera l'utilisation durable de nos ressources naturelles et contribuera davantage à la croissance économique nationale ainsi qu'au développement durable. L'efficacité énergétique a la capacité de stimuler le développement économique en raison du fait qu'elle entraînera les revenues de l'économie nationale. Au Rwanda, de nouveaux bâtiments sont construits pour répondre à la population toujours croissante et à la croissance socio-économique qui l'accompagne. Cela implique donc une augmentation de l'approvisionnement en énergie pour répondre à l'augmentation de la demande énergétique.

Cette recherche a été une enquête menée dans la promotion de la performance énergétique dans le but d'élaborer un nouveau modèle de construction qui sera efficace et contribuera également à une réduction de l'utilisation de l'énergie dans les bâtiments. La tour de la ville de Kigali avec 20 étages a été sélectionnée comme étude de cas dans ce travail. Les données incluant: (i) les données d'audit énergétique des appareils dans ce bâtiment ont été capturées, (ii) les données mesurées obtenues à partir de l'unité de gestion de l'installation, et (iii) les données prédites de l'outil de simulation eQUEST ont toutes été considérées dans cette étude pour mesurer la consommation d'énergie des bâtiments modèle.

Le résultat de l'audit énergétique a montré que parmi les appareils électriques, les ordinateurs de bureau et les lampes fluorescentes linéaires ont la plus consommation totale d'énergie dans les bureaux de 25% et 24% respectivement. En outre, les bureaux du bâtiment ont consommé plus d'énergie, suivis des ascenseurs, puis de l'O-Zone (niveau souterrain) de 72%, 15% et 13% respectivement. La comparaison des données obtenues à partir de l'audit énergétique (données observées) et des données simulées d'eQUEST (données prédites) ont été réalisées. Il a été constaté qu'il existait un bon ajustement entre les ensembles de données (observés et prévus) avec un coefficient de corrélation de 76 et 79% pour l'énergie vérifiée et les données dosées respectivement à un intervalle de confiance de 95%, appelant ainsi à l'adoption d'eQUEST pour la simulation d'énergie des bâtiments au Rwanda. Les consommations d'énergie annuelles dans le bâtiment basées sur les données obtenues à partir des exercices d'audit énergétique, de l'unité mesurée (unité de l'installation) et de la simulation sont respectivement de 951,517kWh, 947,210.7kWh et 928,310kWh. Les performances énergétiques dans les bâtiments ont été affectées par l'enveloppe du bâtiment, les comportements d'occupation et les appareils électriques / électroniques. Plusieurs possibilités de gestion de l'énergie ont été recommandées pour réduire l'énergie utilisée dans ce bâtiment en fonction des résultats de l'audit énergétique. La réplication du même modèle de construction (c’est-à-dire, Le centre-ville de Kigali, avec les enveloppes et autres appareils) dans toutes les provinces du Rwanda, a montré que la consommation d'énergie annuelle la plus faible a été obtenue dans la région du Nord lorsque le bâtiment face à la direction du nord et la plus élevée dans la province du Sud.

Mot-clé: Efficacité et conservation énergétique, Audit énergétique, Les outils de Simulation d'énergie dans le bâtiment

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ABBREVIATIONS AND ACRONYMS

CFD	Computational Fluid Dynamics
CFLs	Compact fluorescent lamps
CO_2	Carbon dioxide
CPU	Central processing units
EAPP	Eastern African Power Pool
EEM	Energy Efficiency Measure
EMOs	Energy Management Opportunities
eQUEST	Quick Energy Simulation Tool
FRW	Rwandan Franc
GDP	Gross Domestic Product
HVAC	Heating, Ventilation and Air-Conditioning
IGMOU	Inter-Governmental Memorandum of Understanding
KCT	Kigali City Tower
kW	kilowatt
kWh	kilowatt hour
LED	Light emitting diode
LFLs	Linear Fluorescent Lamps
MEPS	Minimum Energy Performance Standards
PAUWES	Pan African University Institute of Water and Energy Sciences
TV	Television
W	Watt
Wh	Watt hour

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CHAPTER ONE: INTRODUCTION

1.1 Background

Buildings account for a large proportion of the total energy consumption per year in modern societies. In the European Union (EU), energy consumed in buildings is more than 40% of the total energy consumption (EC, 2002). Throughout the world, energy consumption in buildings is very huge and also not sustainable, most especially in Africa. Rwanda (being one of the countries in Africa) is disadvantaged with unsustainable buildings that are energy inefficient. In 1994, Rwanda went through a genocide that brought down almost all infrastructures such as roads, industries, buildings, power plants, transmission lines etc. This brought about a general reconstruction of infrastructures across the country, especially buildings as witnessed in recent years. The construction sector after the genocide has thus grown rapidly and will continue to grow with the escalating population and socio-economic development. All these have associated impact on energy consumption, since demand for energy is increasing rapidly. Worthy of note is the fact that the current existing buildings are still energy inefficient while the newly constructed ones are also not efficient since they are not considered for energy efficiency, at the design stage. Lack of building energy codes coupled with insufficient/zero knowledge of building energy performance among building designers and developers, make newly constructed buildings unsustainable. Nowadays, building designs are subjected to different parameters such as climate conditions, occupancy behaviors, building envelope and so on, for energy efficient performance. The climate in Rwanda is mild rainfall and temperate, with moderate humidity levels, which make new buildings to last for about 50 to 100 years. Temperature in Rwanda ranged between 10^{o}C and 30^{o}C, while humidity levels range from 40 to 60%, thereby making most large buildings currently available, to have central air-conditioners installed. External insulation walls and double-glazed window are not necessary because envelope heat losses and gains are less, compared to ventilation effects (EWSA, 2014). In Rwanda, energy consumption in buildings will continue to be on the rise, due to: economic growth associated with population increase, migration from low energy consumption rural dwellings to urban centers, and the continuously rising living standards of the citizens. Building energy efficiency codes, building envelopes, behaviors of occupancy are major components to be considered by building designers and owners, in reducing energy consumption in buildings. Therefore, general reduction of building energy use, through proper and energy efficient building designs, is necessary to mitigate the ever-rising energy demand and the associated issues of global climate change.

1.1.1 Geography of Rwanda

Rwanda (also known as the “land of a thousand hills”), is a small land-locked, fertile country, having a size of 26,338km^2 and with a population of approximately 11,689,696 people (MININFRA, 2015). It is located in the East African region, and one of the fifty-five (55) countries in Africa. The country is in the south of the equator, having geographical coordinates of 2°00′S and 30°0′E as her latitude and longitude respectively. It is bordered in the East by Tanzania, in the North by Uganda, in the West by Democratic Republic of Congo, and in the South by Burundi (Figure 1.1). Rwanda is composed of Kigali City as the capital, with four provinces including: Eastern Province, Western province, Southern province, Northern Province. The population density in 2016 was 482 inhabitants per square kilometer (United Nations, 2017). Rwanda is the highest densely populated country in the region when compared with Burundi having 333 persons per square kilometer, Uganda with 173 persons per square kilometer and Kenya 73 persons per square kilometer. The Gross Domestic Product (GDP) was about $7.890 billion, while the GDP per capita was $643 in 2014 (MININFRA, 2015). The climate conditions require natural ventilation against humidity rather than isolation from extreme temperatures. Figure 1.1 shows the provinces of Rwanda and her neighboring countries.

Figure 1.1: Geographical Map of Rwanda

Source: (AfDBG, 2016)

The country is witnessing a rising population and socio-economic growth with more than 8.3% economic growth rate per year, though, government's plan is to reach 11.5% growth rate by 2018 (MININFRA, 2015). This escalating growth in population is being witnessed in all sectors, thus bringing about the increase in energy consumption. Energy use will continue to be on the rise in all sectors in Rwanda e.g. transports, industries, services and buildings. In all the sectors, the share of energy consumption in buildings is the highest while in all the regions, the highest energy use is in Kigali. Kigali is the seat of government and main economic center with a total area of 731km^2. It is located in the center of Rwanda and comprises three districts including: Nyarugenge, Kicukiro and Gasabo (Manirakiza, 2014). In May 2016, Kigali had approximately 1,169,600 population and the number is growing rapidly (Lasalle, 2016). This growth has reflected in increase in new building constructions across the region. Other than in Kigali, building constructions are also on-going in other regions of the country (i.e. the Southern, Western, Northern, and Eastern regions).

Due to the rising growth in buildings globally, powerful techniques are now available to both owners and designers of buildings, for the prediction of better building energy use. Some existing computer simulations/programmes for modeling of building energy performance include: Energy Plus by the United State Department of Energy, Quick Energy Simulation Tool (eQUEST) and other various commercial software for developing models that will predict energy performance of buildings (Tiwari, 2016).

1.2 Motivation

Existing buildings in Rwanda are constructed in such a way that makes them unsustainably and highly energy inefficient, thereby resulting in excessive carbon footprints. At the moment, there are no building energy codes to be adopted for energy efficient buildings in Rwanda; also, there are no assessment conducted for sustainable building locations. Building owners and designers are also not properly informed/trained on energy efficient building designs. Furthermore, there are no incentives at the moment to promote energy efficiency in buildings in Rwanda. Hence, energy consumption in buildings will continue to increase tremendously in the country, with the rising population and socio-economic development. Energy efficiency in buildings is thus, one of the key components needed to reduce energy use and achieve cost savings. Adoption of energy efficient buildings will also reduce energy demand and save necessary costs that may be needed for the construction of new power plant. Simulating the energy performance of buildings before construction will help in developing sustainable buildings throughout the building life time. It will also assist with the efficient use of resources throughout a building life cycle. Sustainable building will further bring about the reduction of both environmental degradation and greenhouse gas emissions to the atmosphere.

1.3 Background of the Research

1.3.1 Overview of Energy in East Africa

The population of Africa will continue to be on the rise. Human activities and natural disaster combined, thus become an issue to human life and for future generation. Global warming, deterioration of public health, deforestation for the use of unclean energy source (fuelwood etc.), is a challenge in Africa. Access to electricity in Africa still remains a problem for leaders; power network is still underdeveloped with inadequate generation systems which make about 620 million African to live without electricity. Electricity per capita is very low, especially in Sub-Saharan African countries reaching an average of 17kWh per year excluding South Africa (Ouedraogo, 2017). The region is facing power blackout problems that bring about economic losses which vary annually from 1 to 5% of the gross domestic products (GDP) of all the countries. The use of fossil fuels to meet the teeming energy demand have also led to increasing greenhouse gas emissions, and associated health challenges. In present days, renewable energy and energy efficiency have been introduced to mitigate the environment, social and health consequences associated with burning of fossil fuels.

Electricity rate in East African region varies from 100% in Egypt to 6% in Burundi; about 80% of the total population have no access to electricity. Hence in 2005, countries in the region namely: Burundi, Democratic Republic of Congo (DRC), Egypt, Ethiopia, Kenya, Rwanda and Sudan signed an Inter-Governmental Memorandum of Understanding (IGMOU) of Eastern African Power Pool (EAPP). The total installed capacity in EAPP countries is 28GW where Egypt alone accounts for 70% of the total installation capacity (Ouedraogo, 2017).

1.3.2 Energy Resources of the Eastern African Power Pool

The electricity mix of the EAPP comes from coal, oil, hydropower, geothermal, natural gas, wind, solar and other renewable sources. In the EAPP, 77% of the existing installed power capacity comes from thermal sources, with hydropower accounting for almost 22% of the total installed capacity (Nkiruka, 2015). Figure 1.2 summarizes the contribution of hydropower in the EAPP countries.

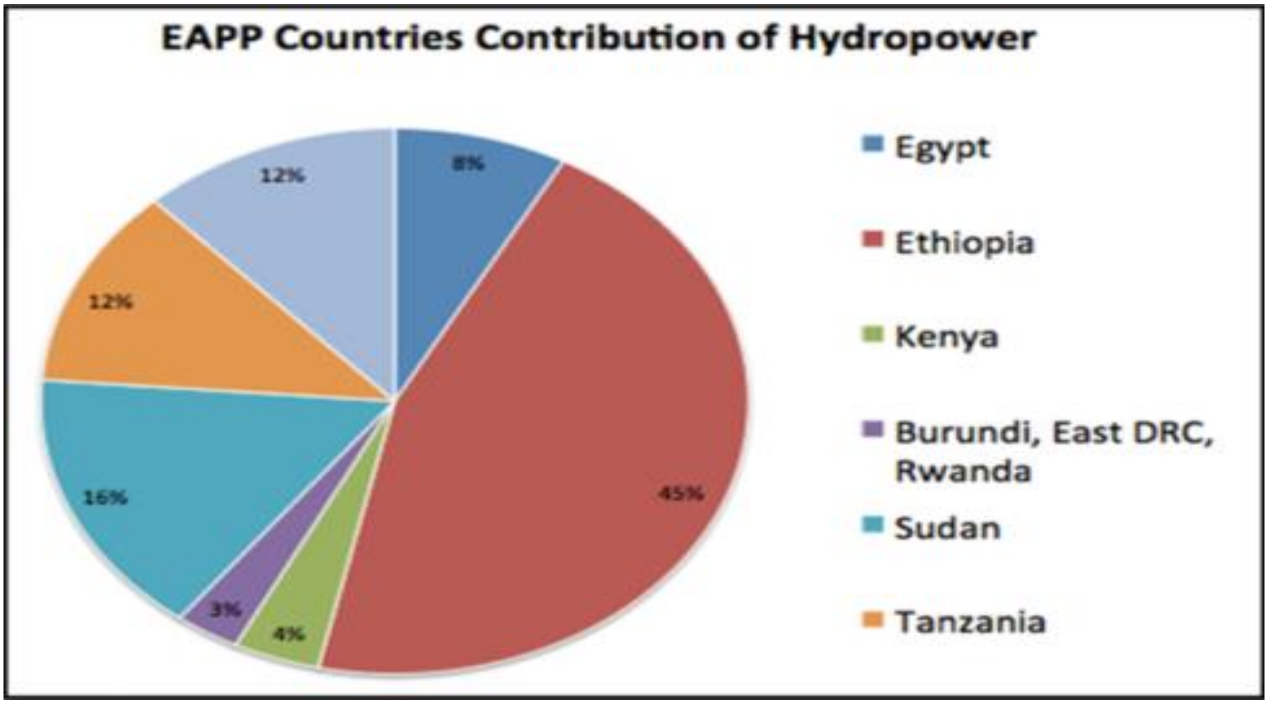


Figure 1. 2: Contribution of Hydropower to the EAPP

Source: (Nkiruka et al., 2015)

It can be observed from Figure 1.2 that the largest contributor of hydropower to the EAPP is Ethiopia, followed by Sudan. Other than hydropower, this region is also rich in other renewable energy sources. Most of the resources in the region are still untapped due to reasons such as lack of policies and regulations, poverty, insecurity, no qualified persons on the exploitation of these sources, lack of awareness on renewable energy resources and so on. The potentials of other sources of renewable energies as found in East African countries are shown in Table 1.1.

Table 1.1: Non-hydro Renewable Resource Potentials in EAPP

Source: (Nkiruka et al., 2015)

	Biomass	**Solar**	**Wind**	**Geothermal**
Ethiopia	32 MW	~5.2kWh/m^2/day PV off-grid: 32MW	10,000 MW	700 - 3,000 MW
Uganda	48MW	5-6 kWh/m^2/day PV off-grid: 70 MW	Some Potential	450 MW
Kenya	159 MW	~5 kWh/m^2/day PV off-grid: 40 MW	~3,000 MW	10,000 MW
Tanzania	102MW	~5 kWh/m^2/day PV off-grid: 35 MW	Short-term 300-500 MW	600MW

1.3.3 Energy Situation in Rwanda

Rwanda is one of the country with the lowest per capita electricity consumptions in the world. The country consumes about 42kWh/capita of energy, compared to 478 kWh average in sub-Saharan Africa, and 1,200kWh for the developing countries (AfDBG, 2013). About 85% of primary energy in Rwanda comes from biomass, the other 15% is from non-biomass sources (petroleum products account for 11%, while mix from renewable and non-renewable sources made up approximately 4%). Rwanda has an installed capacity of 208MW, with 30% of the entire household connected to the grid (REG, 2017). The energy mix of Rwanda (Figure 1.3), consists of hydro (49%), thermal (24%), methane (2%), solar (5%), hydro-off grid (1%), thermal-off grid (9%), while 10% is imported. There is a target to increase the installed capacity to 563MW in order to achieve about 70% of household connectivity to the grid by 2018. Achieving this target does not call for continous generation to increase present capacity, but also the efficient utilization of energy being generated, through efficient energy management practices.

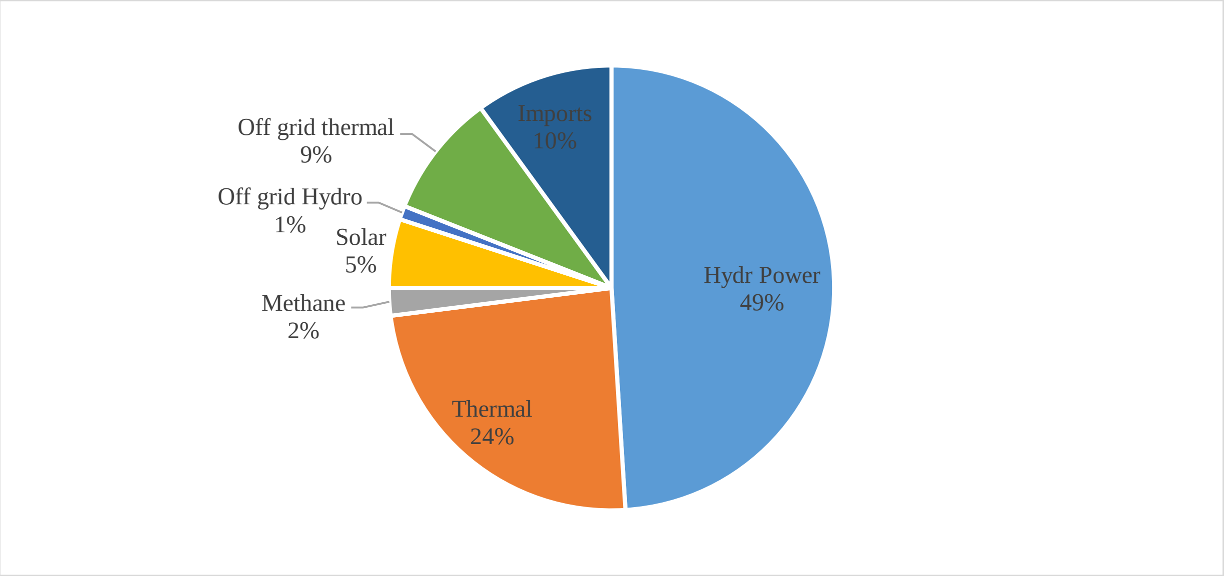


Figure 1. 3: Rwanda energy mix supply

(Source: Rwandan Sustainable energy for All, 2015)

It can be observed from Figure 1.4, that the major consumer of energy in Rwanda is the household with 91%, followed by the transport sector (4%), industry (3%), and public services (2%). On electricity consumption, households are the dominant consumers with 51% (primarily used for lighting). This is followed by the industrial sector with 42%, and public sector with 6% of electricity consumption (found to be largely due to utilizations in existing public buildings, street-lighting and water pumping) (MININFRA, 2016).

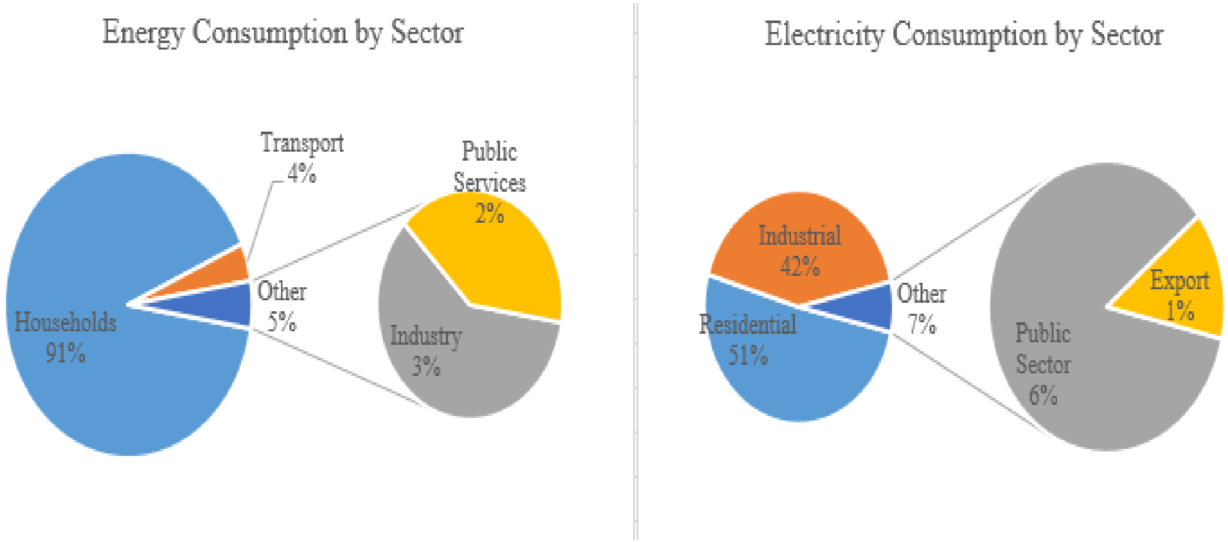


Figure 1. 4: Energy and Electricity Consumption by Sector

Source: (MININFRA, 2016)

1.3.4 Building Energy Consumption

Construction is a major component of investment globally that is closely related to economic growth, and thereby responsible for the rapid increase of buildings worldwide. Globally, energy consumption in buildings is about 40% of total energy consumption (Heravi et al., 2014). Commercial and Residential buildings account for about 20.1% of the total global energy, and with a projected average increase of 1.5% per year between 2012 and 2040 period. In 2014, buildings consumed 31% of the total global energy consumption, followed by industry with 28%, transport with 27% and the rest of the sectors with15% (GABC, 2016). Residential buildings alone are forecasted to consume about 13% of total energy consumption globally by 2040, with an average increase of 1.4% per year between 2012 and 2040 (IEO, 2016). With the escalating population and socio-economic growth being witnessed in the developing world, coupled with the quest for similar quality of life with the developed countries, energy consumption will continue to increase in developing countries. Therefore, the construction sector is expected to grow rapidly.

In Africa, the construction sector is directly associated with development as well as the well-being of its population; building alone consumed about 56% of the total electricity generation. Big cities in Africa account for about 75% of total electricity generated (Figure 1.4)(Kitio Vincent, 2013); new building constructions are thus envisaged to be on the rise. In East Africa, about 80% of the total land area are yet to be built. With this, constructions are expected to be on the rise until 2050; high energy demand is also expected to come from building sect (Kitio Vincent, 2013). With the continous rise in energy utilization associated with building as forecasted, creating a sustainable environment that will meet the demands and needs through energy efficient (or green) building designs, is very necessary. Figure 1.5 shows the comparison in buildings prediction between Europe and East Africa between 2010 and 2050.

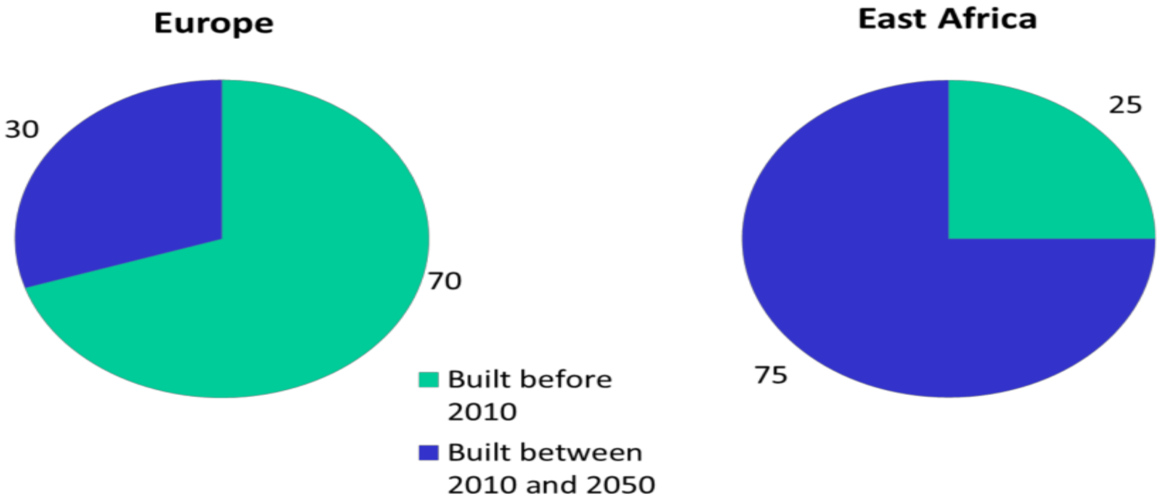


Figure 1. 5: Forecasting building expectation between Europe and East Africa

Source: (Kitio Vincent, 2013)

1.3.5 Building Sector in Rwanda

There are currently no building energy codes in Rwanda. Because of this, energy performance needed to ensure sustainable buildings in Rwanda is not practiced. Worthy of note is the fact that energy efficiency practices, throughout building life cycle is needed for sustainability of all building constructions. Energy efficiency in buildings tends to focus on improved envelope design (i.e. walls, floors, roofs, doors and windows) (Odunfa et al., 2015). It is therefore very necessary to assess and understand how existing buildings perform in terms of energy reduction. In Rwanda, there is increasing investment in the emergence, establishment, growth and development of an effective and sustainable construction industry. It can thus be observed that the construction sector in Rwanda, plays a big role in the country's development in terms of job creation and tourists attraction from all over the world. It can be seen in Figure 1.6 that the GDP in the construction industry grew from 29 billion RWF in 1999 to 426 billion RWF in 2015. The contribution of building sector to GDP from 1999 to 2015 is shown in Table 1.2.

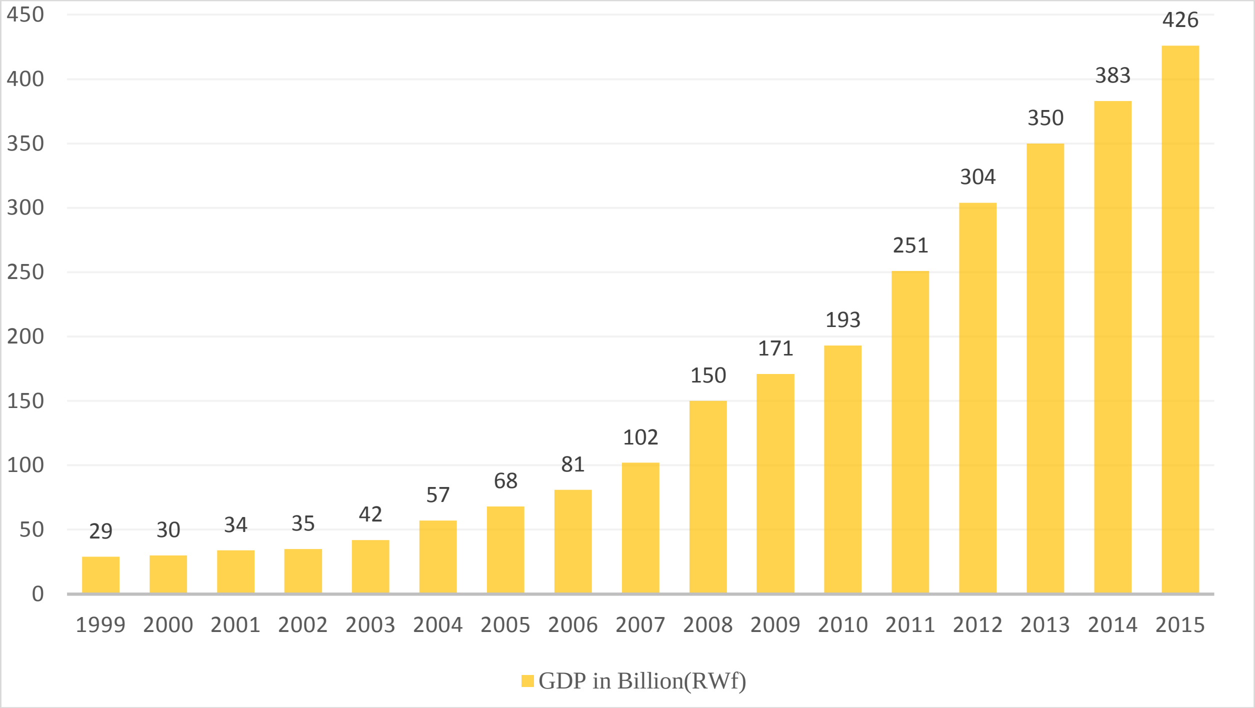


Figure 1.6: GDP for the Construction Industry (RWF Billion)

Source: (NISR, 2016)

Table 1. 2: Building contribution to GDP from 1999 to 2015

Year	GDP Contribution from Buildings(%)
1999	5
2000	5
2001	5
2002	4
2003	4
2004	5
2005	5
2006	5
2007	5
2008	6
2009	6
2010	6
2011	7
2012	7
2013	7
2014	7
2015	7

Source: NISR, 2016

Because of the rise in GDP as shown in Table 1.2, development of building energy efficiency codes, proper building envelope, behaviors of building occupancy, proper building orientation etc., are very essential, if policies are to be enforced to ensure reduction in energy consumption associated to buildings.

1.3.6 Energy Efficiency in Buildings in Rwanda

Energy efficient buildings are those which consume less energy while maintaining the comfort conditions inside, compared to common existing buildings. Energy efficiency is focusing not only on reducing negative environment impact but also supporting energy security, reducing black-outs, improve the access to electricity for all Rwandans, while boosting the economic development of the country. In Rwanda, a large number of buildings are being constructed yearly; constructions are not done to take energy efficiency and conservation into consideration.

Modern buildings and settlements across the country, especially in Kigali city replicate European style without considering the weather, climate and social conditions of the country. In recent years, the construction sector started with some buildings using glass materials, typical of Europe and the USA, without deep survey of the site and the climatic conditions; this led to the need for installation of air conditioning systems for maintaining proper internal comfort of the building, thus bringing about a rise in energy consumption of such buildings (Auziane, 2015). Inadequate information and training of building owners, managers, builders, designer and engineers are found to be prevalent in the country. There are also challenges with specific instruments that can be used to measure energy consumption to know the amount of electricity consumed in the buildings, and appropriate tools that can be deployed for simulating the energy use buildings by architects and engineers during the design phase and construction of the buildings. The lack of awareness of energy efficiency for building occupants as well as the non-existence of minimum energy performance standards and labels for appliances being utilized in buildings. Building energy efficiency can thus be easily incorporated into buildings at the design stage rather than improving building efficiency after decades of building completion.

1.4 Statement of the Problem

Energy access is still a big challenge in Rwanda as a developing country. Other than the finite nature of natural energy resources, the deposit of the energy sources in the country are very limited. Among the different regions of country, Kigali is much suitable for new construction among all the provinces and also preferred by the citizens. Owners and designers of buildings (i.e. public, commercial and residential buildings) are not aware of building energy efficiency, thus leading to the development of builddding structures that are not energy efficient but with associated high energy bills, through excessive consumption of energy. Kigali is a region in Rwanda where new buildings are springing up annually thus accounting for high percentage of energy consumption in Rwanda. This high energy would have been better managed in already completed and existing buildings, if proper simulation of energy in building designs are done with the use of energy simulation tools prior to construction.

1.5 Research Questions

Energy consumption in building takes into consideration, the whole life cycle of the buildings. Some parameters can contribute to building energy consumption. Some of these major parameters include: building design, building envelope, and occupancy schedule etc. Therefore, there is a need to measure how these parameters affect energy demand in buildings, and to consider methods of evaluating the inherent energy performance association with the buildings.

1.6 Aim and Objectives

The aim of this project is to simulate energy performance in buildings in Rwanda, in order to identify energy reduction measures that may be adopted to existing buildings. This will be done to minimize energy costs in buildings and also to reduce carbon-dioxide emission to the atmosphere. This research will also examine how building designs can affect final energy demand during the service life time of building. The objectives of the study are therefore to:

(i) study areas of improvement of energy consumption in buildings in Rwanda;

(ii) assess the significance and impact of key design parameters on building energy use in Rwanda.

1.7 Scope of the Research

The research work is to carry out energy performance in buildings in Rwanda. In this study, energy audit of the building will be carried out to provide data on energy consumed by the building. Thereafter, eQUEST building energy software will be adopted to simulate different building designs through the analysis of hourly weather data of five different regions of the country. A building energy simulation map will then be developed for Rwanda.

1.8 Justification of the Study

Building owners and developers design without considering the climate conditions of the site, and also constructing with the use of any kind of construction materials. One of the significance of this study is to carry out building energy consumption for the different locations across the country. The study will access building design parameters in a bid to developing an energy efficient and sustainable building in Rwanda.

CHAPTER TWO: LITERATURE REVIEW

2.1 Sustainable Buildings

Sustainable buildings can be referred to as “buildings that have minimum adverse impacts on the built and natural environment, in terms of the buildings themselves, their immediate surroundings and the broader regional and global settings” (Kakkar, 2014). It may also be defined as building practices, which strives for integral quality (including economic, social and environmental performance) in a broad way (Clements et al., 2005). Sustainable building considers the lifespan of the buildings by taking into account the environmental quality, operational quality until the building decommissioning with proper building materials disposal (Kassiani et al., 2014). The sustainability of the building starts with building design which comes the ideas from architects, electricians, technicians and builders. In buildings, all aspects such as buildings materials, lighting system, building orientation, cooling and heating system, and internal building equipment have to be considered for making them sustainable (Racquel, 2009).

Globally, about 40% of the total energy was annually consumed by existing buildings (US.DOE, 2012). Buildings account for a large energy consumption per year for modern societies; in European Union (EU) region, energy consumed in buildings is more than 40% of the total energy consumption (EC, 2002). According to the National Building Code (NBC), building accounts approximately 18% of total global carbon emissions, and equivalent to 9 billion tons of carbon emission annually (Nkiruka et al., 2015). Energy consumed in buildings will continue to be on the increase; hence, to alleviate high energy demand, more energy efficient design and proper building energy conservation programs should be enforced (Joseph C. Lam et al., 2008).

Development of sustainability in the building has to result in the creation and responsibility maintenance of a healthy built environment, according to ecological guidelines, and through an efficient use of resources (Heravi G. et al., 2014). Apart from the use of existing resources such as energy and raw-materials, buildings also generate wastes that are very dangerous and harmful to the environment, and that bring about global warming (Alnaser N. W. et al., 2008). Sustainability in buildings is thus one answer to environmental and socio-economic problems (Riduan Y., 2011). As a result of this, green building will be required in balancing long-term economic growth by enhancing productivity of occupants and facilitates sustainable development of the society. By this, deteriorative impacts of buildings on public health and environment will be reduced drastically (Heravi G., 2014).

2.1.1Building Envelope

The building envelope includes the building components separating the out-doors and indoors; this comprises the exterior walls, the roof, floors, doors and windows (Clements et al., 2005). The envelope of the building must be enclosed to maintain the internal comfort of the building. In building design development, the building architecture might vary according to the will of building owners or designers. The problem of this change is made without considering the sustainability of the building in terms of energy consumption of building lifespan. It is more important to consider factors affecting the performance of walls by analyzing the wall's design by allowing necessary airflow, and proper building insulation to keep the interior of the building comfortable. The roof also has impact in creating good conditions for the building, if well designed. The roof shape and orientation, control solar radiation, temperature, and wind; the building's moisture also have an impact on building energy performance (Khan and Asif, 2017). In considering the external environment needed to make the indoors comfortable, all these parameters have to be properly taken into account. The building envelope has to be designed based on the day-lighting, and to also protect the surrounding space against local climate conditions in order to minimize the building energy cost (Clements et al., 2005). The wall provides a good fresh air and comfort inside the building and must be constructed without compromising aesthetics of the building; it forms a predominant fraction of the building envelope. The building energy consumption is influenced by the thermal resistance (R-value) mostly for high rise buildings due to the fact that the ratio between wall and total envelope area is great (Sharma, 2013).

2.2 Energy Performance in Buildings

The minimum standard of energy efficiency is a key player for securing building construction permit in developed countries, so as to reduce energy consumption in building (C40, 2014). Energy performance in buildings is thus fundamental to decisions making concerning energy efficiency, the design of buildings, and to identify the impact of energy conservation measures. In new buildings, energy performance analysis helps to set the appropriate type and size of building and components, carry out the benefits of innovative strategies and study the efficiency of new equipment and design options (Luen, 2010). For existing building, energy performance is done through energy audits and surveys, for the purpose of optimizing the building operation (C40, 2014).

It was discovered in the work of Tiwari (2016), that energy performance in buildings relies upon parameters such as local climate change situation, building envelope, lighting system, HVAC system and efficiency, management team, occupancy, people's behavior (Ateesh Tiwari, 2016). Hence, building envelope has an impact on building energy consumption, whereby changing some building components can thus reduce energy use. Through modification of building orientation, windows position and retrofitting, better building energy performance can be obtained. For instance, it was confirmed that electro-chromic (EC) windows in Mediterranean conditions are better in energy performance when compared to single glazed windows; electro-chromic windows reduce energy needs and thus provide a tighter building envelope (Tavares P.T. et al., 2013).

Due to high emission associated with the use of fossil fuels, sustainability and energy efficiency use are measures adopted in building performance. In developed countries, several research work have been carried out to evaluate energy performance in buildings, based on different building envelopes. However, in sub-Saharan Africa having climate conditions (mostly tropical or sub-tropical) that are very different from that of the developed (temperate) regions (where there is no need for heating systems in building, but only cooling system is required), work is very limited. It is thus necessary to evaluate building performance in this region so as to reduce energy consumption, as well as reducing environment degradation associated with carbon emissions to the atmosphere. Energy performance in building life cycle is found to be affected by geographical location and climatic conditions of region, material production and transportation, construction methods, existing mechanical and electrical facilities, occupancy behavior patterns, norms of occupancy on energy consumption, and architectural design (Alberta, 2016).

2.3 Energy Simulation in Buildings

The energy utilized in buildings is dependent on the temperature distribution within the building and the thermal envelope, as well as the air rate exchanged between the inside and outside of the building. Infiltrations through open channels (e.g. air flow through windows, doors and other air flow channels) make the highest energy demand for cooling or heating depending on the local climate conditions (Srivastava-Modi, 2011). The interaction between the air movement and the temperature in all the room surfaces will bring about temperature distribution. The temperature distribution may be solved using Computational Fluid Dynamics (CFD) which accurately calculates the thermal comfort of the building. This approach is applied for each and every room of the building; the temperature is assumed to be uniform in the rooms. The heat flow across each surface in the building is computed using Equation (2.1) (Srivastava-Modi, 2011):

$$Q = \frac{Temperature\ difference}{Thermal\ resistence} = \frac{\Delta T}{R} \qquad (2.1)$$

where Q is the heat flow in watts per square meter (W/m^2).

Evaluation of heat flow from different heat sources such as heat from lighting, from fans, from people occupants and other building equipment must be included for better understanding of the exact heat required for cooling or heating. With all these parameters, building energy performance can be predicted. Due to advancement in technology, many computational energy simulation tools have been developed to predict building energy performance when the building is operational. In Srivastava-Modi (2011), building energy simulation can be referred to as a powerful method for studying energy performance of buildings and for evaluating architectural design decisions, as well as, choices for construction materials and methods. The building energy simulation tools help the designers to vary the building design options for the purpose of getting more accurate results in terms of energy use the cost effectiveness (Mustafaraj G. et al., 2014). It helps building managers and designers to identify energy saving potentials of the building, analyses the building energy performance, identify and implement energy saving measures.

2.3.1 Energy Simulation Tools

Energy simulation software are useful tools for designing buildings in this century. They provide significant contribution by dealing with climate mitigation and adaptation regarding responsible energy planning (Chun M.Hui, 1996). Energy efficiency is potentially the most important and cost-effective means for mitigating greenhouse gas emissions from industry. They contribute to reduction of energy usage bills in buildings thereby increasing household income. They contribute to meeting energy demand of a country and budget/expenses reduction needed for new power plants.

The software for building energy modeling considers building components such as construction materials, total floor area, building orientation, lighting systems etc. Therefore, in order to assess the performance of buildings, many energy building modeling software such as Energy plus, DOE2.1, eQUEST, Building designer and others are used (Drury B. et al., 2005). Some of the software such as Energy plus are complex and are not users-friendly; they require detailed data that may be very difficult to obtain. Others are simple to use like eQUEST which is users-friendly and faster, easier to use, and also generates outputs which are easy to understand and analyze by non-experts (Hema S. Rallapalli, 2010).

2.3.2. Comparison of Existing Energy Simulation Tools

There is a large list of building energy simulation tools which help architects/building designers in designing, predicting and evaluating energy in which the building could be used, and also provide the alternatives in reducing the energy consumption in buildings. The study has been made to collate existing simulation tools whereby their functionality and differences are compared (Kummert et al, 2006).

Table 2. 1: Available Building Energy Simulation Tools

Name	Application
PowerDomus Version 1.5 **www.pucpr.br/lst**	PowerDomus is the building simulation tool for investigating energy consumption and also thermal comfort of the building. It has been developed to model coupled heat and moisture transfer in buildings when subjected to any kind of climate conditions.
SUNREL Version 1.14 **www.nrel.gov/buildings/sunrel**	Is an hourly building energy simulation program that helps for designing energy efficiency for small buildings. The tool uses the entry data like building envelope, its environment data and the occupants.
eQUEST Version 3.64 **www.doe2.com/equest**	eQUEST is a building energy simulation tool which is easy to use. It is building energy consume analysis tool which provides high quality results by combining a building creation wizard, an energy efficiency measure (EEM) wizard and a graphical results. It uses DOE-2.2 as an engine.
DesignBuilder	DesignBuilder, a whole building energy use analysis simulation tool, is the oldest, easiest to use, most powerful graphical user interface to EnergyPlus available and includes ASHRAE 90.1. It calculates the CO_2 emissions, controls and provides solar shading, natural ventilation, day lighting alternatives.
Designer's simulation toolkits (DeST), Version 2.0	DeST allows detailed analysis of building thermal processes and HVAC system performance. Is also a building simulation from design process and deals with building thermal properties, and natural temperature.
DOE-2	DOE-2 is a widely used and accepted free building energy analysis software that can forecast the energy consume and cost for all types of buildings. DOE-2 uses a description of the building envelope, construction materials, usage of internal equipments, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, and with weather data, it performs an hourly simulation of the building and evaluating utility bills.
EnergyPlus	It is an Energy Simulation tool which analyses and designs thermal comfort of the building. It provides the outputs of

Name	Application
	heating and cooling, lighting loads according to the inputs data. It deals with life cycle assessment and life cycle costing, and scheduling.
EcoDesigner	It deals with Energy balance evaluation, CO2 emissions, overshadowing, heating, cooling, lighting, water use, life cycle costing, Scheduling, and prime energy usage.
ESP-r	It is an environmental design, 3D Design, Thermal design and analysis tool. It has capability of providing the outputs for heating and cooling loads, lighting. It combined heat and electrical power generation and photovoltaic facades. And finally assesses the life cycle and environmental impacts.
Green Building Studio	It is also and environmental design tool. It displays an annual energy consumption (electric and gas), Carbon emissions, water usage and cost, Life cycle costing, and natural ventilation.
LOAD EXPRESS	It designs lighting, heating, ventilation and air-conditioning loads in commercial buildings.
QwickLoad	It is a building tool which design and assessing HVAC system from residential to large commercial buildings.
REM/Design	It is an energy simulation tool for residential buildings
VisualDOE	An energy simulation tool which deals with energy efficiency, energy performance for residential and commercial buildings.
ZEBO	It was designed to support in decision making for zero energy building use. It has an alternative of sensitivity analysis; thermal comfort in hot climate.
TRACE 700	TRACE 700, is Trane Air Conditioning Economics and it has designed to evaluate the effect of building orientation, size, shape, and mass based on hourly weather data and the resulting heat-transfer characteristics of air and moisture.

Name	Application
EFEN	EFEN is an energy analysis tool which uses EnergyPlus simulation engine.
ENER-WIN	A quick energy standard-conformance design tool with graphic interface for whole-building annual energy simulations for residential and commercial buildings.

Source: Contrasting the capabilities of building energy performance simulation programs (Kummert et al, 2006) and on web: “http://www.buildingenergysoftwaretools.com/software”

2.3.3 eQUEST Building Software

The Quick Energy Simulation Tool (eQUEST) is a public domain tool developed in 2007 by James Hirsch and Associates for Southern California Edison. It uses Department of Energy (DOE-2.2) as an engine (Tobias M. et al., 2007). It is a free energy simulation tool which enables all functionalities of the DOE-2.2 simulation engine, and designed to provide the analysis of the performance for the whole building. It calculates heating and cooling loads during a year based on a data entry building description, and has the ability to import .dwg files (Bahar et al., 2013). It has the ability to export enquiry outcomes in Excel (.xls) format and can import building geometry via gbXML (Bahar et al., 2013). eQUEST uses energy creation Wizard and energy efficiency measures Wizard, and displays energy analysis module. The software creates multiple parametric simulations, and compare the different results graphically. The program has defaults values which can be changed by the user, according to the information given by the building design, and building owner. Once all data have been inputted by the user, the software provides a screen that shows if there are any errors. If no errors are found, the software user may generate the output report. Following all simulation directions and building details, the baseline energy model for the case building will be provided or generated. eQUEST requires inputs such as building's architectural features, building materials, occupancy schedules, building's weather location and orientation, and also its heating, ventilating, air-conditioning (HVAC) equipment. When the building model is completed, the simulation results are analyzed in different graphical formats. The eQUEST provides building energy use on monthly or annual basis. It is users friendly, provides reliable results which make it excellent for realistic building energy load data and also does not need complex inputs as found with EnergyPlus software. It is able to simulate building design in different regions of the country and provides the best region to build. In this work, energy simulation design was carried out using eQUEST version 3.64. The following diagram summarizes different inputs and all process of eQUEST.

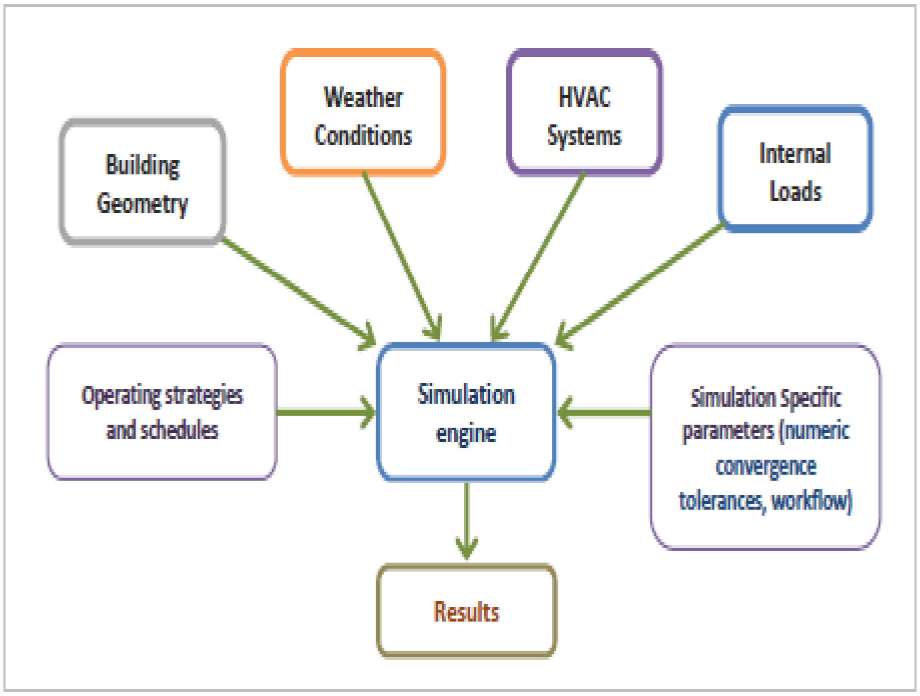


Figure 2. 1: General Inputs Data of eQUEST Software Engine

Source: (Bahar et al., 2013)

CHAPTER THREE: METHODOLOGY

3.1 Data Collection and Simulation

To achieve the desired objective of energy simulation in buildings using eQUEST, the following steps were adopted as methodology:

Step 1: Building specifications needed for the software were gathered through energy audit conducted on the building. Energy audit exercise through interviewing the occupants, civil engineer, mechanical engineer and electrician, and visual inspection of the equipment was used to acquire data. The occupants were interviewed to acquire the daily operation hours and age of the facility/equipment. The civil engineer was consulted to provide information on the construction envelope (design, construction material, orientation and others). The mechanical engineer was interrogated to provide information for cooling system, while the electrician was interviewed on lighting specifications. Discussions were made with the owner of the building to acquire historical information about the building. Through visual observation, the power ratings, models and working conditions of the equipment were acquired. Figure 3.1 shows stages of the energy audit process.

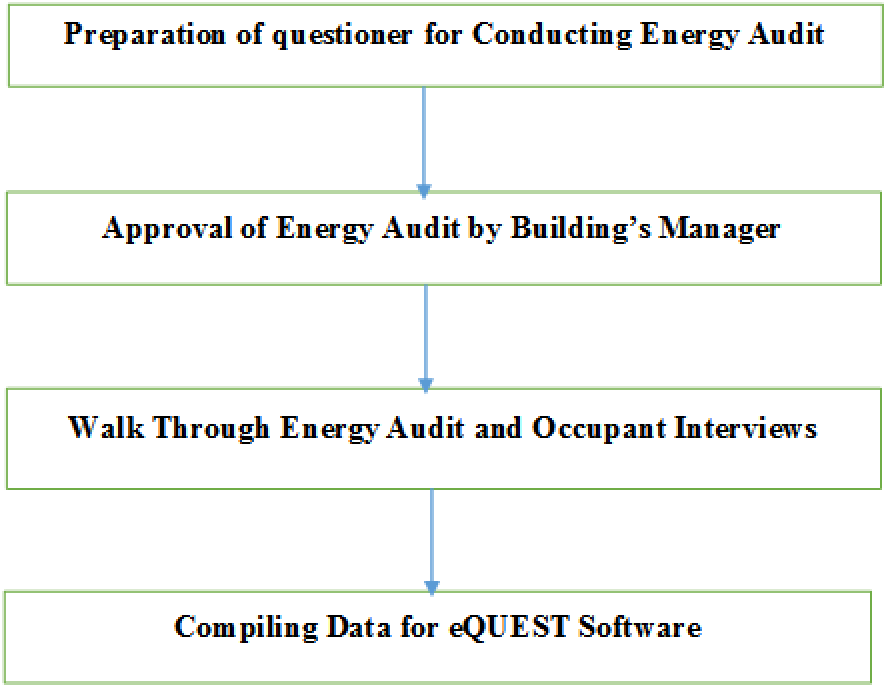


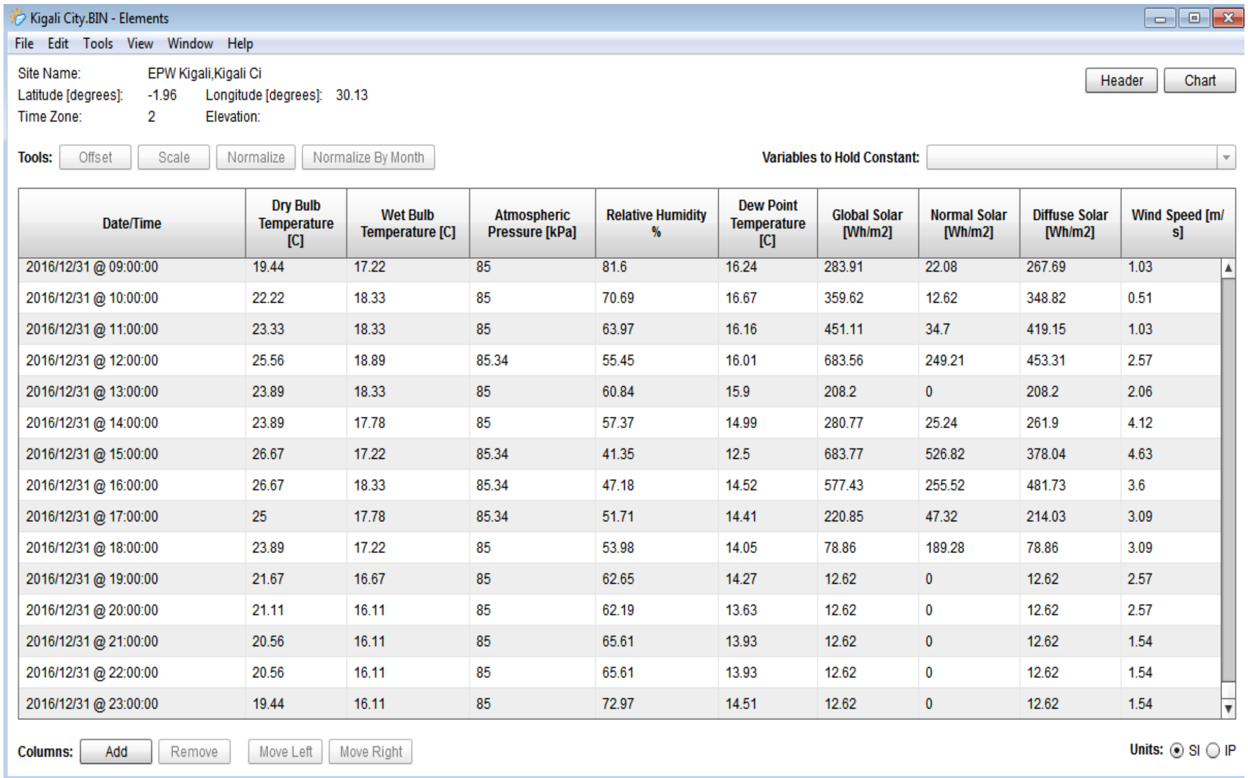
Figure 3. 1: Stages of Energy Audit

Step 2: Data were compiled based on inputs of the building models. These include: architectural features, HVAC equipment, construction materials and their U-values, occupancy schedule, and the building's footprint, orientation and weather location. These information were entered using Design Development Wizard of the eQUEST software. The software generated the monthly building energy consumption which was summed-up to the entire year of 2016, and then compared to data from the building energy audit.

Step 3: The same building was simulated in all the different regions of the country including: Eastern Province, Western Province, Northern Province and Southern province. By changing the weather data, building orientation and applying appropriate energy efficiency measures, the building energy consumption map for Rwanda was provided.

3.1.1 Collection of Weather Data

Big ladder software called ‘Elements’ was used to convert hourly excel sheet weather data format from the different stations in all the provinces of the country, to ‘bin’ format which is readable by eQUEST. It was also used to compute the wet temperatures, dew-point temperatures, normal solar radiation, as well as beam solar radiation for better outcome. The hourly weather data for Kigali was obtained from White Box Technologies: Weather data for energy calculations (www. Whiteboxtechnologies.com). The screenshot is shown in Figure 3.2.



Site Name: EPW Kigali,Kigali Ci
Latitude [degrees]: -1.96 Longitude [degrees]: 30.13
Time Zone: 2 Elevation:

Date/Time	Dry Bulb Temperature [C]	Wet Bulb Temperature [C]	Atmospheric Pressure [kPa]	Relative Humidity %	Dew Point Temperature [C]	Global Solar [Wh/m2]	Normal Solar [Wh/m2]	Diffuse Solar [Wh/m2]	Wind Speed [m/s]
2016/12/31 @ 09:00:00	19.44	17.22	85	81.6	16.24	283.91	22.08	267.69	1.03
2016/12/31 @ 10:00:00	22.22	18.33	85	70.69	16.67	359.62	12.62	348.82	0.51
2016/12/31 @ 11:00:00	23.33	18.33	85	63.97	16.16	451.11	34.7	419.15	1.03
2016/12/31 @ 12:00:00	25.56	18.89	85.34	55.45	16.01	683.56	249.21	453.31	2.57
2016/12/31 @ 13:00:00	23.89	18.33	85	60.84	15.9	208.2	0	208.2	2.06
2016/12/31 @ 14:00:00	23.89	17.78	85	57.37	14.99	280.77	25.24	261.9	4.12
2016/12/31 @ 15:00:00	26.67	17.22	85.34	41.35	12.5	683.77	526.82	378.04	4.63
2016/12/31 @ 16:00:00	26.67	18.33	85.34	47.18	14.52	577.43	255.52	481.73	3.6
2016/12/31 @ 17:00:00	25	17.78	85.34	51.71	14.41	220.85	47.32	214.03	3.09
2016/12/31 @ 18:00:00	23.89	17.22	85	53.98	14.05	78.86	189.28	78.86	3.09
2016/12/31 @ 19:00:00	21.67	16.67	85	62.65	14.27	12.62	0	12.62	2.57
2016/12/31 @ 20:00:00	21.11	16.11	85	62.19	13.63	12.62	0	12.62	2.57
2016/12/31 @ 21:00:00	20.56	16.11	85	65.61	13.93	12.62	0	12.62	1.54
2016/12/31 @ 22:00:00	20.56	16.11	85	65.61	13.93	12.62	0	12.62	1.54
2016/12/31 @ 23:00:00	19.44	16.11	85	72.97	14.51	12.62	0	12.62	1.54

Units: ● SI ○ IP

Figure 3. 2: General Information of Element Screen of Kigali City

3.2 Building Design

A case study of the building which considers all requirements that affect the overall energy consumption in buildings for a public building was selected. The parameters to be considered for the building envelope are the wall, ceiling, doors, and windows, ventilation and cooling system, lighting systems equipment and day lighting, water-heating systems and equipment. Consideration of all parameters from the design to building operation may significantly reduce the energy need and bring about healthy, comfortable and good indoor functioning environment. The design of building envelops and material components have to be prioritized due to their importance in the reduction of building energy use, if all or each component is well considered.

It was proved that a poorly insulated wall, floor, roof, and inappropriate design are responsible for about 40% and 30% of the total heat loss respectively (Birol, 2012).

The improvements of these parameters should be prioritized to have a sustainable public building. Other parameters to consider in building designs are the size, shape, and orientation of the building, and also the occupancy, internal loads, lighting equipment and Heating, Ventilation and Air Condition (HVAC) systems. Putting all these parameters in public/commercial building design into account will positively bring about a reduction in building energy need and diminish the load of the building for the whole operational life of the buildings. Building energy simulation software was used to compile data based on inputs of the building models (architectural features, HVAC equipment, construction materials and U-values for these materials, the occupancy schedule, and the building's footprint, orientation and weather location). All these information were entered using Design Development Wizard of the eQUEST software.

3.3 Description of the Building

The case building selected in this research is Kigali City Tower. It is a 20 storey high-rise office building located in Kigali, Rwanda. It is the tallest building in the country and located in Nyarugenge central business of Kigali. Among the 20 floors of the tower, 18 are partitioned into office spaces. The ground floor is the entrance corridor, the underground floor is O-Zone bar restaurant. The total retail floor space is around 10,000 square metres (110,000 sq. ft.) while office space is 7,000 square metres (75,000 sq. ft.). Each floor of the tower has 336 square metres (3,620 sq. ft.) of office space available. The building faces the north, but the façades are built from glasses to capture daily daylight. This façade orientation, and glass wall largely contribute to the aesthetics and the comfort of the building especially during cold season, by letting in a lot of daylight but also make the building warm during the hot season. The building is 61.25 ft. by 61.25 ft. in dimension, while the height i.e. floor to floor, floor to ceiling are 13 ft. and 9 ft. respectively, with a cooling equipment of DX coils. The building has 3750ft^2 per floor and has the overhang of 1.5ft. distance from the window. Figure 3.3 shows the selected building.

Figure 3. 3: Kigali City Tower building image

(Source: Google search engine)

3.4 Description of Equipment

The main energy consuming appliances in the building include: lighting systems, electronic appliances, kitchen appliances and refrigeration and air conditioning units. The detailed equipment as found in the building are summarized in Table 3.1.

Table 3. 1: Energy Consuming Appliances Available in the Tower

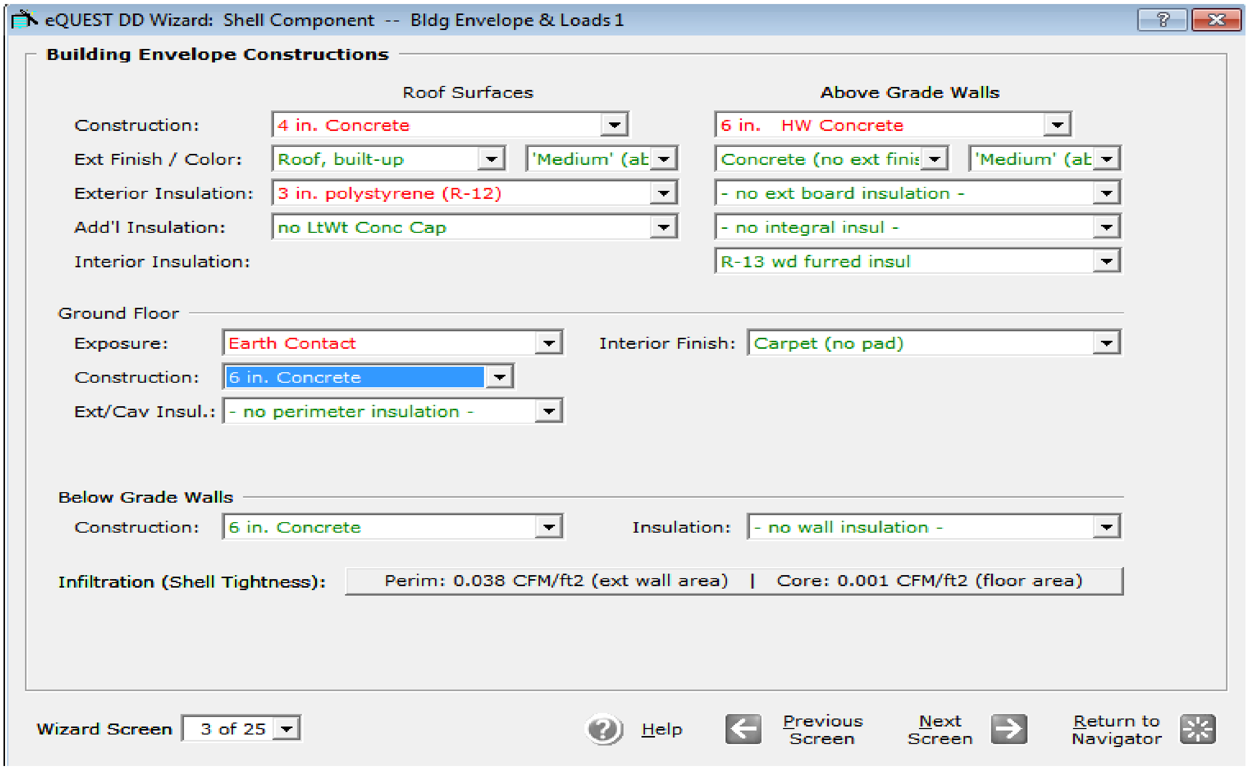
Lighting	**Electronic Appliances**	**Cooking Appliances**	**Others**
Linear Fluorescent lamps	Desktop (CPU and LED Monitor)	Oven	Air-Conditioners
	Security TV		
Compact Fluorescent Bulbs	Laptops	Ice-Maker	Fridges
	Printers	Electric Kettles	Lifts
	Photocopying (big multipurpose)	Blender	Thru scan
	Photocopying Machines	Microwaves	
	Security Cameras	Water Dispensers	
	Scanners	Water Heater	
	Conference Room TVs	Chips fryer Machine	
	Security Camera TVs		
	Projectors		

Source: Researcher’s findings

The audit exercise covered much of electronic appliances because they predominates much of the building energy consumption on a daily basis. Lighting system consists of fluorescent lamps (mainly used inside the rooms), and compact fluorescent bulbs (found inside some of the rooms, stairs, toilets and in the corridors of the building). Manual switches are fixed on the walls and serve as the main lighting controls. Few wall glasses had curtains which could be used to prevent inside warming from day light. Air-conditioners are found in some office rooms and are mainly in operation during the summer.

3.5 Building Material and Envelope

The exterior walls of the building are constructed with 6”/152.4 mm heavy weight concrete with R-12 polystyrene insulation. The floor is also made of 6”/152.4 mm concrete base with ceramic/stone finish. The internal walls are 0.5”/12.5 mm drywall/sheet rock framed on metal studs with insulation on selected interiors. The building is operated under positive pressure, which eliminates any potential envelope infiltration. A screenshot of the eQUEST wizard screen used to input building material and envelope details is displayed in Figure 3.4.



eQUEST DD Wizard: Shell Component -- Bldg Envelope & Loads 1

Building Envelope Constructions

	Roof Surfaces	Above Grade Walls
Construction:	4 in. Concrete	6 in. HW Concrete
Ext Finish / Color:	Roof, built-up 'Medium' (ab	Concrete (no ext finis 'Medium' (ab
Exterior Insulation:	3 in. polystyrene (R-12)	- no ext board insulation -
Add'l Insulation:	no LtWt Conc Cap	- no integral insul -
Interior Insulation:		R-13 wd furred insul

Ground Floor

Exposure: Earth Contact

Interior Finish: Carpet (no pad)

Construction: 6 in. Concrete

Ext/Cav Insul.: - no perimeter insulation -

Below Grade Walls

Construction: 6 in. Concrete

Insulation: - no wall insulation -

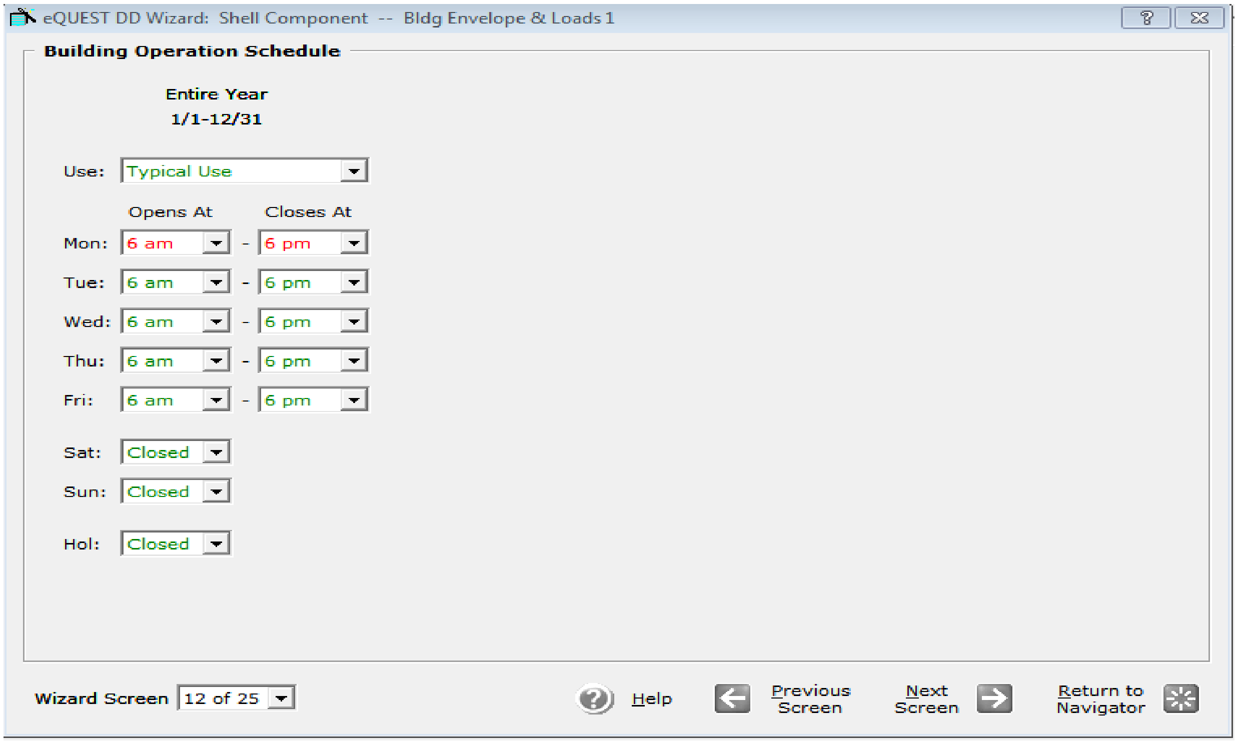
Infiltration (Shell Tightness): Perim: 0.038 CFM/ft2 (ext wall area) | Core: 0.001 CFM/ft2 (floor area)

Wizard Screen: 3 of 25

Figure 3. 4: Building Envelope Wizard Input Screen in eQUEST

3.5 Building Schedule and Loads

Offices in the building are presumed to be open for work during weekdays (Monday to Friday) where the building is assumed to be occupied from 6 am to 6 pm, but shut down all weekends and during public holidays. The underground floor (O-zone bar and restaurant) are in operation seven (7) days a week and 12 hours per day.



Entire Year
1/1-12/31

Use: Typical Use

	Opens At	Closes At
Mon:	6 am	6 pm
Tue:	6 am	6 pm
Wed:	6 am	6 pm
Thu:	6 am	6 pm
Fri:	6 am	6 pm

Sat: Closed
Sun: Closed
Hol: Closed

Wizard Screen 12 of 25

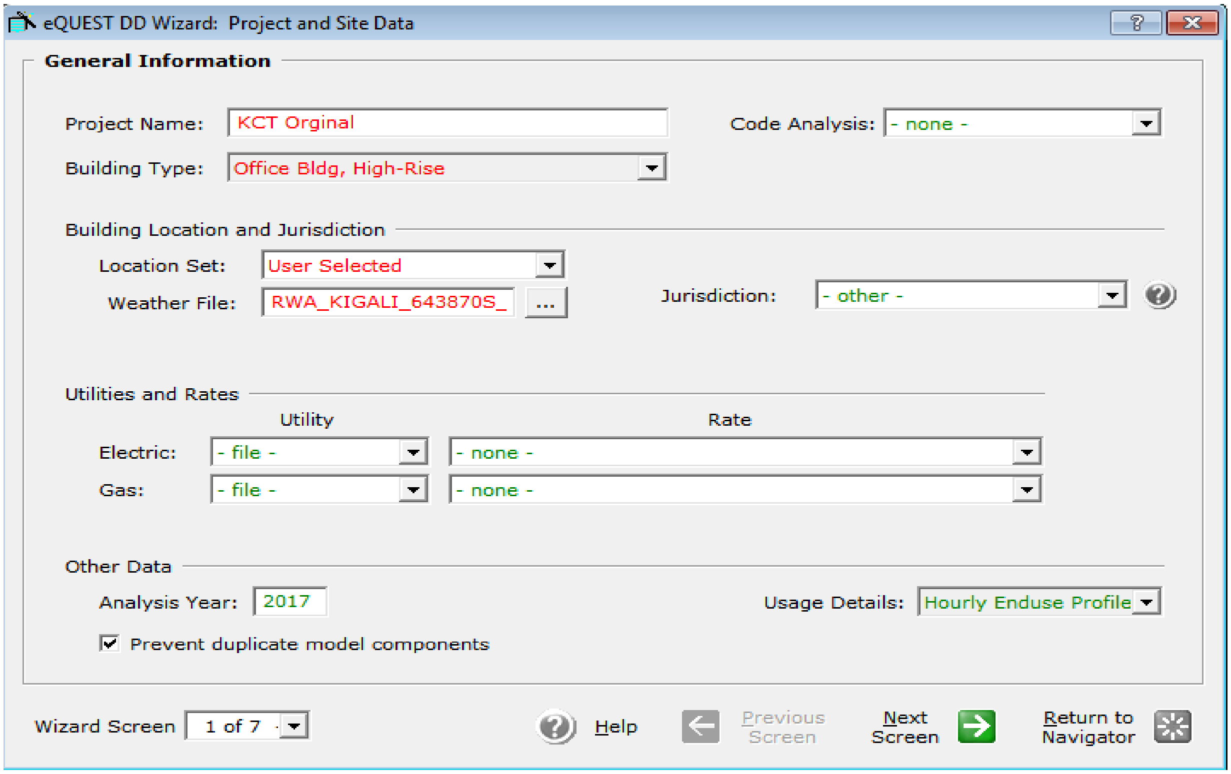
Figure 3. 5: Office Building Operation Schedule on eQUEST

The maximum occupancy value was assumed to be 200ft^2 per person. The interior energy uses are: interior (ambient) lighting, cooking equipment, miscellaneous equipment. The interior lighting was assumed to require 1.24W, the cooking equipment was assumed to require 1 W, and the miscellaneous equipment was assumed to require 0.75W. The seasonal thermostat set-points are occupied/unoccupied cool of 78ºF.

3.6 The eQUEST Model

Output of the building energy model (eQUEST) was used in this study. The eQUEST software uses the DOE-2.2 simulation engine which performs an hourly simulation of the building using inputs parameters including: building envelope, orientation, HVAC zones, walls, windows, occupants, plug loads, lighting. All inputs used in the simulation are provided by facility manager and architects. The simulation from eQUEST uses appropriate default values for building specifications not known to the user (Ateesh Tiwari, 2016).

After entering all inputs, the user performs the simulation where the screen identifies if there are some errors. Once there are no errors, the output reports are generated. Figure 3.6 shows the starting input data in eQUEST.



eQUEST DD Wizard: Project and Site Data

General Information

Project Name: KCT Orginal
Code Analysis: - none -
Building Type: Office Bldg, High-Rise

Building Location and Jurisdiction
Location Set: User Selected
Weather File: RWA_KIGALI_643870S_
Jurisdiction: - other -

Utilities and Rates

	Utility	Rate
Electric:	- file -	- none -
Gas:	- file -	- none -

Other Data
Analysis Year: 2017
Usage Details: Hourly Enduse Profile
☑ Prevent duplicate model components

Wizard Screen 1 of 7

Figure 3. 6: General Information Wizard Screen in eQUEST

After generating the output report through eQUEST simulation, the building energy consumption was later compared with the metered data captured from the building tenants, and the energy consumption obtained during the building energy audit exercise. The same building design was simulated in all the other regions of the country.

3.7 Sensitivity Analysis of Building Orientation

In order to get real less building energy consumption location, some measures have been taken such as changing the building orientation in all five country’s regions. For the all five country’s regions, the building has faced in North-West, South-East, West, South, East, and North-East. This was allow to compare with the building energy consumption when it is originally facing in North orientation.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Building Energy Audit

The audit exercise was focused on electrical appliances in the building, and also provided some recommendations on available Energy Management opportunities (EMOs). Due to non-availability of energy audit equipment such as wattmeter, circutor etc., electricity utilization of the building was estimated based on power ratings of equipment in the building while their hours of operation were acquired from building occupants. Energy consumption in tower is divided into three categories including: (i) energy consumed by offices and ground level, (ii) energy consumed by underground level (O-Zone) and (iii) energy consumed by three lifts of the tower. The electrical energy consumed in the offices, ground level and lifts was calculated by considering that the tower is in operation 22 days per month while also taking into account the public holidays. By calculating the annual electrical energy consumption by the offices and ground level, it was assumed that in the months of April, October, November and December all air-conditioners were switched off because they are rainy periods in Rwanda. The monthly electrical energy use in the 19 floors (offices and ground level) and monthly energy use by lifts as indicated in Table 4.1 and 4.3, were calculated by considering that the tower opens for activities 22 days per month and all air conditioners are in operation during the energy audit month. Information obtained from facility providers showed that the O-Zone is working 30 days per month and 12 hours per day as indicated in the Table 4.2; air conditioners are switched on during the whole month and even the whole year because they are used for cooling in the kitchen. Expenditures on electricity were estimated based on electricity tariff set by the utility company. The pieces of electrical equipment vary from floor to floor according to office activity. The overall monthly energy consumption on electrical equipment for the 19 office floors, monthly O-Zone bar and restaurant, the three (3) lifts were summarized in Tables 4.1, 4.2 and 4.3.

4.1.1 Energy Consumed in the Offices and Ground Level

The monthly electrical energy consumed in the offices and ground level is dominated by desktops, linear lamps, air conditioning and photocopiers with shares of 25%, 24%, 16% and 14% respectively of the total monthly electrical energy consumption in the 19 floors of the tower. This monthly electrical energy consumption was obtained by considering that all offices work five days a week, and nine hours a day. Operating time of the office appliances was taking into consideration as provided by the daily offices' occupants. Figure 4.1 details the energy consumption rate of each electronic appliance in the offices and ground level.

Table 4. 1: Monthly Energy Consumption in Offices

Electrical Appliances	Quantity	Monthly Energy Consumption (kWh)
Laptop	194	2433.42
Desktop(CPU and Monitor)	209	16698
Scanner	11	154.6974
Printers	24	5296.5
Photocopy(Multi-Function)	11	9405
Lighting Bulbs	920	3638.88
Linear Lamps	3060	16008.84
Water Dispenser	21	952.38
Kettles	15	343.2
Projector	14	232.32
Air Conditioning	26	10499.28
Microwave	1	52.8
Fridge	2	23.54
TV Screen	1	0
D-link	1	0.5049

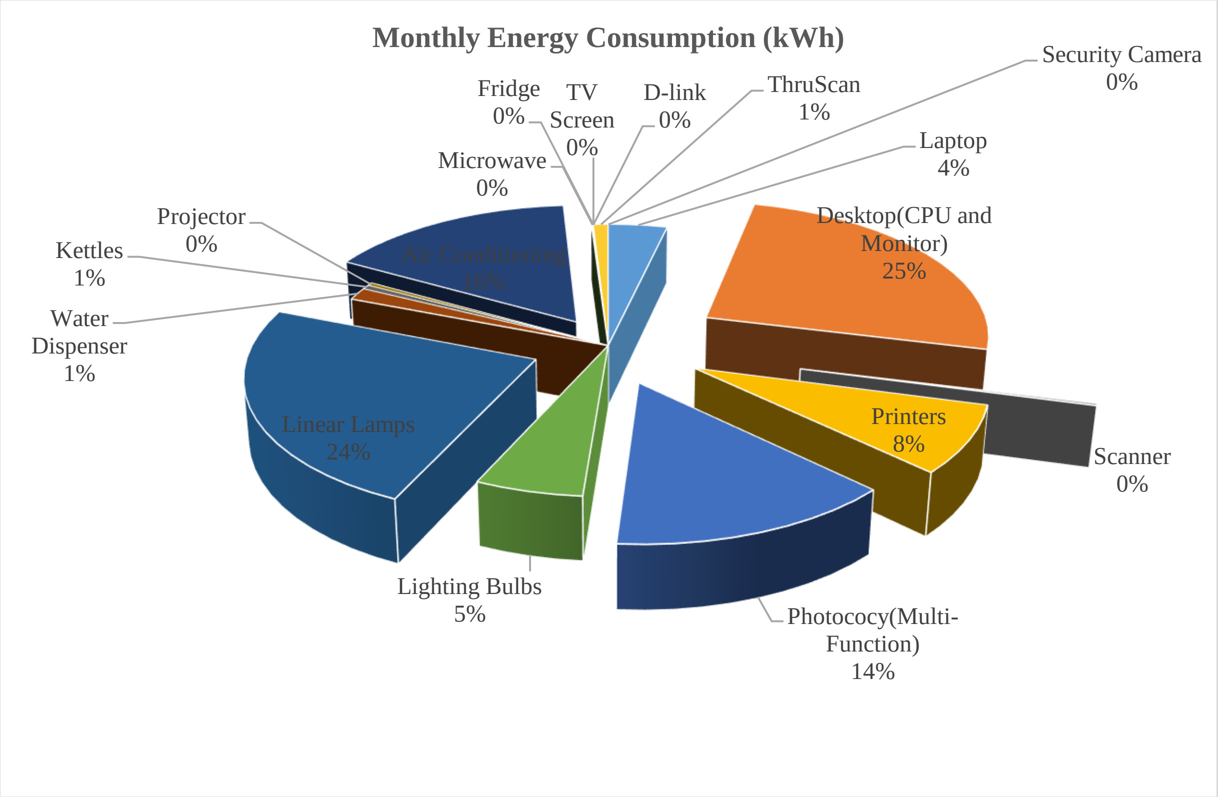


Figure 4. 1: Breakdown of Primary Electrical Energy Consumption

4.1.2 Energy Consumed in the Underground Level

The electrical energy consumed by O-zone bar and restaurant is especially dominated by air conditioning having 54% of the total monthly electrical energy utilized in the O-Zone. Air-conditionals are used here for cooling and hence work for seven days a week and twelve (12) hours a day. Figure 4.2 shows all the electronic appliances in terms of monthly electrical energy consumption.

Table 4. 2: Monthly Energy Consumption at the O-Zone

Electrical Appliances	**Quantity**	**Power Rating**	**Daily Operating Hours**	**Monthly Operation Hours**	**Energy Consumption (kWh)**
Laptop	1	65	12	360	23.4
Desktop(CPU and Monitor)	2	300	12	360	216
Printers	1	720	12	360	259.2
Lighting Bulbs	50	7	12	360	126
Linear Lamps	12	36	12	360	155.52
Kettles	2	1200	12	360	864
Air-Conditioning	7	2600	12	360	6552
Fridge	1	400	12	360	144
Screen TV	4	140	12	360	201.6
Microwave	2	600	12	360	432
Ice maker	1	450	12	360	162
oven	1	13280	3	90	1195.2
Blender	1	400	12	360	144
Fryer	1	3250	12	360	1170
Water Heater	1	1500	12	360	540

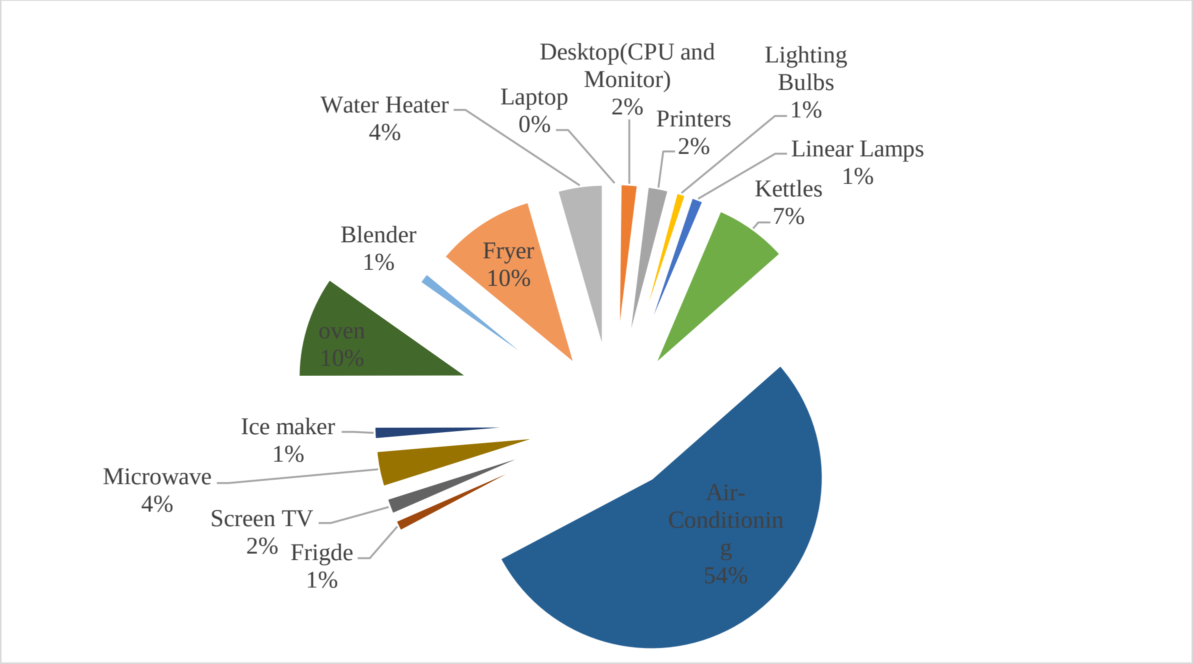


Figure 4. 2: Breakdown of Primary Electrical Energy Consumption

Table 4. 3: Annual Electrical Energy Use in O-Zone

Equipment	Annual Energy Use (kWh)
Laptop	280.8
Desktop(CPU and Monitor)	2592
Printers	3110.4
Lighting Bulbs	1512
Linear Lamps	1866.24
Kettles	10368
Air-Conditioning	78624
Frigde	1728
Screen TV	2419.2
Microwave	5184
Ice maker	1944
oven	14342.4
Blender	1728
Fryer	14040
Water Heater	6480

Table 4. 4: Monthly Electrical Energy Consumption by Lifts

Equipment	Quantity	Power (kW)	Rating	Daily Operating Hour	Monthly Operation Hour	Energy Use (kWh)
Lift 1	1		17	12	264	4,488
Lift 2	1		17	12	264	4,488
Lift 3	1		17	12	264	4,488
Total						**13,464**

As already mentioned above the electrical energy utilized in the building is sub-divided into three categories including: offices, underground level and the energy consumed by lifts with the different operation time. The monthly electrical energy consumption is dominated by offices followed by that of the lifts and lastly electrical energy consumed by O-Zone (Tables 4.4 and 4.5). The energy consumed in the offices, O-Zone and lifts are 72%, 15% and 13% respectively as indicated in Figure 4.3.

Table 4. 5: Monthly Electrical Energy Consumption in the Tower

Electrical Energy Consumption (kWh)	
Offices	66432.1423
O-Zone	12184.92
Lifts	13,464

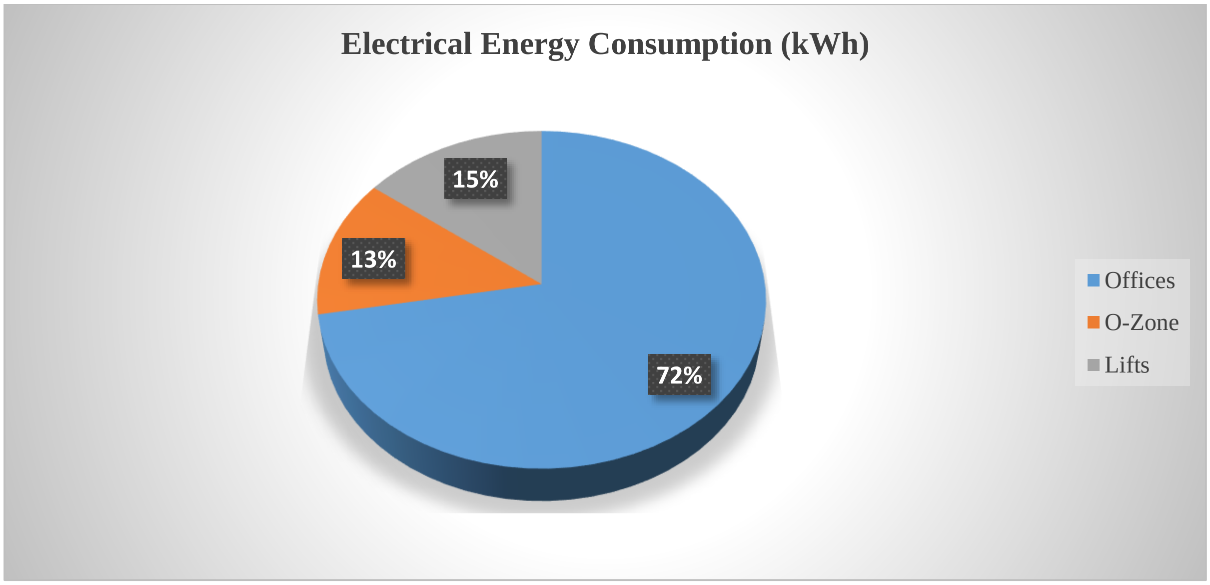


Figure 4. 3: Monthly Electrical Energy Consumption in the Tower

4.2 Identification of Energy Management Opportunities (EMOs)

The EMOs were classified under four (4) main group of appliances including: lighting, electronic appliances, cooking appliances, water use gadgets, air conditioning and refrigeration.

4.2.1 Suggested Energy Management Opportunities for Lighting Systems

The following EMOs were identified for the lighting system:

- All office switches should be sited at the departmental control room thereby preventing inefficient use of energy that may arise if switches are located at individual office.
- Each of the offices have more than the required illumination, hence, group de-lamping is necessary.
- Daylight/motion sensors should be adopted to control all lights in open offices.

- The lights in the tower are controlled using manual switches. There should be consideration for the use of occupancy or motion sensors for the offices, corridors and stairs.
- Sensitization programs are essential in order to train occupants on energy management principles especially when there is adequate daylight or proper illumination from the Sun.

4.2.2 Suggested Energy Management Opportunities for Electronic Appliances

The following EMOs were identified for electronic equipment:

- All photocopy machines, scanners and printers in the building should be replaced with multi-purpose (3-in-1) photocopiers that will be configured and centralized for multi-user. With this, energy utilization using each individual appliance will be conserved, while there will be reduction in maintenance costs that may be associated with the appliances.
- The government of Rwanda should consider setting Minimum Energy Performance Standards (MEPS) and Labels for appliances and equipment that will be produced or imported into the country. These will ensure that appliances being sold and utilized in the country are energy efficient.

4.2.3 Suggested Energy Management Opportunities for Refrigeration and Air-Conditioning Units

The following EMOs were identified for refrigeration and air-conditioning equipment:

- Air-conditioners should be switched off in cold weather or when the use are not necessary.
- The enforcement of energy efficient air-conditioning units. These must be certified MEPS units with appropriate energy Labels that shows their energy efficiency ratings.
- Energy conservation through the use of curtains should always be utilized to retain fresh air within the building for longer period of utilization during the summer.

4.2.4 Suggested Energy Management Opportunities for Water Usage

The following EMOs were identified for water use equipment:

- Constant checking and sealing of leakages.
- Use of energy efficient taps e.g. push taps or motion sensor taps.

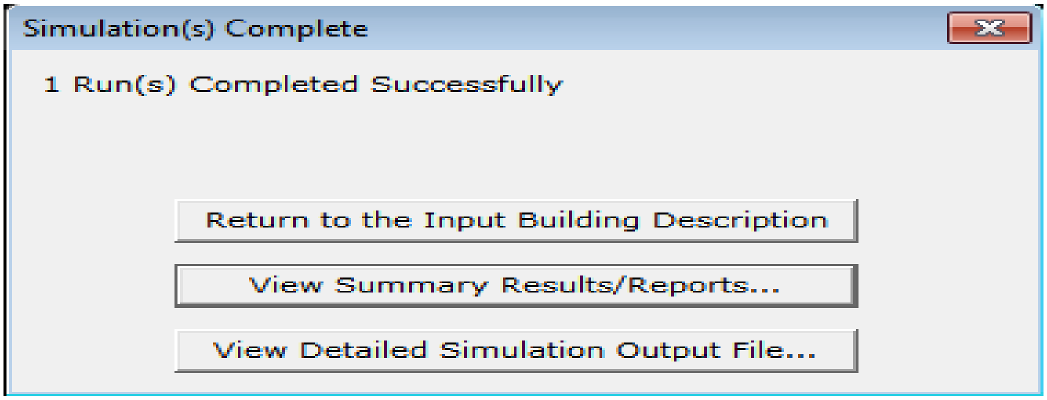
4.3 Implementation of Energy Management Opportunities

To avoid further energy inefficiencies, the following EMOs were identified for immediate implementation; such implementations may be carried out to sensitize workers on energy conservation practices through trainings and the use of posters etc. Workers may be trained to maximize the use of daylight/sunlight (e.g. switching off all lights inside rooms during the day to maximize day-light), shutting down of computers after work, the utilization of air-conditioners and cooking equipment only when needed. Others include:

- Cleaning of luminaries as well as windows, to maximize lighting illuminance.
- De-lamping of over-illuminated room(s).
- Decommissioning of excess printers and centralization of photocopiers for each floor.
- Check and repair any water leakages especially in the toilets and baths.
- Re-lamping office lamps and bulbs to ensure maximization of illumination.
- Installing additional switches and controllers including occupancy-motion sensors especially in corridors, toilets and offices.

4.4 Comparison of Captured Data with Predicted Data

The building design was simulated using eQUEST using data obtained from the building designer, weather data from Rwanda Meteorology Agency, and data purchased from White Box Technologies i.e. weather data for energy calculations (www.Whiteboxtechnologies.com). Two forms of outputs were provided by the eQUEST simulation software. These include summary results/reports and a view of detailed simulation output file. The options to select for graphical and energy consumption outputs are shown in Figure 4.4.



1 Run(s) Completed Successfully

Figure 4. 4: Simulation Output Window in eQUEST

The comparison between the monthly building energy consumption obtained from energy audit, with the monthly energy consumption simulated using eQUEST shows that, the building consumes more than the energy simulated according the building design inputs; though the simulated output compares reasonably well with the observed data. The annual building energy consumption from actual metered and audited are 947,210.7kWh and 951,517kWh respectively compared to 928,310kWh obtained from the eQUEST simulation. Table 4.6 shows the summary of the comparison between observed (audited and metered results) and the predicted (i.e. simulation of monthly energy consumption). A good fit can be observed between the observed data and the predicted data having returned a correlation coefficient of 76 and 79% for the audited energy and metered data respectively at 95% confidence interval.

Table 4. 6: Comparison of Energy Consumption (kWh)

	Observed Data		**Predicted Data**
Months	**Audited Energy (kWh)**	**Metered Data (kWh)**	**Energy Simulation from eQUEST (kWh)**
January	81,798	80,759	80,800
February	84,605	81,374	69,820
March	76,878	79,272	82,210
April	69,934	69,274	73,550
May	84,605	83,273	79,350
June	84,605	82,405	79,050
July	79,001	77,703	73,790
August	81,798	82,359	85,610
September	84,605	80,209	74,540
October	76,878	77,201.7	79,180
November	76,878	79,183	74,080
December	69,934	74,198	76,330
Total	**951,517**	947,210.7	**928,310**

According to Figure 4.5, some months consume high energy, this is due to temperature variations characterizing some months than others, thus allowing buildings to be cool during the day; it may also be linked to occupancy behaviors whereby building equipment are utilized inefficiently.

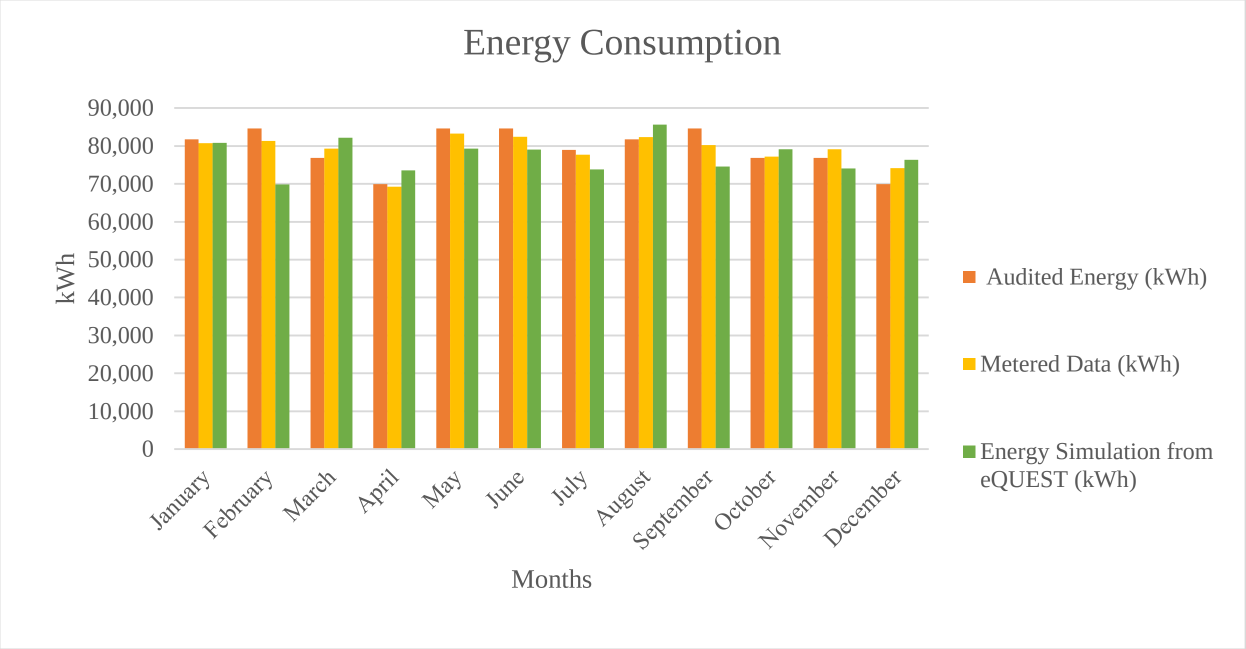
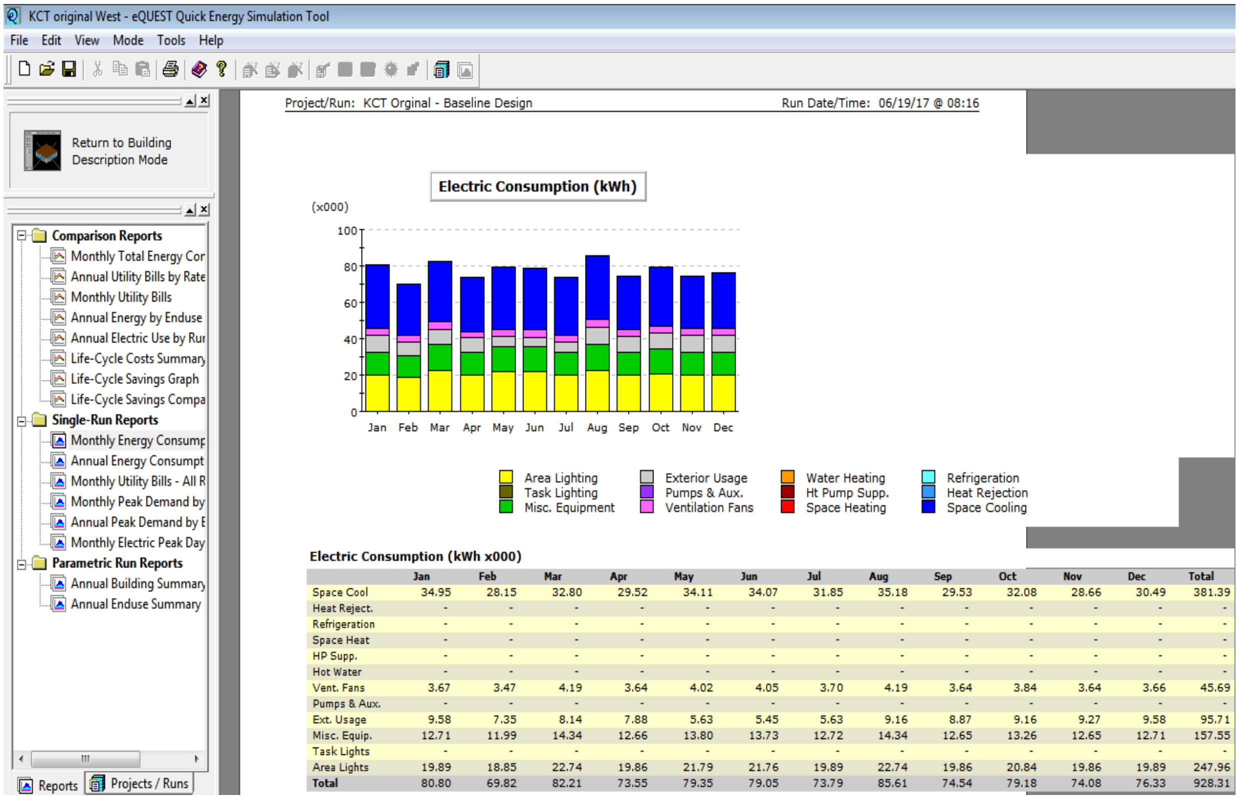


Figure 4. 5: Energy Consumption based on Observed Output and Predicted

4.5 Simulation of Energy Consumption for the Five Regions of Rwanda

4.5.1 Kigali City

The energy consumption output of the sample building in Kigali city using eQUEST software is shown in Figure 4.6. From the eQUEST windows report, monthly energy consumption, annual energy consumption, monthly peak demand by end-use, annual peak by end-use and monthly electric peak day load profiles can be displayed.



Project/Run: KCT Orginal - Baseline Design

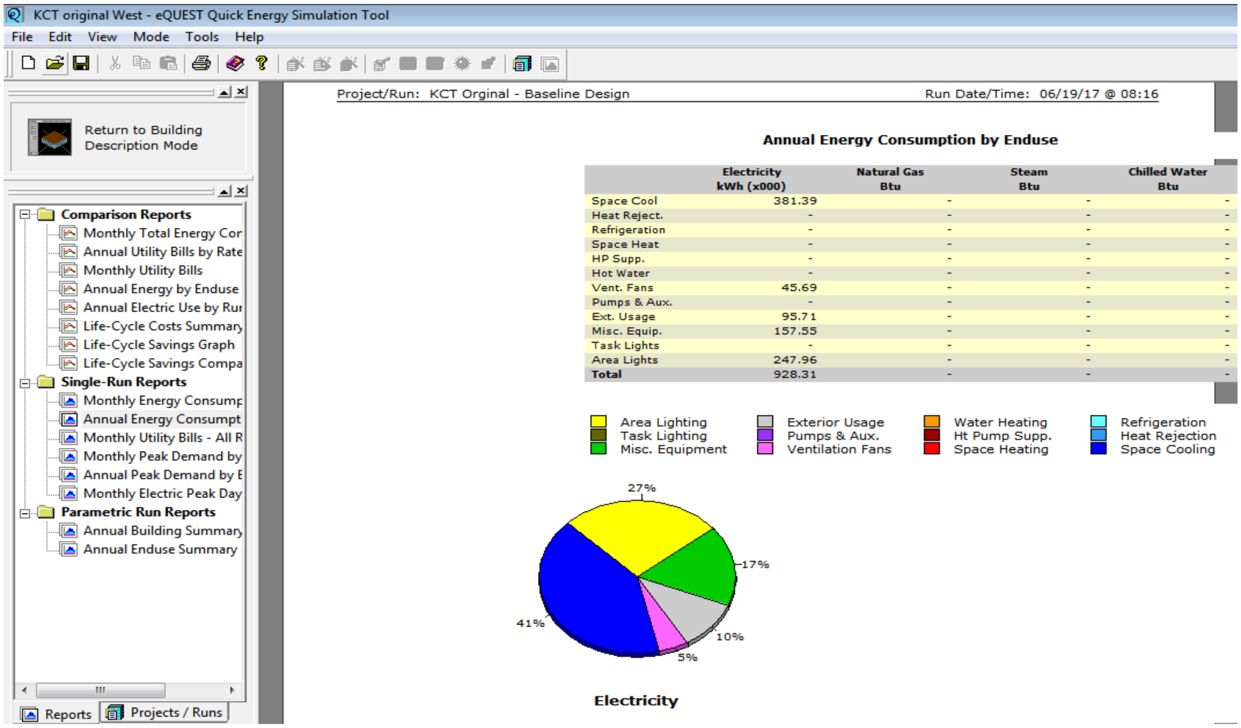
Run Date/Time: 06/19/17 @ 08:16

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	34.95	28.15	32.80	29.52	34.11	34.07	31.85	35.18	29.53	32.08	28.66	30.49	381.39
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	3.67	3.47	4.19	3.64	4.02	4.05	3.70	4.19	3.64	3.84	3.64	3.66	45.69
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	9.58	7.35	8.14	7.88	5.63	5.45	5.63	9.16	8.87	9.16	9.27	9.58	95.71
Misc. Equip.	12.71	11.99	14.34	12.66	13.80	13.73	12.72	14.34	12.65	13.26	12.65	12.71	157.55
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	19.89	18.85	22.74	19.86	21.79	21.76	19.89	22.74	19.86	20.84	19.86	19.89	247.96
Total	80.80	69.82	82.21	73.55	79.35	79.05	73.79	85.61	74.54	79.18	74.08	76.33	928.31

Figure 4. 6: Predicted Electric Consumption of Kigali City

The baseline simulation for the building shows that the annual energy consumption is dominated by cooling system followed by lighting load, miscellaneous equipment, exterior usage and ventilation. This indicated that Rwanda’s climate is hot thereby resulting in huge energy utilization by cooling system. The cooling system consumes a lot of energy in January, March, May, June, July, August and October when compared to the other months which that are found to be the rainy months. In Rwanda, there are two season such dry season and rain season; the dry season is sunny and occurs from June to September and from January to March. The remaining months are rainy season. Figures 4.7 shows graphically the detailed annual energy consumption.



Project/Run: KCT Orginal - Baseline Design Run Date/Time: 06/19/17 @ 08:16

Annual Energy Consumption by Enduse

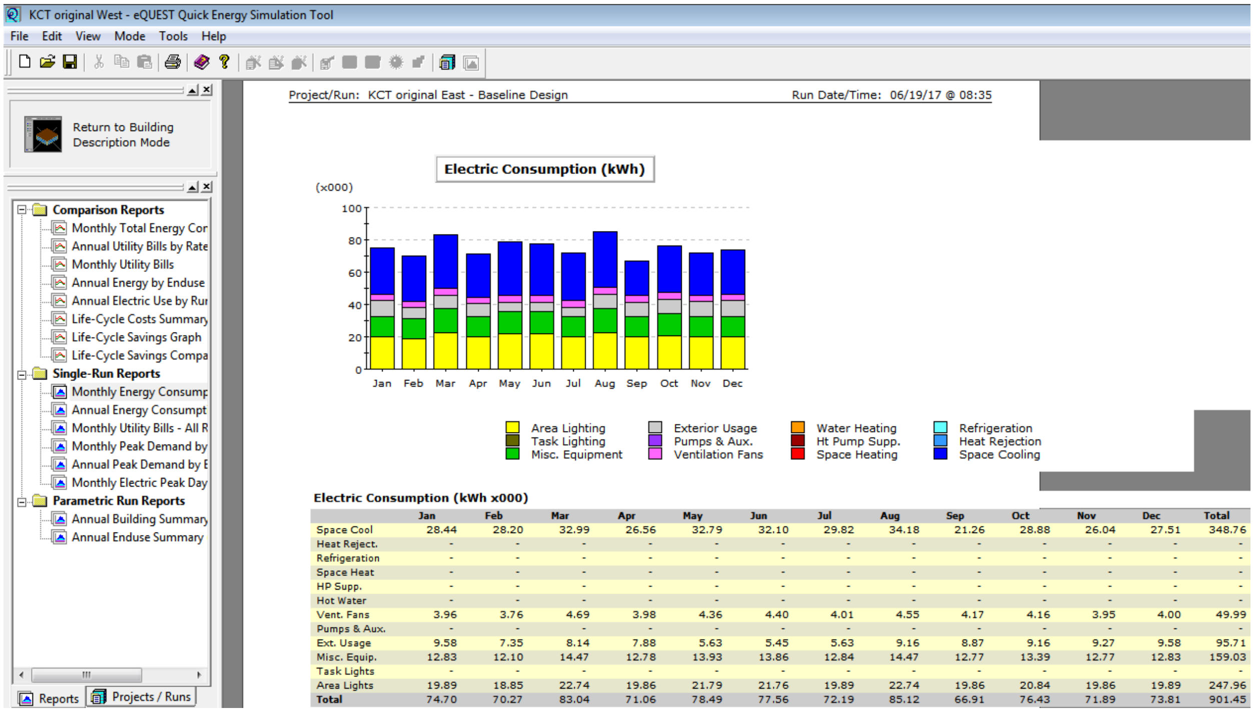
	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	381.39	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	-	-	-	-
Vent. Fans	45.69	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	95.71	-	-	-
Misc. Equip.	157.55	-	-	-
Task Lights	-	-	-	-
Area Lights	247.96	-	-	-
Total	928.31	-	-	-

🟨 Area Lighting	⬜ Exterior Usage	🟧 Water Heating	🟦 Refrigeration
🟫 Task Lighting	🟪 Pumps & Aux.	🟥 Ht Pump Supp.	🟦 Heat Rejection
🟩 Misc. Equipment	🟪 Ventilation Fans	🟥 Space Heating	🟦 Space Cooling

Figure 4. 7: Predicted Annual Energy Consumption by End-use

4.5.2 Eastern Region

Figure 4.8 summarizes the monthly energy consumption by categories; in this region, it was found that energy consumption through cooling system is more than that of the others. As indicated in the figure, energy consumption through cooling in March dominated other monthly consumption from cooling system in other months.

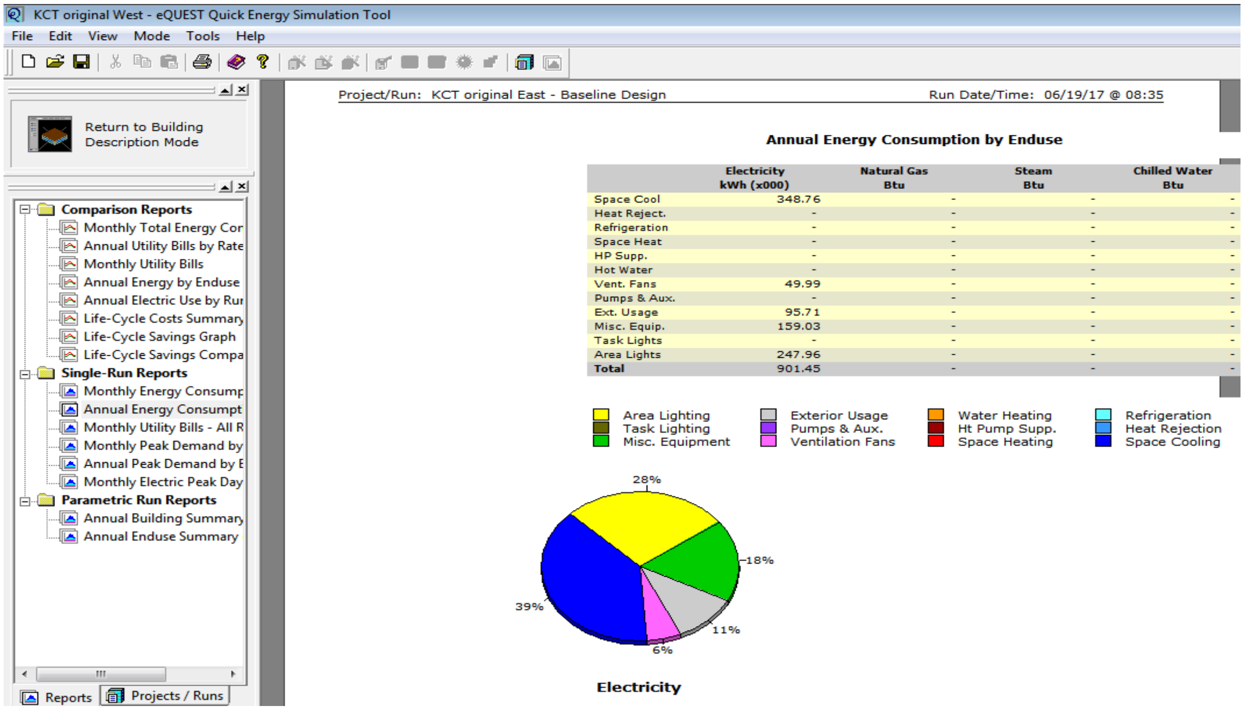


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	28.44	28.20	32.99	26.56	32.79	32.10	29.82	34.18	21.26	28.88	26.04	27.51	348.76
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	3.96	3.76	4.69	3.98	4.36	4.40	4.01	4.55	4.17	4.16	3.95	4.00	49.99
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	9.58	7.35	8.14	7.88	5.63	5.45	5.63	9.16	8.87	9.16	9.27	9.58	95.71
Misc. Equip.	12.83	12.10	14.47	12.78	13.93	13.86	12.84	14.47	12.77	13.39	12.77	12.83	159.03
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	19.89	18.85	22.74	19.86	21.79	21.76	19.89	22.74	19.86	20.84	19.86	19.89	247.96
Total	74.70	70.27	83.04	71.06	78.49	77.56	72.19	85.12	66.91	76.43	71.89	73.81	901.45

Figure 4. 8: Predicted Electric Consumption of Eastern Region

It can also be observed in Figure 4.9 that space cooling consumes more electricity annual when compared with the other categories, this is followed by lighting and other miscellaneous equipment including all electronic appliances used in the building for daily services.



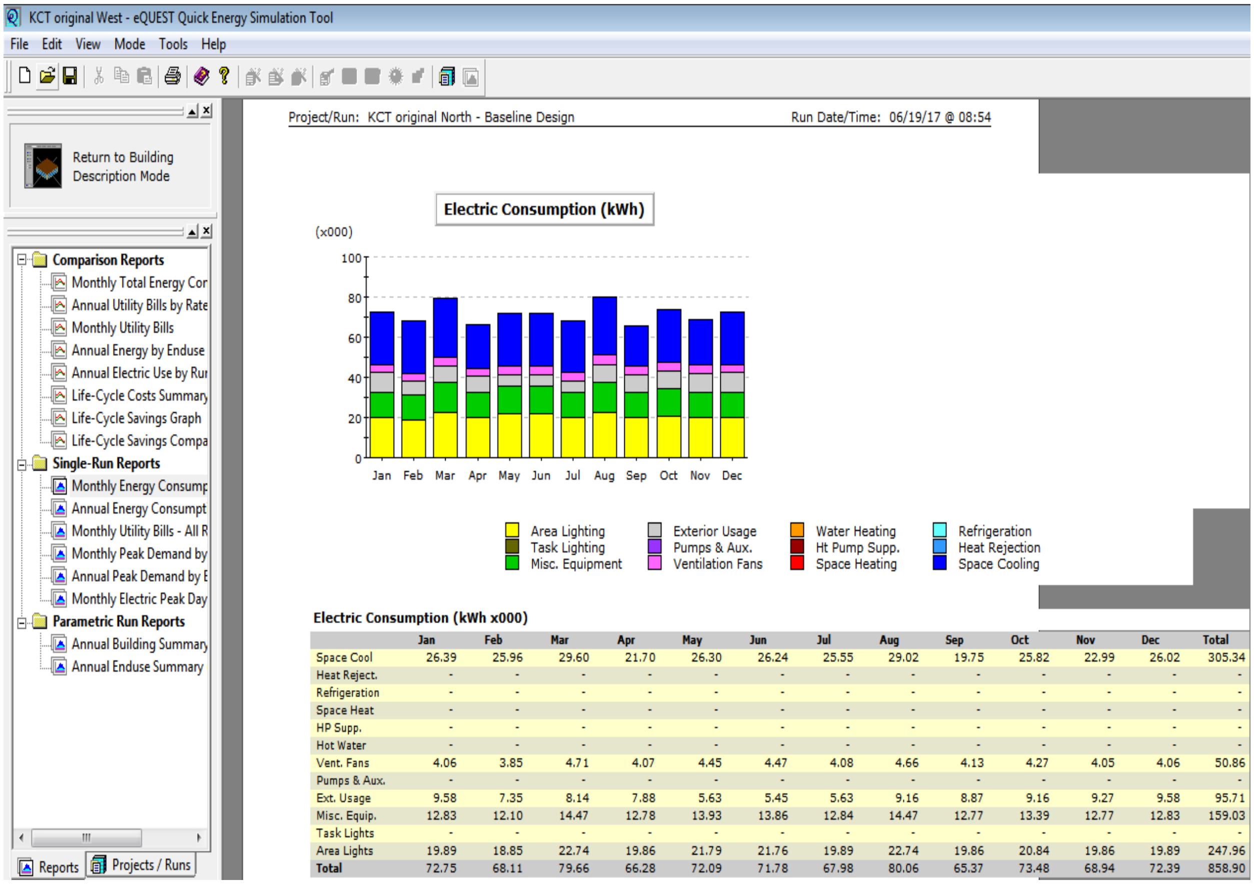
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	348.76	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	-	-	-	-
Vent. Fans	49.99	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	95.71	-	-	-
Misc. Equip.	159.03	-	-	-
Task Lights	-	-	-	-
Area Lights	247.96	-	-	-
Total	901.45	-	-	-

Figure 4. 9: Predicted Annual Energy Consumption by End use

4.5.3 Northern Region

The predicted monthly energy consumption by categories for Northern region of Rwanda is shown in Figure 4.10. It can also be observed that cooling system dominated other appliances in energy consumption. Furthermore, the months of March and August showed greater consumption of energy on cooling and other appliances than the other months whereby in this region is considered as cold place in which it is raining almost the whole year therefore cooling system is not required like the other regions.



Project/Run: KCT original North - Baseline Design

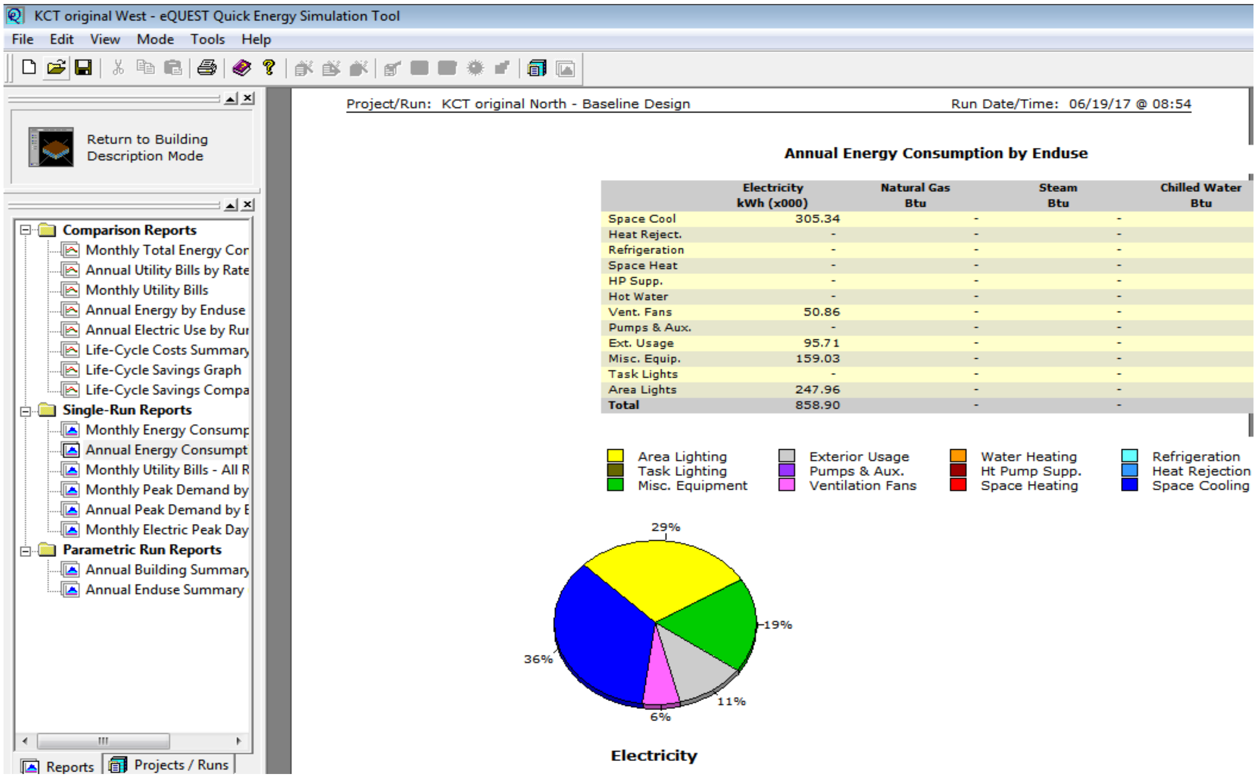
Run Date/Time: 06/19/17 @ 08:54

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	26.39	25.96	29.60	21.70	26.30	26.24	25.55	29.02	19.75	25.82	22.99	26.02	305.34
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	4.06	3.85	4.71	4.07	4.45	4.47	4.08	4.66	4.13	4.27	4.05	4.06	50.86
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	9.58	7.35	8.14	7.88	5.63	5.45	5.63	9.16	8.87	9.16	9.27	9.58	95.71
Misc. Equip.	12.83	12.10	14.47	12.78	13.93	13.86	12.84	14.47	12.77	13.39	12.77	12.83	159.03
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	19.89	18.85	22.74	19.86	21.79	21.76	19.89	22.74	19.86	20.84	19.86	19.89	247.96
Total	72.75	68.11	79.66	66.28	72.09	71.78	67.98	80.06	65.37	73.48	68.94	72.39	858.90

Figure 4. 10: Predicted Electric Consumption in Northern Province

For the annual energy consumption by end-use in Northern Province (Figure 4.11), more consumption of energy can be seen to be utilized by space cooling followed by the lighting appliances.



Project/Run: KCT original North - Baseline Design Run Date/Time: 06/19/17 @ 08:54

Annual Energy Consumption by Enduse

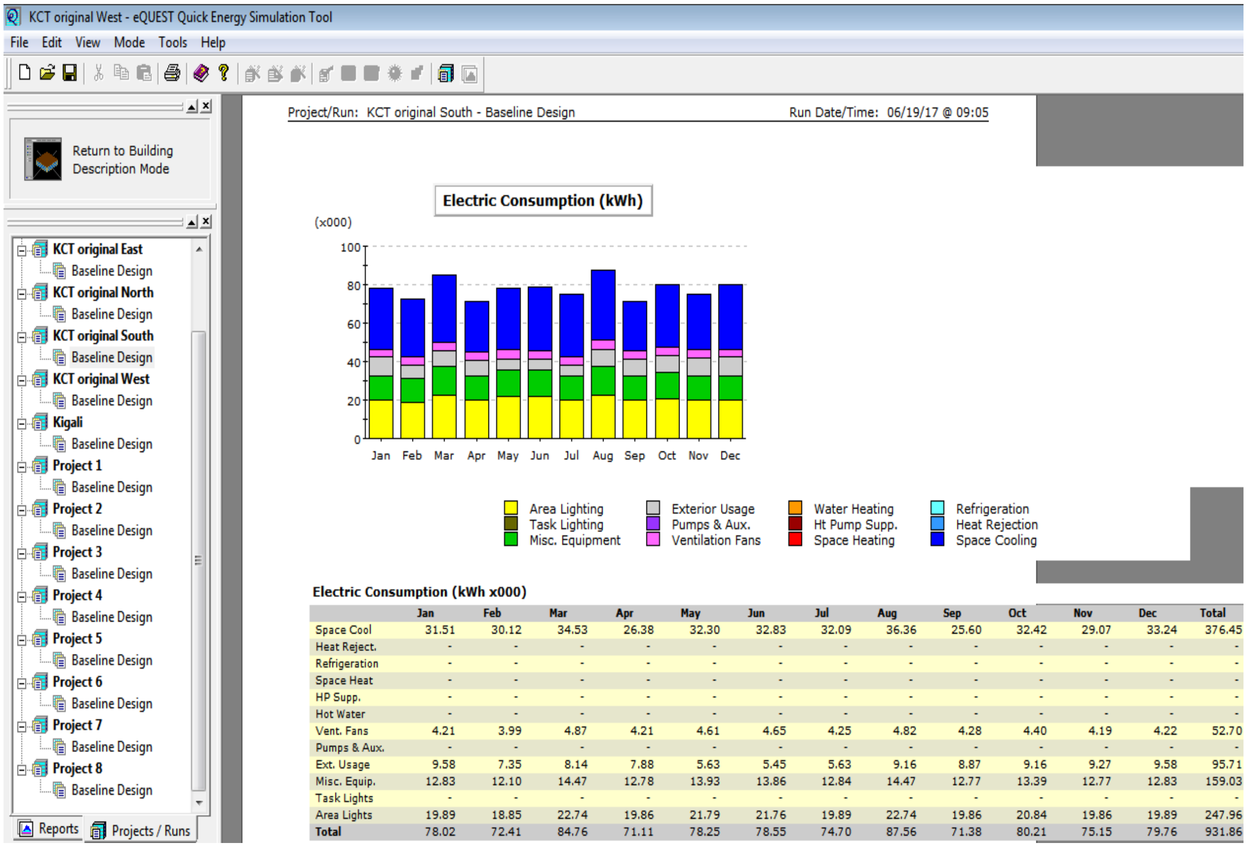
	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	305.34	-	-	
Heat Reject.	-	-	-	
Refrigeration	-	-	-	
Space Heat	-	-	-	
HP Supp.	-	-	-	
Hot Water	-	-	-	
Vent. Fans	50.86	-	-	
Pumps & Aux.	-	-	-	
Ext. Usage	95.71	-	-	
Misc. Equip.	159.03	-	-	
Task Lights	-	-	-	
Area Lights	247.96	-	-	
Total	858.90	-	-	

🟨 Area Lighting	⬜ Exterior Usage	🟧 Water Heating	🟦 Refrigeration
🟫 Task Lighting	🟪 Pumps & Aux.	🟥 Ht Pump Supp.	🟦 Heat Rejection
🟩 Misc. Equipment	🟪 Ventilation Fans	🟥 Space Heating	🟦 Space Cooling

Figure 4. 11: Predicted Annual Energy Consumption in Northern Region

4.5.4 Southern Region

Summary of the monthly energy consumption by categories in the Southern region, is shown in Figure 4.12. It can be seen from the figure that more consumption of energy is also with the cooling system than the rest of the appliances. As indicated in Figure 4.12, the highest consumption of energy is in August, followed by March; in August and March, the temperature is high, hence the building consumes a lot of energy for cooling. Annual energy consumption by end-use (Figure 4.13), is dominated by space cooling followed by lighting, in the Southern Province.

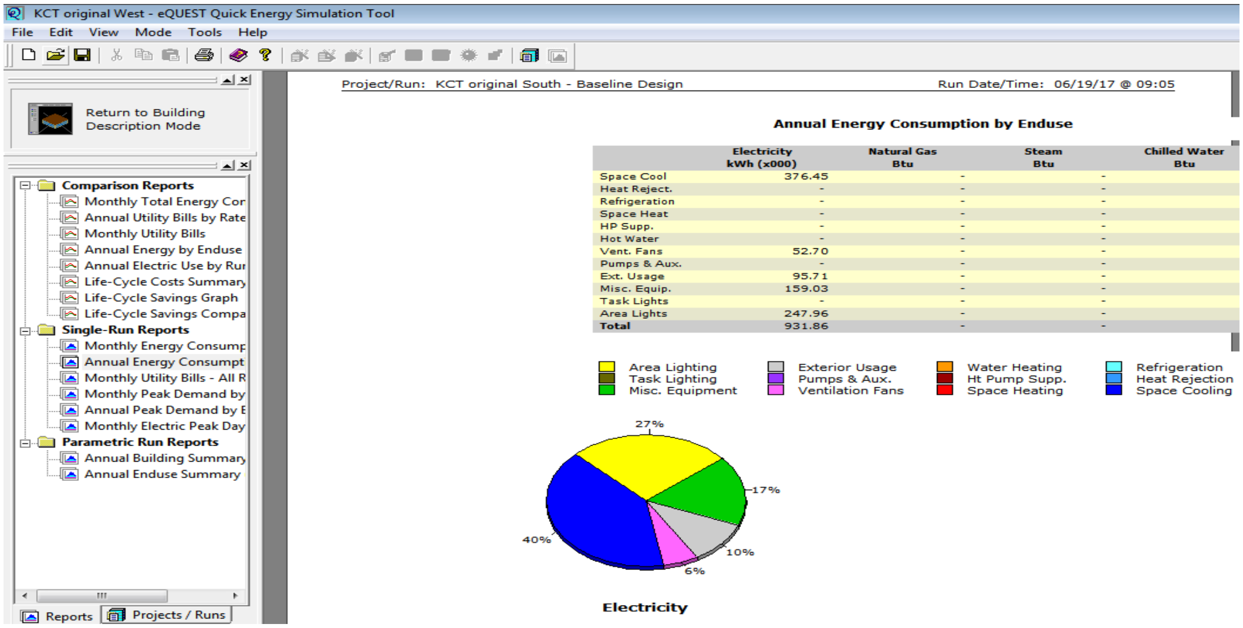


Project/Run: KCT original South - Baseline Design Run Date/Time: 06/19/17 @ 09:05

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	31.51	30.12	34.53	26.38	32.30	32.83	32.09	36.36	25.60	32.42	29.07	33.24	376.45
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	4.21	3.99	4.87	4.21	4.61	4.65	4.25	4.82	4.28	4.40	4.19	4.22	52.70
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	9.58	7.35	8.14	7.88	5.63	5.45	5.63	9.16	8.87	9.16	9.27	9.58	95.71
Misc. Equip.	12.83	12.10	14.47	12.78	13.93	13.86	12.84	14.47	12.77	13.39	12.77	12.83	159.03
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	19.89	18.85	22.74	19.86	21.79	21.76	19.89	22.74	19.86	20.84	19.86	19.89	247.96
Total	78.02	72.41	84.76	71.11	78.25	78.55	74.70	87.56	71.38	80.21	75.15	79.76	931.86

Figure 4. 12: Predicted Electric Consumption of Southern Region



Project/Run: KCT original South - Baseline Design Run Date/Time: 06/19/17 @ 09:05

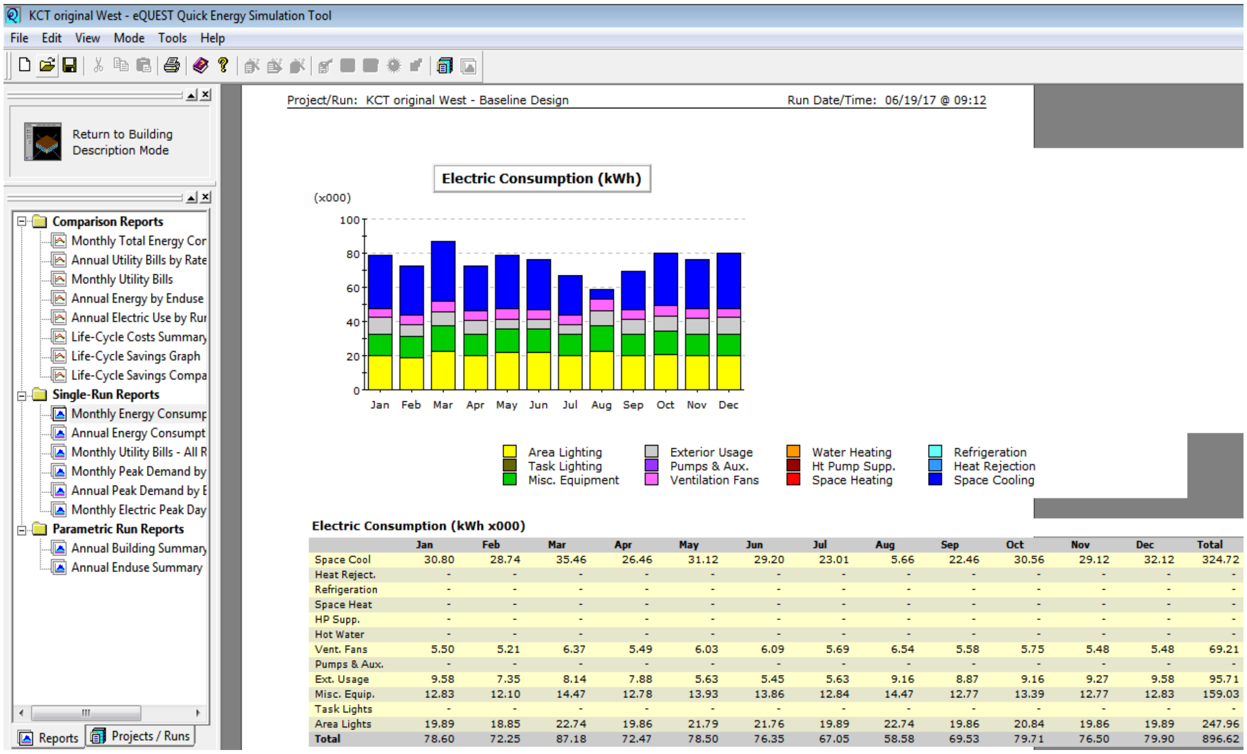
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	376.45	-	-	
Heat Reject.	-	-	-	
Refrigeration	-	-	-	
Space Heat	-	-	-	
HP Supp.	-	-	-	
Hot Water	-	-	-	
Vent. Fans	52.70	-	-	
Pumps & Aux.	-	-	-	
Ext. Usage	95.71	-	-	
Misc. Equip.	159.03	-	-	
Task Lights	-	-	-	
Area Lights	247.96	-	-	
Total	931.86	-	-	

Figure 4. 13: Predicted Annual Energy Consumption in Southern Region

4.5.5 Western Region

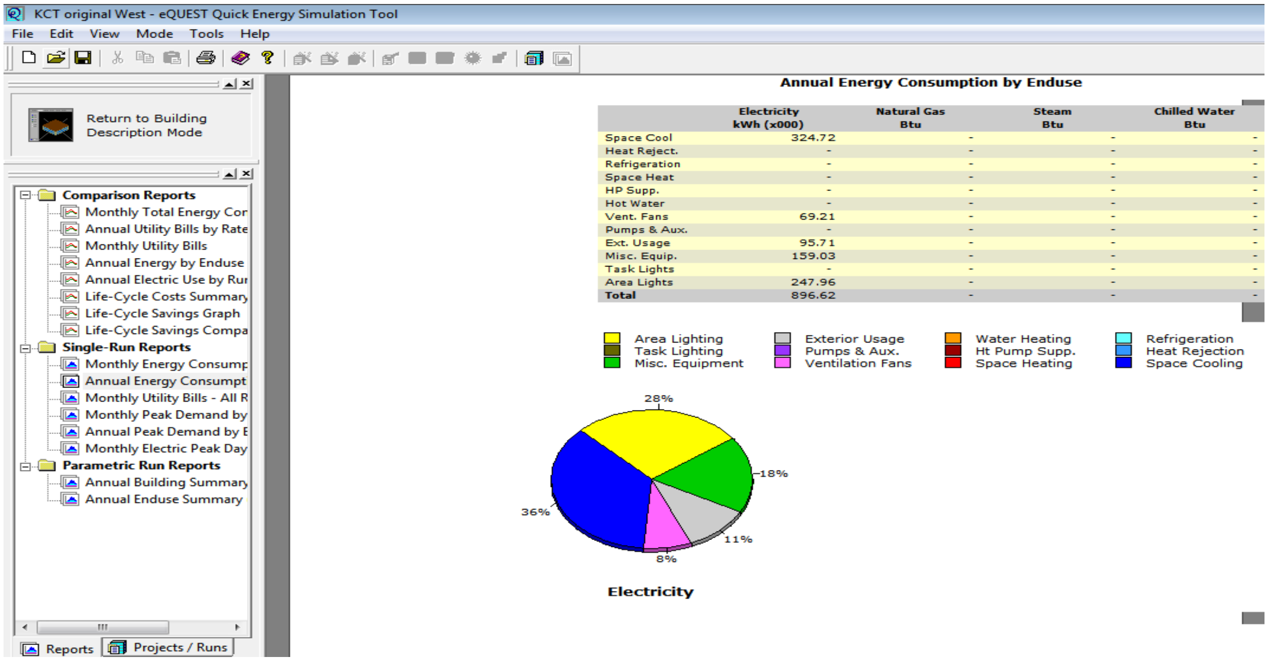
The monthly energy consumption by categories for the Western Region of the country is shown in Figure 4.14. Energy consumption through cooling system was found to dominate other appliances in this region. The energy needed for cooling was found to be highest in March while the lowest was in August, when compared to other months. The Western province of Rwanda is a temperate region and more ventilation is thus required than cooling in August. Annual energy consumption by end use in this Province is dominated by space cooling followed by lighting (Figure 4.15).



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	30.80	28.74	35.46	26.46	31.12	29.20	23.01	5.66	22.46	30.56	29.12	32.12	324.72
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	5.50	5.21	6.37	5.49	6.03	6.09	5.69	6.54	5.58	5.75	5.48	5.48	69.21
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	9.58	7.35	8.14	7.88	5.63	5.45	5.63	9.16	8.87	9.16	9.27	9.58	95.71
Misc. Equip.	12.83	12.10	14.47	12.78	13.93	13.86	12.84	14.47	12.77	13.39	12.77	12.83	159.03
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	19.89	18.85	22.74	19.86	21.79	21.76	19.89	22.74	19.86	20.84	19.86	19.89	247.96
Total	78.60	72.25	87.18	72.47	78.50	76.35	67.05	58.58	69.53	79.71	76.50	79.90	896.62

Figure 4. 14: Predicted Electric Consumption of Western Region



Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	324.72	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	-	-	-	-
Vent. Fans	69.21	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	95.71	-	-	-
Misc. Equip.	159.03	-	-	-
Task Lights	-	-	-	-
Area Lights	247.96	-	-	-
Total	896.62	-	-	-

Figure 4. 15: Predicted Annual Energy Consumption in Western Region

4.6 Sensitivity Runs Outcomes

4.6.1 Western Region

According to the Table 4.7, the building energy consumption in Western Region is high when the building is facing in North-West direction. And the building consumes much energy in March followed by December as showed by Figure 4.10.

Table 4. 7: Energy Consumption in Western in kWh

	Western Region					
	West	**South**	**East**	**North-East**	**South-East**	**North West**
Jan.	78,740	78,600	78,520	79,720	79,730	79,850
Feb.	72,360	72,190	72,150	73,910	73,910	74,030
March	87,330	87,070	87,030	90,070	90,050	90,220
April	72,570	72,410	72,390	74,810	74,800	74,880
May	78,600	78,350	78,340	79,950	79,940	80,030
June	76,460	76,240	76,240	76,910	76,860	77,030
July	67,100	66,930	66,940	67,820	67,790	67,870
Aug	58,620	58,550	58,570	59,950	59,950	59,990
Sept.	69,600	69,490	69,480	71,940	71,950	72,000
Oct.	79,790	79,650	79,630	81,990	82,010	82,060
Nov.	76,660	76,420	76,350	77,790	77,810	77,900
Dec	80,020	79,810	79,740	80,650	80,650	80,780
Total	**897,850**	**895,710**	**895,380**	**915,510**	**915,450**	**916,640**

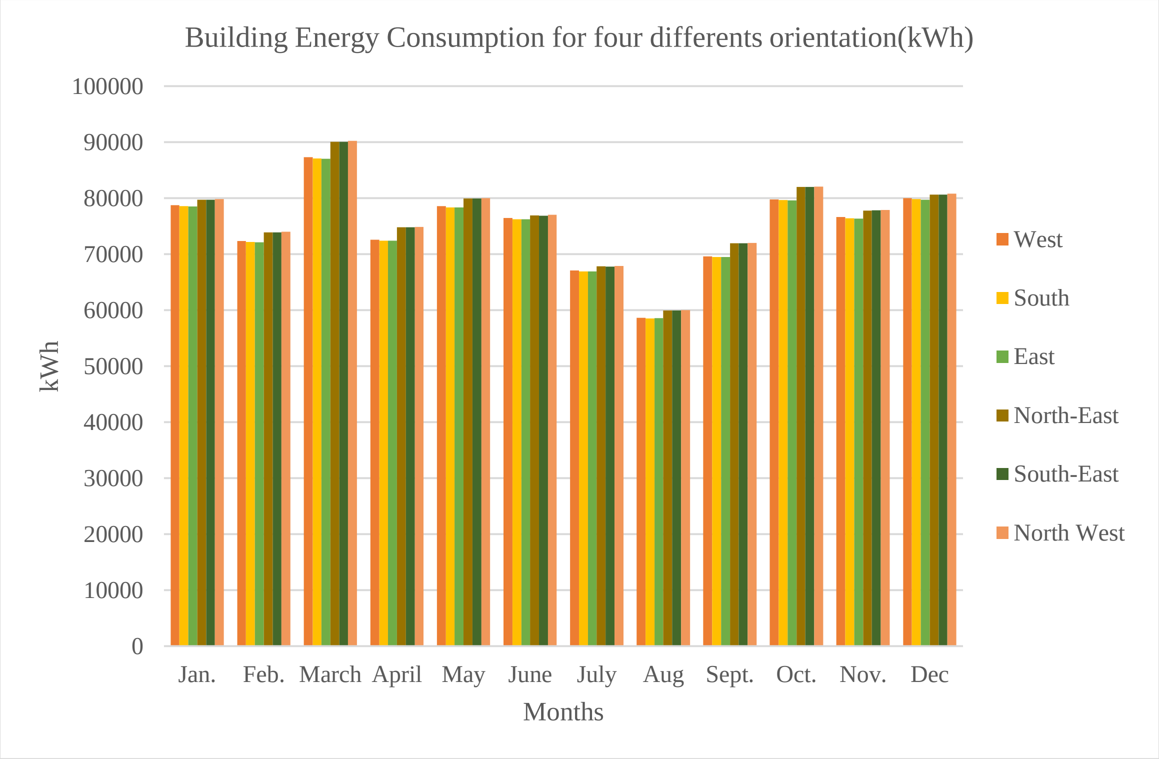


Figure 4. 16: Building Energy Consumption in Western Region

4.6.2 Southern Region

The building is consuming much energy when it faces in North-West orientation. In August the building has high energy consumption and followed by March.

Table 4. 8: Energy Consumption in Southern (kWh)

	Southern Region					
	West	**South**	**East**	**North-West**	**South-East**	**North-East**
Jan.	78,120	78,080	78,020	78,600	78,510	78,490
Feb.	72,500	72,460	72,410	73,390	73,300	73,300
March	84,860	84,880	84,850	86,600	86,470	86,490
April	71,180	71,220	71,210	72,410	72,330	72,340
May	78,300	78,370	78,360	79,090	78,990	79,010
June	78,580	78,580	78,590	78,980	78,900	78,920
July	74,730	74,690	74,700	75,090	75,000	75,030
Aug	87,600	87,540	87,540	88,970	88,890	88,910
Sept.	71,430	71,400	71,390	72,850	72,800	72,800
Oct.	80,290	80,300	80,270	81,560	81,510	81,490
Nov.	75,240	75,250	75,200	75,820	75,720	75,720
Dec	79,870	79,810	79,730	79,990	79,910	79,890
Total	**932,700**	**932,580**	**932270**	**943,350**	**942,330**	**942,390**

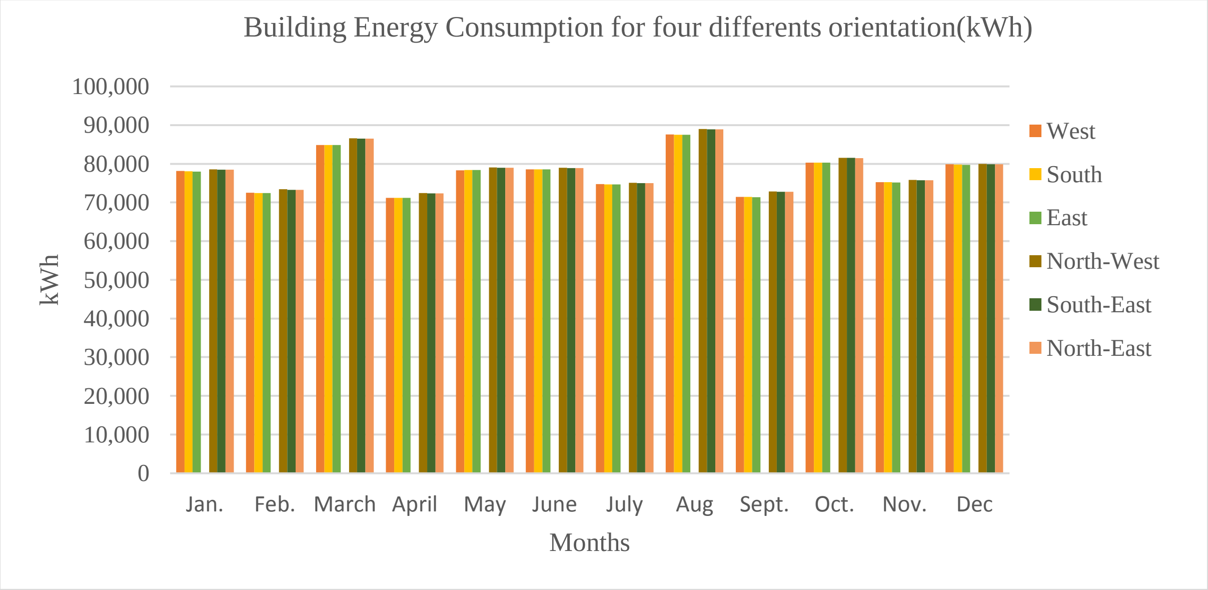


Figure 4. 17: Building Energy Consumption in Southern Region

4.6.3: Northern Region

By Orienting the building in North- West would make the building consuming a lot of energy and it is better if the building is facing in East direction. The Building uses much energy August followed by March as indicated in table 4.9.

Table 4. 9: Energy Consumption in Northern (kWh)

	Northern Region					
	West	**South**	**East**	**North-West**	**South-East**	**North-East**
Jan.	72,840	72,810	72,760	73,230	73,160	73,140
Feb.	68,200	68,160	68,130	69,060	68,980	68,980
March	79,750	79,710	79,690	81,440	81,340	81,340
April	66,330	66,340	66,330	67,420	67,370	67,350
May	72,150	72,140	72,130	72,910	72,830	72,840
June	71,830	71,810	71,810	72,050	71,970	72,000
July	68,020	68,030	68,030	68,440	68,370	68,390
Aug	80,110	80,150	80,150	81,480	81,420	81,420
Sept.	65,440	65,440	65,440	66,690	66,660	66,650
Oct.	73,550	73,560	73,550	74,880	74,860	74,820
Nov.	69,020	69,020	68,980	69,580	69,500	69,490
Dec	72,500	72,510	72,450	72,700	72,630	72,610
Total	**859,740**	**859,680**	**859450**	**869,880**	**869,090**	**869,030**

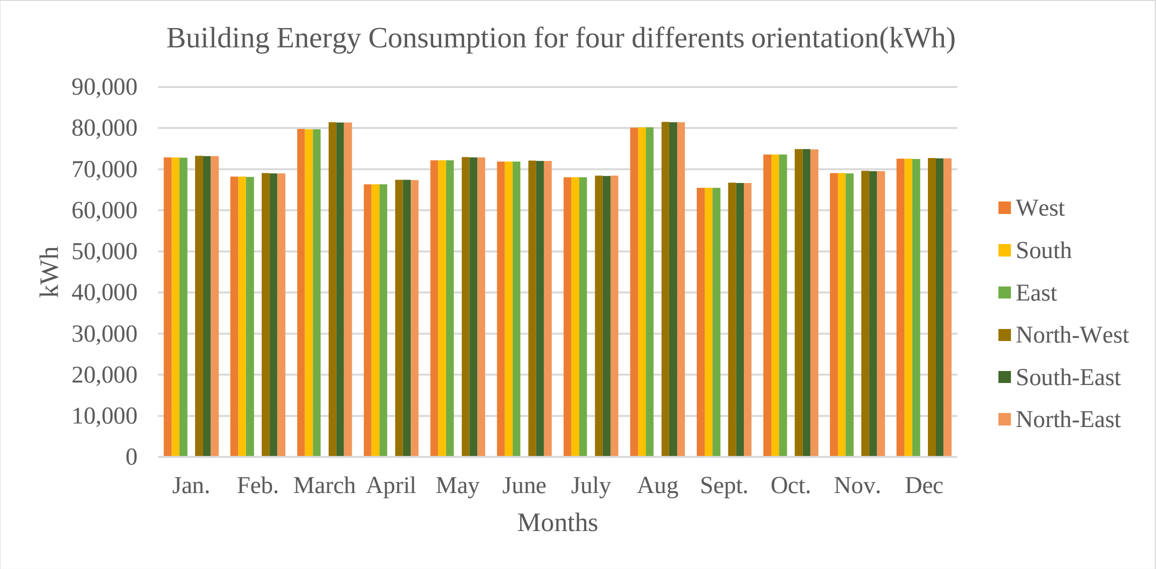


Figure 4. 18: Building Energy Consumption in Northern Region

4.6.4 Eastern Region

The Table 4.10 and Figure 4.19 show that the building is consuming much energy when it is facing North-West where by the building is faced in the side of solar radiation and this making it to absorb much radiation and therefore the building requires air conditioners to cool down for maintaining the comfort of the building.

Table 4. 10: Energy Consumption in Eastern (kWh)

	Eastern Region					
	West	**South**	**East**	**North-East**	**South-East**	**North-West**
Jan.	74,780	74,730	74,680	75,120	75,130	75,200
Feb.	70,340	70,320	70,290	71,120	71,130	71,200
March	83,110	83,080	83,070	84,720	84,720	84,810
April	71,100	71,110	71,110	72,360	72,370	72,400
May	78,540	78,560	78,560	79,290	79,280	79,340
June	77,600	77,630	77,640	78,030	78,010	78,080
July	72,220	72,240	72,250	72,630	72,620	72,670
Aug	85,160	85,210	85,210	86,650	86,650	86,690
Sept.	66,950	66,970	66,970	68,260	68,270	68,290
Oct.	76,490	76,490	76,480	77,770	77,800	77,820
Nov.	71,980	71,930	71,890	72,430	72,450	72,510
Dec	73,900	73,870	73,810	73,980	74,000	74,070
Total	**902,170**	**902,140**	**901,960**	**912,360**	**912,430**	**913,080**

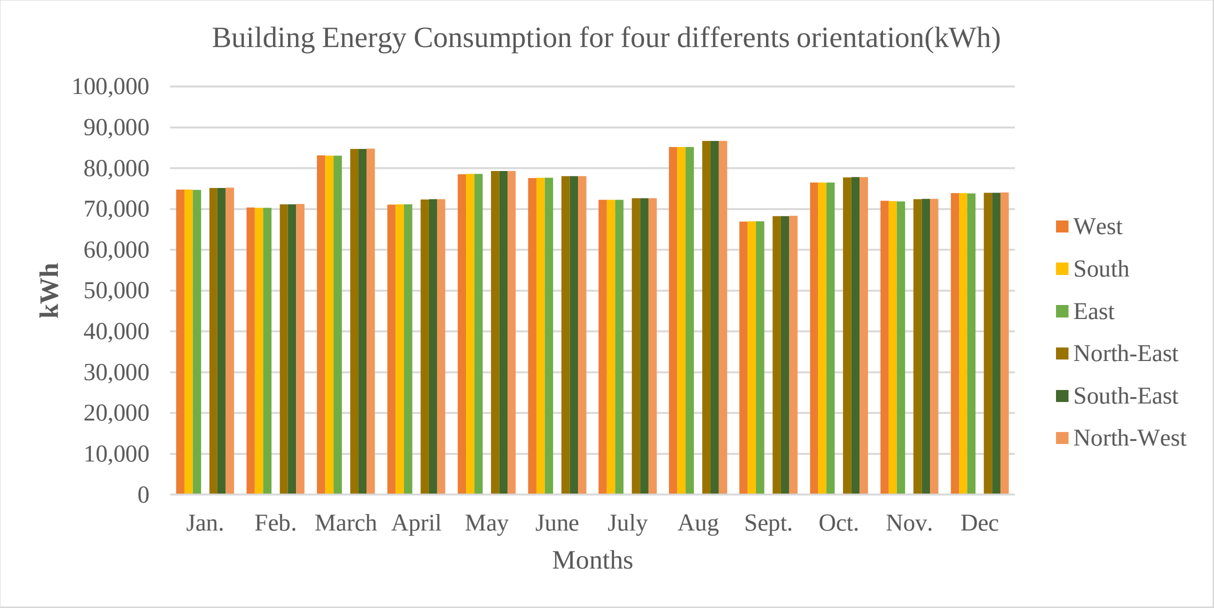


Figure 4. 19: Building Energy Consumption in Eastern Region

4.6.5: Kigali City Region

In Kigali where the building is located, by changing the orientation of the building the results show that it could use much energy when it is facing in South-East direction. This direction is facing the sun shine direction which makes the building to absorb much heat and therefore the building needs the air conditioners for cooling down in order to maintain the comfort for the building occupancy. According to Table 4.11 and Figure 4.20, the building consumes much energy in August followed by much for the reason that during that period the temperature is high comparing to the rest of the months.

Table 4. 11: Energy Consumption in Kigali City (kWh)

	Kigali Region					
	West	**South**	**East**	**North-East**	**South-East**	**North-West**
Jan.	80,850	80,900	80,880	81,920	82,000	81,920
Feb.	69,850	69,880	69,900	71,770	71,830	71,770
March	82,240	82,280	82,300	85,460	85,510	85,460
April	73,580	73,590	73,620	75,840	75,860	75,840
May	79,370	79,380	79,410	81,060	81,070	81,050
June	79,060	79,080	79,110	80,160	80,170	80,150
July	73,790	73,810	73,850	75,150	75,150	75,140
Aug	85,620	85,640	85,680	88,020	88,040	88,010
Sept.	74,570	74,600	74,620	77,450	77,490	77,450
Oct.	79,210	79,250	79,270	81,760	81,810	81,760
Nov.	74,120	74,150	74,140	75,400	75,460	75,400
Dec	76,380	76,420	76,410	77,250	77,330	77,260
Total	**928,640**	**928,980**	**929,190**	**951,240**	**951,720**	**951,210**

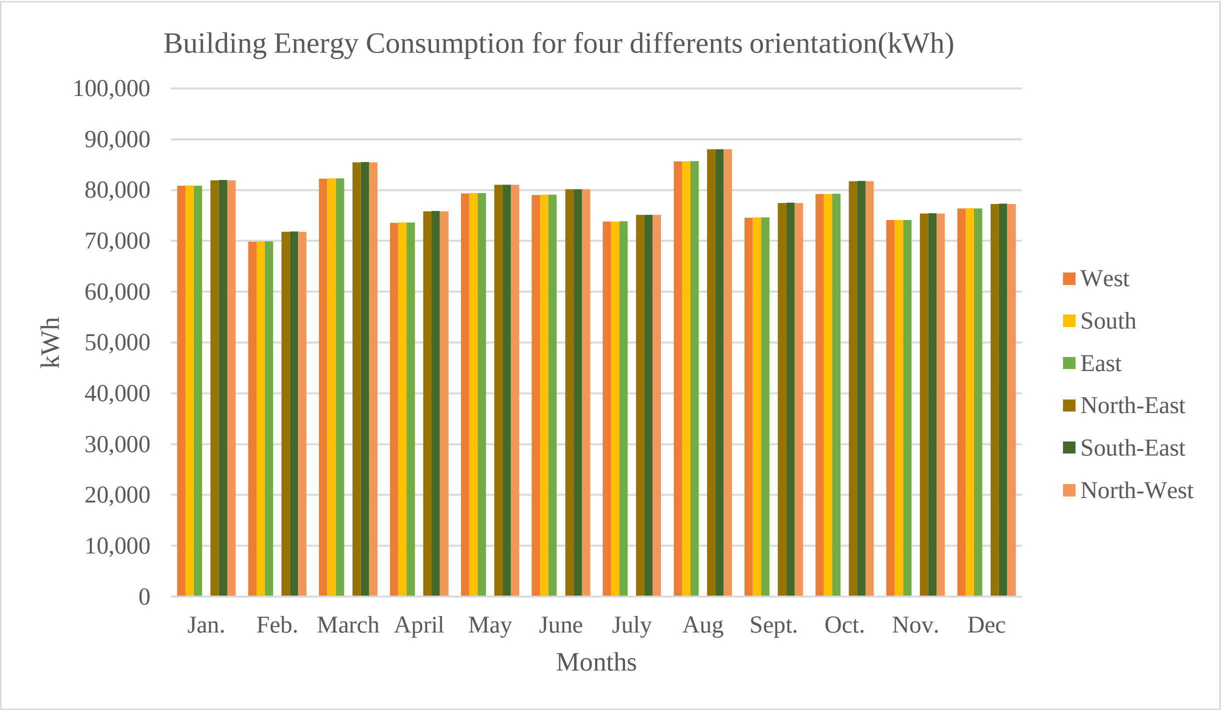


Figure 4. 20: Building Energy Consumption in Kigali City Region

4.7 The Overall Energy Consumption in Different Building Orientations

The overall building energy consumption in different orientations indicates that the building consumes less energy in Northern region and when the building is facing in North. The building consumes much energy in Southern regions especially when the building is facing in North-East as indicated by Table 4.12.

Table 4. 12: Annual Energy Consumption by region

	West	**South**	**East**	**North**	**North-East**	**South-East**	**North-West**
Kigali	928,640	928,980	929,190	928,310	951,240	951,720	951,210
Eastern Region	902,170	902,140	901,960	901,450	912,360	912,430	913,080
Northern Region	859,740	859,680	859,450	858,900	869,880	869,090	869,030
Southern Region	932,700	932,580	932,270	931,860	943,350	942,330	942,390
Western Region	897,850	895,710	895,380	858,900	915,510	915,450	916,640

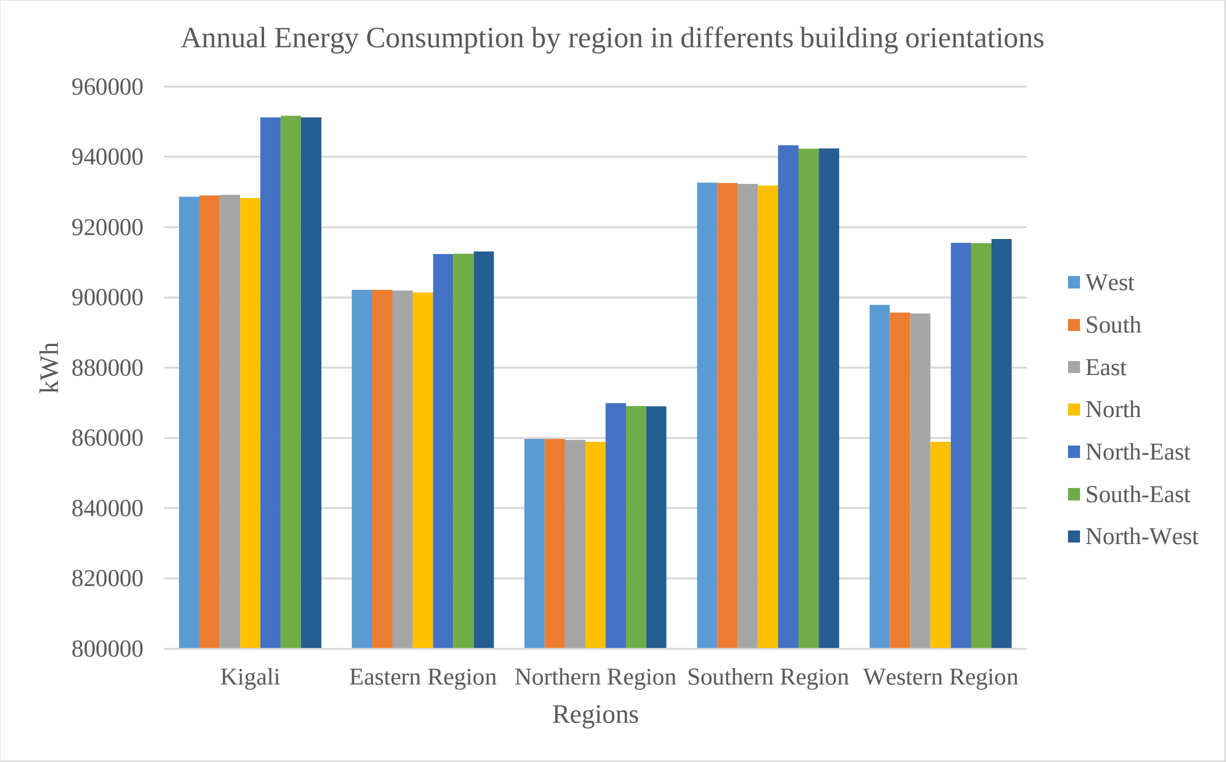


Figure 4. 21: Annual Energy Consumption by building orientation

4.8 Energy Performance Map for Buildings in Rwanda

The simulated energy consumption in buildings based on eQUEST for the five regions of the country is shown in Table 4.13. It can be observed from the table that all the regions have almost similar energy consumption pattern round the year. With the simulation, the highest annual energy consumption is in the Southern province while the lowest consumption of energy in building is found in the Northern Province (Figure 4.22); on monthly basis, the highest energy consumption is obtained in August (Figure 4.23). This is due to the hot weather pattern in this month that brought about the need for increased energy utilization for cooling and ventilation.

Building design adopted for this simulation can be altered, and also equipped with modern and efficient technologies, tested with different orientations, or designed with improved construction materials, in order to obtain a much lower annual energy consumption that can be recommended for the different Provinces of Rwanda. Some regions are found to be hot thus requiring more energy in cooling and ventilation.

Table 4. 13: Monthly Energy Consumption by Regions (kWh)

	Eastern	**Kigali**	**Northern**	**Southern**	**Western**
January	74,700	80,800	72,750	78,020	78,600
February	70,270	69,820	68,110	72,410	72,250
March	83,040	82,210	79,660	84,760	87,180
April	71,060	73,550	66,280	71,110	72,470
May	78,490	75,350	72,090	78,250	78,500
June	77,560	79,050	71,780	78,550	76,350
July	72,190	73,790	67,980	74,700	67,050
August	85,120	85,610	80,060	87,560	58,580
September	66,910	74,540	65,370	71,380	69,530
October	76,430	79,180	73,480	80,210	79,710
November	71,890	74,080	68,940	75,150	76,500
December	73,810	76,330	72,390	79,760	79,900
Total	**901,450**	**928,310**	**858,900**	**931,860**	**896,620**

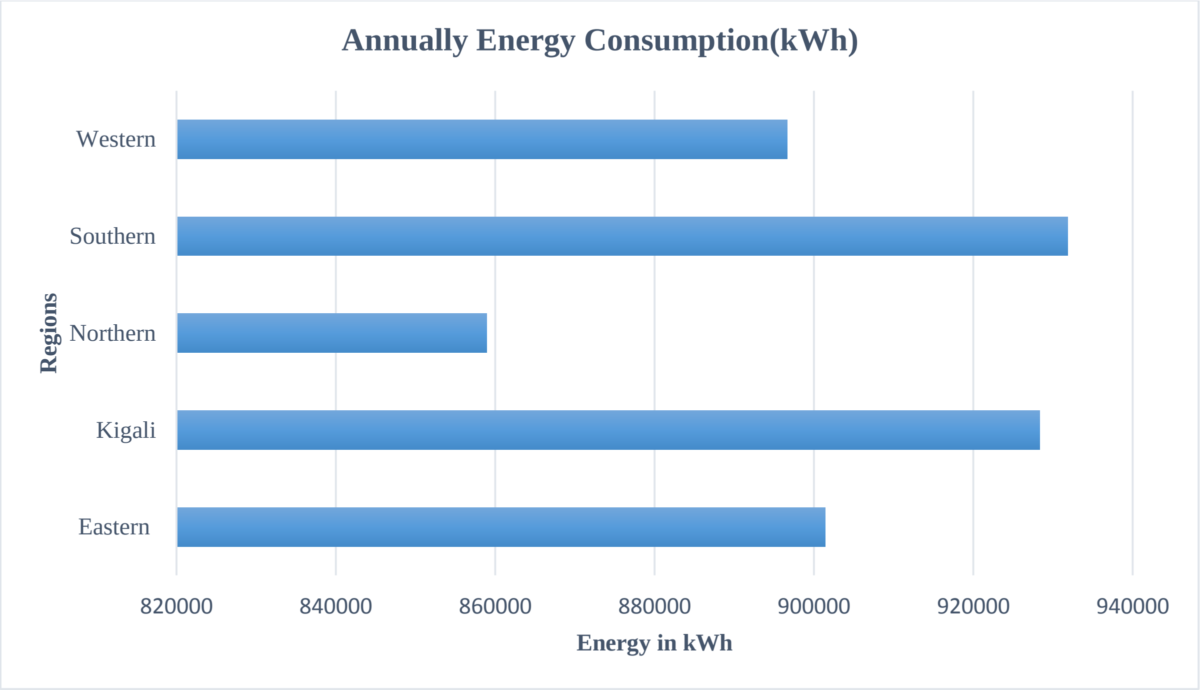


Figure 4. 22: Annual Building Energy Consumption by Region

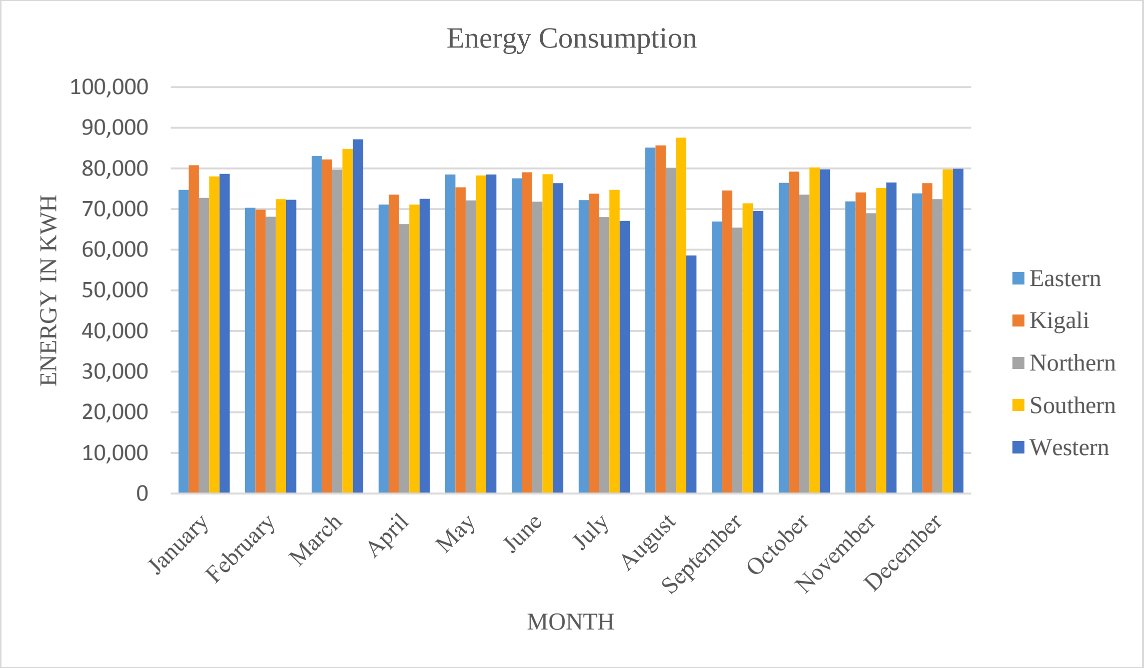


Figure 4. 23: Map of Monthly Energy Consumption for Rwanda

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In Rwanda, new buildings are being constructed to meet the ever increasing population and the accompanying socio-economic growth of the country. This thus implies increase in energy supply to meet the escalating energy demand. Energy efficiency in building could be a major area of consideration for energy supply reduction. This research was an investigation carried out in promoting energy performance in building in a bid to developing a new building model that will be efficient and also support a reduced energy utilization in buildings. The Kigali City Tower with 20 floors was selected as a case study in this work. Data including: (i) energy audit data of appliances in this building were captured, (ii) metered data obtained from facility management unit, and (iii) predicted data from eQUEST simulation tool were all considered in this study to measure energy consumption of the model building.

The energy being utilized in the building was categorized into three including: offices, underground level (O-Zone) and the lifts (taking the different operational time into consideration) especially in the offices and O-Zone. Energy audit result showed that among the electrical appliances, desktops computers and linear fluorescent lamps have the highest of the total energy consumption in the offices with 25% and 24% respectively. Furthermore, offices in the building were found to consume more energy, followed by the lifts and then the O-Zone (underground level) with 72%, 15% and 13% respectively. Several Energy Management Opportunities were recommended to reduce energy being utilized in this building, based on the energy audit results.

The building energy performance was investigated using eQUEST. This started with the building design phase throughout the building operations. Comparison of the data obtained from energy audit (observed data) and simulated data from eQUEST (predicted data) were made. It was found that there was a good fit between the datasets (observed and predicted) with a correlation coefficient of 76 and 79% for the audited energy and metered data respectively at 95% confidence interval, thus calling for the adoption of eQUEST for energy simulation of buildings in Rwanda. The annual energy consumptions in the building, based on data obtained from energy audit exercise, metered (facility unit) and simulation results are 951,517kWh, 947,210.7kWh and 928,310kWh respectively.

Energy performance in building was found to be affected by building envelop, occupancy behaviors and electrical/electronic appliances. Upon examination of the same model of building (i.e. Kigali City Centre, with the envelopes and other appliances) in all the Provinces in Rwanda, the lowest annual energy consumption was obtained in the Northern region when the building is facing in North direction and the highest in the Southern Province.

5.2 Recommendations

Energy efficiency in building should be promoted extensively, by focusing on energy-saving through energy efficient building designs and constructions, in Rwanda. Building codes that will guide the design and construction of new buildings, to ensure an energy efficient building must be generated for Rwanda.

Active and passive building designs incorporated with renewable energy technologies should be encouraged in Rwanda. Buildings should also be designed to maximize the use of natural day-lighting. This may be accomplished by introducing clear glass as replacement for solar-absorbing or solar-reflecting glazing. Set regulations, policies, standards and specifications in promoting energy efficiency in buildings.

Rwanda Housing Authority together with all concerned ministries and stakeholders should introduce general guidelines about implementation of building energy efficiency, and also set policies and mechanisms for energy audit of facilities.

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APPENDICES

Appendix A. 1: 18th floor equipment with power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Laptop	9	65	9	198	115.83
Laptop	8	36	9	198	57.024
Laptop	3	90	9	198	53.46
Desktop(CPU and Monitor)	6	300	9	198	356.4
Scanner	1	49.9	9	198	9.8802
Printers	3	720	9	198	427.68
Photocopy(Multi-Function)	1	2500	9	198	495
Lighting Bulbs	55	14	9	198	152.46
Water Dispenser	1	585	3	66	38.61
Kettles	1	1200	1	22	26.4
Projector	1	340	2	44	14.96
Total					**1747.7042**

Appendix A. 2: 17th floor equipment with power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Laptop	18	65	9	198	231.66
Laptop	1	32	9	198	6.336
Laptop	1	90	9	198	17.82
Desktop(CPU and Monitor)	10	300	9	198	594
Scanner	1	49.9	9	198	9.8802
Printers	1	720	9	198	142.56
Photocopy(Multi-Function)	1	2500	9	198	495
Lighting Bulbs	50	14	9	198	138.6
Linear Philips	180	18	9	198	641.52
Water Dispenser	1	585	3	66	38.61
Kettles	1	1200	1	22	26.4
Projector	1	340	2	44	14.96
Air Conditioning	1	2600	6	132	343.2
Total					**2700.5462**

Appendix A. 3: 16th floor equipment with power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Laptop	12	65	9	198	154.44
Desktop(CPU and Monitor)	7	300	9	198	415.8
Scanner	1	49.9	9	198	9.8802
Printers	1	720	9	198	142.56
Lighting Bulbs	50	14	9	189	132.3
Linear Philips	180	18	9	189	612.36
Water Dispenser	1	585	3	66	38.61
Kettles	1	1200	1	22	26.4
Projector	1	340	2	44	14.96
Air Conditioning	2	2600	6	132	686.4
Total					**2233.7102**

Appendix A. 4: 15th floor equipment with power rating

Equipment	**Quantity**	**Power Rating (W)**	**Daily Operating Hour**	**Monthly Operation Hour**	**Monthly Energy Use (kWh)**
Laptop	12	65	9	198	154.44
Desktop(CPU and Monitor)	7	300	9	198	415.8
Scanner	1	49.9	9	198	9.8802
Printers	1	720	9	198	142.56
Lighting Bulbs	50	14	9	198	138.6
Linear Philips	180	18	9	198	641.52
Water Dispenser	1	585	3	66	38.61
Kettles	1	1200	1	22	26.4
Projector	1	340	2	44	14.96
Air Conditioning	2	2600	6	132	686.4
Total					**2269.1702**

Appendix A. 5: 14th floor equipment power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Laptop	12	65	9	198	154.44
Desktop(CPU and Monitor)	7	300	9	198	415.8
Scanner	1	49.9	9	198	9.8802
Printers	1	720	9	198	142.56
Lighting Bulbs	50	14	9	198	138.6
Linear Philips	180	18	9	198	641.52
Water Dispenser	1	585	3	66	38.61
Kettles	1	1200	1	22	26.4
Projector	1	340	2	44	14.96
Air Conditioning	2	2600	6	132	686.4
Total					**2269.1702**

Appendix A. 6: 13th & 3rd floor equipment with power rating

Equipment	Quantity	Power Rating(W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use(kWh)
Laptop	10	65	9	198	128.7
Desktop(CPU and Monitor)	20	300	9	198	1188
Scanner	1	49.9	9	198	9.8802
Printers	1	720	9	198	142.56
Lighting Bulbs	100	14	9	198	277.2
Linear Philips	360	18	9	198	1283.04
Water Dispenser	1	585	3	44	25.74
Kettles	1	1200	1	22	26.4
Projector	1	340	2	44	14.96
Air Conditioning	2	2600	6	132	686.4
Total					**3782.8802**

Appendix A. 7: 12th floor equipment with power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Laptop	10	65	9	198	128.7
Laptop	6	45	9	198	53.46
Laptop	2	120	9	198	47.52
Laptop	2	90	9	198	35.64
Desktop(CPU and Monitor)	13	300	9	198	772.2
Scanner	1	49.9	9	198	9.8802
Printers	1	625	9	198	123.75
Photocopy(Multi-Function)	1	2500	9	198	495
Lighting Bulbs	50	14	9	198	138.6
Linear Philips	180	18	9	198	641.52
Water Dispenser	1	585	3	66	38.61
Kettles	1	1200	1	22	26.4
Projector	1	340	2	44	14.96
Total					**2526.2402**

Appendix A. 8: 11th floor equipment with power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Laptop	4	65	9	198	51.48
Desktop(CPU and Monitor)	10	300	9	198	594
Printer	1	720	9	198	142.56
Lighting Bulbs	50	14	9	198	138.6
Linear Philips	180	18	9	198	641.52
Water Dispenser	1	585	3	66	38.61
Kettles	1	1200	1	22	26.4
Fridge	1	150	5	110	16.5
Microwave	1	600	4	88	52.8
Air-Conditioning	2	2370	6	132	625.68
Total					**2328.15**

Appendix A. 9: 10th floor equipment with power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Laptop	3	65	9	198	38.61
Desktop(CPU and Monitor)	9	300	9	198	4811.4
Scanner	1	36	9	198	64.152
Printers	1	625	9	198	1113.75
Photocopy(Multi-Function)	1	2500	9	198	4455
Lighting Bulbs	50	14	9	198	1247.4
Linear Philips	180	18	9	198	5773.68
Water Dispenser	2	585	3	66	231.66
Kettles	1	1200	1	22	26.4
Projector	1	340	2	44	29.92
Air Conditioning	2	2600	6	132	4118.4
Total					**21910.372**

Appendix A. 10: 9th floor equipment with power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Laptop	10	65	9	198	128.7
Laptop	11	45	9	198	98.01
Laptop	1	90	9	198	17.82
Desktop(CPU and Monitor)	15	300	9	198	891
Scanner	1	36	9	198	7.128
Printers	1	625	9	198	123.75
Photocopy(Multi-Function)	1	2500	9	198	495
Lighting Bulbs	50	14	9	198	138.6
Linear Lamps	180	18	9	198	641.52
Water Dispenser	2	585	3	66	77.22
Kettles	1	1200	1	22	26.4
Projector	1	340	2	44	14.96
D-Link	1	2.55	9	198	0.5049
Total					**2660.6129**

Appendix A. 11: 8th, 7th and 3rd floors equipment with power rating

Equipment	**Quantity**	**Power Rating (W)**	**Daily Operating Hour**	**Monthly Operation Hour**	**Monthly Energy Use (kWh)**
Laptop	20	65	9	198	257.4
Desktop(CPU and Monitor)	50	300	9	198	2970
Printers	3	625	9	198	371.25
Photocopy(Multi-Function)	3	2500	9	198	1485
Lighting Bulbs	150	14	9	198	415.8
Linear Lamps	540	18	9	198	1924.56
Water Dispenser	3	585	3	66	115.83
Kettles	3	1200	1	22	79.2
Projector	3	340	2	44	44.88
Total					**7663.92**

Appendix A. 12: 6th floor equipment with power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Laptop	17	65	9	198	218.79
Desktop(CPU and Monitor)	20	300	9	198	1188
Printers	7	720	9	198	997.92
Photocopy(Multi-Function)	1	2500	9	198	495
Lighting Bulbs	55	14	9	198	152.46
Linear Lamps	180	18	9	198	641.52
Water Dispenser	2	585	3	66	77.22
Total					**3770.91**

Appendix A. 13: 5th, 4th floors equipment with power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Laptop	15	65	9	198	193.05
Desktop(CPU and Monitor)	14	300	9	198	831.6
Scanner	2	36	9	198	14.256
Printers	7	720	9	198	997.92
Photocopy(Multi-Function)	2	2500	9	198	990
Lighting Bulbs	100	14	9	198	277.2
Linear Lamps	360	18	9	198	1283.04
Water Dispenser	2	585	3	66	77.22
Projector	1	430	2	44	18.92
Air-Conditioning	5	2600	6	132	1716
Total					**6399.206**

Appendix A. 14: 1st floor equipment with power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Laptop	7	65	9	198	90.09
Desktop(CPU and Monitor)	20	300	9	198	1188
Printers	2	720	9	198	285.12
Lighting Bulbs	50	14	9	198	138.6
Linear Lamps	180	18	9	198	641.52
Water Dispenser	2	585	3	66	77.22
Kettles	2	1200	1	22	52.8
Air-Conditioning	8	900	6	132	950.4
Projector	1	430	2	44	18.92
Fridge	1	64	5	110	7.04
Screen TV	1	140	2	44	6.16
Total					**3455.87**

Appendix A. 15: Ground floor equipment with power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Desktop(CPU and Monitor)	1	300	10	220	66
Lighting Bulbs	5	7	9	198	6.93
Linear Lamps	0	36	9	198	0
Screen TV	0	0	0	0	0
Security Camera	1	15	24	528	7.92
ThruScan	1	2500	11	242	605
Total					**685.85**

Appendix A. 16: Underground floor equipment with power rating

Equipment	Quantity	Power Rating (W)	Daily Operating Hour	Monthly Operation Hour	Monthly Energy Use (kWh)
Laptop	1	65	12	360	23.4
Desktop(CPU and Monitor)	2	300	12	360	216
Printers	1	720	12	360	259.2
Lighting Bulbs	50	7	12	360	126
Linear Lamps	12	36	12	360	155.52
Kettles	2	1200	12	360	864
Air-Conditioning	7	2600	12	360	6552
Fridge	1	400	12	360	144
Screen TV	4	140	12	360	201.6
Microwave	2	600	12	360	432
Ice maker	1	450	12	360	162
Oven	1	13280	3	90	1195.2
Blender	1	400	12	360	144
Fryer	1	3250	12	360	1170
Water Heater	1	1500	12	360	540
Total					**12184.92**