UNIVERSITY OF THE WITWATERSRAND, SCHOOL OF ARCHITECTURE AND PLANNING

Decentralised electricity generation through rooftop solar photovoltaics (PVs) in Zambia- A case study of the Engineering Institute of Zambia (EIZ) office building project, Lusaka.

Supervisors: Dr Gerald Chungu
& Prof Daniel Irurah

Joseph Samunete (1537615)

A research report submitted to the Faculty of Engineering and the Built Environment at the University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Architecture (Sustainable and Energy Efficient Cities)

Johannesburg, May 2018.

Declaration.

I declare that this research report is my own unaided work. It is being submitted for the degree of Master of Architecture in the field of Sustainable and Energy Efficient Cities to the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

………………………………………………

Joseph Samunete

May, 2018

Abstract.

Whereas there has been significant study and development of national strategic plans on electricity generation from renewable energy in general in Zambia, specific studies and research on decentralised electricity generation via rooftop solar PVs from buildings and their potential to enhance Zambia's electricity generation goals have not systematically been done.

The study applies a case study of the Engineering Institute of Zambia office building that is at construction stage but is determined to incorporate a rooftop solar PV system. Using DesignBuilder and Energyplus simulation software, the building was modelled and analysed for this potential. In addition, based on interview data from various experts and secondary data from national plans, the study evaluated policy, regulatory and market frameworks which could catalyse the increased deployment of such systems in Zambia. Using financial analysis tools of payback period, return on investment and net present value the study undertook a number of business case scenarios in order to conceptualize a responsive business model.

The study finds that from the initial estimate, the available roof space had the capacity to net out the baseline annual electricity consumption of 287,707kWh and generate a surplus of 63,519kWh/year before optimisation. Optimisation of the baseline consumption through a combination of two viable energy efficiency interventions reduced the baseline annual consumption by 35% to 186,904kWh with related payback period of nine years, ROI of 518% over a 25 year analysis period and a NPV of 623,344.00 ZMK. Based on these findings, three business case scenarios for the solar PV system were analysed and two out of the three were adopted. One scenario assumed a net-zero building and another one assumed that the surplus electricity generated on non-business days is exported to the grid were adopted. Following this finding, a business model centred on an integrated energy service company (IESCo) was identified as the most appropriate model to respond to the uptake barriers of this technology and thus leverage on the emerging progressive support mechanisms.

The overall findings of the study thus support the working hypothesis of the study which deemed that through the framework of a responsive business model, decentralised electricity generation through rooftop solar PV can greatly enhance energy security and mitigate GHG-emission for Zambia.

Key words: Decentralised electricity generation, Rooftop solar PV, energy efficiency, grid interactive, business model.

Dedication

To my family and the dear brethren in the Lord.

Acknowledgements

This work would never have been completed without the help of many people and it is with great pleasure that I thank those who unreservedly sacrificed themselves for me to bring this work to completion.

How can I refrain from thanking the Lord God Almighty for his saving grace in his Son the Lord Jesus Christ, his preserving grace that I stand in to this day and his sustaining grace for "morning by morning I see new mercies"?

I would like to express my deepest gratitude to my supervisor, Dr Gerald Chungu and my co-supervisor Prof Daniel Irurah for their wise guidance, advice, encouragement and insight throughout the compiling of this report. I am privileged to have tapped from their knowledge store.

I am thankful to Chilufya Lombe and Marloes Reinink at Solid Green consultancy firm for the help with the Designbuilder software.

I am also thankful to the Copperbelt University in Zambia for granting me the scholarship to pursue this program.

The limitless mainstay of my family gave me the energy to persist upon this report. Thank you all more profoundly for your spiritual, financial and emotional support. Your support has always been the most meaningful certainty throughout my life.

To my course mates and friends I came to know in Johannesburg: - Samuel Ipinmoroti, Nyasha Muzhizhizhi, Chima Ichendu, Ceaser Migisha, Lawrence Chetty, Ntokozo Sibande, Tsholofelo Makgwa and Gareth Davies, you have been motivators who expanded my horizons and gave me strength to carry on.

Finally, I thank the believers at Berario Chapel for their warm fellowship and being nearest to me during my stay in Johannesburg. I could never be so persevering without your caring support.

Table of contents

List of Tables

List of figures

Acronyms

BOS	Balance of System
CAPCO	Central African Power Corporation
CEEEZ	Centre for Energy, Environment and Engineering Zambia
CFL	Compact Fluorescent Light
COP	Conference of Parties
CPV	Concentrating Photovotaics
DoE	Department of Energy
DREG	Decentralised Renewable Energy Generation
EIA	Energy Information Administration
EIZ	Engineering Institute of Zambia
EPD	Equipment Power Density
EPW	EnergyPlus Weather
ERB-Z	Energy Regulation Board of Zambia
ESCOs	Energy Service Companies
IESCo	Integrated Energy Service Company
IPCC	Intergovernmental Panel on Climate Change
GEF	Global Environment Facility
GET	Global Energy Transfer
GET-FiT	Global Energy Transfer Feed in Tariffs
GHG	Greenhouse Gas
GIZ	Gesellschaft Internationale Zusammenarbeit
HVAC	Heating Ventilation and Air Conditioning
IDC	Industrial Development Corporation
IGC	International Growth Centre
IPPs	Independent Power Producers
IRENA	International Renewable Energy Agency
Kw	Kilowatt
kWh	Kilowatt hour
kWp	Kilowatt peak
LCOE	Levelized Cost of Energy
LED	Light-Emitting Diode
LPD	Light Power Density
MFEZ	Multi-Facility Economic Zone

MMEWD	Ministry of Mines Energy and Water Development
MW	Megawatt
NASDEC	National Sports Development Centre
NEP	National Energy Programme
NGOs	Non-Government Organisation.
NPV	Net present Value
NZEB	Net Zero Energy Building
OPPPI	Office for Promoting Private Power Investment
PPA	Power Purchase Agreement
PV	Photovoltaic
RE	Renewable Energy
REA	Rural Electrification Authority
REFiT	Renewable Energy Feed in Tariff
REIPPP	Renewable Energy Independent Power Producers
REN 21	Renewable Energy Policy Network for the 21st Century
RES	Renewable Energy Sources
RETs	Renewable Energy Technologies
ROI	Return on Investment
SADC	Southern African Development Community
SAS	South African Standard
SNC	Second National Communication
SNDP	Sixth National development plan
SWOT	Strength, Weakness, Opportunity and Threats.
SHGC	Solar Heat Gain Coefficient
UI	User Interface
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VRF	Variable Refrigerant
WBDG	Whole Building Design Guide
ZDA	Zamia Development Agency
ZESCO	Zambia Electricity Supply Corporation
ZMK	Zambian Kwacha

Chapter 1. Introduction and background of the study

1.1 Introduction

The general model of Zambia's electricity sector has not undergone significant revolution for the past 40 years or so. The central model of electricity generation can be traced back to the decision to construct the Kariba Southbank power station in 1963 which came to be owned by the Central African Power Corporation (CAPCO) established to take responsibility of bulk electricity power generation and supply (Kapika and Eberhard, 2013). Thereafter, the completion of Zambia's indigenous hydro power plants around the 1970s after independence saw the formation of the Zambia Electricity Supply Corporation ZESCO in 1969 to take the responsibility for generation, transmission and distribution throughout the whole country. Over the following years, the rights, obligations and assets of existing electricity utilities became vested in ZESCO (*ibid.*). This model has largely remained unchanged, apart from the major power sector reform in 1995 that abolished the statutory monopoly of ZESCO and allowed the participation of other private operators in the sector (IRENA, 2013).

ZESCO built more capacity with assistance from the World Bank (the main financier for power projects in the country) in the late 90s and early 20s building more hydro plants. With surplus generation capacity and stagnant consumption and growth (as a result of economic decline), there seemed to be no motivation to grow capacity (Kapika and Eberhard, 2013). However, the country started recording robust economic growth in the first decade of the new millennium resulting in rapidly rising demand for electricity. Meanwhile, ZESCO's power system expansion and requisite refurbishments were constrained partly because of low revenues as a result of highly subsidized tariffs, leading to a decline in power quality and reliability and making load shedding and even nationwide power blackouts an increasingly common phenomenon (*ibid.*).

Despite early electricity demand forecasts and warnings of reduced capacity contained in the power system master plans (due to increase in economic activity, population and effects of droughts), the stakeholders in the sector were still caught unprepared and thus exposing the weaknesses and unsustainability of mitigating measures. This unpreparedness affects the economic and social well-being. Prospects for on-grid extension as well as growing capacity to meet up with the demand by investing in more hydro power options have done little to avoid these crises because usually they require major capital investments amidst need to rehabilitate existing infrastructure.

Following the dynamics in the power sector, new insight and awareness among decision makers on the cross-cutting role of energy in socio-economic development prompted a review of the first National Energy Policy (NEP) of 1994 (IRENA, 2013; MMEWD, 2008). The new National Energy Policy (NEP 2008) considers the need to recognise the significant role of renewable energy. More specifically, the objective of the NEP is to address barriers to the wide deployment of Renewable Energy Technologies (RETs). In order to translate the objectives of the NEP 2008 into a practical implementation plan, a draft Renewable Energy Strategy was developed in 2010. Some of the strategies include long-term renewable energy targets for specific applications. In terms of electricity, the targets are to generate 100 MW from solar, 200 MW from small hydro and 100 MW from biomass by 2030 (IRENA, 2013; MMEWD, 2008). In addition, it envisages the dissemination of 500,000 solar home systems and installation of 350,000 solar water heaters to reduce the demand load by 150 MW.

Some plans such as the Scaling Solar initiative by the Industrial Development Corporation (IDC) and the World Bank are already in implementation. The scaling solar project has also formed the foundation for much policy on solar electricity generation. Notwithstanding this positive step, a more holistic long-term integrated resource planning that incorporates technologies such as decentralised electricity generation from rooftop solar PVs has not yet been systematically laid out. Even though solar PV has been prioritised in rural off-grid and mini-grid systems, they have been proven insufficient to narrow the electrification gap, mitigate electricity shortages and guarantee the desired resilience.

With increasing economic activity, emergence of a middle class in provincial towns and major cities and increased urbanisation, there is a construction boom primarily focussing on commercial buildings (US foreign commercial service and department of state, 2011). However, most new buildings in Zambia are still being built without net-zero design considerations. Building industry experts (architects, engineers, planners) and stakeholders like ZESCO have not collaborated well enough to exploit the potential that buildings (both new and old) offer towards energy efficiency and electricity generation. Green building codes and standards (mandatory or voluntary) are almost non-existent to motivate both building industry experts and clients, developers to consider energy projects. Policies on feed-in tariffs, grid interaction, are being formulated and implemented with more emphasis on utility scale projects but very little consideration of future building-scale electricity generation. Evidence from leading countries like Germany and USA show great support for building-scale electricity generation by developing smart grids and net-metering policies.

Decentralised electricity generation systems are arguably very resilient compared to central systems. The central utility model which is still about ZESCO is especially susceptible to many disturbances. Energy efficiency and decentralised electricity generation at building scale from rooftop solar PVs offers great potential to significantly reduce escalating costs, reduce demand for grid electricity, hedge against inconveniences from power cuts, and mitigate electricity shortages arising from climate change impacts. Piece meal and generic solar PV policies have failed to exploit this potential to the fullest. Studies conducted on incorporating rooftop solar PV systems and examples from leading countries have shown positive results. While many countries are actively developing this potential, in Zambia it is still largely theoretical and uncoordinated.

In light of the challenges of the central model of electricity generation and the electricity crisis currently facing Zambia, it is imperative that a variety of innovative measures including decentralised electricity generation from building rooftops (apart from the other variants such as utility-scale and rural mini-grids) are systematically explored in delivering both energy efficient, net-zero buildings and clean electricity. This study explores the potential of building scale electricity generation in terms of the technology, policy evolution, economic viability and related practical dimensions.

1.2 Background and context

Zambia is a lower-middle income country with an approximated 2015 population of 16.2 million people, expected to grow to 25 million by 2030 (World Bank, 2017). The country has a vision to develop and diversify its economy into a wealthy middle-income nation-state by 2030. "In part, the vision aims to provide universal access to clean, reliable and affordable energy at the lowest total economic, financial, social and environmental cost, consistent with national development goals" (IRENA, 2013:2). This indicates how crucial energy is to any economy that is striving to grow and sustain economic well-being. Energy also forms a strong interrelation with water and food, and it is thus the basis of any resilient economy.

Zambia's average gross domestic product has continued to grow by an average of 5.5% as a result of the increase in mining, manufacturing and agricultural activity. The country's population and rate of urbanisation has also continued to increase rapidly. Given these factors, the demand for electricity, as the most important source of energy for the country, has been growing at an average of 3% to 4% per annum (Zambia Development Agency, 2014). The demand is expected to increase beyond 2,800 MW by 2020, thereby creating pressure on the already strained electricity supply in the urban regions (Kapika and Eberhard, 2013). Currently ZESCOs installed capacity stands at 2500MW (Energy Regulation Board of Zambia (ERB-Z), 2016). There is wide consensus that the only viable solution to meet the growing demand is by providing long term clean, renewable electricity at lower environmental and economic cost.

The country has for a long time operated on a model of centralised electricity generation through state owned hydro and fossil fuel-based power plants. The national electricity utility company, the Zambia Electricity Supply Corporation (ZESCO) generates, transmits and distributes more than 90 % of electricity in the country, 94% of which comes from hydropower (IRENA, 2013). Shortages in bulk electricity supply, a growing backlog, on–going deterioration of electricity transmission/redistribution infrastructure and consumers' insecurity have compromised this centralised model to the point of crisis. The increasing dysfunction and unreliability of electricity supply has revealed how this centralised model of electricity generation has outlived its appropriateness. Conversely, emerging technology, and a growing interest in renewable energy generation from various consumer segments has revealed that there is a need to have energy generated closer to where it is used.

The unreliability of the central model of electricity generation was demonstrated when a scorching drought across the entire Southern Africa region during the 2014/15/16 rainy season, compromised the country's hydro generation which serves as the main source of electricity, thus triggering a power deficit estimated at 1,000 megawatts (MW) as at May 2016 (Sladoje, 2016 & Mfula, 2016). Some commentators blame poor planning, government mismanagement of the water resources and hydro dependency as other contributing factors limiting the country's power generation capacity. As a result, Zambia has been experiencing a crippling electricity crisis with consumers forced to endure up to eight hours of load-shedding per day since July 2015. Experts have predicted that this is likely to persist for a few more years due to climate change (Sladoje, 2016). Businesses are stifled and emergency power imports at enormous costs have been undertaken to safeguard the economy from grinding to a halt (Mfula, 2016). The crisis and its related impacts have brought to the fore the need for Zambia to diversify electricity generation mix and circumvent recurrence of similar crises in future.

Whereas policies that recognise the potential to diversify to renewable energy (RE) have been in existence, they place emphasis on the expansion of hydro generation despite its vulnerability to droughts (IRENA, 2013). Other alternative sources of electricity like geothermal, wind, biomass, and solar have not been optimally integrated into policy or programs. Of these options, solar power is the highly preferred source of electricity in Zambia because it is available in abundant supply, which makes it possible to initialize electrification at a relatively minimum initial capital. Given the country's rich solar irradiation of roughly "5.5 kWh/m²/day and, with approximately 3,000 sunshine hours annually, the potential for generation through solar thermal and photovoltaic (PV) exploitation is immense, but has remained untapped" (MMEWD, 2008: Un-paginated).

Decentralised generation of electricity through solar PV has a great potential to alleviate Zambia's electricity predicament if facilitated to take off on a large scale (Tembo and Marvin, 2010). According to Pepermans *et al* (2005), the reliability paybacks that can arise from increased investment in decentralised electricity generation include: self-sufficiency, availability of backup power, increased power quality, as well as reduced vulnerability.
Decentralised electricity generation through solar PVs in Zambia has been proactively pursued to address the needs of the population in remote areas through subsidized rural electrification programs driven by the central utility with help from donors and development agencies. This electrification includes schools, health clinics, community centres, as well as individual households. Although rural areas have received more attention in solar electricity generation, their relative contribution to energy consumption and greenhouse gas emissions in Zambia is minimum compared with middle-and high income residential, as well as commercial buildings. The economic feasibility of private investment in solar PV systems for urban residential and commercial areas has not even systematically started. The International Renewable Energy Agency's report on the renewable energy readiness for Zambia, highlights the strides in solar PV exploitation but is concerned with the slow uptake and the lack of business models to scale up private investment (IRENA, 2013).

Whereas most offices and commercial buildings require massive amounts of electricity to operate, energy efficiency intervention optimisation through building simulation and retrofits can help reverse the over-consumption of buildings of all types. Moreover, these buildings offer larger, unobstructed roof space suitable for roof-mounted solar PV systems capable of generating clean energy and subsequently reducing greenhouse gas emissions. Existing buildings represent electricity saving and generation opportunities by retrofits, because their efficiency performance is far below in expected optimised potential. New buildings on the other hand, are an ideal opportunity to focus on building electricity efficiency and generation potential right from the start by design update (UNEP, 2016). In this way, they present ideal opportunities for the early adoption of solar PV systems capable of opening up a trend and wider transformation towards distributed electricity generation in Zambia.

1.3 Problem statement

The predominant model of electricity generation in Zambia has been through centralised hydro-generation systems. The Zambia Electricity Supply Corporation (ZESCO) provides over 90% of electricity generated from hydro as well as diesel power plants which supply far-flung rural areas. This system of electricity generation has been undermined by unreliability in supply, huge costs resulting from transmission and conversion losses, repairs and upgrading of infrastructure while the diesel power plants also lead to greenhouse gas emissions (Tembo and Marvin, 2010). Decentralised electricity generation has been used in many areas of the world to mitigate the aforementioned shortfalls of centralised systems. Countries like Germany and the US are leading the way in using these systems. South Africa is also several steps ahead in pursuing decentralised electricity generation through solar PVs as evidenced by the growing number of private commercial and retail business investments in building-scale electricity generation (Cooke, 2016).

Although the country has immense hydroelectricity potential and the generation is almost exclusively from hydro, concerns of drought as a result of climate change have made it a risky renewable source to solely depend on. Currently (2015-2017), the country faces a crippling electricity crisis which has necessitated the need to adapt to alternative means of electricity generation. Despite the ability of buildings to generate their own power via solar PV and export the surplus to the grid, this potential has remained untapped in Zambia; where there is 6-8 sunshine hours per day. Although there is a renewed interest in solar energy systems from different consumer segments, the diffusion and mechanism of implementation for a widespread transformation to distributed generation is lacking.

The proposed study aims to conceptualise and motivate for a business model by which building integrated solar photovoltaic technology could be facilitated for take–off to the expected levels in the energy sector in Zambia. Within the limited context of the case study of the Engineering Institute of Zambia (EIZ) building, the research aims to explore how a building that is determined to go completely off-grid could be modelled as a prototype for the possibility of attaining building scale electricity generation and subsequently stimulate large scale uptake of the technology.

Given that the prevailing electricity crisis has hit businesses and the socio-economy of Zambia, the cost of providing alternative energy supply is an utmost concern for most stakeholders. Most offices and organisations provide standalone diesel/petrol generators because a lot of energy is required to achieve a conducive and productive environment for the users. These generators then lead to emissions of greenhouse gases and escalating expenses. The life-cycle benefit and potential of building efficiency and self-generation of electricity through the use of design simulation and retrofitting has not been systematically appraised as yet. Conversely, investment in building energy efficiency is usually accompanied by significant direct and indirect savings, which could help offset incremental electricity costs (UNEP, 2016).

1.4 Rationale of the study

In light of the failure of the central electricity generation system to meet the growing demand, and as a consequence of the increased unreliability of service which has led to the frequent electricity crises in Zambia, this study aims to explore how the building scale generation of energy could open up a wider transformation to distributed systems in new and existing buildings in Zambia, and thus contribute towards a viable business model to catalyse the scale-up of such opportunities. This study has assessed the policy and market potentials as well as identified key impediments in order to conceptualise, and expand into an appropriate responsive business model.

1.5 Research questions

Main research question

What is the potential of rooftop solar photovoltaics (PV) in grid interactive distributed generation as an intervention towards enhanced energy security and climate change mitigation for Zambia, and what would be the responsive business model as well as policy and regulatory support mechanisms?

Sub research questions

- What is the baseline consumption of the case study building and what opportunities exist for energy efficiency intervention or optimization?
- What is the capacity of solar PV generated electricity in the case study building, and how does it compare to optimised energy consumption of the building?
- What is the opportunity for surplus export to the grid, and what would be the supportive frameworks required for such grid-interactive distributed-generation?

- What would be the responsive business model (including funding and financing arrangements), and what policy or regulatory mechanisms would be required to catalyse the scale-up of such opportunities in new and existing buildings?
- What would be the case-study and scale-up contribution to climate-change mitigation and enhancing of energy security for Zambia?

1.6 Working hypothesis

Within the framework of a responsive business model, decentralised electricity generation through rooftop solar PVs has the potential to alleviate Zambia's electricity crisis in both the short and long-term while also stimulating co-benefits such as climate-change mitigation, job creation, green-skills and innovation development.

1.7 Research approach

An explorative approach involving an assessment of the case study building was used to answer part of the questions. Primary data in the form of whole building energy use based on the design specifications, material specifications, tenancy end-use energy consumption coupled with interviews with the project managers and client representative were obtained. Where drawings and specifications did not provide detail, appropriate standards from building guides were referenced as secondary data.

Following the data collected, a model was developed using DesignBuilder software to simulate the baseline electricity consumption through a reiterative process.
In order to reveal the outlook of the solar PV exploitation in Zambia and the regulatory framework and supportive mechanisms, interviews were conducted with key informants from a variety of stakeholders. Secondary data was accessed from literature and reports from the university library as well as internet searches.

1.8 Limitation and delimitation of the study

The study seeks to explore the potential of decentralised electricity generation from rooftop solar PVs on the EIZ building which is still under construction. This case study is unusual with respect to informing about dynamics that come with energy projects that are at the construction stage. A case study approach was used to inform a more real life simulated situation of the potential and opportunity of solar PV electricity generation and the delivery process of such projects in Zambia. This study does not explore the socio-political and economic theories and evolution of solar PVs.

The design documents did not have the complete specifications of materials needed to derive thermal values and environmental performance details. In addition, there were no specific minimum comfort requirements from the client's brief which could be used as targets when running simulations. Therefore, most of the inputs had to be estimated and assumed according to the general international environmental performance standards. Given that the offices will be rented out and the tenants have not yet been determined, the occupancy and equipment schedules had to be estimated.

The other limitation involved the mechanism for feeding into the grid, related feed-in tariffs and billing arrangements which to the best of the researcher's findings are issues still at development stage. Therefore, the business model was conceptualised based on an assumed ideal case of policy, regulation and technical support mechanisms which are expected to emerge in the near future, especially if catalysed through opportunities such as the one presented by the case study building.

1.9 Definition of key concepts

Decentralised electricity generation: This concept refers to the use of small scale electric power generation systems in respect to place and utility (Pepermans *et al*, 2005; Martin, 2009; Shabha and Kori, 2013). In contrast to large centralised electricity generation facilities that also transmit the electricity through long transmission grids to the end-user, this concept has been applied in this study to represent electricity generation next to the point of use (utilised by the host of the facility first(EIZ)).

Rooftop solar PVs: This concept refers to the technology that uses energy from sunlight to generate electricity via modules mounted on the EIZ building rooftop. This electricity generated is first consumed within the EIZ building. This concept is contrasted from other technologies such as building integrated photovoltaics (BIPVs) and solar thermal technologies. BIPV technologies substitute conventional building materials in the climate envelope of the building and makes them power generators (Jelle and Breivik, 2012) while solar thermal technologies harness the solar energy and convert it into thermal energy.

Energy efficiency interventions: This concept refers to the strategies (both passive and active) to reduce the baseline electricity consumption of the building without reducing the quality of the electricity supplied. In this study these energy efficiency interventions are those that are technically viable for the EIZ building case study.

Business case: This concept refers to a financial justification made for a particular proposed investment. In this study the concept is used to make comparison of the opportunity cost of undertaking alternative energy efficiency interventions applied to the EIZ building as well as installing the solar PV system against maintaining the status quo.

Business model: This concept describes how the third-party framework of the integrated energy service company (IESCo) captures and creates value for the EIZ as the owner of the building and the investor through the three structures of ownership, operation and financing. The essence of the business model as described in this study was to be responsive to the policy, regulatory and market environment while addressing the key barriers to drive the required increased deployment of decentralised rooftop solar PV electricity generation from buildings in Zambia.

Baseline energy consumption: This concept is used interchangeably with "baseline electricity consumption". In this study the concept refers to the simulated minimum annual electricity consumption of the equipment and operations of the EIZ building.

Optimised energy consumption: This concept refers to the annual electricity consumption of the EIZ building that maximizes the use of energy efficiency interventions to lower the annual baseline consumption.

Grid-tied system: In this study, this concept has been used interchangeably with grid-integrated system. It refers to the system of electricity generation from the rooftop solar PVs that assumes that the system is connected to the utility grid (ZESCO) via a bi-directional meter. The concept assumes that the solar PV facility is able to feed into and tap from the grid. In addition, it assumes exclusion of the battery for simplicity in connection.

Feed-in-tariff: This concept refers to a payment for the surplus electricity generated by the EIZ rooftop solar PV system and exported to the ZESCO grid (as off-takers) fixed by policy in Zambia to run for a period of 25 years.

1.10 Outline of the research report

The overall structure of this research report, in reference to the contents of the six chapters is presented as follows:

In chapter one, which is the introductory chapter, an introduction and explanation of the background and context of the study is given in the earlier section. Thereafter, the problem statement, rationale of the study and working hypothesis are presented. This is followed by the main research question and five sub questions. After this, the research approach, limitations of the study and definition of key concepts are presented. Finally, the structure of the research report is given to conclude chapter one. In chapter two, the theoretical framework of this report is laid out. It is divided into eight main sections. The first section opens with a background of the global growth in the renewable energy and solar PV market. Thereafter, a section discussing the Zambian solar PV sector then follows before a section appraising literature on main business models. This section focuses on the emerging models and structures that define business models. Another section discusses the net-zero building concept as a fast-growing concept in the building industry. Finally, a section on energy efficiency in buildings is discussed. Under this section, various aspects pertaining to buildings and climate change and opportunities for energy and cost saving through application of passive interventions are discussed.

The third chapter explains in detail the methods and techniques that are used to collect and analyse the data in this study. These methods are directed towards answering the sub-questions of the research presented in Section 1.5.1. The chapter gives a simple four stage process that is followed to address the sub questions of the research. The chapter also contains a simple table summarising the data collection tools and analysis methods. Ethical considerations which guided this research have also been presented in this chapter.

Chapter four is dedicated to addressing the sub-questions related to the determination of the baseline electricity consumption of the case study building (EIZ) and opportunities for optimization. The other sub-question that chapter four addresses relate to the capacity of solar PV generated electricity from the EIZ building roof and how this compares to optimised electricity consumption. In addition, this chapter also addresses part of sub-question three with regards to determination of the opportunity for generation of surplus electricity. The chapter is divided into seven main sections excluding the introduction. It starts off by giving a brief overview of the EIZ location. Thereafter, the second section deals with the description of the EIZ building based on the building drawings, specifications and field observations. The third section presents the estimated potential of electricity generation from the available roof space. A procedure taken to model the building and simulate for the baseline electricity consumption then follows before the interpretation and presentation of the simulated results. The sixth section deals with the energy efficiency interventions that are simulated to optimise the baseline electricity consumption. The final section presents the preliminary findings of the chapter.

Chapter five analyses the data from interviews which is categorised in key themes. These themes address the sub-question of the research relating to the possibility of grid-integration for the export of the surplus electricity to the grid and the supportive framework for grid-tied systems in Zambia. The main themes in this chapter highlight aspects such as progressive policy on grid codes, solar PV feed-in tariff-programs, the regulation and legislation on solar PVs, the central utilities involvement, financing mechanisms for solar PVs and technical and market situation in Zambia.

Chapter six utilizes some of the findings of chapter four and five to address the sub-questions relating to what could be the responsive business model (including financing and policy measures) required to scale-up the opportunity for rooftop solar PV decentralised electricity generation in new and existing buildings. The chapter goes on to interpret the findings towards the scale-up contribution of such technologies in enhancing the energy security goals as well as its contribution to reduction in greenhouse gas emissions in Zambia. The chapter starts off by using the simulated results in chapter four to make a business case for the various energy efficiency interventions in order to adopt the most financially viable. Another section develops a business case for three scenarios of the rooftop solar PV system in order to determine the most viable. The third section analyses a number of business models based on ownership, operation and financing structures using a SWOT analysis to come up with the most appropriate business model that will drive market penetration of the technology under study assuming fast implementation of the progressive support mechanisms. This section refers to the findings of chapter five relating to the drivers and barriers of decentralised rooftop solar PVs in Zambia to come up with an appropriate business model. By drawing upon the entire report, a section presents the consolidations of the findings of the study. The chapter ends with some recommendations.

Chapter 2. Literature review

2.1 Introduction

This section covers a review of the related literature by drawing on a selection of sources such as academic papers, national government documents, and organisation reports. The review highlights the global context in terms of growth in the renewable energy industry in general, before narrowing on solar photovoltaic markets. Appraisal of literature is captured through a summary of the state of harnessing and the outlook of the PV technology in Zambia, - including the energy status of the country, technical aspects, cost, and policy. Mention is made of the maturation of business models that are in use and those emerging in solar PV, in other countries such as the U.S.A in order to guide formulation of responsive models for commercial and office buildings for the Zambian context. Since the study explores building scale electricity generation, literature on energy efficiency in buildings, net-zero energy buildings (NZEB), simulation, retrofitting, and emerging solar rooftop PV technologies provide an understanding on the study in order to achieve the aim and objectives of the study.

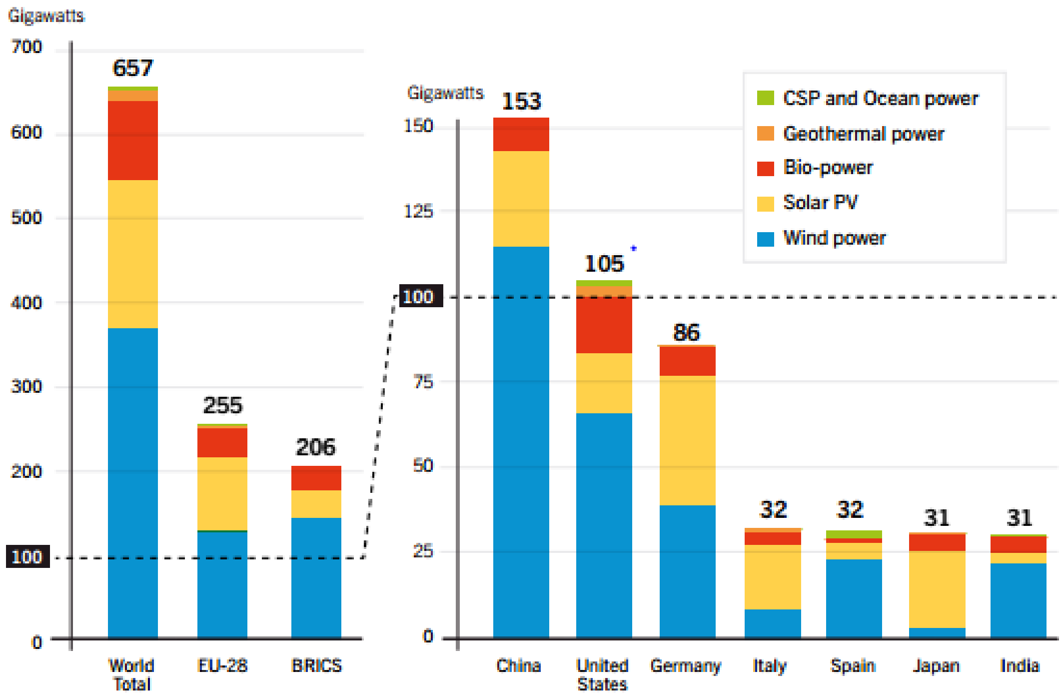
2.2 Global context

2.2.1 Global attention to renewable energy and climate change

The Renewable Energy Policy Network for the 21st Century (REN 21) report highlights that renewable energy has continued to grow in parallel with global energy consumption and is fast becoming a mainstream energy resource (REN, 2015). In addition, the report recognises the UN Secretary-General's initiative on Sustainable Energy for All (SE4ALL 2014-2024), which aims at among other things to double the share of renewable energy in the global energy mix by 2030 (*ibid).*

A number of countries have committed to the pursuit of climate change mitigation. The United Nations climate change conference in Paris in December 2015 (commonly known as the COP21) produced an unprecedented agreement among 195 countries to act for zero net emissions in the second half of the century (McCrone *eta al*, 2016). Nevertheless, the global trend in greenhouse gas emissions remains worrying (*ibid).* It has been stated by the BP energy outlook that carbon emissions would rise 0.9% per year between 2014 and 2035, reaching a level 20% higher than 2014-levels mainly due to increased coal-firing (*ibid*).

Figure 1: Renewable power capacities in world, EU-28, BRICS, and top seven countries. Source (REN 21, 2015: 33)



2.2.2 Solar PV-global increase in installed capacity and spread to new markets

Solar PV is already playing a substantial role in decentralised electricity generation in many countries especially following on the fast falling costs which have made solar PV–generated electricity cost competitive relative to conventional sources and thus attracting private-sector investments (REN21, 2015). "In 2014 solar PV grew with an estimated 40GW added capacity, for a total global capacity of about 177GW" (*ibid: 58*).

Figure 2: Solar PV global capacity, 2004-2014. Source: (REN21, 2015:59)

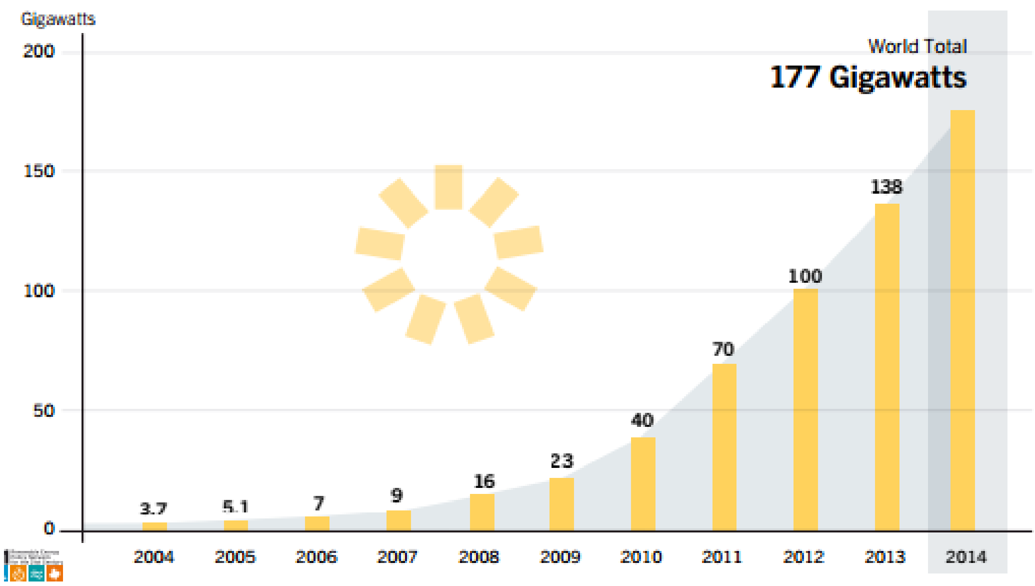
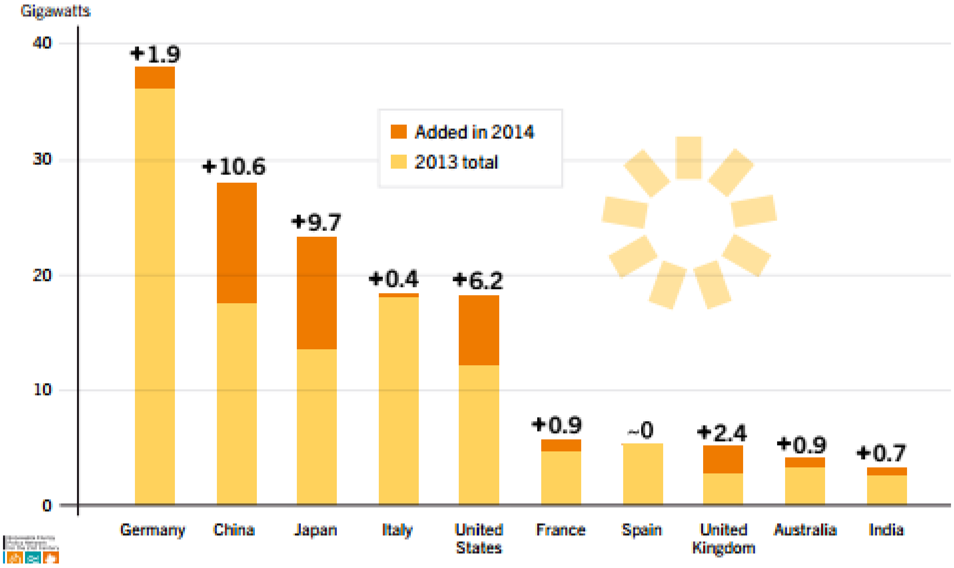


Figure 3: Solar PV capacities and additions, top 10 countries, 2014.Source: (REN21, 2015: 5)



Despite global capacities increasing (as shown in Figures 1, 2 and 3), this growth has largely bypassed Africa, despite solar irradiation in African countries being 52% to 117% higher than in Germany (IRENA, 2016). However, this is starting to change with technological improvements and lower solar PV costs. This has spurred many local, international and social entrepreneurs into the Solar Home System (SHS) market and in stand-alone mini-grid markets, while in the utility-scale sector – systems larger than 1 megawatt (MW)-support policies are beginning to bear fruit (*ibid.*). Currently, South Africa and Kenya continue to lead in solar PV installations.

2.3 The Zambian context

2.3.1 Current electricity access situation

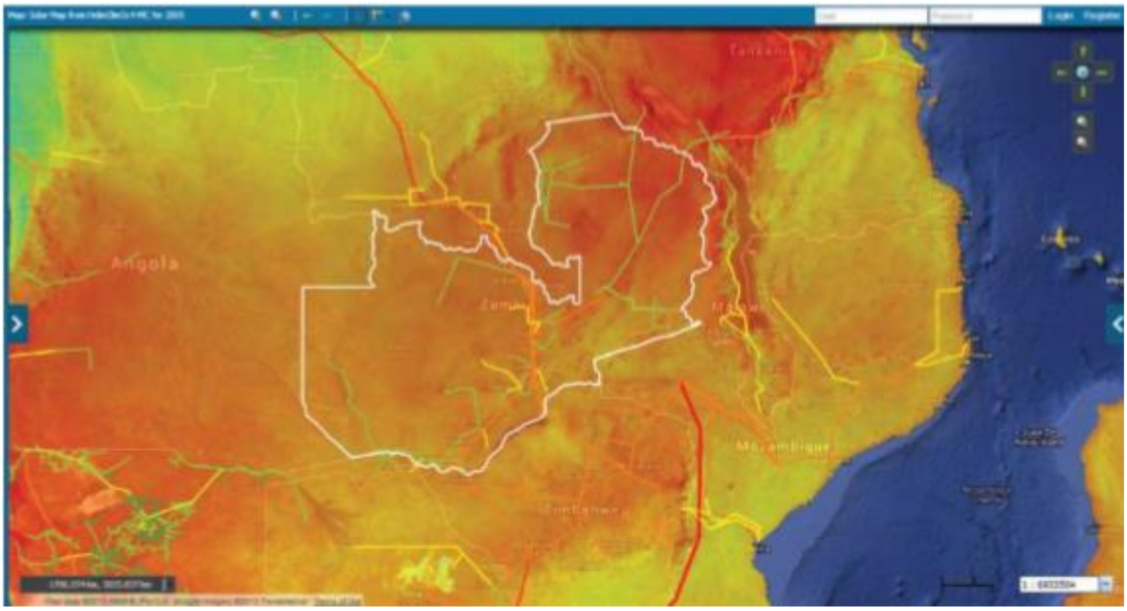
Currently, Zambia's national electrification rate stands at a meagre 23% (World Bank, 2015). This figure indicates that more needs to be done in transforming the electricity sector by ensuring an efficient and diverse mix of supply sources in order to attain universal access to clean electricity for all. While electrification for urban households has reached over 47% compared to 3% for their rural counterparts (*ibid.*) the central electricity utility is still grappling with a huge backlog to keep up with the growing demand from new buildings in the urban areas. Delays in connectivity, increase in tariffs, coupled by inefficient monitoring by the utility, have increased the rate of illegal connections especially among low income groups in urban areas. These connections pose risks of overloading and damage to infrastructure that result in losses in revenue for the utility. Notably, those that cannot wait in line have resorted to alternative means of electricity generation from renewable sources.

2.3.2 Solar PV electricity generation and its potential in Zambia

Zambia is endowed with immense renewable energy resources. According to the department of energy (DoE), renewable energy resources in the country include solar energy (both thermal and photovoltaic); small hydro power; biomass (agricultural waste, forest waste, industrial waste, energy, crops and animal waste); geothermal and wind (Mfune, 2008). The government has placed a high priority on diversification of the country's energy mix through the use of renewable energy. For a long time now, hydropower generation has been the predominant electricity source. However, according to the Ministry of Mines, Energy and Water Development (MMEWD, 2008) large hydroelectricity facilities are no longer classified as renewable because of their resultant environmental impacts and vulnerability to droughts. Therefore, solar electricity generation remains one of the alternatives with the greatest potential and thus a prioritised electricity source because of its relatively easy installation and is a generation source that can be rapidly deployed independent of the grid (Mfune, 2008).

"Zambia has an average solar insolation of 5.5 kWh/m^2/day. With approximately 3,000 sunshine hours annually, this provides good potential for solar thermal and photovoltaic applications" (IRENA: 2013: 16). Figure 4 displays Zambia's solar irradiation resource potential built on Geographic Information System data. Red regions have the highest solar irradiance values up to 2,750 kWh/m^2. Zambia's northern areas represent the highest global solar irradiation of 2,300 kWh/m^2/year (*ibid*).

Figure 4: Global solar irradiation in Zambia. IRENA Global atlas (Resolution 13KM) Source: (IRENA: 17)



According to Haford (1998), the marked advent of photovoltaic panels in Zambia was in the early 80s with BP solar Zambia as the major supplier of PVs to the market (Harford, 1998). Since then, the application of solar PV technology has continued to grow gradually albeit at a very slow pace. To date most installations of solar PV technology have been of small solar PV home systems for households and mostly in rural areas. In a bid to increase access to electricity, many institutions such as NGOs, clinics, government ministries (especially Health and Education), and churches have been adopting solar energy technologies (GEF, 2013). Through the help of government and donor support, the Rural Electrification Authority (REA) and energy service companies (ESCOs) have been spearheading the implementation of rural electrification targeting households and social infrastructure such as chief's palaces, health centres, schools, as well as rural enterprises in order to achieve commercial viability and economies of scale (IRENA, 2013). Examples of implemented solar mini grids can be found in Samfya District of Luapula province with an electricity generating capacity of 60kW (Kapambwe, 2011). Other notable projects are in Nyimba, Chipata and Lundazi in the Eastern province of Zambia (*ibid*). However, these projects are said to have a poor implementation track record, as they rely on donor-driven distribution of free or highly subsidised solar PV systems (IRENA, 2013). Notwithstanding all the aforementioned projects, major solar projects by urban residential and commercial entities are limited (*ibid*).

From the technological perspective, the stand-alone solar PV systems have been the predominant system with a few adopting solar water heaters. With the growing interest in the solar PV systems, potential for sales in the household and commercial market segment are great (Kapambwe, 2011). Opportunities for investment in this domain include local production of solar system components, setting up isolated micro-grids, sale of solar panels and related accessories (IRENA, 2013). According to GEF (2013), quite a few companies are already engaged in the design, installation and servicing of solar based power generation facilities although the most recent ones are mostly related to mini grid solar PVs. Some local companies such as "Solartech Zambia Limited have even started to explore manufacturing of solar thermal systems such as stoves and geysers" (Kapambwe, 2011:34). All these concepts of small scale solar PV implementation is testament of the huge potential of this segment in Zambia and proves that solar PV technology has gone past the piloting stage. As stated in Section 2.3.1, an opportunity for solar PV systems exists where customers intend to ameliorate the inconvenience of delayed electricity connection due to a huge backlog of over 25,000 customers yet to be connected from the utility. According to the World Bank group-doing business in Zambia (2017), it would take approximately 123 days for a business to obtain electricity connection for a newly constructed building in Zambia. This is from the time an application is made to ZESCO to receiving a meter installation and final connection. For sites that are located far from the grid this period could extend to 240 days. Most customers would prefer a reliable alternative electricity source such as solar PV to take care of certain electric demands during this waiting period.

2.3.3 Building energy efficiency and electricity generation from solar PVs in Zambia

Most of the literature on solar PV electricity in Zambia is focussed on the rural electrification via sponsored mini grids and isolated small home systems because that is where it has had the largest usage (CEEEZ, 2013; GEF, 2013; Hanyika 2008). There is insufficient discussion and statistics of commercial, industrial and urban residential building applications of the solar PV systems and the direction in which this industry is going. Moreover, very few existing and new buildings in Zambia have seriously and systematically incorporated aspects of energy efficiency and electricity generation from solar PVs (CEEEZ, 2013). One of the reasons is that because of a history of somewhat abundant, subsidized electricity many designers and their clients did not see the need to prioritise for energy efficiency (GEF, 2013). Despite the fact that energy efficiency design forms a great part of the curriculum, almost no building industry professionals and developers incorporate this aspect holistically in their designs. Moreover, the non-existence of standards, codes and ratings on energy efficiency performance means that it is even more difficult to enforce legislation around energy efficiency in buildings.

At the very least, the utility and related stakeholders have seen the need to sensitize on the need for energy efficiency and management, targeting mainly the behaviour side of the consumer (UNECA, 2014). The intention is mainly to reduce the pressure on the supply which has been outstripped by the demand and resulted in extensive load shedding to all sectors of the economy including households, industry/commercial and to some extent the mines (CEEEZ, 2013). Part of the calls are for buildings to incorporate technologies and energy optimisation and management standards, and onsite electricity generation (*ibid*). In addition, domestic and commercial entities are called upon to integrate air conditioning efficiency, load control measures, use of Compact Florescent Lights (CFL) or Light Emitting Diodes (LED) and solar water heaters (*ibid*). Although there is an observed increase in the use of energy efficient lights in the recent past, some literature argues that this is more of consumer preference market driven impulse than the pursuit of efficiency gains (UNECA, 2014). As yet, no coordinated standards exist to achieve a wide scale pursuit of energy efficient interventions. For instance the incandescent light bulb is still in common use compared to other countries like South Africa where there is mandatory provision for its exclusion from the market. Furthermore, many consumers, suppliers and distributors are hardly concerned about checking for the equipment energy ratings before purchase.

However, some general measures have been designed to sensitize for energy efficiency and they aim at developing energy efficiency and management systems, creating awareness, reducing greenhouse gas emissions and providing financial incentives to industry commercial/ service and municipalities (CEEEZ, 2013). In addition, the aim is to formulate the national energy efficiency management policy towards the creation of licence conditions on energy efficiency (*ibid*). Notably, no organisation or body related to the building industry sector participated in the policy formulation process out of all the action plan actors including the department of energy (DoE), Ministry of Commerce, Trade and Industries, Bureau of Standards, (ZESCO), and financial institutions. This undermines the opportunity to intervene in energy efficiency at the building level as an object of significant energy consumption in any modern economy such as Zambia.

2.3.4 Policy environment on renewable energy

Whereas key government policy instruments allude to the importance of exploiting multiple renewable energy resources to meet the continuous growing electricity needs, Zambia's main energy policy has put more emphasis on grid connected hydropower than other renewable energy technologies (IRENA, 2013). On a progressive note, the country is putting in place some conducive policies, strategies, laws and regulatory and institutional frameworks to promote renewable energies. In particular, the development of a specific policy on solar PV to set the tone for the increasing activity in solar PV has reached an advanced stage (Walimpi, 2013). However, these upcoming frameworks need strengthening beyond mere action plan documents in order to achieve the desired results in solar PV industry development (*ibid*). Policy coordination will undoubtedly help build the sort of institutional capacity needed to create the necessary conditions for investment.

It is worth noting that the electricity sector, which once was monopolised by the central utility, has now been liberalised to some extent with participation of the private sector, albeit small and in relative maturation (CEEEZ, 2013). This restructuring of the energy sector and privatization is being pursued in phases and is attracting private investors. The modern concepts such as Independent Power Producers (IPPs) and Energy Service Companies (ESCOs) are already being implemented (ZDA, 2014)

With regards to the legislative and regulatory framework, "Zambia has put in place an energy regulator and developed a Domestic Electric Act and Energy Regulation Act providing oversight over the electricity sector" (Walimpi, 2013). In addition, the Zambian grid code has been developed to include essential provisions for the integration of variable power into grid networks (IRENA, 2013). The new National Energy Policy (NEP) formed in 2008 set out the government's aims to ensure that the energy sector's potential to drive economic development and reduce poverty is harnessed. More specifically, regarding renewable energy, the objective of the NEP was to tackle barriers affecting the wide deployment of renewable energy technologies (RETs) (*ibid*). In 2010, a draft on Renewable Energy Strategy (RES) was developed in order to translate the objectives of the NEP into a practical implementation plan which included RETs but with no specific direction for solar exploitation.

The country has made attempts in promoting private sector investment in the power sector by the establishment of the Office for Promoting Private Power Investment (OPPPI). The OPPPI assists in reducing the complexities, procedures, and restrictive regulations associated with acquiring approvals, permits and licences (*ibid*).

A number of Independent Power Producers (IPPs) and Energy Service Companies (ESCOs) have been generating and transmitting electricity to the main grid. This forms a good basis for models of grid interactive systems.

The International Renewable Energy Agency (IRENA) revealed that most off-grid renewable energy projects rarely survive because they are driven by non-mainstream investors, often supported by short term donor support (IRENA, 2013). The potential to benefit the majority through renewable energy projects calls for substantial private investment in the sector (*ibid*). Some of the recommended actions towards enhanced renewable energy investment in Zambia include:

- Development of integrated resource planning for all renewable sources.
- Revised approach to setting renewable energy targets.
- Revision and adoption of the draft Grid Code, including renewable power provisions.
- Development of policies and regulations for private-sector involvement in decentralised renewable technologies.
- Development of utility-scale renewable power projects with bankable purchase agreements.
- Establish business models for private-sector off -grid renewable energy
- Build capacity for renewable energy deployment (IRENA, 2013)

2.3.5 Barriers and opportunities to solar PV exploitation

The barriers to solar PV development in Zambia are similar to those of other renewable energies and most of them are not limited to Zambia but apply to the region as a whole. Although Zambia has some experience in the implementation of renewable energy projects funded by bilateral agencies, there are a number of generic barriers to renewable energy development and widespread adoption in the country. The barriers include financial, institutional, technical, information and human resource constrain. (GEF, 2013)

Policy and Institutional Barriers

Although the government has accorded priority to the use of renewable energy for rural electrification, there are several policy and institutional barriers that limit the spread of renewable energy technologies (GEF, 2013). For instance there is not yet a long-term policy to outline specific targets on solar energy development to accelerate the scale up and strengthen the fast-growing solar PV market (Walimpi, 2013 and Hanyika, 2008). Until recently the development plans on the energy policy of 2008 have put emphasis on grid hydroelectricity compared to solar energies. Another notable challenge relates to outdated building codes, weak/or non-existent norms and standards relating to solar energy performance, manufacture, installation and maintenance that are crucial for carrying out technical audits and developing appropriate licensing conditions on energy efficiency (GEF, 2013). Although there are program goals under the national development plan to include cost effective solar electricity feed-in-tariffs, the implementation of these goals is very slow due to highly subsidized tariffs (UNECA, 2014). However, the Scaling solar project which was commissioned in early 2016 will speed up the formulation and coordination of feed-in-tariffs (IDC, 2016).

Financial Barriers

Given the high inflation rates, declining value of national currency and overall deficit budget scenario in Zambia, financial barriers have been identified as the key obstacles to the private sector investments in solar PV electricity generation across all market segments. (ZDA, 2014 and GEF, 2013). The uniform low electricity tariff has led most people in Zambia to always expect low cost electricity services. This makes it difficult to recognize and accept the actual costs of generation and distribution of renewable energy based mini-grids, which tend to be higher because of the small generation capacity and upfront higher costs of the technologies (GEF, 2013). Another notable financial barrier relates to interest rates. Bank interest rates averaging 15.5% over the year increase the hurdle of meeting upfront investment costs and discourage customers from borrowing (Lusaka times, 2017).

Technical Barriers

There are a number of technical barriers in Zambia that need to be addressed in order for the solar technologies in the local industry to flourish. Furthermore, these barriers need to be addressed to build national capacity to manufacture, build, operate and maintain solar based technologies. Although the local skills, knowledge and expertise to operate solar PV technologies are available in Zambia, the capacity to manufacture and/or assemble solar technology components locally is still very limited (ZDA, 2014). Zambia's grid capacity to handle increasing levels of intermittent power from solar generated electricity is another barrier. The current grid network and infrastructure by ZESCO is not smart enough to deal with this variability.

Information Barriers

Poor information dissemination, general lack of awareness and indifference towards available solar PV products and technologies are some of the identified information barriers to solar PV development in Zambia. There is inadequate or lack of information on comprehensive evaluation of solar systems already installed and their performances in the country. Many potential investors and equipment suppliers are not fully informed about the relevant government policies and programmes (ZDA, 2014). Awareness level among the general public as well as decision-makers about the potential of solar energy resources and the potential of providing electricity and energy services with long term attractive payback on investments is generally low (*ibid*).

For a long time now, electricity supply has been regarded a social welfare service in Zambia. Due to the low electricity tariffs charged by ZESCO, many people wait to be connected to the national grid despite the inconvenience, rather than having a mini-grid operated by an investor and paying the investor at the commercial electricity rate. Local consumers need to be sensitized on commercial viability of solar energy investments and the financial benefits of it. (GEF, 2013).

Human Resource Barriers

Although training in renewable energy for officials, utilities and service providers is offered at the country's main institutions, the training facilities offered are not specific to solar PV technologies and do not reflect local priorities (GEF, 2013). There is inadequate skilled and trained manpower in this sector, which may have impact on dissemination and replication of investment projects (*ibid*).

2.4 Business models in solar PV

Due to major structural changes and the paving of way for the broad diffusion of decentralised renewable energy generation, most central utilities are facing major changes, and this will call for different and adaptive business models (Martin, 2009). An example is the unbundling of the production and electricity distribution system from grid ownership and grid operation towards decentralised renewable energy generation (DREG) systems (*ibid*). All these will require revisiting the old models in Zambia, especially given the insights from other countries where electricity from the renewable resource plants is prioritised and supported by feed-in tariffs. The role of the centralised utility will change so significantly that large scale generation and distribution will be significantly challenged (Marko, 2014).

The literature review clearly shows that essentially, profitable business models in solar PV must address and integrate aspects of installation, ownership, operation and financing (Marko, 2014 and Meier, 2014). The benefit must accrue to both the customer and the investor who should enjoy guaranteed electricity rates without assuming much risk while the investor makes adequate returns on investment.

Foremost, the lifecycle costs of the solar PV technology must make economic sense in order to allow for faster diffusion of the technology. In developing countries like Zambia, high interest rates, lack of awareness of financial environment and solar PV investment opportunities are some notable impediments to the diffusion of these systems as highlighted in Section 2.4.5. However, the increase in the global uptake, reduction in global cost of systems, the current electricity crisis and increases in electricity tariffs has sparked an interest in solar PV systems. In the past, the uneven business environment and subsidized electricity disadvantaged businesses from driving the innovation (GEF, 2013). With returns–responsive business models, the building is rapidly becoming an asset capable of generating electricity and income for the mutual benefit of the owner and investor. In particular commercial buildings and their owners/developers are better placed to access financing, leverage on incentives and cushion risk while gaining paybacks from electricity savings.

For the sake of this study, a business model is simply defined as a strategy to invest in energy efficiency interventions and rooftop solar PV system which creates value or money for the company and leads to an accelerated penetration of the technology in the market (Frantzis *et al*, 2008; Würtenberger, 2012). There are many business models in the world for the deployment and diffusion of solar PV which are defined by various factors. In Zambia, a number of business models are in use albeit in relatively early stages of maturation especially championed by ESCOs for specific projects (Hanyika, 2008; Kapambwe, 2011). Since business models revolve primarily around the resolution of financing and lifecycle costs and returns, they depend on many factors such as policy on grid inter-connection, feed-in tariffs, and net metering among others (Meier, 2014) According to Frantzis *et al* (2008), business models can be adapted and modified to suit the local area of consideration.

Frantzis *et al* (2008) attributes the steep growth of distributed PV in the U.S to the shifting to a new paradigm with the potential underpinned by new business models. The same author identifies three basic types of business models based on who owns, benefits and controls the PV system (*ibid*). The first relates to the third party or customer-controlled and owned PV business model where the customer or third party controls as well as owns the system (Frantzis *et al*, 2008:35). "It is considered as the most likely to become established in the absence of outside influence" (*ibid*: 36). The second is the utility-controlled, but third party or customer owned PV business model, where the key difference with the earlier model lies in the operation and control of the systems. This is handled by the utility as a way to increase on its value of assets. The third model is the utility-controlled and owned business model, which represents the greatest departure from the consumer-controlled model. Under the third model, the utility reaches to the other side (consumer-side) of the meter and owns assets and provides a range of services to the customers. Of the three main models identified by Frantzis *et al* (2008), the leading-edge PV models focus on third party ownership, primarily as a means of addressing the barrier of high upfront investment cost of the system, "thus making the technology accessible to a broader market especially given that commercial buildings can be designed/built to generate and supply electricity to the end-user and control the system or later interact with the utility" (*ibid*: 34).

Lessons from leading solar PV markets

Global leading solar markets are found in China, U.S, Germany and Japan. In the case of the U.S, most residential and commercial solar PV markets are transferring to a new third-party model of the solar system ownership (Hou, 2014). Many different companies have come up with their unique business models and third-party finance has helped propel the decentralised solar PV market.

Case study: SolarCity

SolarCity is an American company founded in 2006 that specializes in delivering solar energy services to homes and businesses (SolarCity.com, 2016). Ranking as America's number one full-service provider in solar energy, SolarCity has succeeded in providing an alternative to lower utility bills for thousands of customers and through its model has helped deploy these systems. SolarCity generates its revenues from individual customers, commercial and government entities with high credit through selling solar energy and other energy services and products. Coupled with the provision of the full-service to the customer, SolarCity has established strong linkage with the local building departments and authorities which makes it easier for building owner to go green by knowing in advance how to design solar systems to meet or exceed city electrical and building codes (Hou, 2014). Through this all-in-one service, SolarCity takes care of each step for clean energy revolution, including engineering, permits, financing (solar Power purchase Agreements (PPAs) and solar leases), installation and ongoing monitoring from the beginning to the end of the contract. Other services include energy efficiency services and products aimed at reducing energy loss which eventually lowers customer electricity bill. Apart from these services, SolarCity has established strong sales channels and marketing strategies from door–to–door sales, virtual sales offices to direct outside sales. Although SolarCity is not involved in manufacturing, it purchases adequate components directly from chosen local and international manufacturers at competitive prices. The choices are based on expected cost, warranty, ease of installation and other ancillary costs. By establishing and expanding relationships with customers, suppliers and other third parties, SolarCity's customer base is enlarged.

The profitability of SolarCity's model depends on whether the revenue can cover the cost (variable and fixed) incurred during installation and related solar energy systems. This being the case, it relies to a greater extent on various government incentives to the end users, distributers, system integrators, including tax credits, cash grants, tax abatements in order to provide competitive solar prices and increase uptake of the systems. The Zambian government could take a leaf and provide cost effective incentives that target private investment in solar PV systems.

As stated in Sections 2.3.2 and 2.3.4 concepts such as Independent Power Producers (IPPs), ESCOs and solar companies that are spearheading investments in mini-grids in Zambia could leverage on existing incentives, diversify solar energy service provision and fast attain commercial viability with lessons from SolarCity. The fact that some of the solar companies such as Solartech are already engaged in design, installation and servicing. This coupled with the possibilities of manufacturing some components provides sufficient proof that there are great opportunities in Zambia.

2.5 Net Zero design

In the discourse of energy building projects, the concept of net-zero design cannot be overlooked. Essentially, net-zero energy in buildings is "the measure of a buildings energy performance, so that the building produces as much energy as it uses over the course of the year in operation" (Hootman, 2013: 4). However, the definition of net-zero energy buildings is still somewhat generic and does not adequately inform on the targeted "energy threshold" to optimize the baseline consumption of energy in building prior to the integration of renewable systems (Mcnabb, 2013). Some buildings that are said to have achieved net zero energy status "do so by way of surplus renewable energy generation without optimizing basic building energy consumption" (*ibid*: 38.).

In terms of the renewable energy source classification, a net-zero building can be defined as a "building that offsets all its energy use from renewable energy resources available within the footprint" (Crawley *et al*, 2009:24). Across all definitions and classifications, one design rule remains constant: first tackle demand and then supply. This means that owners and designers should first use all possible cost effective energy efficient strategies and then incorporate renewable energy to address the demand–supply gap, "weighing the many possible supply options and giving preference to sources available within the building footprint".(*ibid:* 24).

Many buildings around the world have already streamlined the net-zero concept and clients and architects are embracing it. Net-Zero design offers the chance to express and resolve and exploit the building potential to resolve energy solutions with program, site and climate (Hootman, 2013). The many benefits of pursuing net-zero energy buildings are social, economic and environmental while offering quality returns and dramatic reduction in greenhouse gas emissions (*ibid*). Even though the process is challenging (often requiring a totally different procurement process and capacities which could be the reason why there are very few existing examples), these types of buildings are being embraced along with their improvements and high performance. In the pursuit of climate change mitigation, and the built environment as a primary contributor, net-zero energy goal should be adopted as a norm in delivering all new buildings as well as the retrofitting of existing stock. Ultimately all buildings (existing and new ones) have the potential for a net-zero energy future. Buildings have a significant impact on energy use and the environment. It is already clear that high performance commercial buildings (some net-zero energy buildings (NZEBs) and some almost NZEBs) can now be constructed cost effectively thus "providing productive environments for occupants, reducing operational costs, and enhancing the competitiveness of commercial property" (Crawley *et al*, 2009:19).

2.6 Building efficiency design considerations

2.6.1 Buildings and climate change

This subject is discussed from both the perspective of the buildings susceptibility to climate change as well as their contribution to it. From the earlier perspective, there is a need to modify the way buildings are designed, constructed, managed and maintained to respond to climate change impacts. From the latter viewpoint, buildings impact on climate primarily by their construction technology and consumption of energy. Owing to growth in population, increased time spent inside buildings, and a shift to more service sectors (covering both public and commercial buildings) with a variety of energy uses (lighting, HVAC, refrigeration etc) energy consumption in buildings world over has increased (Scott *et al*, 1994). Buildings are crucial to mitigating climate change related threats and steer significant transition to sustainable futures, especially due to the following reasons: residential and commercial buildings are estimated to consume 60% of the world's electricity (UNEP, 2016). In addition, the building sector is said to constitute the highest contribution to global GHG emissions and most of their contribution is attributed to their use/consumption of fossil fuel during operation. Given that buildings have relatively long lifespans, energy efficiency interventions taken now in the form of reducing electricity consumption will have continuous benefits for the medium to long-term and presents the cheaper and viable, decentralised option compared to perpetual expansion of the supply-side of the energy infrastructure (UNEP, 2009).

UNEP, through the COP 15 agenda, has therefore prioritised the building sector in the climate change action plans and proposed the adoption of specific policies, building blocks to reduce emissions in both new and existing buildings (UNEP, 2009). The COP 15 strategy states that the building sector has the most potential for delivering least cost effective GHG emission reductions while the failure to adopt energy efficiency and low carbon measure especially in developing countries in new and existing buildings will lock the developing countries into disadvantages of poor performance buildings into the long-term (*ibid*.). The co-benefits of building with energy efficiency would include employment, improved economy and improvement to the social environment.

As a way to mainstream and prioritise the actualisation of this contribution to emissions reduction strategies, the COP 15 agenda calls for support investment into energy efficiency building programs in developing countries as well as the need to develop baselines for building related GHG emissions towards performance monitoring and reporting (UNEP, 2009).

Fundamentally, in scaling up the implementation of energy efficiency measures, countries and decision makers will need to begin with energy performance indicators to measure the energy use and efficiency in buildings (UNEP, 2009). However, in many developing countries there are no existing agreed-on indicators against which energy efficiency performance can be benchmarked. As these indicators are crucial to the mainstreaming of building energy efficiency, there is a need to reinforce them into national and regional levels for effective diffusion (*ibid*). Examples of these performance requirements are often integrated in building codes (especially under mandatory as opposed to voluntary situations such as standards of energy performance and certification of buildings), building commissioning, self-regulation and fine tuning of energy use as well as national greenhouse gas inventories. Building generation of electricity entails that designing for energy efficiency in the building is an important precursor to the whole process.

2.6.2 Potential of buildings energy saving

Energy and architecture have always been intertwined. "Architecture has always been informed by energy resources of its era" (Hootman, 2013: 89). In the industrial revolution era, energy became primarily the realm of the engineer and thus divorced from architectural concerns. This ought not to have happened. All those who are concerned with buildings and use buildings should have some basic fluency in energy (*ibid.*) Net-zero building design offers architects the opportunity to rediscover one of the most fundamentals of architectural design which was displaced by cheap fossil fuels (*ibid*). Energy efficiency in buildings leads to savings on personal income, reduction of consumption and ensures efficiency in installed systems; thereby reducing the need to ration electricity (Kahu, 2014). Technologies for energy and cost saving in buildings range from passive strategies, use of energy efficient equipment, use of advanced controls and renewable energy. However, optimised energy design through passive strategies are very fundamental to the design of a net zero energy building (including natural ventilation, day lighting, thermal mass and shading strategies) (Attia *et al*, 2012). Kahu (2014: 9-10) further argues that the choice of energy saving techniques vary greatly but are influenced by:

- Climate around the site;
- Internal heat gains from occupants and their activities, lights, and electrical equipment;
- Building size and massing;
- Illumination requirements;
- Hours of operation; and
- Cost of electricity and other energy sources.

Relating to occupancy, the following basic energy saving techniques are recommended:

- Siting and organising the building configuration and massing to reduce loads;
- Reducing cooling loads by eliminating undesirable solar heat gains;
- Reducing heating loads by using desirable solar heat gain;
- Using day light as a substitute for (or complement to) electrical lighting;
- Using natural ventilation (whenever possible);
- Using more efficient heating and cooling equipment to satisfy reduced loads; and
- Using smart/automated building control systems.

Strategies for achieving energy efficiency fall into three broad categories as follows:

- Strategies that reduce the whole energy load within the building;
- Strategies that improve the efficiency of the systems; and
- Strategies that involve on-site generation of electricity via the use of renewable energy resources (*ibid*: 10).

Paradis (2012) in the whole building design guide (WBDG) gives some of the building load reduction strategies essential for preparing the building for energy efficiency which should work around the following interventions:

- Fenestration- opening design strategies to achieve building load reduction;
- Air barriers- to bridge or reduce the degree of air infiltration through the façade;
- Wall, roof and slab- reduce the use of energy and taking advantage of building envelope by balancing insulation;
- Optimize natural daylight and provide daylight dimming controls for perimeter areas;
- Variable Ach (Air change per hour) Ventilation rates;
- Lighting and occupancy sensor lighting controls;
- High efficiency chiller systems;
- Cogeneration- combined heat and Power; and
- Energy recovery.

2.6.3 Building energy modelling, simulation and analysis

Buildings are complex physical objects. They interact with their immediate surroundings while trying to provide a comfortable living and working environment to the occupants. By providing comfortable thermal, visual and acoustic indoor environmental conditions, buildings do so by consuming energy (Rallapalli, 2010). The way a building performs is dictated to a greater extent by the choice of building materials and components incorporated in building enclosures (walls, windows, roofs), and different systems (lighting, HVAC, etc.).

In recent years, the variables affecting energy use have increased so much that understanding the behaviour of the building has become a very daunting task. However, technological advancements in computer software have provided energy modelling, simulation and analysis tools that are more effective at predicting energy performance once the building is operational. These tools are capable of dynamically modelling thermal, visual, ventilation and other energy consuming processes taking place within a building to predict its energy and environmental performance (Rallapalli, 2010). The energy calculation processes take into account the external climatic factors, internal heat sources, building materials and systems to accurately model the building. Using building energy simulation tools to study energy performance in buildings is crucial for evaluating architectural design decisions as well as choices for construction materials and methods (*ibid.*). Complicated design issues can be examined, and their performance can be quantified and evaluated.

2.7 Key elements of a solar PV system

2.7.1 Grid-connected verses Stand-alone solar PV systems

The extent of decentralization usually determines whether the system operates in either grid-connected or stand-alone mode. According to Kaundinya *et al* (2009), grid-connected systems can be distinguished into two types. In the first type, the system's main priority is to carter for the local electricity needs and any surplus generation is fed into the grid, and when there is a shortage, electricity is drawn from the grid (*ibid.*) The other option is the utility-scale, wherein decentralised stations are managed by the utility in the same way as large electric power plants and any output is fed into the utility grid without paying heed to local needs. Stand-alone systems on the other hand produce power independently of the utility grid. Most stand-alone systems are more suitable for remote locations where the grid cannot penetrate and there is no other source of energy. Dali *et al* (2010) state that essentially stand-alone consist of the array, battery bank, charge controller, inverter, protection devices and the system load. Notwithstanding its wide application in most small systems, stand-alone systems suffer from inert disadvantages like low capacity factor, excess battery cost and limited capacity to store electricity forcing them to essentially throw away the extra electricity generated (Kaundinya *et al,* 2009).

2.7.2 Photovotaic power system components

Solar photovoltaics (PVs), solar cells, or just PV are systems or electronic devices that convert solar radiation to electricity (IRENA, 2015). They are distinguished from solar thermal panels which use solar radiation to heat water, air and other media (*ibid*). Generally, a photovoltaic power system will consist of the components mentioned under the stand-alone system. These are briefly discussed below:

Solar photovoltaic panel/array

This is the main component of the PV system. A combination of the panels connected in series and parallel create an array or PV module (Saleh *et al*, 2015).

PV cell technologies have evolved in terms of the primary material used and level of commercial maturity; from the first generation of wafer-based crystalline silicon (c-si) technology to the second generation-based on thin-film amorphous silicon (a-si) technologies and the third-generation systems which include concentrating PV (CPV) and organic PV cells which have recently passed the demonstration stage (Abd El-Basit *et al*, 2015*)*. The crystalline silicon-based modules have continued to dominate the market. New advanced versions of monocrystalline (mono-Si) have emerged with greater efficiencies owing to their high-quality surface passivation meaning that they have higher bulk carrier lifetimes (ibid.)

Storage batteries

Storage batteries are used to supply the load during non-sunshine hours whilst being charged by the PV during periods of high solar radiation. Although most grid-tied systems will use the grid for backup some would have smaller capacity storage systems in addition to the grid (Dali *et al,* 2010).

Charge controller

The charge controller (also known as voltage regulator) coordinates the power flow between the PV array and the battery hence protecting the battery from voltage fluctuation. The ultimate charge controllers are the Maximum Power point tracking (MPPT) with efficiencies in the range of 94% to 98% and provide more power to the battery. Modern inverters come with in-built charge controllers.

Inverter

An inverter (also known as a power conditioning system) is essential to meet the load requirements. Most applications in a building use alternating current (AC) whereas PV module and battery banks produce direct current (DC). The inverter converts DC power to AC power in a PV system (Saleh *et al*, 2015).

Balance of system components

Components such as protective devices, blocking and bypass diodes, lightning protection system and cable wiring constitute what is known as the balance of system components.

Loads

Loads are the power consuming units of the PV system. Proper load estimation is necessary when designing a PV system. This can be done through an inventory of the equipment or simulating the load using appropriate load standards per square meter.

2.7.3 Technical aspects (components and performance)

While the solar PV systems have systematically developed, the basic solar PV system accessories are rapidly improving in performance as well. The capacity of electricity generation from a PV installation is modelled as shown in the following equation:

E= A x r x H x PR, ………………………………………………………………… (1)

Where:

E is the average annual electricity production (kWh)

A is the total area of PV (m^2)

r is the solar panel yield (kWp/area of 1 panel)

H is the solar irradiation ($kWh/m^2/year$)

PR is Performance ratio (ratio of conversion of solar radiation to electricity).

2.7.4 Levilised cost of electricity (LCOE)

"Levilised cost of electricity is used to evaluate the financial viability of solar PV generation and is denoted as the price of electricity needed for a solar PV venture where revenues would equal costs, including making a return on the capital invested equal to the discount rate,"(IRENA, 2014: 92). Abd El-Basit *et al* (2015) describe the LCOE as the cost per watt of the solar cell modules affected by the recurring costs of operating and maintenance of the system. The levilised cost in $/kWh is given by the equation:

E = 105 (C.F)/U.S) + OM. It is the ratio of the total costs incurred throughout the life of the system, divided by the number of peak kilowatt hours of energy the system produces in its useful life.

C: is the installation cost of the system in $/Wpk.

S: is the ratio of the energy in kWh generated annually to the power rating of the system in kWPk such that under ideal conditions, S equals the number of hours in a year divided by the daily average to peak insolation.

U: is the utilization factor, accounting for factors that tend to reduce system output or its value.
OM: is the operation and maintenance cost, $/kWh.
F: is the fixed-charge rate that represents the cost of financing the system. It is equal to the sum of the annual capital-related charges divided by the initial installed cost of the equipment.

2.7.5 Grid parity

Most literature acknowledges that PV has made remarkable advancement in dropping costs and is rapidly approaching grid parity thus competing with fossil fuels in terms of levelised costs. IRENA, 2015 defines grid parity as "the point where the LCOE of PV, without subsidies, is the same or lower than the conventional electricity price, excluding taxes" (IRENA, 2015: 15).

2.7.6 Cost parameters:

The cost of a PV system is largely made up of PV module costs and balance of system (BOS) costs. The PV module normally takes up a third to a half of the total capital cost of the system (IRENA, 2015). Other contributors to the cost of PV arise from operation and maintenance. Most of the literature states that with the fast-growing PV market, efficiency in modules, and advanced storage systems, the cost of PV systems will continue to decline (IRENA, 2015; Abd El-Basit *et al* ,2015).

2.8 Conclusion

The literature reveals that there is unprecedented interest in renewable energy which is especially triggered by climate-change related threats. The solar PV industry is poised to assume a bigger role in global energy markets because of its continued drop in the installation costs. The literature also reveals that Zambia has rich solar resource and relatively low levels of conducive investment environment. By using appropriate business models as shown from the case study of SolarCity, Zambia can adopt the lessons and leap frog many developed countries in solar electricity generation by building on its resource potential and enhanced regulatory/policy frameworks. It is also evident that building scale electricity generation is fast becoming commonplace. By achieving energy efficiency and optimization through design procedures, buildings can reduce the amount of electricity consumption and attain decentralised electricity generation as pathway towards net-zero energy buildings for both new and existing stock.

Chapter 3. Research method

3.1 Introduction

The study involved an assessment of a case study to determine the potential of a site-specific building to adopt energy efficiency initiatives and generate enough electricity to offset the demand and possibly export the surplus to the grid. In addition, the study sought to review the design of the EIZ building to integrate energy efficiency measures/interventions and optimise the building for solar PV electricity generation. Following this, an appraisal of the support policy, regulatory and market potential was undertaken in order to conceptualize a business model that would potentially drive the market penetration of this system. This section presents the methods used in collecting and analysing the data in order to answer the sub questions presented in Chapter 1. The chapter begins by presenting the research approaches and methods used for collecting data followed by the section on methods used to analyse the data and derive findings. The chapter ends with a section that highlights the ethical considerations that were made.

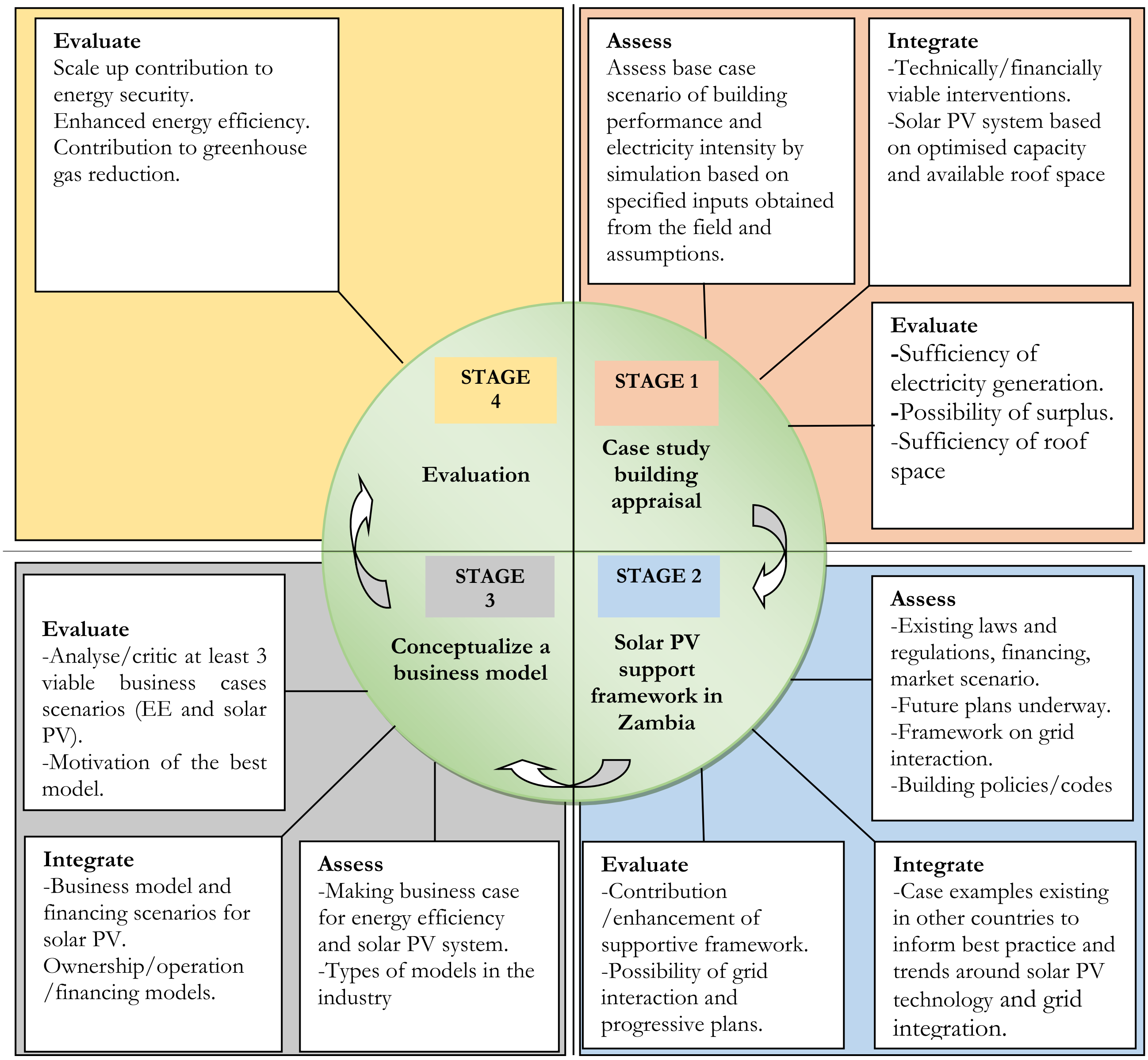
3.2 Research design approach

The study adopted a qualitative research methodology in data collection and analysis as the main method for the investigation. The method applied the framework of a case study where the EIZ building was examined, analysed and tabulated to evaluate the potential of electricity generation through rooftop solar PVs and the possibility of adopting building electricity efficiency interventions. A case study research is an experimental inquiry that investigates a contemporary phenomenon within its real life context where the boundaries within phenomena and context are not clearly evident and in which multiple sources of evidence are used (Sarantakos, 2005; Yin, 1994). It therefore allows in-depth investigative research and "permits exploration and understanding of complex issues" Zaidah (2009 cited in Kahu, 2014: 36). Studying the EIZ building assisted the study in appraising the real-life dynamics and processes associated with a building that was still in the construction stage but in which an energy upgrade project could be incorporated. In addition this case study contributed to the understanding of the scale-up contribution of decentralised rooftop solar PV electricity generation from a building towards the enhancement of energy security and reduction in greenhouse gas emissions for Zambia.

In this research, an explorative case study approach was appropriate because it facilitated for the assessment of the effectiveness of the building system optimization towards distributed/demand-side electricity generation. According to Yin (1994: 5), "if the research question focusses mainly on the "what" question, it is justifiable rationale for conducting an exploratory study, the goal being to develop pertinent hypotheses and propositions for further inquiry".

The question was to determine the potential of building scale electricity generation from the EIZ building and then to conceptualise a business model based on the policy, regulatory environment and other factors that support or hinder the wide scale deployment of such technologies in the country. In order to achieve this objective, a simple four stage process was followed in addressing the salient sub-questions and reporting the key findings. Figure 5 below illustrates the process followed by the study.

Figure 5: Research design and overall approach



The first step was to establish the baseline electricity consumption for the EIZ building. In order to determine this, the building was modelled in *DesignBuilder*, an energy modelling software and then simulated with Energyplus. Pullock, *et al* (2007 cited in Kahu, 2014: 37) highlights that simulation of a case is an appropriate approach for the evaluation of buildings of all types in order to assist in the delivering of sustainable green buildings and "high rating of energy performance." Section 2.6.3 highlights the necessity of building energy modelling and simulation in determining energy baselines.

In order to run an effective simulation and obtain authentic outputs, the required inputs were fed into the software. Most of the information that was inputted in the software and primarily based on data extracted from the building drawings. However, the drawings were not explicit with regard to some of the required data such as specifications of elements, materials and schedules. Logical assumptions were therefore made. Given that the building was not occupied, and the prospective tenants had not yet been determined, details relating to plug/equipment loads, occupancy schedules had to be assumed based on appropriate standards and practices in the use of offices. The project referred to the South African Green Star and the American Energy Star standards for most parameters to establish the environmental goals and to guide the model and analysis process (GBCSA, 2013; Autodesk sustainability workshop, 2015). It should be noted that due to either the lack of or weak green building standards in Zambia, most building projects refer to the South African standards. This is also logical given that most of the building materials and products are imported from South Africa and China. Details of these assumptions that were inputted in the model were systematically presented in Chapter 4, Section 4.5.2.

The next step was to ascertain the solar PV generation potential of the building. This procedure involved a calculation to estimate the roof area in order to determine the capacity and output of the system. This was essential because according to Hootman (2013), conducting a resource assessment helps to ascertain the constraints imposed by the building at the outset where the available roof space constitutes one such constraint. This assessment was done through a user-friendly online tool (LG solar calculator) that made the estimation of solar PV output from the available roof in a straightforward manner. The estimated output was then compared with the simulated baseline electricity consumption to guide necessary interventions for optimization and deriving estimates on surplus generation. Details of how the estimated roof capacity was calculated and the assumptions of the building's best-case interventions to attain maximum electricity generation capacity are presented in Chapter 4. After the potential of electricity generation was estimated, another procedure of establishing the potential and amount of electricity for export followed. Here, prioritised passive and active interventions were applied for simulation in order to reduce the simulated baseline load to a level below the estimated potential of solar PV system.

The next stage involved establishing the support environment and frameworks that would influence the building-scale decentralised solar PV generation in Zambia. Interview data and secondary data were collected and applied to appraise policy and regulations on grid interactive possibilities and applicable tariffs. Policy documents on the Global Energy Transfer Feed in Tariffs (GET-FIT) Zambia initiative (which is aimed at promoting grid-connected renewable energy with a focus on small-scale grid-connected RE generation projects (1MW – 20 MW)), and the scaling-up solar project by the industrial development corporation (IDC) were used to explain the current strides and policy direction of solar PV sub-sector. The policy and scale-up project appraisal also formed the main bedrock of explaining the progressive policies on grid interactive distributed generation.

After this had been done, the procedure to select the appropriate business model was undertaken. This started off with analysing the financial viability of the different adopted energy efficiency interventions and the solar PV systems based on the findings of the simulation process. The financial analysis methods as well as the scenarios considered for evaluation are presented in Section 6.2. Based on the findings of the analysis of the rooftop solar PV market, policy and regulatory environment as well as the analysis of the different business cases for both energy efficiency interventions and solar PV systems, a business model was conceptualised. Through a strength, weakness opportunity and threat analysis, different models of ownership, operation and financing of the rooftop solar PV system were analysed for their ability to address the identified barriers in the scale-up deployment of this technology. The models were also appraised for their ability to take advantage of the progressive policies currently in place.

In the final stage, the building scale electricity generation from the case study was evaluated for its potential scaled-up contribution to the energy security of Zambia and its ability to guide progressive policy formulation/standards to deal with such initiatives. In addition, with reference to the literature appraisal presented in Section 2.7.1 on buildings and their contribution to greenhouse gas emissions through their energy use intensity, an evaluation of the case study buildings contribution to reduction of greenhouse gas emission and climate change mitigation was undertaken and presented in Section 6.5.

3.3 Research data and data collection tools

In order to address stage one of the research, the data required included predicted whole building baseline energy use data of the EIZ building which was based on the design specifications. As earlier stated in Section 3.2 of this chapter, other data required to complete the first stage such as the predicted tenancy energy use and end-use energy consumption from electrical equipment, lighting and appliances (E.g., HVAC, IT, services, office equipment, lighting, elevators, water heating, etc.) were referenced from appropriate standards such as the Green Star and Energy Star (GBCSA, 2013, Autodesk sustainability workshop, 2015)).

Apart from that, data on the roof area and design, type of building facades and elements such as shading, and their effects, orientation and massing were obtained. This data was necessary to identify weak areas and opportunities for energy efficiency intervention in order to accurately optimise the base load case and do the initial estimation of the solar PV system size. The data was collected through interviews with the project manager of the EIZ building and the client representative. Furthermore, both AutoCAD and printed EIZ building drawings were obtained from the project architects (A+ urban technics), and included the latest revisions of floor plans, electrical drawings and specifications. In order to supplement this data, a survey of the building was done through a site visit where still photos of the building under construction were taken, together with informal/open-ended interviews with the clerk of works on the site.

Other data required to complete stage one was the general weather data of the case study area that were required for the simulation for heating, day lighting and cooling. With data on the prevalent weather, design weeks and days, additional data on incident solar radiation for the building orientation and optimum tilt angles for different months were equally important for determining the electric loads of the building. This data was obtained from the online weather sources such as (Weatherspark.com, 2016) while more detailed data on the same were utilised from the weather files embedded in the DesignBuilder simulation software.

Stage two involved investigation of the support mechanisms for the possibility of the rooftop solar PV system to interact with the grid. This was done with reference to the findings of the first stage regarding the possibility of surplus generation. The main data collection tool for the investigation was semi-structured face to face interviews and discussions. The desk research for secondary data was also used to establish the structure and current state of Zambia's solar PV sector; the laws and regulations that govern and shape the sector, including general measures that impact on tax and investment and other political, social and economic factors that have a bearing on investment in solar PVs.

Semi- structured interviews and discussions were conducted with six stakeholders who had been purposefully sampled. For the semi-structured interviews, the interviewer prepared some open-ended questions to guide the interview process but added or omitted questions depending on responses by the interviewee. The strategy of the interview process was to achieve as much scope as possible. The participants (key informants) were therefore selected from a variety of backgrounds while ensuring their expertise in their respective field. Interview sample questions have been attached in the Appendix section of this report.

A key informant responsible for the renewable energy section at the Zambia Electricity Supply Corporation Limited (ZESCO), the national electricity utility company, was interviewed for information regarding the utility's general policy and plans regarding grid interaction and infrastructure. In addition, the interview focused on the possibility for feed-in tariffs and ZESCO's involvement in exploitation of decentralised building scale electricity generation from rooftop solar PV.

The researcher also conducted an interview with five experts at the Department of Energy-Ministry of Mines, Energy and Water Development (DoE-MMEWD) and one expert from the Office for Promoting Private Power Investment (OPPPI) in order to obtain data on policy direction on investment in decentralised solar PV electricity generation. This data assisted in the analysis and sub-findings presented in Chapter 6. In addition, an expert from the Centre for Energy, Environment and Engineering Zambia (CEEEZ) (an independent non-governmental organisation involved in close collaboration with government and various institutions) was interviewed in order to gain insight on the general research and development and capacity building on solar PV. The organisation has also been involved in a number of consultancies with international organisations on environmental issues such as the Zambia country study guide on Climate Change and GreenHouse Gas emission which is supported by Deutsche Gesellschaft Internationale Zusammenarbeit (GIZ). Most recently, the expert interviewed in this case, was involved in the formulation of the feed-in tariff policy and the execution of the 100MW utility solar mini-grid initiative by the Industrial Development Corporation (IDC) and the World Bank. In connection with data on available financing mechanisms and donor support initiatives, a representative from a leading NGO by the Keeper Zambia (which oversees the Power Africa initiative) was interviewed. A representative from Stanbic (a banking institution which is leading in financing renewable energy investments) was also interviewed. This bank was selected because it was the major funder of rooftop solar PV related projects with a dedicated division for rooftop solar PV investments in Zambia. Data collected included the financing conditions, interest rates and the general economics surrounding investments in solar PV which are presented in Section 5.4.3.

Data on the regulatory environment on solar PV electricity generation and technologies in Zambia was obtained by interviewing an expert from the Energy Regulation Board of Zambia (ERB-Z) which is the country's energy regulator. However, since this organisation collaborates with the central utility and the department of energy, these bodies also supplemented information about the regulations related to decentralised solar PV electricity generation. Information on regulations related to building industry standards pertaining to solar PV electricity generation and energy efficiency were obtained through interviewing a representative from the upcoming Green Building Council of Zambia.

Data relating to the solar PV technologies market, emerging local market trends, available channels and products, entry strategies, customer segments, people's behaviour towards embracing the technology and some applicable business models were obtained by interviewing an expert at one of the local leading solar PV companies. This interview also supplemented information regarding the responses from the solar PV companies and consumers regarding the incentives and procedures that the government has put in place.

Interview questions were adapted to respondents and focussed on the collection of views and information relating to policies, markets, products, and regulations on solar PV electricity generation from buildings. Interviewees were asked to comment on as many aspects as possible and dwelling on current plans/policies and debates which might influence conditions in the future in order help in theorising on future possibilities.

The interviews were recorded using an audio recorder with permission from the respondents, except for one specific case where the respondent objected to an audio recording. In this case, hand notes of the main points of the responses were taken.

3.4 Sample and sampling techniques

A purposive sampling technique was used where the case study was chosen because it fell within the category of buildings which are transforming in order to operate fully on decentralised electricity generation from rooftop solar PVs. The participants interviewed for the study were purposefully chosen by virtue of their being key stakeholders and actors in the energy sector in Zambia.

3.5 Data analysis and interpretation

In order to analyse the baseline energy consumption of the building which was at the construction stage and make appropriate recommendations related to the selection of the most suitable optimization interventions, a building energy simulation tool was used. Building energy simulation is an analysis of the dynamic energy performance of a building using computer modelling and simulation techniques (Rallapalli, 2010). Such tools support the integrated use of multiple investigation and visualization during the design evolution process—from the conceptual and schematic phases to the detailed specification of building components and systems (*ibid.*).

There is a wide range of simulation tools available today which help predict various aspects of building behaviour such as energy performance, acoustical performance, fire movement, anti–seismic performance, and life cycle assessment simulators among others. For this study, the building was modelled using DesignBuilder version 4.7 and simulated using EnergyPlus version 8.3 which comes pre-installed with DesignBuilder. A simple procedure in going about the creation of the computational model and simulation (which anyone with basic building engineering knowledge could do) are presented in more detail in Section 4.5.

3.5.1 DesignBuilder software

The DesignBuilder software is arguably the most popular interface developed for EnergyPlus that includes a simplified CAD interface, templates, wizards, and most compact air system configurations of EnergyPlus. The building geometry represents the definition of geometry needed for the simulation of the building's thermal performance. In addition, one can import DXF files from compatible software as footprints for the creation of the geometric model. DesignBuilder software is known to be the oldest, most user friendly and arguably the most powerful graphical user interface UI to EnergyPlus. (Ibarra & Reinhart, 2009)

3.5.2 Energy Plus simulation engine

EnergyPlus is argued to be the most advanced and sophisticated building load simulation and energy analysis program available today (Rallapalli, 2010). It has become one of the most widespread energy simulation/ modelling software among architects, engineers, and researchers.

It has superior capabilities and sub-hourly time steps in simulation which renders it as one of the most powerful software for energy analysis and energy efficiency design for buildings.

In order to have an accurate energy analysis of the case study building using EnergyPlus, the procedure required the entering of data representing the building and its operational conditions. A geometrical model of the EIZ building was created, its orientation and location (longitude, latitude, and elevation) defined, and its corresponding weather file chosen as Lusaka weather file. Weather files in EnergyPlus consist of average weather data for a specific location as created from data recorded over a long period of time. Appropriate construction materials must be inputted into the software in order to allow for the calculation of the heat transfer rates throughout the simulation. Internal gains were used to estimate the loads inside the building thus allowing for the right choice of the HVAC system. The HVAC system schedule was also defined, and a customised equipment schedule was set. While each room could be simulated as a thermal zone, some rooms of similar activity and those which shared similar conditions were combined into single zones. This also helped in the reduction of simulation time and data input requirements.

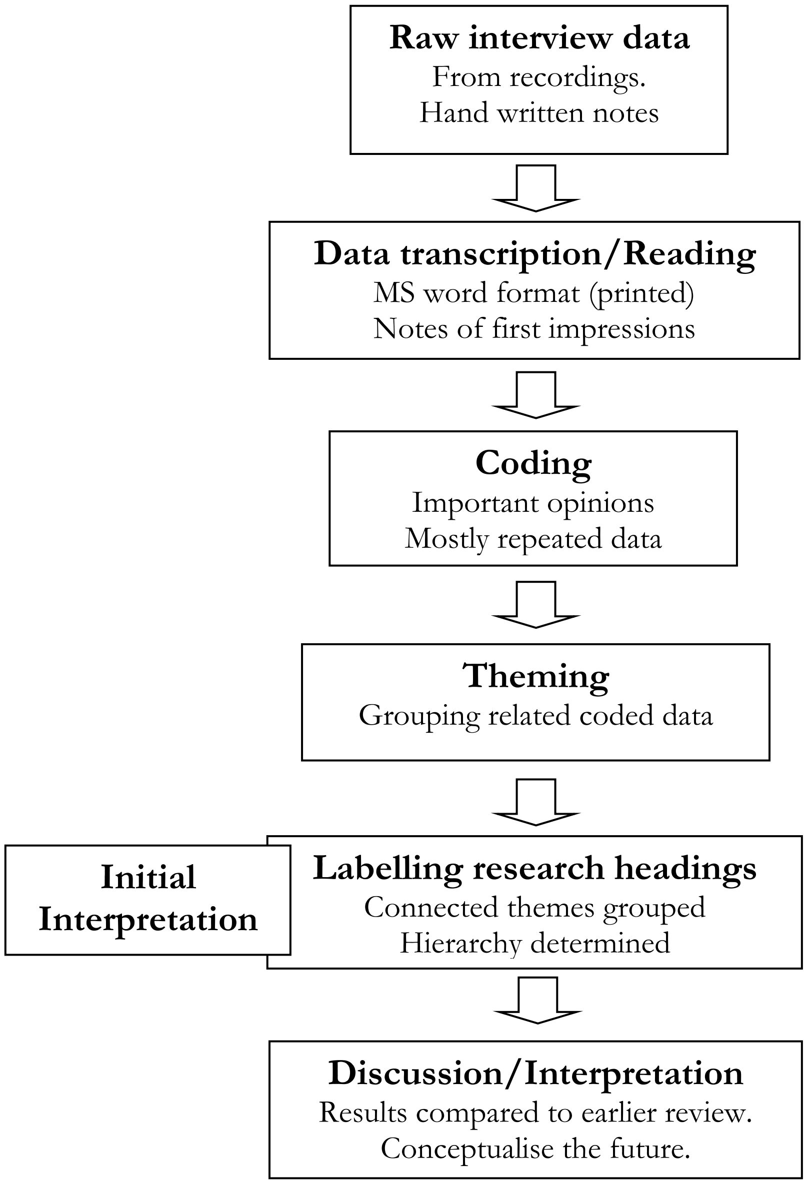
3.5.3 Data analysis from interviews

As earlier mentioned, interview data were mainly utilised to address stage two, three and four of the research which involved an investigation on the possibility of surplus generation and policy requirements that affect grid interaction. Furthermore, this information was used to guide the conceptualization of a responsive business model. Analysis of interview data was done using a simple six stage process as adapted from Creswell (2009) and shown in Figure 6.

After the interview data was transcribed into a Microsoft Word document, the first step involved a browing through the entire set of transcripts. Thereafter, the author made general important notes of the first impressions from the interviews. The transcripts were then re-read but this time one by one in a careful manner, line by line to coordinate the views of the interviewees. The second step involved coding of the data in which relevant pieces of data were labelled (with multi coloured highlighters on printed transcripts) based on the data being identified as either a responsive phrase or word. Data was coded and expressed as either an opinion or by how much emphasis the interviewee used, and how it related to secondary data reviewed in Chapter 2.

The next step was to identify the most important codes selected depending on how much they related to the interview data needed, for instance on responding to the policy on grid interaction, and solar PV exploitation research sub-questions. These selected codes were grouped together to form themes. Following the development of themes, most connected themes such as those dealing with grid interaction and feed in tariffs, building energy efficiency, and financing were grouped into discussion themes and placed in an order that the author deemed the most hierarchical. This is presented in various sections in Chapter 5. In each theme, interpretation of the data is initially made followed by a discussion section on general findings which are then compared to the data appraised in the literature review as well as what had been envisaged under the working hypothesis of the study as presented in Chapter 1.

Figure 6: Process of analysing interview data (Source: Adapted from Creswell, 2009)



Utilising the findings in Chapter 5, the next procedure was to motivate for an appropriate enabling mechanism and business model to scale up the opportunity of decentralised electricity generation from rooftop solar PV based on the identified progressive support mechanisms and existing barriers. Making a business case was done as a precursor to conceptualising a business model. The main financial analysis tools that were used are the Payback Period, Return on Investment (ROI) and the Net present Value (NPV) which are discussed in detail in Section 6.2.1. By using a general template adapted from the work of Würtenberger *et al* (2012), some identified potential business models were analysed for their ability to address barriers and increase the deployment of the technology assuming an ideal case of all supportive policy. A simple SWOT analysis of the identified models preceded conceptualisation of an appropriate model.

After motivating for a business model, the final analysis involved the key findings of the study. Interpretations of the scale-up contribution of decentralised electricity generation was carried out by comparing current plans towards improving electricity generation capacities and methods. Based on the findings of the opportunities of reducing energy intensity in buildings and CO_2 emissions by adopting decentralised rooftop solar PV technology, the resultant contribution to reduction in GHG emission was evaluated. In particular a comparison between the GHG emissions levels as a result of moving from fossil fuel-based electricity generation to rooftop solar PV generation was analysed. The whole research design approach is summarised in the table below.

Table 1: Summary of the research design approach

Research sub-questions and overall research question	**Data needed and data collection tools and processes.**	**Data analysis processes**
What is the baseline consumption of the case study building and what opportunities exist for energy efficiency intervention or optimization?	*Primary data needed.* - Predicted whole building energy use data of the new EIZ building based on the design specifications and building energy performance of the existing building. - Predicted tenancy energy use and end-use energy consumption (E.g., HVAC, IT, services, office equipment, lighting, elevators, water heating, etc.). - Identified the weaknesses in the design for energy efficiency in respect to building elements, materials, day lighting, building massing and form. - The incident solar radiation for the building orientation and optimum tilt angle for different months? *Primary data collection tool.* -Data was collected through interview of key informant at EIZ and review of building drawings and specifications. -Data was collected by reviewing current office building activity data, employee lists, review of drawings for areas and electrical specifications. - Surveyed the building - The data was collected through observation and review of data from the local climate experts. *Secondary data needed.* - Office building design standards and requirements - Procedure for redesign and retrofitting. - How to optimise building energy. *Secondary data collection tool* - Data was obtained through review of books from the internet and library.	- Categorised the data for energy use calculations. - Inputted the data in Building energy modelling and analysis software (Design builder) and environmental analysis software and optimized building performance by employing energy modelling. - Inputted mean data and simulated energy consumption for different conditions and predicted behaviours for different systems. - Minimised energy consumption by undertaking thermal and daylight analysis by manipulating data fed into the model. Proposed passive interventions. - Simulated for daylight and determined the availability of natural light reaching the interior space. - Presented the data and results from analyses through graphical display- load curves, tables, maps, drawings and pictures

What is the capacity of solar PV generated electricity in the case study building and how does it compare to optimised energy consumption of the building?	*Primary data needed.* - Roof area and design. - Building façade orientation. - The appropriate type of solar PV system for the case building in respect to capacity, cost, design etc. - Specific brief system requirements from the building owner (EIZ). *Primary data collection tools.* - Reviewed building drawings. - Interviewed with solar energy expert (solar company, distributer and manufacturer). - Interviewed key informants (client and project manager). *Secondary data needed.* - The most suitable type of solar PV system for the case building? - The most suitable energy efficient components to be incorporated. Secondary Data collection tool. - Documents were reviewed for design guidelines. -Internet sources were reviewed for company products. - Whole building design guides.	-Inputted data in the software and modelled the building in Design builder software. - Evaluated and predicted generation capacity and performance behaviours of different systems by simulation of different conditions to select the type of system to be used. -Simulated energy retrofits/ passive strategies to archive mean optimum consumption of the building. - Compared mean values of solar PV electricity generated and optimum consumption and load demand then presented the data in a comparison chart or table.
What is the opportunity for surplus export to grid and what would be the supportive frameworks required for such grid-interactive distributed-generation?	*Primary data needed.* - The maximum power produced by the solar PV system to supply the load and charge the battery in the simulated case. - The simulated consumption pattern and peak demand time. - The regulatory framework regarding grid interaction - The possibility for feed-in tariffs and revenue stream? - What regulation exists for infrastructure - The utility's policy. - What building types make-up the nearby community? *Primary data collection tools.* - Modelled and simulated the case with Design builder. - Surveyed of grid infrastructure - Interviewed and discussed with an expert from the supply utility. *Secondary data needed.* - How to optimise the solar PV system by design for surplus generation. - Cost benefits of grid interactive - Policy and regulatory frameworks in Zambia. *Secondary data collection tools.* - Desk research and review of literature.	- Segmented different energy loads. - Total energy intensities were plotted against the area to examine the distribution of intensity within the building - Simulated for the best option load type to be used in the model and tested different situations for surplus. - Prepared and organised the data from interviews and discussions; read through all the data to obtain a general sense of the information; coded the data by theme with the computer in order to represent it in a qualitative narrative, and finally made an interpretation of the meaning of the data.

What would be the responsive business model (including funding and financing arrangements) and what policy or regulatory mechanisms would be required to catalyse the scale-up of such opportunities in new and existing buildings?	*Primary data needed.* - The kind of business models being implemented by solar PV companies. - Some of the existing sources of funding/financing for solar PV based investments in Zambia. -The specific policies and regulations governing investment in building generation of electricity from solar PV grid-interactive systems. -The market distribution channels available in the solar PV market to reach the different segments of customers. *Primary data collection tool.* -Semi- structured interviews with key informants-expert from organisations, government agency, financial institution, solar PV Company etc. *Secondary data needed.* -How to develop solar PV business models. -Examples of effective solar PV business models for commercial buildings. *Secondary data collection tool.* -Reviewed of literature on business models from books and internet sources	Prepared and organised the data from interviews and discussions; read through all the data to obtain a general sense of the information; coded the data by theme with the computer to be represented in a qualitative narrative, and finally made an interpretation of the meaning of the data.
What would be the case-study and scale-up contribution to climate-change mitigation and enhancing of energy security for Zambia?	*Primary data needed.* - Zambia's carbon goals. - Statistics of contribution to greenhouse gas emissions from commercial buildings. - Scale of measuring climate change mitigation from buildings generating electricity from solar PV. *Primary data collection tool.* - Interviewed key informants involved in climate change studies. - conducted an inventory of greenhouse gas emissions *Secondary data needed.* - How to mitigate climate change through buildings. - Existing examples *Secondary data tools.* - Literature review and archival data.	Prepared and organised the data from interviews and discussions; read through all the data to obtain a general sense of the information; coded the data by theme with the computer to be represented in a qualitative narrative, and finally made an interpretation of the meaning of the data. Presented findings in tables and graphs.

3.5 Ethical considerations

According to Orb, Eisenhaur, and Wynaden, 2000), ethical problems in qualitative research are more subtle than in quantitative research (*ibid*).

This research was guided by and adhered to the University of the Witwatersrand's research ethical principles in relation to human subjects/participants. Ethics review and clearance was obtained before commencing the research (a copy of the ethics clearance certificate is attached in the Appendix part of this report). Formal permission to use the case study building drawings and access the site was obtained from the project architects (A+urban technics). The letter of permission is attached in the Appendix part of this report.

Access to the participants was achieved by means of an introductory letter from the University and consent from the participant was obtained before commencing with the interviews. The researcher used legal funding sources. In qualitative research, the researcher participation may often lead to subjective interpretation of data and findings. The researcher therefore endeavoured to be genuine and objective in reporting of the data and findings. Sensitive information such as relating to incomes or proprietary business information was not disclosed unless with specific permission from the participants concerned.

Chapter 4. Determining the potential of electricity generation via roof top solar PVs from the EIZ building

4.1 Introduction

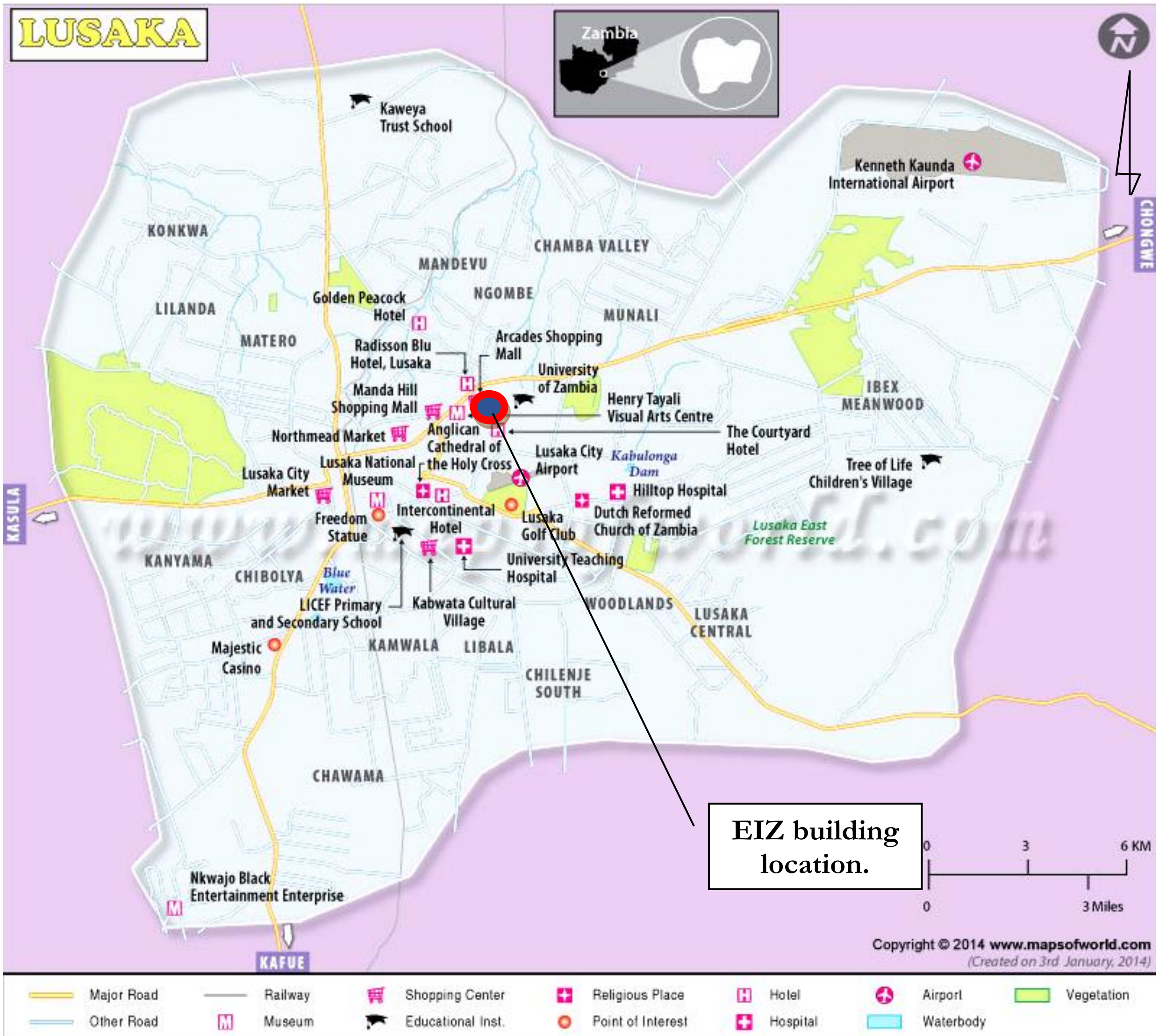
This chapter provides the analytics carried out to arrive at the preliminary findings of the study on the potential of electricity generation from the EIZ building. The chapter starts off by introducing the case study context area and a concise description of the case study building in terms of the construction, site, specifications and targets needed to ascertain the base case scenario. Thereafter, a section dedicated to the procedure followed in determining the base case using the DesignBuilder software is presented. The software inputs and interaction are also highlighted. After the presentation of the base case findings, a section proposing interventions to optimise the baseline electricity consumption followed with the reporting of the results. The chapter ends by presenting the preliminary results.

4.2 A brief on Zambia

Zambia is a Southern African Development Community (SADC) country covering an area of 752,618 Km^2 and is endowed with diverse natural resources, geographical locations and economic activities in many sectors including energy. The country's economy is heavily dependent on copper mining and rain-fed agricultural production. Copper mining also accounts for a significant consumption of energy followed by residential and industrial sectors (ERB-Z, 2014). Although Zambia is said to be a very good local and international investment destination owing to its political stability and flexibility in doing business, unstable policies instigated by successive regimes continue to create an unstable environment thus distorting development plans (US foreign commercial service and department of state, 2011). Most sectors are uncompetitive, thus leaving plenty of room for new entrants. Great opportunities abound in many sectors including manufacturing, agriculture, energy, and construction (*ibid*). There are commercial opportunities emerging in Zambia. The emergence of a middle class in the major cities and provincial towns has resulted in a proliferation of many South African retail franchises, a construction boom primarily focussing on commercial buildings (with South African architectural influence), and a formidable (although risk averse) banking sector. (US foreign commercial service and department of state, 2011).

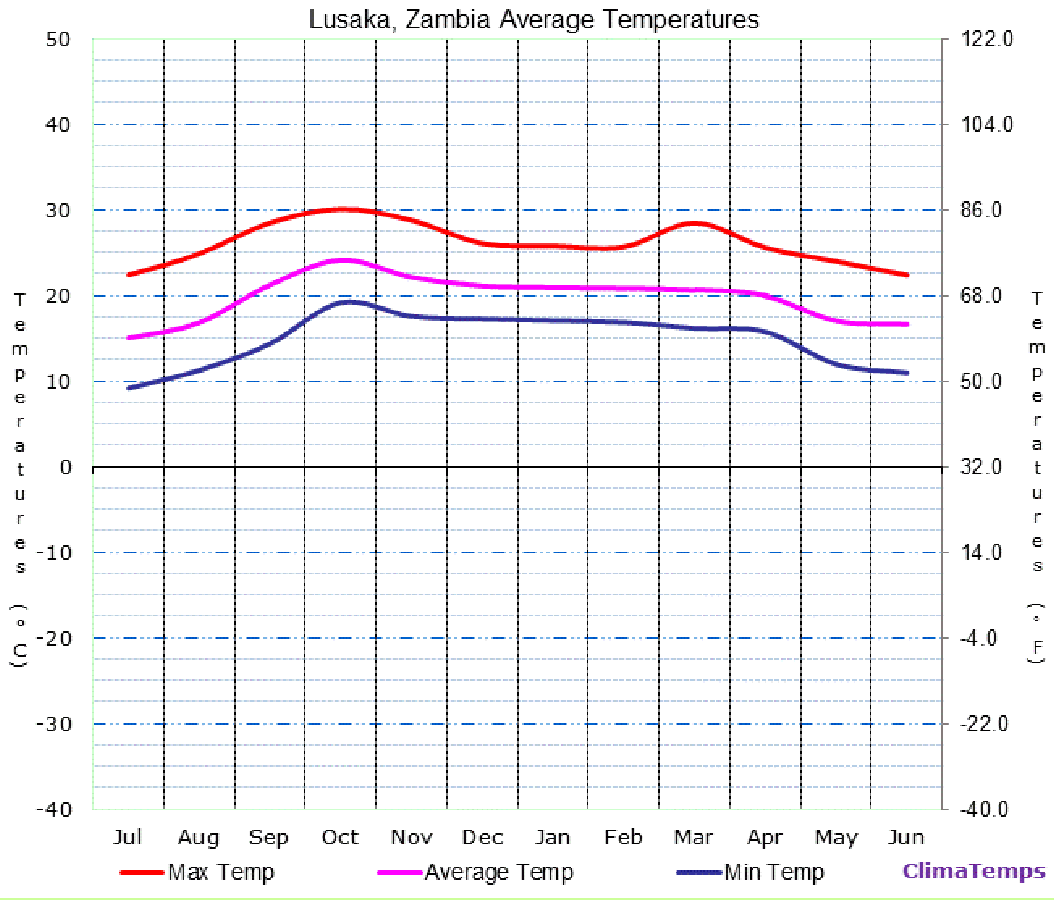
Lusaka is the capital city of Zambia and covers an area of over 360 km^2. Recently it has become a booming city, being classified as one of the fastest developing cities in Southern Africa. New buildings are "going up everywhere," many chain stores and shopping malls are opening, and sprawling suburbs are developing.

Figure 7: Map of Lusaka (Source: Mapsoftorld.com)



The city of Lusaka lies in the central-to-southern part of Zambia and located at 15° 25' S, 28°27' E, 1280m. (Mulenga, 2003). It enjoys a humid subtropical hot summer climate moderated by altitude that is characterised by mildly warm but dry winters and hot humid summers (Climatetemps.com, 2016). The warm season lasts from September to November with October as the hottest month. The warm season has daily average high temperatures of 30° and lows of 15° (weather spark, 2012). The cold season lasts from June to August with the coldest month in July at average daily high temperature reaching 24° and lows of 9° in the night time (*ibid*). The temperature typically varies from 9° to 32° over the course of the year and is rarely below 6° or above 35°, although the past few years extremes in both high and low temperatures have been recorded. The average monthly temperatures vary by 9.2°. The maximum daily sunshine hours are 12 during October. The wettest month in Lusaka is January with an average rainfall of 800mm. (Climatetemps.com, 2016)

Figure 8: Lusaka average temperatures per month (Source: climatemaps .com)



4.3 Description of the case study- The EIZ building project

4.3.1 Overview

This section provides an overview, introducing the EIZ building that is modelled in this study (see Figures 9-11), which is based on the design drawings and specifications. The analysis describes the location and orientation. In addition, the description includes the building type, designed occupancy, design case lighting type, and proposed equipment drawn from standards. A description of the heating, ventilation and air conditioning (HVAC) system is also included.

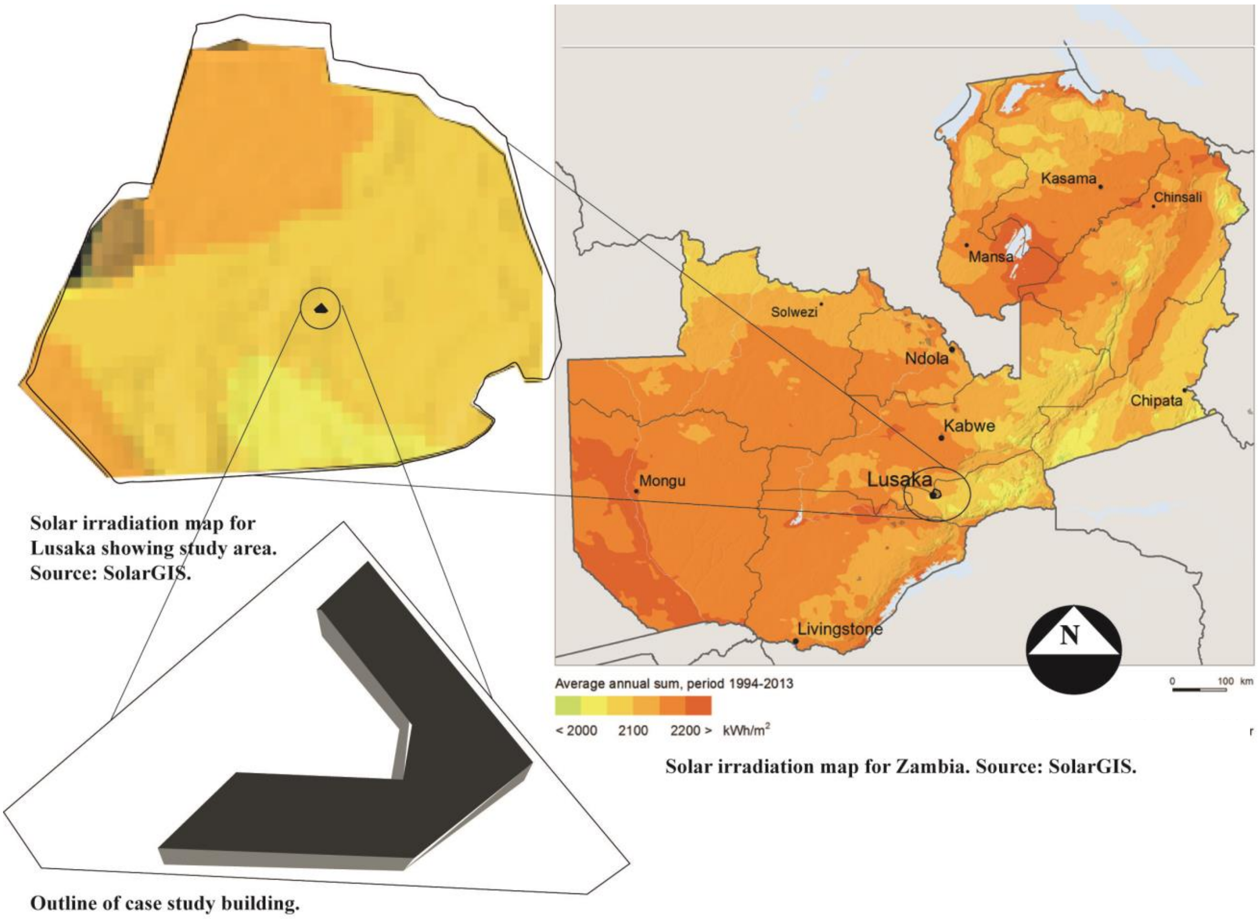
Figure 9: Aerial photograph of the EIZ building (Source: Google earth 2016)

Figure 10: Artistic impression of the EIZ building (Source: A+ Urban technics)

Figure 11: EIZ building under construction

Figure 12 below shows the location of the EIZ building in relation to Zambia's solar irradiation distribution and 3D images of the building.

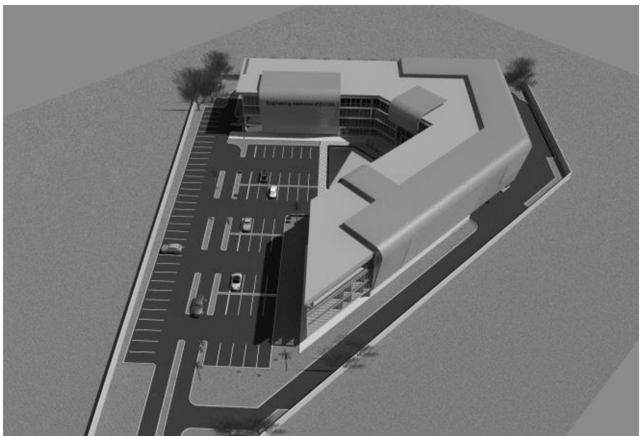
Figure 12: Solar irradiation map, location of EIZ building and 3D images. (Source: Solar GIS & A⁺ Urban Technics)



Solar irradiation map for Lusaka showing study area. Source: SolarGIS.

Solar irradiation map for Zambia. Source: SolarGIS.

Outline of case study building.

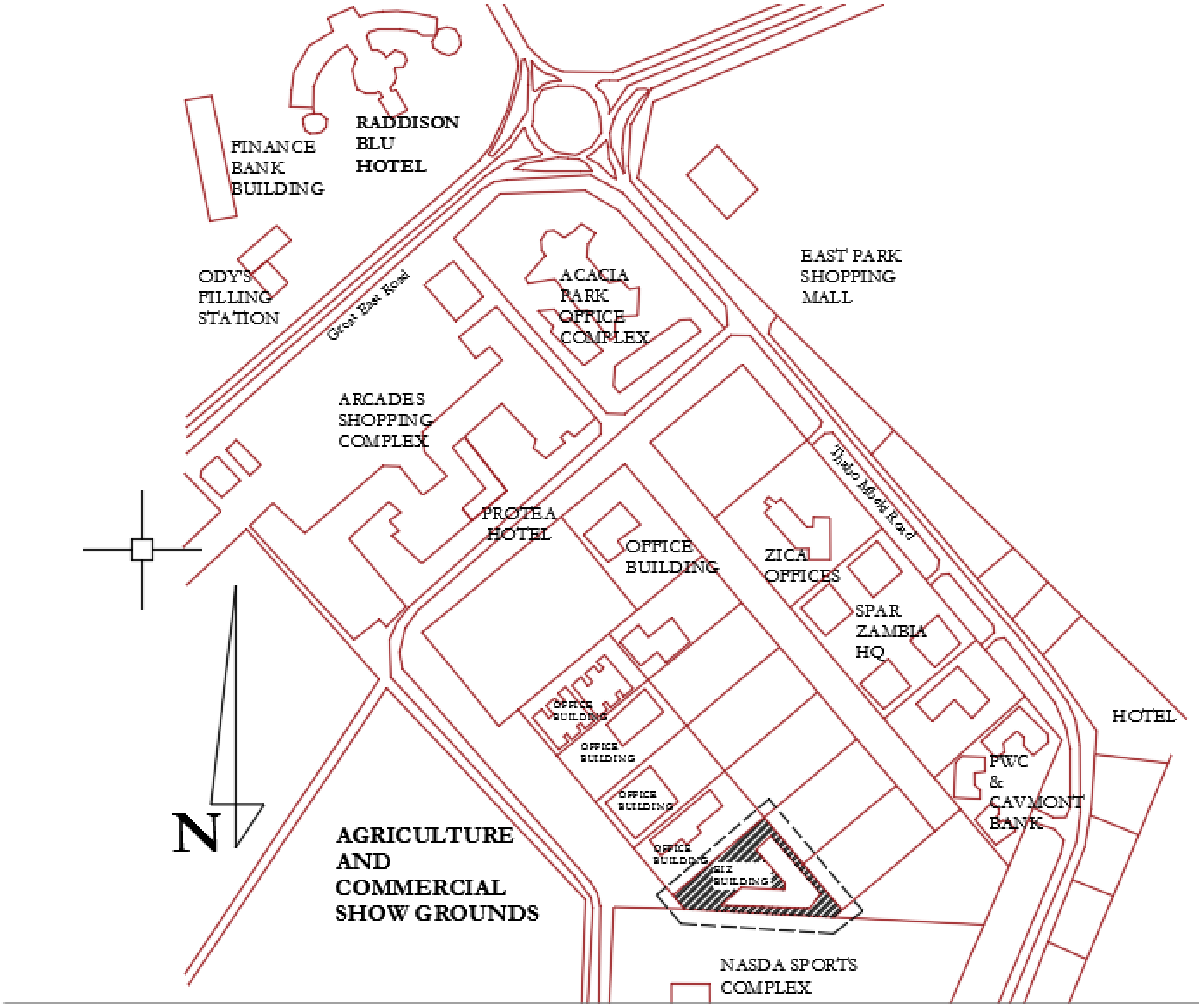


Aerial 3D artistic impression of EIZ building. Source: A+ Urban Technics-Architects

Eye level 3D artistic impression of the EIZ building. Source: A+ Urban Technics-Architects

The Building is located on a 6,131m² plot at the agriculture and commercial show grounds and within a site located in an area zoned for commercial development with several office buildings already erected (see Figure 13). Some 300m north of the site is Arcade's shopping mall and Protea hotel. Bounding the site on the North is the NASDEC sports complex. Although the building is owned by the Engineering Institute of Zambia, its design features rentable office space for other prospective tenants on selected floors. Considering that the tenants have not yet been determined, their occupancy and population was determined by calculating the standard occupancy density using the South African SANS 10400(South African National Standards, 2011). The proposed activities of the building are typical office work predominantly involving the use of computers.

Figure 13: Surrounding context of the EIZ building (Source: Adapted from A+Urban technics drawings)



The scheduled working hours are drawn from the standard business schedules in Zambia which are typically nine hours from 8:00a.m to 5:00 p.m. with lunch break from 1:00 p.m. to 2:00 p.m. This schedule runs from Monday to Friday. Given that most offices operate half day on

Saturday, and assuming that the offices will operate on a similar schedule, the average working hours per week will be 50 hours. Zambia does not as yet participate in daylight savings time as an energy efficiency strategy. (US foreign commercial service and department of state, 2011).

Table 2: General building information

Building information	
Owner	The Engineering Institute of Zambia
Building type	Offices
Architects	A+ Urban technics
Number of floors	4 Floors
Phase	Construction phase
Climatic zone	ASHRAE 3B
Office net floor area	2501sqm
Design occupancy times (hours/day/days per week)	9 hours/day- 5days/week
Design population (Density)	1 person / 15m^2 (SANS 10400XA standard) =167
Utility rates for commercial	$0.057/kWh

4.3.2 The building envelope

The building layout follows a rotated 'V' shape opening towards the North Western side (see floor plans in Appendix B). The building massing is a column grid structure with the building envelope predominantly curtain walling with most of the large windows located on the northern and north eastern sides (see elevations in Appendix B). As shown in the southern elevation in Appendix B, there are no windows on the southern side. There are windows on the eastern façade albeit on the second and third level offices. Surprisingly, despite the absence of openings on the southern side (and the area not being subject to exposure to direct sunlight), the design proposes a terracotta aesthetic element. In areas like the north-eastern, north-western south-western, western and northern facades, the same terracotta element has been specified for shading purposes which is more justifiable. This feature has also been specified on the eastern side to cover the parking area on the ground and first floors. There are no near adjacent buildings with significant effects on the building. The building site is proposed to have mainly paving with a water feature at the centre.

The main exterior and interior walling materials applied are 200mm (8 inch) light weight hollow concrete blocks for the exteriors walls and 150mm (6 inch) equivalent for the interior. The walls are to be plastered internally and externally with 10mm and 15mm plaster respectively. The proposed curtain walling specification is double pane glass on aluminium framing, but the actual opening sections and thermal properties are not specified. Reasonable assumptions were therefore made as presented in Table 3. The typical ceiling heights are 3 meters as shown in the section in Appendix B.

Internal wall ceilings and floors

The specified internal walls of the building combine single leaf 150mm (6 inch) hollow concrete block walls with 10mm plaster while plasterboard partitions are specified in certain places. Although the actual placement of the partitions is not specified, this study assumed general open plan arrangement for the offices. The type of ceiling specified is the acoustic suspended ceiling in most of the office space. The floors are of concrete and will receive porcelain tile finish for most open plan offices.

Fenestration and doors

Although the openings are not clearly labelled, the exterior curtain glazing is specified to 10% minimum for habitable rooms. The standards of all glazing have been specified to comply with part N of the SANS0137-2000 code of practice while safety and laminated glass is to conform to SANS 1263.

Roof

The roof is a 200mm thick flat concrete slab roof. Part of the roof is covered by the decorative terracotta shading. The roof also houses the air conditioning plant and lift plant rooms. Data on the building envelope has been summarised in Table 3 below.

Table 3: Summary of building envelope materials

Element	Description	U-values (W/m²K
Exterior walls	200mm (8 inch) thick lightweight hollow concrete block. 15mm cement/sand plaster internally and externally. Curtain wall- 6mm double glazing	0.24 1.4 70% SHG
Internal walls	150mm (6 inch) thick lightweight hollow concrete block.	0.24
Windows	Glazing size	
	Glazing material-6 mm double glazing	1.4
	Framing- Aluminium	
Shading	Terracotta shading	
Floors	200mm thick cast concrete 40mm screed, Porcelain tiles.	
Ceiling	Gypsum board 12.7mm	
Roof	200mm thick dense concrete roof	

4.3.3 Proposed lighting design and calculated loads

Lighting loads in a building are often referred to in terms of "Light Power Density "(LPD) that is measured in Watts per square meter (W/m^2). The design proposes different types of lighting for different zones. The Table 4 captures in the best detail the proposed lighting design obtained from the electrical drawings.

Table 4: Lighting design and calculated light power density

Ground floor				
Space	**Description of Lighting type**	**Quantity (No)**	**Power (Watt)**	**Total power**
Terrace	3W LED Ø65mm and 62mm long recessed down light fitting	115	3W	345
Cafe	- 6-9 W LED 105x105mm 50mmØ	75	9W	675
Gallery	- 6-9 W LED 105x105mm 50mmØ recessed down light fitting.	75	9W	675
Toilets	3W LED Ø65mm and 62mm long recessed down light fitting	28	3W	84
Lobby and reception areas	3-5W LED Ø85 x81mm long recessed down light fitting.	68 18x5W	5W	340
Parking	18W LED lamp 1200mm long , Ø30mm suspended fluorescent light fitting	75	18W	1350

Stair well and lift	-3W LED Ó65mm and 62mm long recessed down light fitting - 6-9 W LED 105x105mm 50mmØ	12 3	3W 6W	54
Plant room	18W LED lamp 1200mm long , Ø30mm suspended fluorescent light fitting	7	18W	126

First floor				
Space	**Description of Lighting type**	**Quantity (No)**	**Power (Watt)**	**Total Power (Watt)**
Open plan office 1	34W LED 600x600mm module power balance recessed fitting.	46	34W	1564
Open plan Office 2	34W LED 600x600mm module power balance recessed fitting.	48	34W	1632
Lobby and reception area	- 6-9 W LED 105x105mm 50mmØ recessed down light fitting.	8	9W	72
Toilets	3W LED Ó65mm and 62mm long recessed down light fitting	20	3W	60
Parking	18W LED lamp 1200mm long , Ø30mm suspended fluorescent light fitting	89	18W	1602
Stair well and lift	-3W LED Ó65mm and 62mm long recessed down light fitting - 6-9 W Led 105x105mm 50mmØ	12 3	3W 6W	54

Second floor				
Space	**Description of Lighting type**	**Quantity (No)**	**Power (Watt)**	**Total Power (Watt)**
Open plan office 3	34W LED 600x600mm module power balance recessed fitting.	46	34W	1564
Open plan Office 4	34W LED 600x600mm module power balance recessed fitting.	72	34W	2448
Open plan office 5	34W LED 600x600mm module power balance recessed fitting.	81	34W	2754
Lobby and reception area	- 6-9 W LED 105x105mm 50mmØ recessed down light fitting.	55	9W	495
Auditorium				
Toilets	3W LED Ó65mm and 62mm long recessed down light fitting	20	3W	60

Stair well and lift	-3W LED Ó65mm and 62mm long recessed down light fitting - 6-9 W Led 105x105mm 50mmÓ	12 3	3W 6W	54

Third floor				
Space	**Description of Lighting type**	**Quantity (No)**	**Power (Watt)**	**Total Power (Watt)**
Open terrace	3W LED Ó65mm and 62mm long recessed down light fitting	115	3W	345
Open plan office 6	34W LED 600x600mm module power balance recessed fitting.	24	34W	816
Open plan Office 7	34W LED 600x600mm module power balance recessed fitting.	72	34W	2448
Open plan office 8	34W LED 600x600mm module power balance recessed fitting.	81	34W	2754
Lobby and reception area	- 6-9 W LED 105x105mm 50mmÓ recessed down light fitting.	100	9W	900
Toilets	3W LED Ó65mm and 62mm long recessed down light fitting	20	3W	60
Stair well and lift	-3W LED Ó65mm and 62mm long recessed down light fitting - 6-9 W Led 105x105mm 50mmÓ	12 3	3W 6W	54

Total power (W)	**23040**
Total calculated net floor area (m^2)	**6883**
Calculated LPD (Total power/net area-W/m^2)	**4.46**

According to the Autodesk sustainability workshop (2015), the standard specified for the internal lighting loads per square meter for offices is 11 to 30W/m^2. Considering that the spaces for which the LPD is calculated is general office space, the LPD of 4.46W/m2 reveals that this is way below the standard. This is attributed to the use of LED lights.

4.3.4 Proposed building HVAC system

The EIZ building proposes a Variable Refrigerant Flow (VRF) zoning HVAC system. VRF zoning is a method of providing precise comfort control to buildings with multiple floors and areas by moving refrigerant through piping to the zone to be cooled or heated. VRF zoning system can simultaneously cool some zones while heating others. Regardless of time of day, sun or shade, season of the year or special requirements. The outdoor units are to be located on the roof of the building with a compressor that varies the motor rotation speed, allowing it to precisely meet each zone's load requirement by transferring refrigerant through ceiling suspended ducts. The central controller in the mechanical room located on the ground floor would monitor, schedule and control all indoor units. (Hu & Agarwal, 2016)

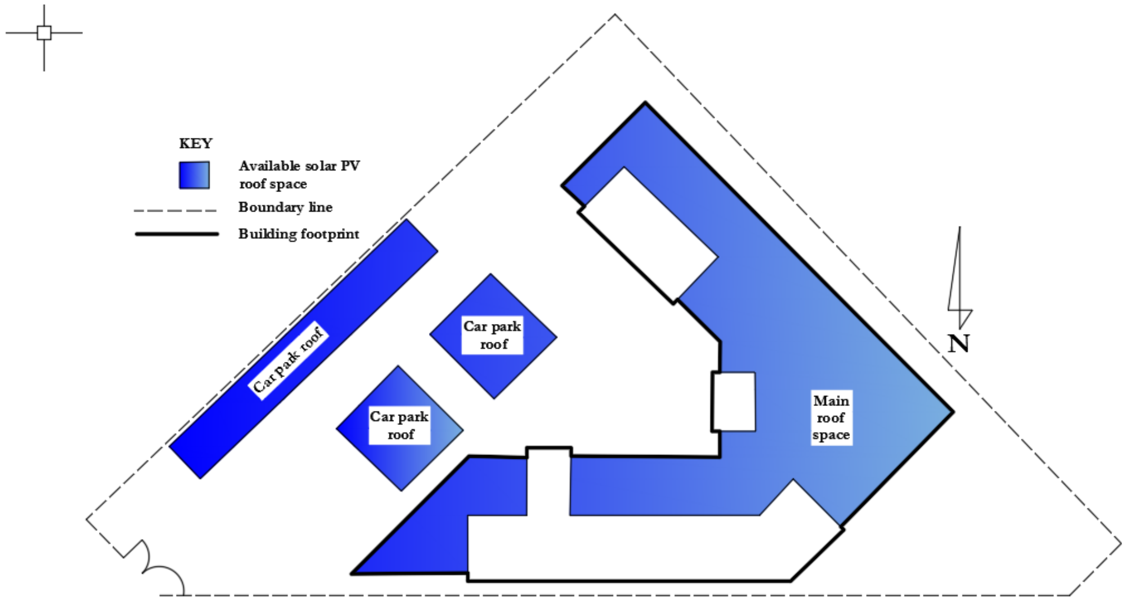
4.4 Estimate available roof space and solar PV potential of the EIZ building

According to the technical and commercial requirements of the EIZ for the proposed solar photovoltaic system, the power supply requirements of the building to handle the predicted loads would be supplied first from the ZESCO power grid as the main supply then from an integrated solar PV system. The requirements also propose a stand-by generator set for back up during worst case interruption. However, for this research the generator has been omitted from the analysis for simplicity. Although the brief emphasises on grid electricity from the ZESCO as the main supply, the project aims at appraising for the possibility of the building to net out its demand by generating electricity from rooftop solar PVs and also simulating the possibility of generating surplus for export to the grid once the support mechanisms are in place. According to a discussion with the EIZ project manager, the EIZ is strategically positioned itself as a leader in the engineering industry having sufficient influence to steer policy. EIZ is therefore determined to go ahead with the generation of electricity via rooftop solar PV and are positive about providing excess for export to the grid once the mechanisms are in place. The appropriate procedure therefore was to start off by determining the available roof space (as the key constraining factor) for the solar PV system followed by an estimated capacity. The estimated capacity of the system would then be used as the target and reference by which simulated baseline demand and subsequent interventions would be gauged.

Estimating usable roof space on site

By reviewing the roof plan and site plan the maximum usable roof space to be dedicated for solar PV was determined. Assuming that the roof design is upheld in its form, the unobstructed roof space of the building comprises 1,215m^2 while the proposed car park shading roof area comprises 570m^2 thus giving a total of 1,785m^2. This area is shown in blue in Figure 14 below.

Figure 14: Available roof area for solar PV system



After determining the available unobstructed roof space, the next procedure involved estimating the solar PV capacity using the LG-solar calculator. This is a simple free online solar PV estimator software. Even though the calculator is for LG panels it allowed for the estimation of panels likely to fit on the roof. In addition, the estimator allowed for the selection of multiple roof areas on the building. After assuming a fixed tilt for the panels, a simple method to estimate the best tilt angle was used. The rule of thumb is to multiply the latitude of the building location by 0.87 if the latitude is below 25° (Landau, 2015; Dike *et al*, 2012). Lusaka's latitude being approximately 15°, the appropriate tilt angle was calculated as 13°. After specifying the tilt angle, zooming into the building area using Google Maps allowed for the unobstructed roof area to be identified and outlined. Once the direction in which the panels should face was set, the software generated the number of panels and areas for each roof which allowed comparison with the calculated roof. It was found that there was a 100m^2 difference. This was attributed to errors when specifying the roof perimeter on the Google Earth plans. The software provides an option to specify the solar panel type from a range of specifications based on wattage capacity. For this case, the LG300N1K-G4 (300Watts) was selected because it fell in the mid-range, has longer warranties and has higher efficiencies suitable for commercial purposes. After inputting the various parameters, the software simulated the results shown in Table 5 below. Figure 15 shows the graphical layout of the rooftop solar PV array.

Table 5: Estimated solar PV system results from LG-calculator

Estimated available roof space (Drawing)	1,785sqm
Total panel roof space (LG-calculator)	2,133sqm
Tilt angle	13°
Total solar panels	830
Solar panel type	LG300N1K-G4 (300Watts)
Total solar output (W) (Kw-conversion)	249,000W (249Kw)
Estimated system size	Commercial system

Figure 15: Estimated area for rooftop area and solar PV panels from LG software

4.5 Modelling of baseline case

After estimating the roof potential and the solar PV capacity, the next procedure was to determine the building's baseline energy intensity which was then compared to the system capacity to offset this and generate excess. This was done by use of the DesignBuilder software version 4.7 described in Section 3.5.2 of the previous chapter. A virtual building model was created and dynamically represented as close as possible the actual building and any systems that consume power along with their corresponding manner of operation. In this study, the model was built with complete information of structure, occupancy, equipment, and HVAC. With DesignBuilder software, a complex building can be reduced to a simple box for the purpose of energy modelling, often with little loss in accuracy. The software program in its current form allows for several simplifications to be made. This ability greatly assisted in inputting assumed parameters. Some of the required building inputs fed into the program included: dimensions, window to wall ratio, enclosure thermal resistance, window thermal conductance, window solar heat gain coefficients (SHGC), infiltration rate, roof and wall solar absorbance, occupant density, lighting and plug load density, and indoor temperature set points.

4.5.1 Software inputs and modelling assumptions

An accurate building model was created using the full-zone method, where all thermal zones were modelled with full information in construction, occupancy, equipment, and HVAC. When beginning a new project, the location and analysis type is chosen. For this project, the Lusaka hourly weather data EPW (EnergyPlus weather) file was used. Figures 16 and 17 below show a full zone model of the EIZ building.

Figure 16: Axonometric view of the EIZ model in design builder-Northern view

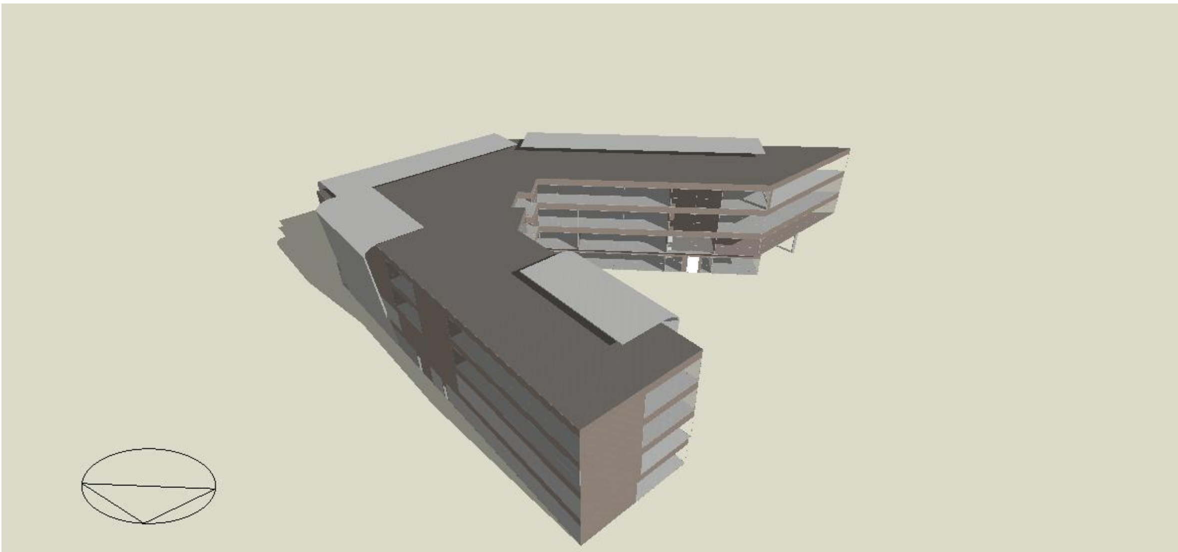
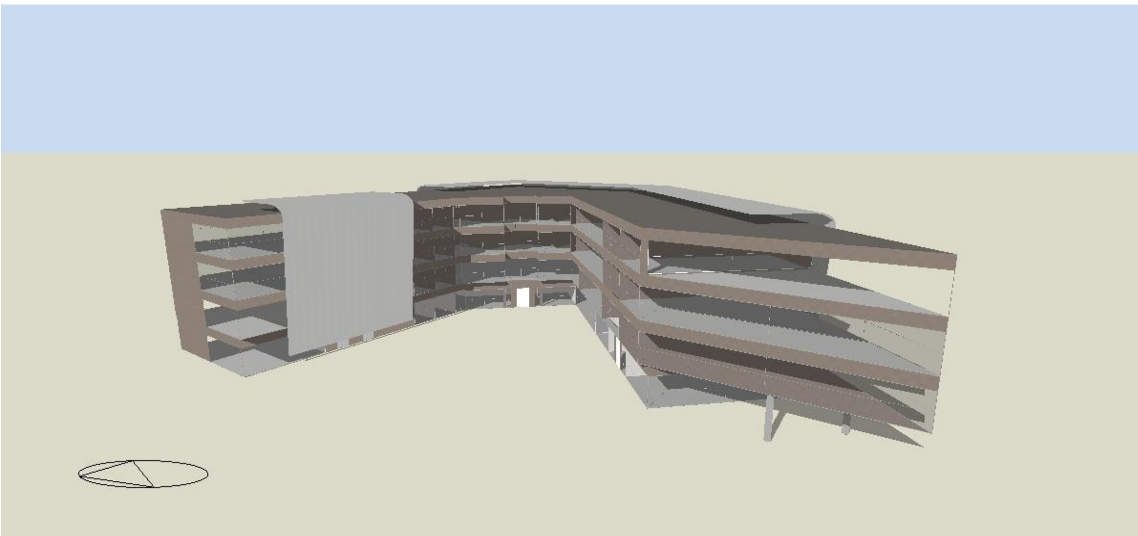


Figure 17: Axonometric view of the EIZ model in design builder-Western view



Occupancy assumptions

As stated in Section 2.7.3 on energy modelling and simulation, during energy modelling for either new build or existing buildings, there is a likelihood where the modeller encounters unknown or missing information. In such cases, the requirement of the missing information has to be fulfilled via accurate engineering assumptions and estimations. It was also stated in section 3.2 that international and South African standards such as the Green Star SA –Office V1 technical manual would be used to guide on missing information for the EIZ building. (Avastthi, 2014 and GBCSA, 2013). Under the design criteria section of the Green star SA technical manual as well as the SANS 10400, the occupancy requirement is set at 15m^2 per person for both notional and actual buildings.

Equipment Loads/Plug loads assumptions

Equipment, like lighting and HVAC equipment, consume energy in the form of either electricity or fuel and are important inputs for whole building energy analysis simulation. Plug loads are the electricity used for equipment like computers and appliances. They are sometimes included in "Equipment Power Density" EPD and sometimes they are separated (Autodesk sustainability workshop, 2015). By ascertaining the building's intended use, the buildings equipment/plug loads can be determined. The Energy star data base provides some plug loads for specific items and internal loads for different space types (*ibid*). However for the EIZ model, reference was made to the Green Star SA–Office technical manual for an assumed equipment load. The standard provides 11W/m^2 for notional and actual building (GBCSA, 2013).

4.5.2 EIZ building simulation inputs in design builder software

Before modelling the EIZ building, as shown in Figures 16 and 17, the location and analysis type were specified. For this study, Lusaka location and weather file and EnergyPlus simulation tool were selected, respectively. Another important aspect involved definition of zones in the model. Zones can be created by drawing internal partition walls or virtual walls and they can be modelled separately in simulations. Zoning phase separates the different thermal zones. Some of the crucial data that was inputted in the software prior to simulation are described below.

Site level inputs

This information was adopted from the standard EnergyPlus Weather (EPW) weather file integrated in the software. In instances where the information did not correspond with latest information, climatic data from online sources was utilised. Table 6 shows the site data which defined the EIZ building.

Table 6: Site details inputted in design builder

Location	Lusaka, Zambia	
Latitude	-17.92	
Longitude	31.13	
ASHRAE climate zone	3A	
Elevations above sea level	1503.0	
Exposure to wind	Normal	
Winter design weather	Outside design temperature	7.0°C
	Wind speeds	10.4m/s
Summer design weather:	Design temperature period	Single design month (99.6% coverage based on dry bulb temperature)
	Maximum dry bulb temperature	30.5°
	Coincident wet-bulb temperature	16.5°
	Minimum dry-bulb temperature:	20.1°
Summer design week	Start day/Month	6th October
	End day/Month	12th October
Winter design week	Start day/Month	8th July
	End day/Month	15th July

Figures 18 and 19 show the annual distribution of solar irradiation and temperature for the EIZ building site respectively. From Figure 18, it is shown that the highest period of direct solar irradiation is experienced from May to October averaging 230kW/m^2. Meanwhile Figure 19 shows that the highest temperature is recorded in October and is at its lowest in July. Figures 20 and 21 graphically depict the sun positions of the typical summer and winter design days.

Figure 18: Annual Solar radiation distribution simulated from design builder

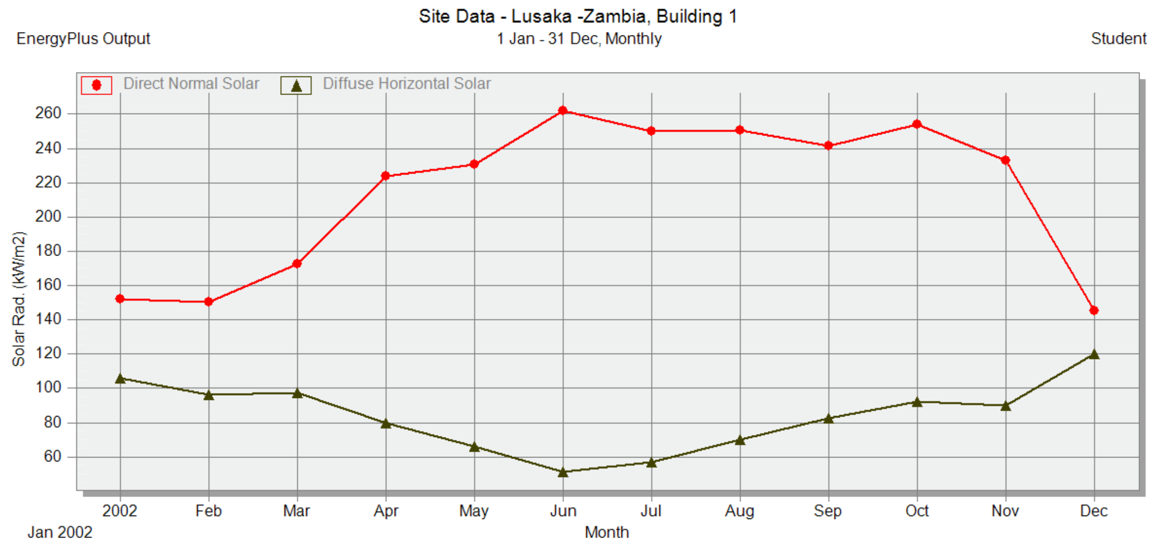


Figure 19: Annual temperature distribution simulated from design builder

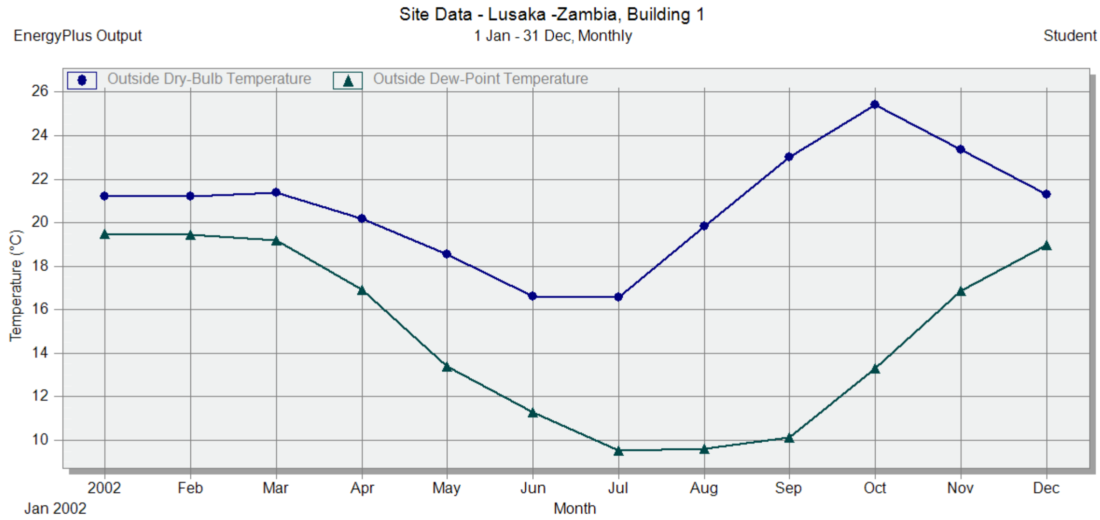


Figure 20: Sun and shadow position at 11th July 15pm-plan and axonometric (winter design day)

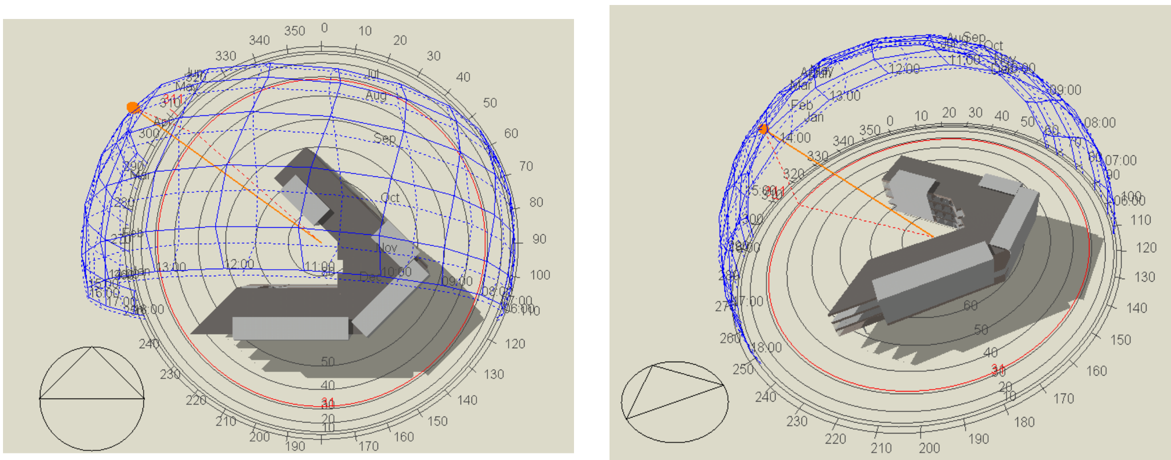
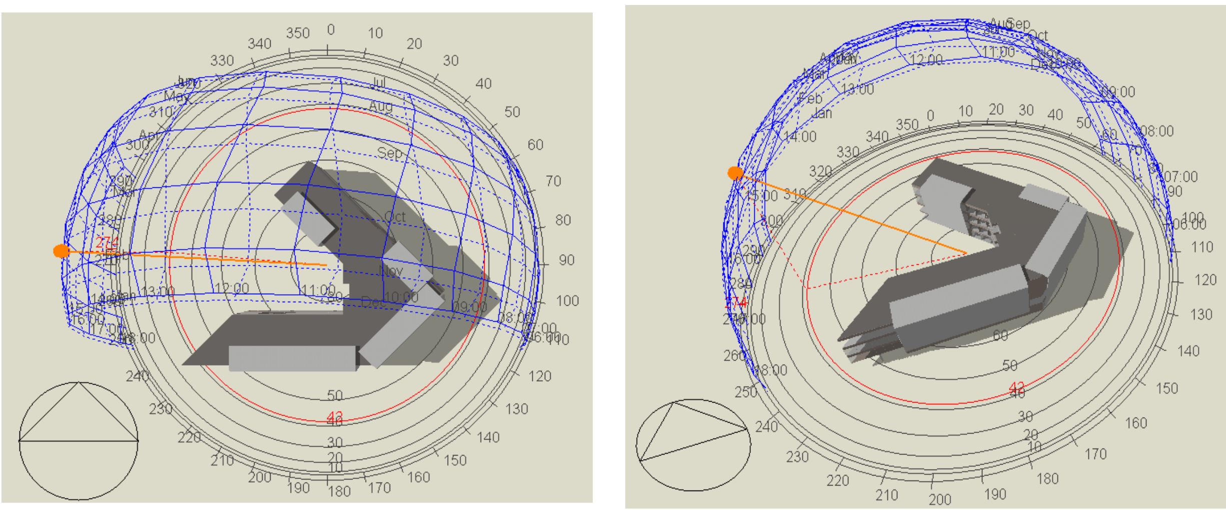


Figure 21: Sun and shadow position at 16th October-plan and axonometric 15pm (summer design day)



Building level inputs

Activity.

Activity data describes among other things occupancy density, metabolism, environmental control with natural ventilation set points and internal gains from equipment. The activity tab in DesignBuilder software allowed for the schedules of occupancy and equipment usage to be inputted. There are many with default modifiable activity data. For this study a "generic office area" was selected from the default templates and then modified to suit the assumed use pattern. This template was defined as "areas to perform office work including offices and meeting rooms". It can include internal corridors providing access to the office spaces, tea making facilities or kitchenettes within the office space, areas for photocopiers and fax machines and staff lounges. Table 7 below details the activity data input into the building model. Any varying data specific for a zone were modified at that zone level.

Table 7: Activity details inputted in designer builder

Occupancy	0.1110 (people per m^2) - Green star SA guide (15m^2 per person)	
Template type	Open plan office occupancy schedule.	
Occupancy schedule	Schedule	Compact
	Through	31 Dec
	Weekdays Summer Design Day	-From 08:00 to 12:00 -Lunch from 13:00 to 14:00 -From 14:00 to 17:00
	Weekends	Un occupied
	Holidays	Un occupied
Metabolic	Light office work/Standing/Walking	
Domestic hot water (DHW):	Not applicable	
Environmental control	Computers	Gain: 0 W/m^2
	Schedule	Compact
	Weekdays	From 08:00 to 17:00
	Weekends	Off
	Equipment	Gain: 11W/m^2 (SA green star)
	Weekdays	From 08:00 to 17:00
	Weekends	Off
	Heating setpoint temperatures	Heating : 22°C Heating set back : 12°C
	Heating setpoint temperatures	Cooling: 24°C Cooling set back: 28°C
	Natural ventilation	Min indoor temp: 24°C Max indoor temp: By schedule (default value)
	Min fresh air	10 l/s per person (Standard)
	Lighting	Target illumination: 400 Lux (default value)

Construction

Under the construction category of inputs, opaque fabric elements of the building such as external wall, roofs, floors and internal partitions with their respective properties were specified. Although the study assumed the building to be airtight, DesignBuilder includes air infiltration by default based on the template specified to suit the envelope's air tightness. Most of the construction elements and characteristics were specified at the building level and inherited by the zones. The wall envelope material specifications were obtained from the drawing specification as described in Section 4.3.4. The corresponding U-values where obtained from a standard schedule provided by Autodesk (Autodesk sustainability workshop, 2015). Table 8 shows the construction data input into the software for the EIZ building model.

Table 8: Construction data inputted in the DesignBuilder software

External wall (Concrete hollow block external wall-230mm thick)-Unbridged	Outermost layer	Cement sand render	0.0150m thick
	Middle layer	Concrete block lightweight	0.2000m thick
	Innermost layer	Cement sand render	0.0150m thick
	Convective heat transfer coefficient-outside surface		11.540 W/m^2
	Convective heat transfer coefficient-inside surface		2.5 W/m^2
	Calculated wall U-Value		0.798 W/m^2-K
Flat roof (concrete roof) Unbridged	Outermost layer	Asphalt	0.01m thick
	Middle layer	Cast concrete	0.20m thick
	Innermost layer	Cement sand render	0.03m thick
	Calculated roof U-Value		2.168 W/m^2-K
Internal partitions:	Outermost layer	Cement sand render	0.0150m thick
	Middle layer	Concrete block lightweight	0.15m thick
	Innermost layer	Cement sand render	0.0150m thick
	Calculated wall U-Value		0.926 W/m^2-K
Ground floor (unbridged)	Outermost layer	PVC sheeting	0.001m thick
	Layer 1	Cast concrete	0.1m thick
	Layer 2	Cement sand screed	0.04m thick
	Innermost layer	Porcelain/ceramic tiles	0.01m thick
	Calculated wall U-Value		2.441 W/m^2-K
Internal floor	Outermost layer	Cast concrete	0.2m thick
	Middle layer	Porcelain/ceramic tiles	0.01m thick
	Calculated wall U-Value		2.199 W/m^2-K
Model infiltration	Constant rate		0.700 c/h (default figure)
	Schedule		On 24/7

Openings

Under the openings tab, all the glazing elements of the building fabric were specified by editing relevant parameters in a selected template. The same window specification was applied to the whole building. As highlighted under Section 3.2, since the detailed thermal specifications of the window were not specified in the drawing, an appropriate specification was selected according to the worst-case glazing element performance guided by the South African National Standard (SANS204, 2011). The amount of glazing and openings on the building was specified by manually drawing the openings in the virtual building model as shown in Figures 16 and 17. Table 9 shows the data inputted in DesignBuilder software for the EIZ model.

Table 9: Openings data inputted in the software

Glazing type (Simple definition)	Total solar transmission	Simple
	Total solar transmission (SHGC)	0.700
	Light transmission	0.744
	U-value	1.400W/m^2 (Drawn from SANS-204 standard)
	Frame and dividers	Aluminium window frame –no break.
Shading	Window shading	No
	Local shading	No

Lighting

Under the lighting tab, data related to the energy consumption of the lighting were inputted. After making a generic selection of the LED lighting template based on the specifications obtained from the electrical drawings, the actual casual gains or light power densities were manually inputted at building level and inherited at all zone levels. This figure represented the light power density (LPD) calculated in Table 4 of Section 4.3.5. Table 10 shows the lighting data inputted in the software.

Table 10: Lighting data inputted in the software

Lighting template	LED	
Normalised power density	4.46 W/m^2	
Schedule	Schedule	Compact
	Through	31 Dec
	Weekdays Summer Design Day	From 08:00 to 1900
	Weekends	Off
	Holidays	Off
Luminaire type	Specified at zone level	
Lighting control	Off	
Exterior lighting	Design level	100W (default)
	Schedule	24/7
	Control option	Schedule + override off

HVAC

The heating, ventilation and air conditioning data were input into the HVAC tab. The fan coil unit (4-Pipe), air cooled chiller template was selected to best represent the proposed VRF system of the EIZ building.

Table 11: HVAC data inputted in the software

HVAC template	The fan coil unit (4-Pipe), air cooled chiller	
Mechanical ventilation	Outside air definition method	Min fresh air (Sum per person + per area)
	Operation-schedule	compact
	Through	31Dec
	Weekdays Summer Design Day	From 08:00 to 17:00
	Weekends	Off
	Holidays	Off
Heating	Boiler	Gas-fired condensing boiler
	Max supply air temp	35°C
	Max supply air humidity ratio (g/g)	0.0156
	Schedule Weekdays winter design day	From 08:00 to 19:00
Cooling	Chiller	Water cooled-DOE-2 Centrifugal/5.50COP
	Chilled water set point temperature	7.2°C
	Condenser water set point temperature	29.4°C
	Cooling tower type	Single speed
	Min supply air temp	12°C
	Min supply air humidity ratio (g/g)	0.0077
	Schedule Weekday summer design day	From 08:00 to 19:00
DHW	Off	
Natural ventilation	Outside air definition method	By zone

Zone level inputs

Simulation output options in DesignBuilder can be assessed at building, block, zone or surface and opening levels giving control of the model for which output data will be generated. DesignBuilder follows a 'model data hierarchy' where data specified at a higher level is inherited to the lower levels. For example, a selection of a type of wall at the building level will affect all walls in the building whereas a selection at block or level will only affect that block or zone. Zoning phase separates the different thermal zones. For this study, the building was divided into nine different zones based on location and activity. Moreover, some zones like parking which have intermittent loads and schedules and those without specific detail could be omitted from the simulation for simplicity. Therefore, for more accurate results some zones had to be excluded from the simulation. The zones where defined as shown in Figures 22, 23, 24 and 25.

1. *Ground level block.*

Figure 22: Zones at ground level block and orientations

Table 12: Ground level block zones and areas considered for simulation.

Zone	Area m²	Software Activity template	Lighting type	Inclusion in simulation	Normalised LPD w/m²
Parking	1031		6-9 W Led 105x105mm 50mmØ	Off	
Lobby and waiting area	175	Generic open office area (Inherited from building level)		On	1.8
Café	105	Rest, Public_ Eating & drinking	6-9 W Led 105x105mm 50mmØ	On	6.3
Gallery	103	Library, museum ,gallery	6-9 W Led 105x105mm 50mmØ	On	6.5
Circulation areas	51			Off	
Terrace	138			Off	
Plant rooms	44			Off	
Toilets	39			Off	

2. *First level block.*

Figure 23: Zones at first level block and orientations

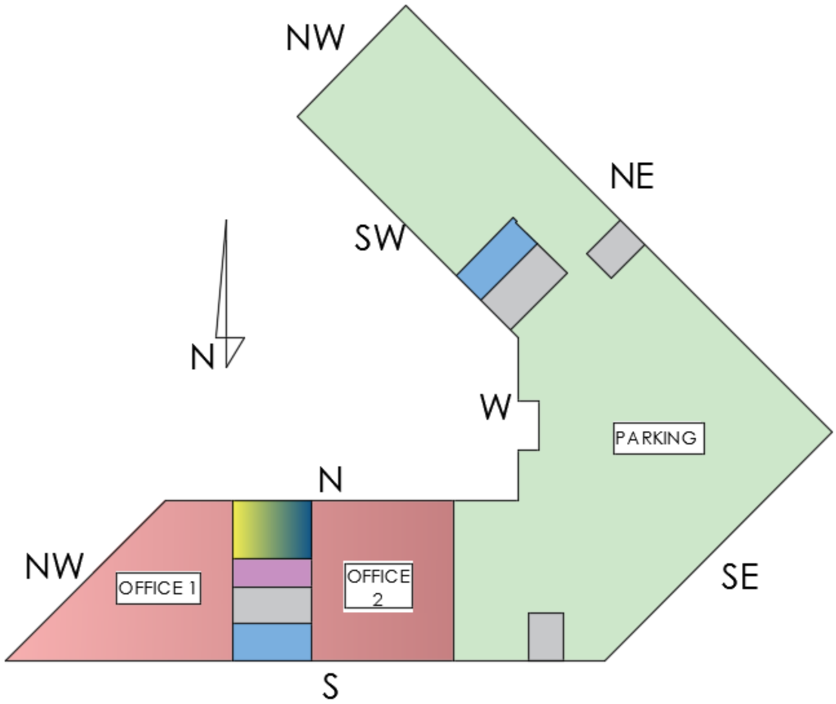


Table 13: First level block zones and areas considered for simulation

Zone	**Area m²**	**Software activity template**	**Lighting type**	**Inclusion in simulation**	**Normalised LPD w/m²**
Parking				Off	
Open office 1	228	Generic open office area (Inherited from building level)	34W LED 600x600mm module power balance recessed fitting.	On	6.9
Open office 2	217	Generic open office area (Inherited from building level)	34W LED 600x600mm module power balance recessed fitting.	On	7.5
Atrium				Off	

3. Second level block

Figure 24: Zones at second level block and orientations

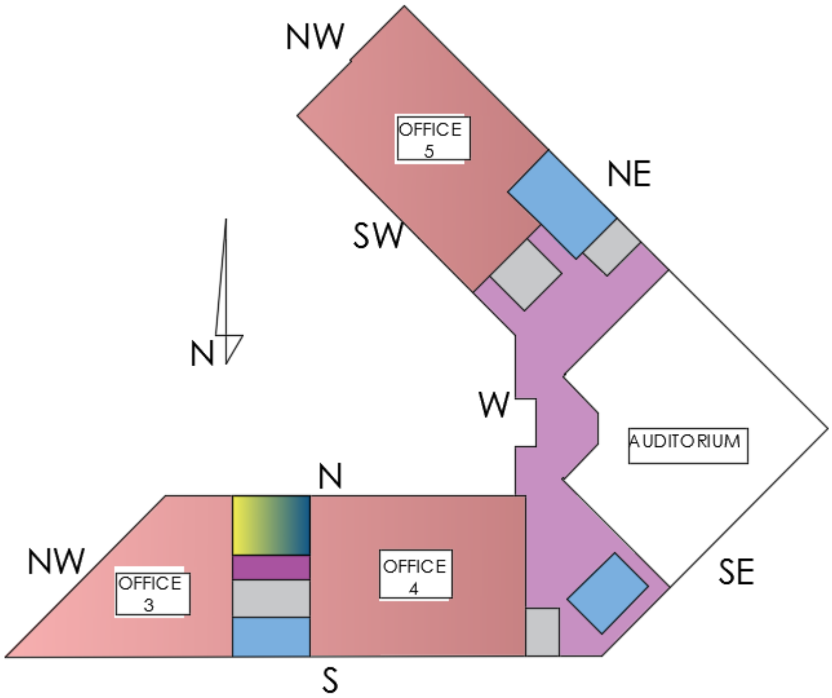


Table 14: Second level block zones and areas considered for simulation

Zone	Area m^2	Software Activity template	Lighting type	Include in simulation	Normalised LPD w/m^2
Open plan office 3	228	Generic open office area (Inherited from building level)	34W LED 600x600mm module power balance recessed fitting.	On	6.9
Open plan office 4	328	Generic open office area	34W LED 600x600mm module power balance recessed fitting.	On	7.4
Open office 5	326	Generic open office area	34W LED 600x600mm module power balance recessed fitting.	On	8.4
Auditorium	433			Off	
Lobby and waiting area	339	Generic open office area		On	1.4

4. Third level block

Figure 25: Zones at third level block and orientations

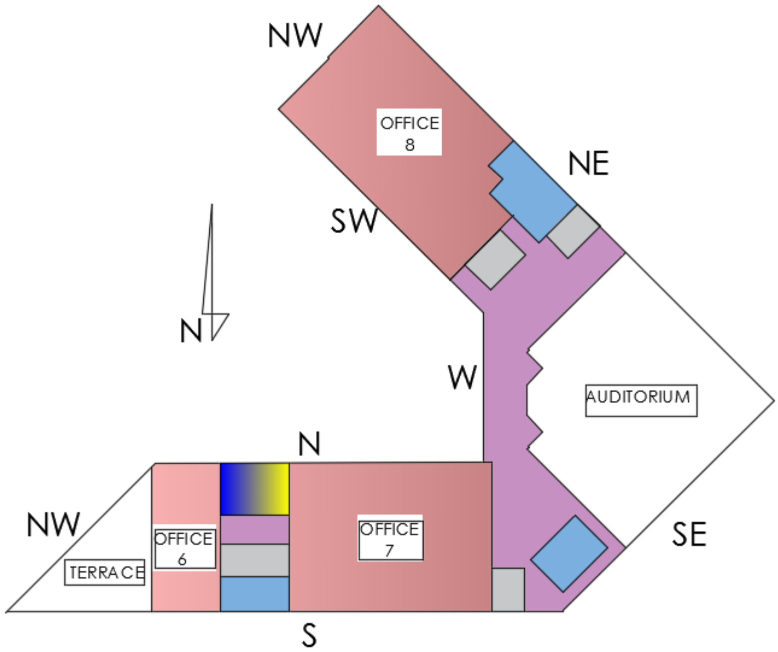


Table 15: Third level block zones and areas considered for simulation

Zone	Area m²	Activity Template	Lighting type	Inclusion in simulation	Normalised LPD w/m²
Open plan office 6	114	Generic open office area (Inherited from building level)	34W LED 600x600mm module power balance recessed fitting.	On	7.4
Open office 7	328	Generic open office area	34W LED 600x600mm module power balance recessed fitting.	On	7.4
Open office 8	326	Generic open office area	34W LED 600x600mm module power balance recessed fitting.	On	8.4
Lobby and reception area	339	Generic open office area	6-9 W LED 105x105mm 50mmØ recessed down light fitting.	On	2.6
Auditorium top				Off	
Toilets	128		3W LED Ø65mm and 62mm long recessed down light fitting	Off	
Stair well and lift	56			Off	
Open terrace	114			Off	

4.6 Presentation and interpretation of baseline case study simulated results

Following the input of simulation data into the model, the next step was to simulate in Energyplus by selecting the start and end day of simulation and the mode of data output whether monthly, daily, hourly or sub hourly. Because hourly and sub hourly data produces large amounts of data which makes it difficult to present, the simulation prioritised the annual and monthly energy intensity analysis.

As shown in the previous section, some zones such as parking and circulation space were excluded from thermal and energy analysis because of their assumed minimal impact. Furthermore, an analysis of the external building fabric was done considering that it was one of the opportunities where passive interventions could be applied to optimise the electricity consumption. A CO_2 analysis was also done in order to understand the relationship between electricity intensity and CO_2 emission. A daily peak demand simulation of the highest energy intensity month was carried out in order to allow for comparison of the result with the estimated "full roof" solar PV peak output capacity presented in Section 4.1.

4.6.1 Energy assessment

DesignBuilder software only calculates electricity/fuel totals at annual and monthly intervals and at building level not zone level. Figure 26 shows the simulated baseline annual electricity/fuel consumption of 287,707kWh (287.71MWh) while Figure 27 shows the monthly distribution intensity and Figure 28 shows the breakdown of the electricity/fuel consumption by category.

Figure 26: Baseline annual electricity/fuel consumption (287,707kWh)

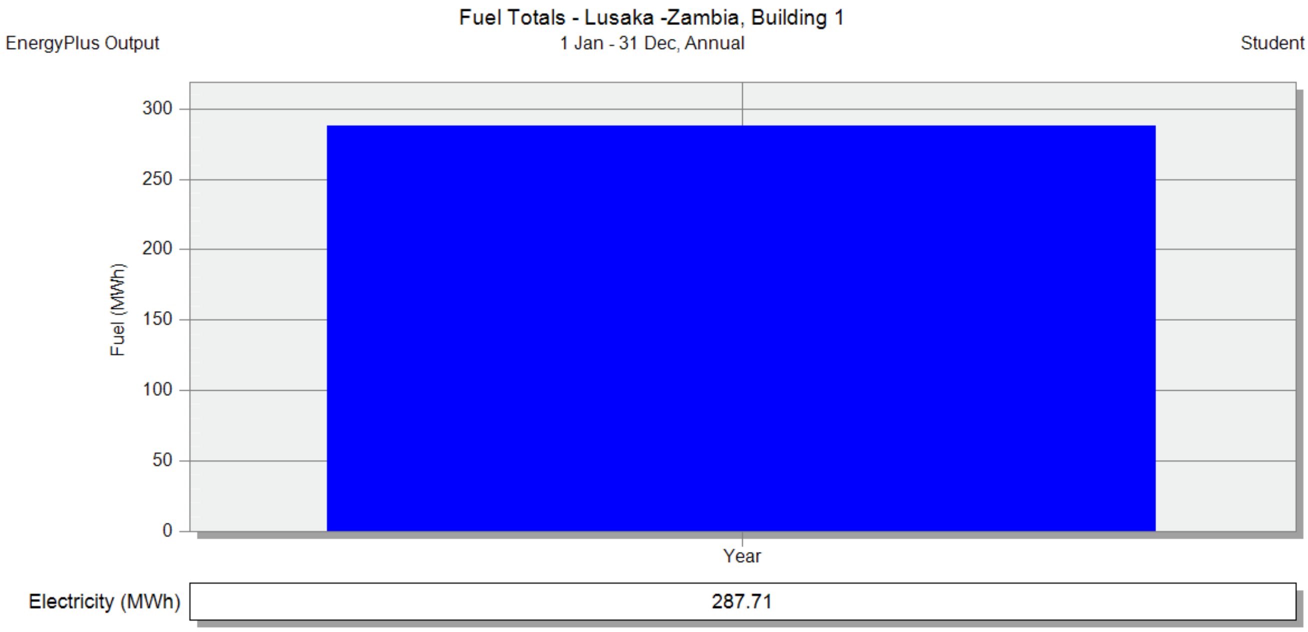
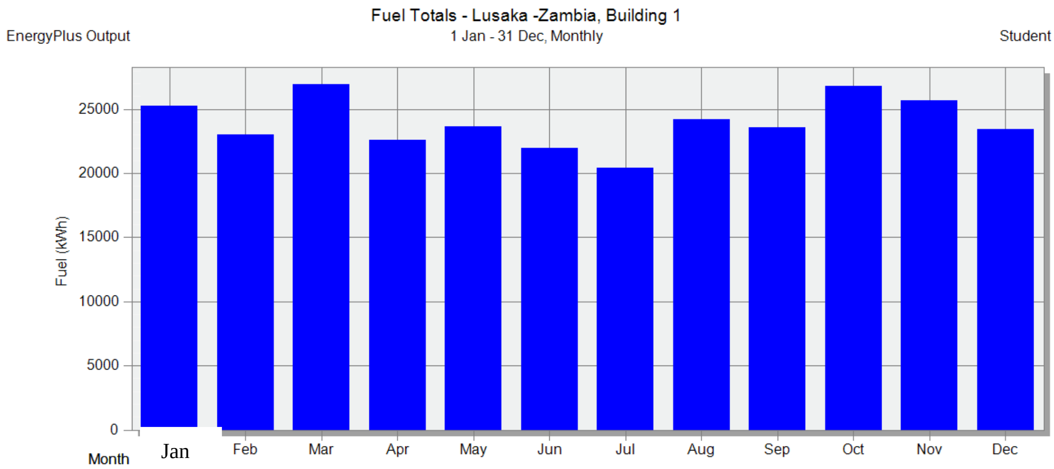


Figure 27: Monthly electricity fuel consumption



Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Electricity (kWh)	25236.93	23047.29	26959.83	22618.52	23656.31	21985.95	20456.85	24202.56	23602.94	26802.25	25696.25	23441.05

Figure 28: Annual electricity/fuel usage per source

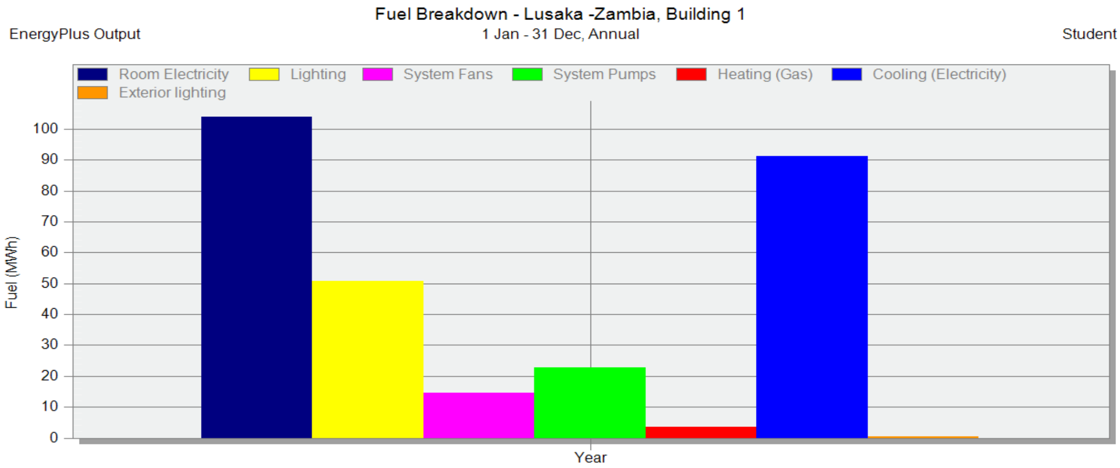
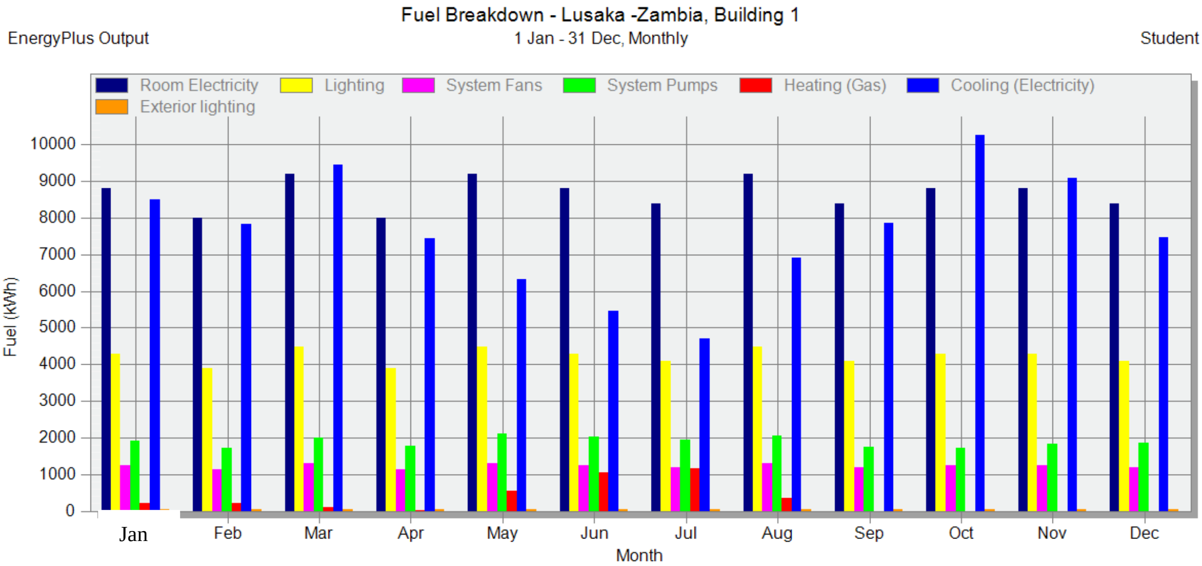


Figure 29: Monthly electricity/fuel usage per source



Baseline energy analysis

The annual baseline electricity/fuel consumption as revealed from Figure 36 was 287,707kWh or 287.71MWh. The highest intensity month was March with a slightly higher figure than October while the lowest fuel intensity month was July. As depicted in Figure 28, room electricity (plug loads) accounted for the most consuming category followed by cooling electricity, then lighting, and finally exterior lighting.

From the monthly fuel breakdown graph (Figure 29), it was evident that apart from the months of March, October and November, which showed cooling electricity as the highest consuming category, room electricity was the highest fuel/electricity consuming category for the other months. The total room electricity was highest in March, May and August at 9,690kWh and lowest in February. Whereas ordinarily October month should have been the highest fuel/electricity consuming month because of the high temperatures requiring cooling, March reflected the highest energy consuming month. According to Hu and Agarwal (2016), a month like March in the study area is classified as a "shoulder" month and usually exhibit a high uncertainty due to large fluctuations in temperature over the month coupled with the building's corresponding occupancy variations.

Cooling electricity arising from the cooling loads (being a summer design location) was the next highest electricity consuming category. The highest loads were in October with 9,269kWh followed by March while the lowest were in July. This corresponds to the temperature distribution of the year although the case of March could be that of a shoulder month with large fluctuations. In addition, the sun position in October and March are the same although March is regulated by higher humidity levels. It is justified that the annual figure of room electricity is slightly higher than cooling electricity because cooling loads higher in summer and lower in winter whereas the plug loads remain relatively uniform throughout the year. Lighting electricity was the third most fuel/electricity consuming category following the same pattern of room electricity with the highest month being March, May and August at 4480kWh. Exterior lighting was the lowest with an average of 37kWh for the whole year.

4.6.2 Baseline internal heat gains assessment

Internal heat gains lead to the need for sensible cooling. The highest internal heat gains were as a result of solar heat gains through the exterior windows as shown in Figure 30. Even though the solar heat gains were higher from March to September, the corresponding cooling load were lower due to the lower temperatures in this period. This demonstrated that the building orientation enjoys the advantage of the passive heating from the sun through its fabric in the winter season. In addition, the solar gains were higher in June because of the incident suns vertical angle position which meant that the sun hits the building (openings) at an angle (near horizontal). The next highest contributor to internal heat gains were the computers and equipment. Internal gains from general lighting followed in third and lastly gains from occupancy. Apart from solar heat gains through exterior windows, all the other internal heat gain sources demonstrated a reasonably uniform profile throughout the year as shown in Figure 31. This revelation led to simulation of different zones for their external fabric performance to reveal the most affected areas. The results were presented in Section 4.7.1.

Figure 30: Internal gains breakdown and sensible cooling.

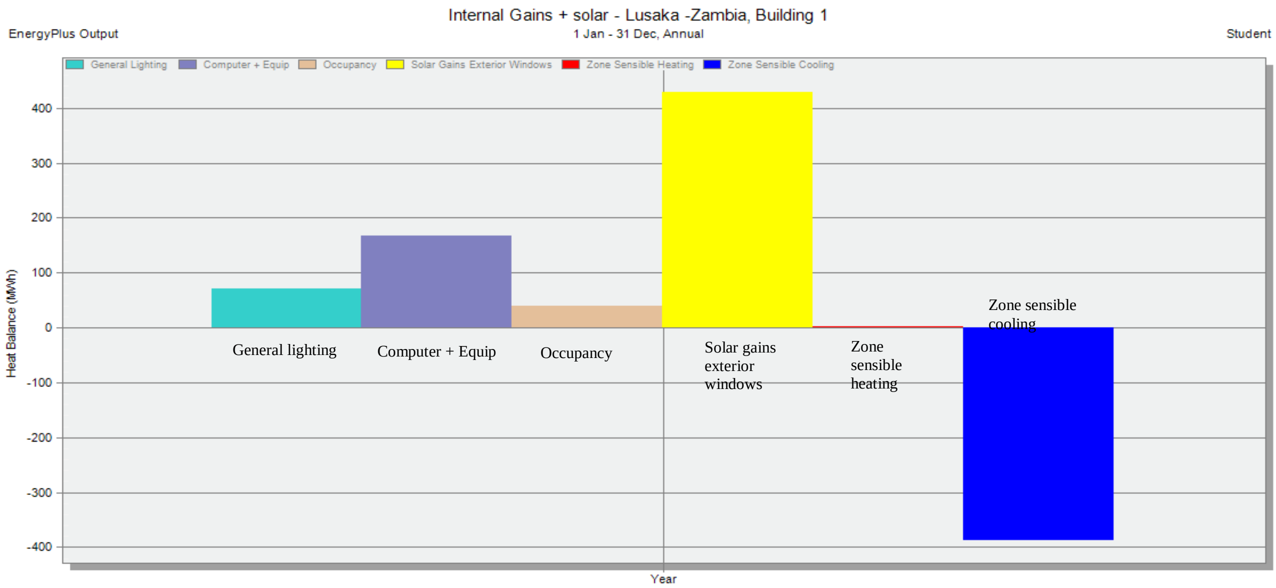
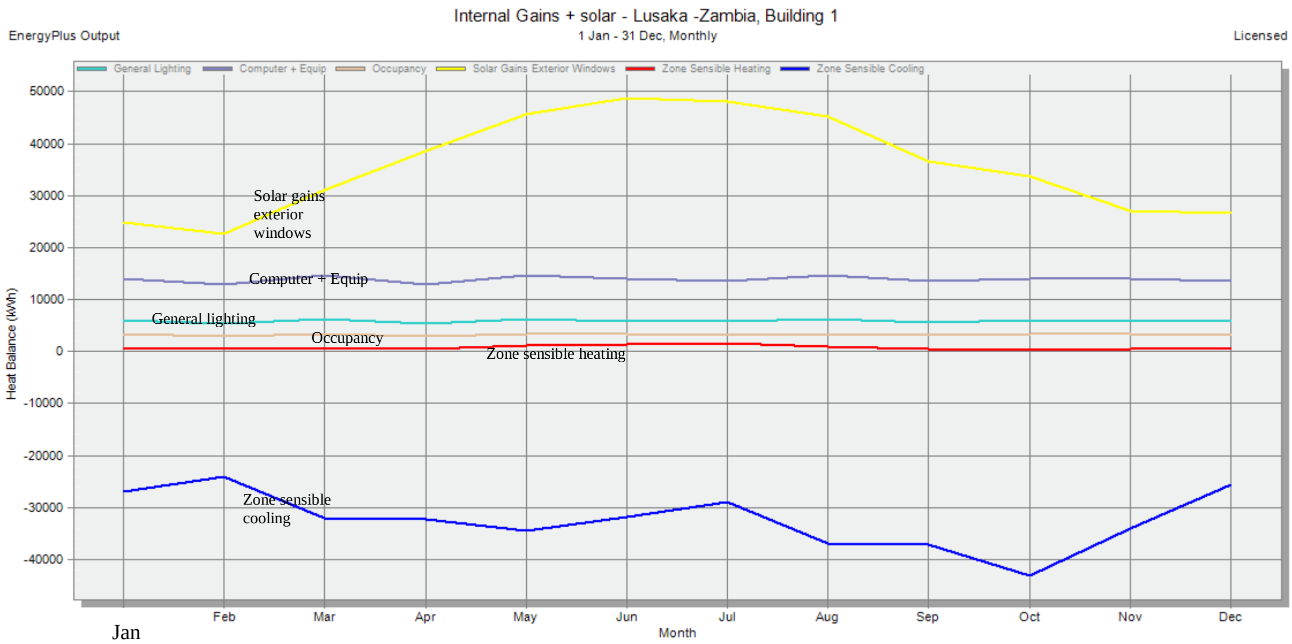


Figure 31: Internal gains breakdown and sensible cooling.



4.6.3 Baseline CO_2 assessment

The CO_2 analysis was done to review the projected CO_2 emission of the building as a result of the fuel/electricity consumption. A CO_2 emission factor for Zambia which is determined by the mix of energy and technology used to generate the electricity, the quality and factors such as production of carbon was used to determine the CO_2 produced. According to the Energy Research Centre (2012), Zambia's national CO_2 emission factor from energy is 74.1kg/GJ=0.2667676Kg/kWh. By multiplying this factor with the simulated annual baseline electricity (287, 707kWh), the annual CO_2 emission was calculated as 76, 754.47Kg.

4.6.4 Baseline daily peak energy consumption

The average total kilowatt hours per day was obtained by running a daily simulation of the highest energy consumption month of March. From Figure 32 below, the baseline daily consumption/demand was obtained as 1,318kWh. Going by the information provided in Section 2.4.2, the average sunshine hours for Lusaka were eight hours in a day. However, according to Whatstheweatherlike.org, during the rainy season for Zambia, the sun only shines 4-7 hours per day due to precipitation. Therefore, six sunshine hours were picked as the appropriate hours for analysis. Dividing the average kilowatt hours per day by the sun hours of the day (six hours) gave 220Kw as the baseline peak load. Table 16 compares the estimated full roof solar PV electricity output to the simulated baseline peak load based on the month of March.

Figure 32: Daily energy profile for the month of March (troughs indicate weekends).

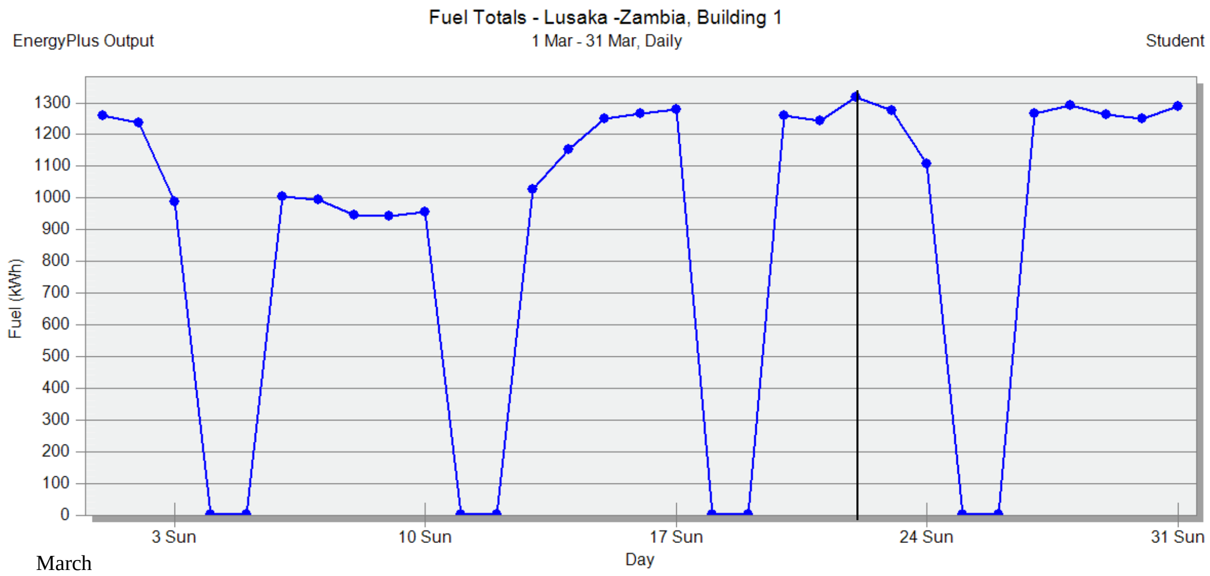


Table 16: Comparison of estimated "full roof" solar output and simulated baseline peak load for March.

Estimated full roof total solar output (kW)	Simulated baseline peak load (kW)
249	220

This initial assessment revealed that by using the full capacity of the roof space available for solar PV electricity generation including the roof of the parking area as shown in Section 4.1, the estimated solar PV electricity output is capable of offsetting the baseline electricity consumption of the building and leave a surplus of 29kW (63,519kWh/year) power even before optimisation of the building through appropriate energy efficiency interventions.

4.7 Design intervention and optimisation of energy towards net zero

Although the initial assessment in the previous section shows a surplus of 29kW power (63,519kWh/year), a further optimisation of the building energy intensity would further increase the electricity saving. Based on the baseline fuel/electricity breakdown graphs, internal heat gain graphs and fabric performance analysis, the priority areas for passive and active intervention were identified for analysis. It is worth noting that even though room electricity was identified as one of the highest energy consuming categories, it was not prioritised for intervention because the type of equipment could not be ascertained in order to optimise given that the building is still under construction. As stated in Section 4.51 the equipment loads were based on an assumption of 11W/m^2. Electricity optimisation methodologies were chosen to reduce cooling loads (reducing heat gain from major sources such as windows), and lighting loads. The first stage involved identifying opportunities for intervention followed by a brief appraisal of the technical viability of the selected interventions. The financial viability of the selected interventions was done as reported under the business case appraisal in Section 6.2.2.

4.7.1 Passive interventions

Using passive design strategies can help reduce the amount of energy that active systems need to use (Autodesk sustainability workshop, 2015). Passive interventions for this project were selected and each was analysed for its impact in reducing the simulated baseline electricity consumption (287,707kWh). Figure 30 above showed that the solar gains through the fabric accounted for the greatest contribution to internal heat gains. This thermal balance graph also showed that this gain is what significantly contributes to corresponding demand in sensible cooling, which was identified as the second most consuming category from equipment electricity.

Some ways of reducing heat transfer through fabric include, changing the glazing specification, introducing shading and adjusting the levels of natural ventilation. Good glazing properties are important because they control the amount of daylight, quality of light in addition to controlling the amount of heat gain let into the building. The heat gain makes it advantageous in winter and disadvantageous in summer (Autodesk sustainability workshop, 2015). Three approaches were chosen to reduce the cooling load and eventually the electricity consumption. These were: changing the glazing type, introducing shading in vulnerable zones and insulating the roof.

Changing glazing type

Figure 14: Reduction in annual energy consumption after glazing intervention.

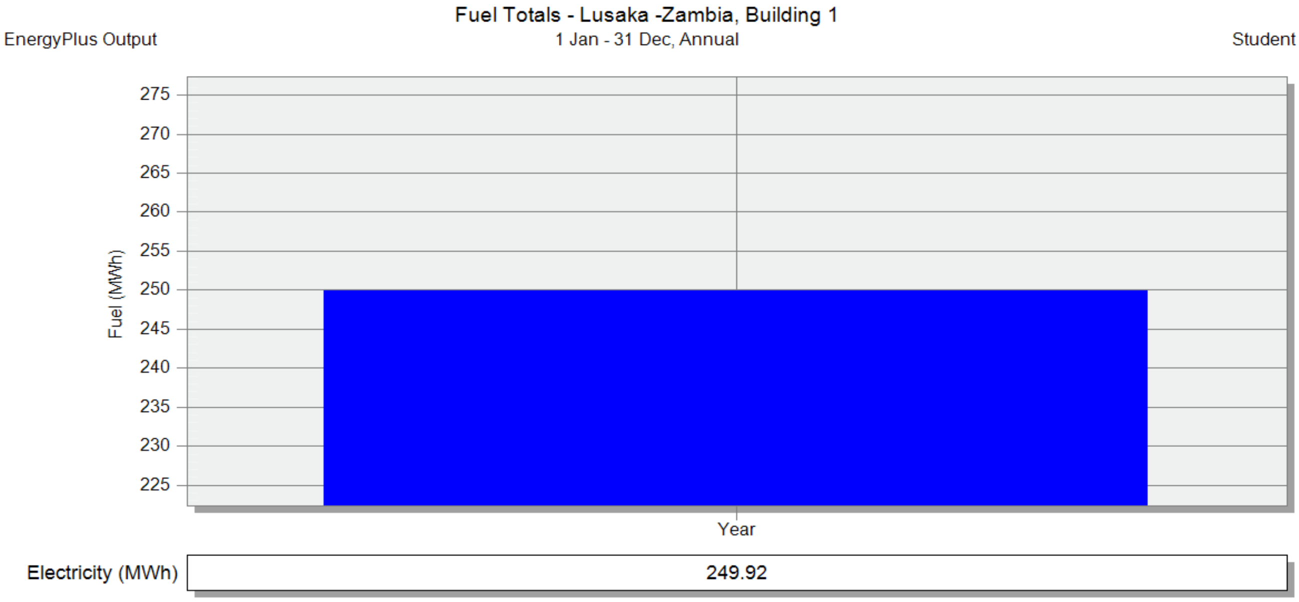
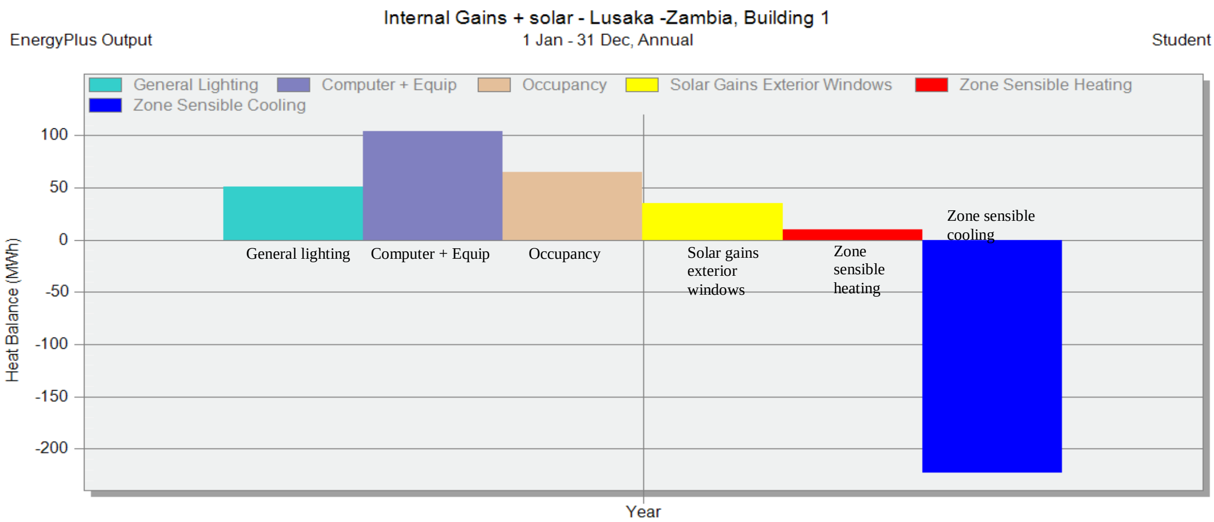


Figure 34: Reduction in annual solar heat gain and sensible cooling.



As shown in Figures 33 and 34 above, by applying high-performance windows, the solar gains and corresponding sensible cooling loads were dramatically reduced and consequently the baseline annual electricity/fuel consumption. The type of window selected for analysis was laminated glass, 6 mm thick double pane (insulated) with 13mm air filling to improve insulation properties (Dbl, LoE-e2=1 clear 6mm). Air, rather than argon, was selected for the gap because it was deemed cheaper. Moreover, air achieved very close results to argon for the same glazing specifications. In addition the glazing had a clear, with light low emissivity (Low-E) tint that appears slight blue when closely inspected in order to regulate the light entering the building (glare control) considering that the window areas are big and mostly north facing.

Table 17: Results obtained by glazing intervention.

Solar heat gain –exterior windows	Annual status quo	428, 560.00 kWh (428.56 MWh)
	After intervention	34, 637.43 kWh (34.64 MWh)
Sensible cooling	Annual status quo	-387,070.00 kWh (-387.07 MWh)
	After intervention	-222,887.50 kWh (-222.89 MWh)
		43% reduction
Annual energy consumption	Annual status quo	287,706.7 kWh (287.71 MWh)
	After intervention	249, 916.3 kWh (249.92 MWh)
		13% reduction

Table 17 shows that changing the glazing type only yielded a 13% reduction in the annual baseline electricity/fuel consumption.

Introducing shading in vulnerable zones and insulating the roof

A cooling design simulation carried out for a typical summer design day (15 October) revealed the results as shown in Figures 35-38 about solar heat gains and exterior fabric performance. Simulating for different office zones and other spaces with various orientations shows that the solar gains peak in the north-western facing offices 1 and 3 (see drawing in Figures 22, and 23) and significantly at around 15:00 hours up to a maximum of 8.6kWh. This is shown in Figure 35 below by the red line.

In the north-eastern zones (i.e. offices 5, 8, refer to Figure 23 and 24), the maximum solar peak gains of 7.15kWh and 6.5kWh were at around 9:00 in the morning and 15:00 in the afternoon respectively as shown by the red line in Figure 36. This showed that the eastern sun in the morning was quite advantageous for the cooler mornings and colder winters. Therefore, the shading was to be introduced only on the western facing façades.

The rest of the offices 2, 4, 6,7, and those facing northwards demonstrated maximum solar peak gains of 2.51kW at 12:00 (12pm) which were considered as reasonable to compensate for colder winters. Top floor zones such as office 6 and 8 revealed high solar gains through the roof. This created an opportunity for applying interventions on the roof.

Figure 35: Example of north-western facing zone- Office 1(red line shows glazing-peak 8.86kW). Office 2 follows similar profile

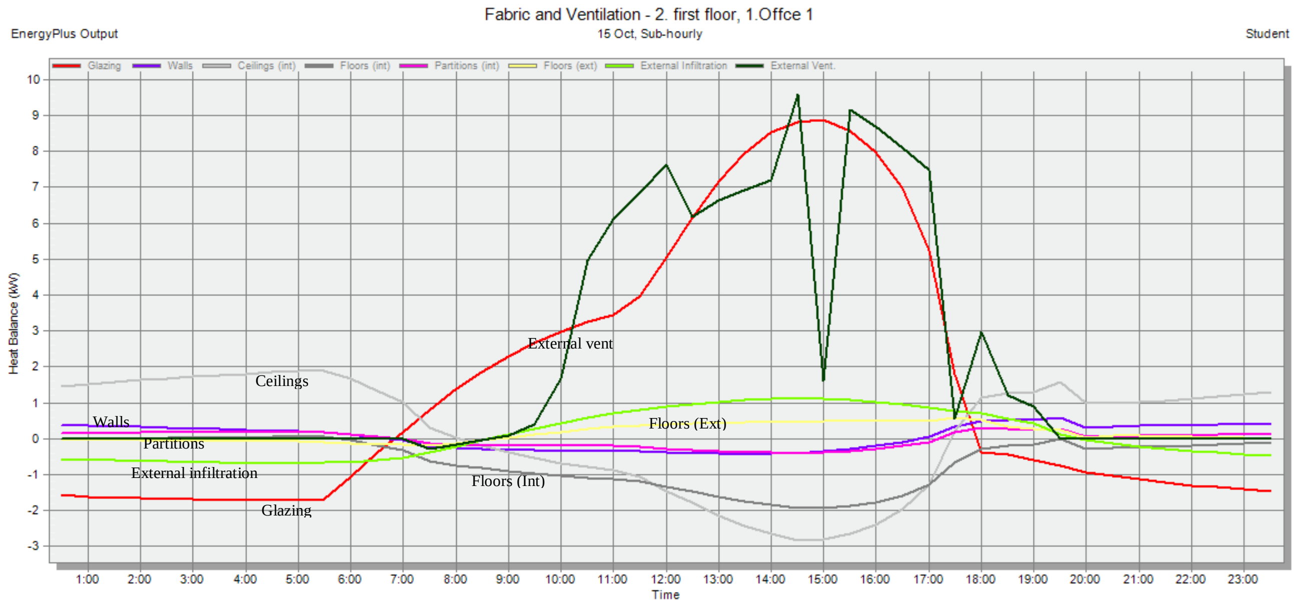


Figure 36: Example of north-eastern facing zone- Office 5 (red line shows glazing –peak 7.15kW & 6.52kWh). Office 8 follows similar profile

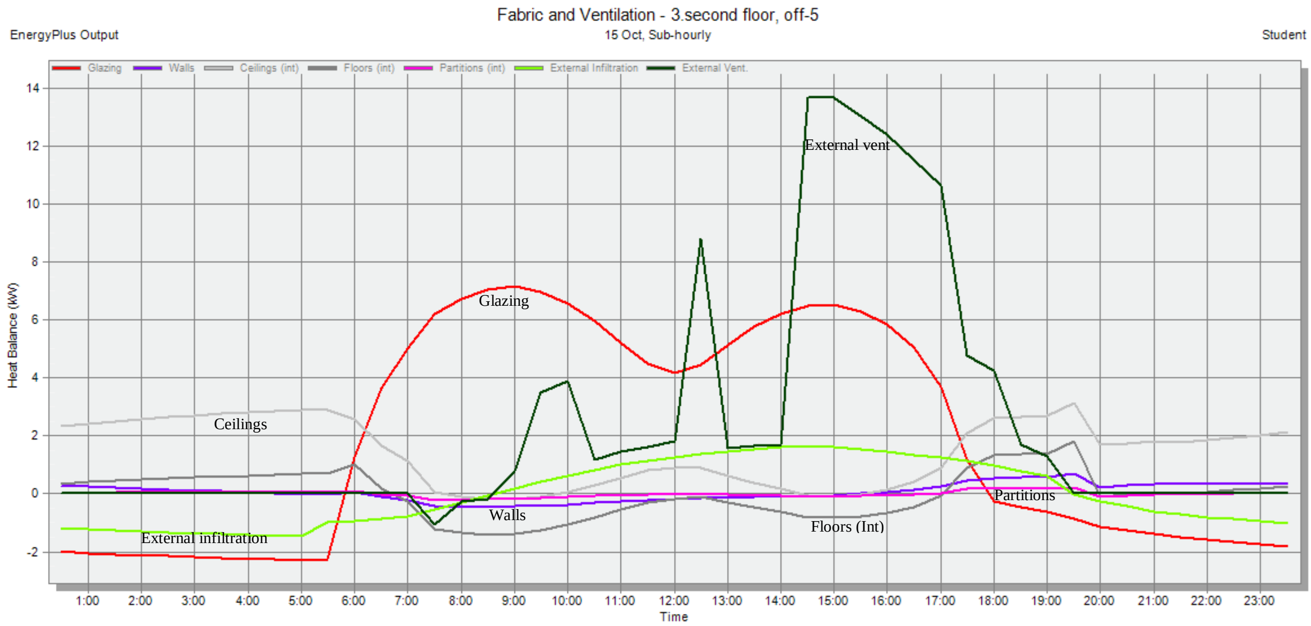
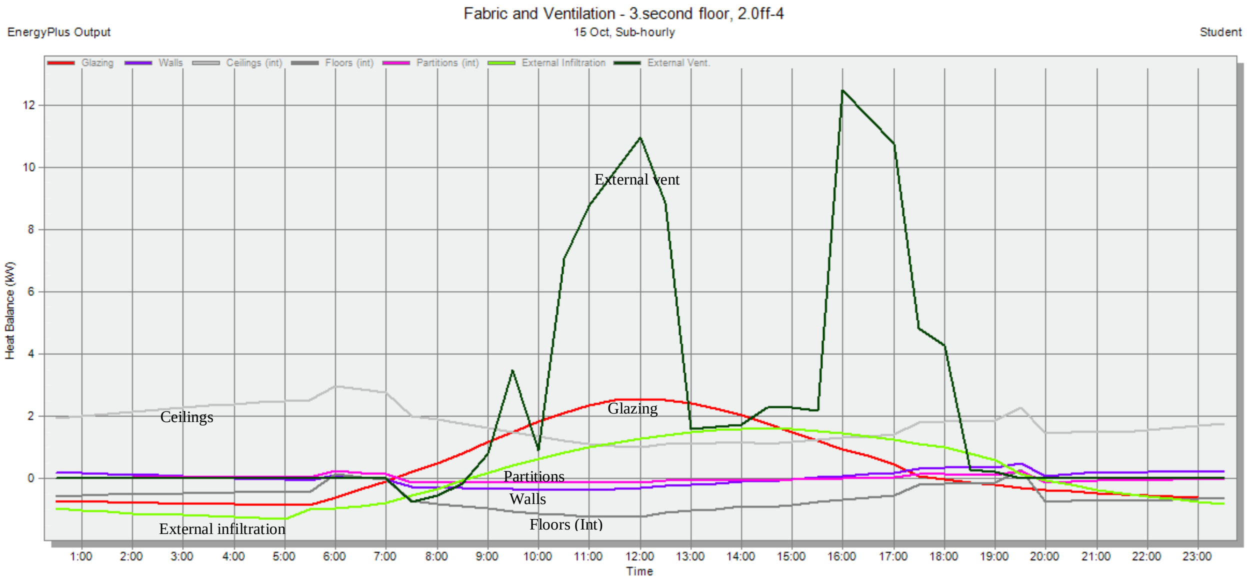
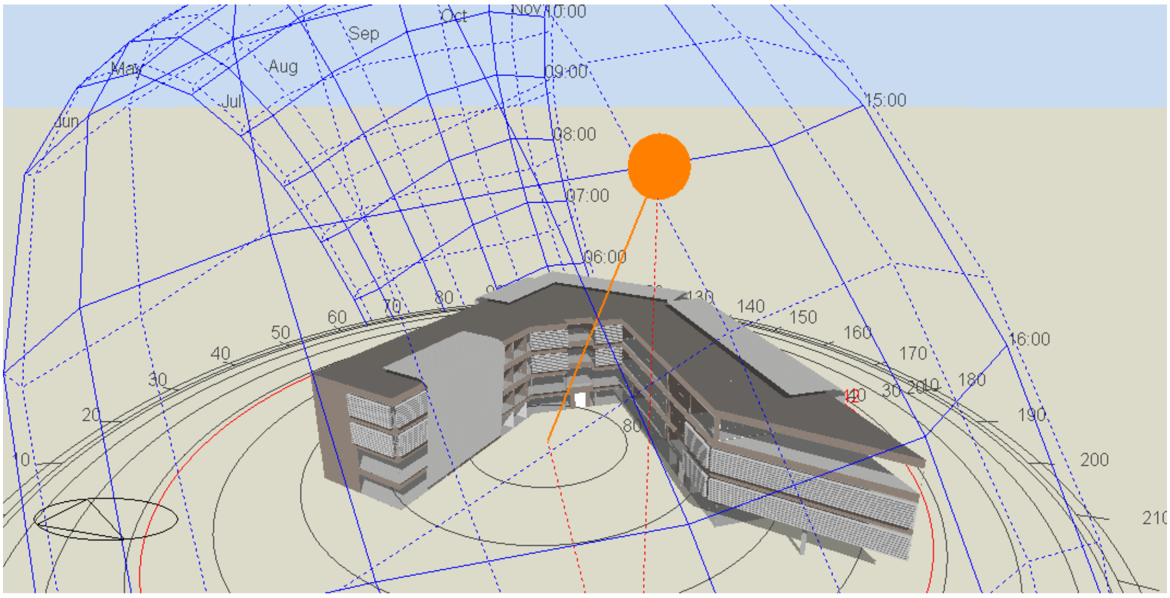


Figure 37: Example of north facing zone-Office 4 (red line shows glazing –peak 2.51kW). Offices 2, 6, 7 follow a similar profile



Based on the above analysis local shading (louvers) were introduced in zones with high solar gains through windows as shown in Figure 38 below.

Figure 38: Louvre shading on north eastern zone facades and summer design day sun position



Local shading was selected from DesignBuilder templates for simplicity, permanence and for the fact that it could perform as an aesthetics feature. By modifying the existing template with bespoke model data and trying different options, the following details of the shading were specified in the model for best result over a total window area of 345m^2.

Table 18: Specification for the shading louver

Blade material	Aluminium (To mimic the buildings shading features)
Blade thickness (m)	0.002
Number of blades	10
Vertical spacing (m)	0.30
Angle (°)	15
Blade depth (m)	0.4
Distance from window (m)	0.30
Window Area covered (m^2)	345

Comparing the impact of this shading in the office 1 zone revealed a reduction in the peak solar gain by around 50% to just over 4.3kW from 8.6kW as shown in Figure 39 below. Reviewing the results of the office 5 zone revealed that the solar heat gain was reduced by around 35% from 6.52kW to 4.2kW at 15:00 but did barely reduce for the 9:00 morning gains as shown in Figure 40.

Figure 39: Reduced solar gain in office 1 zone

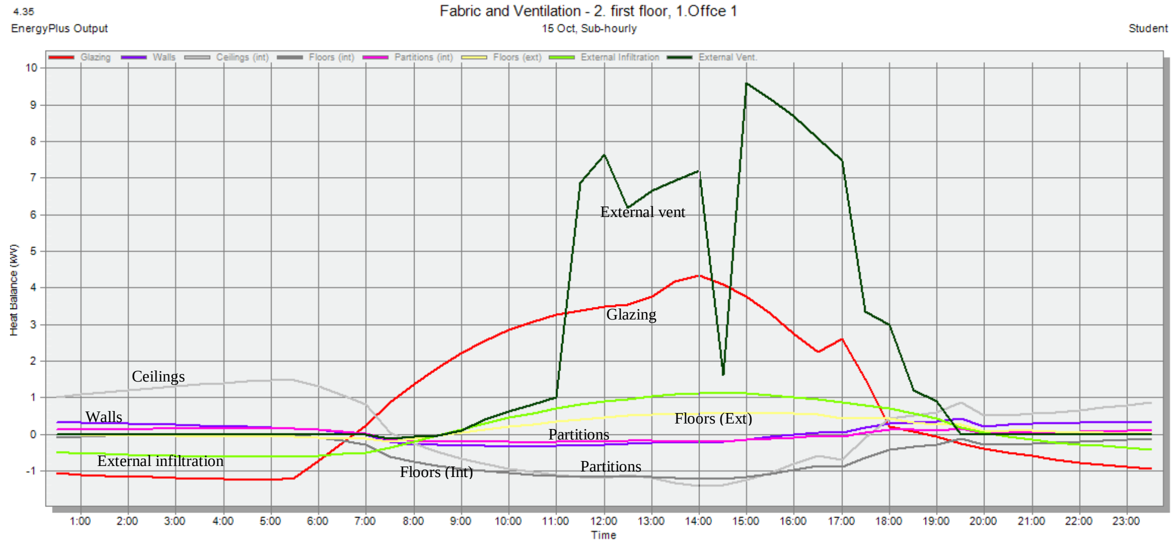
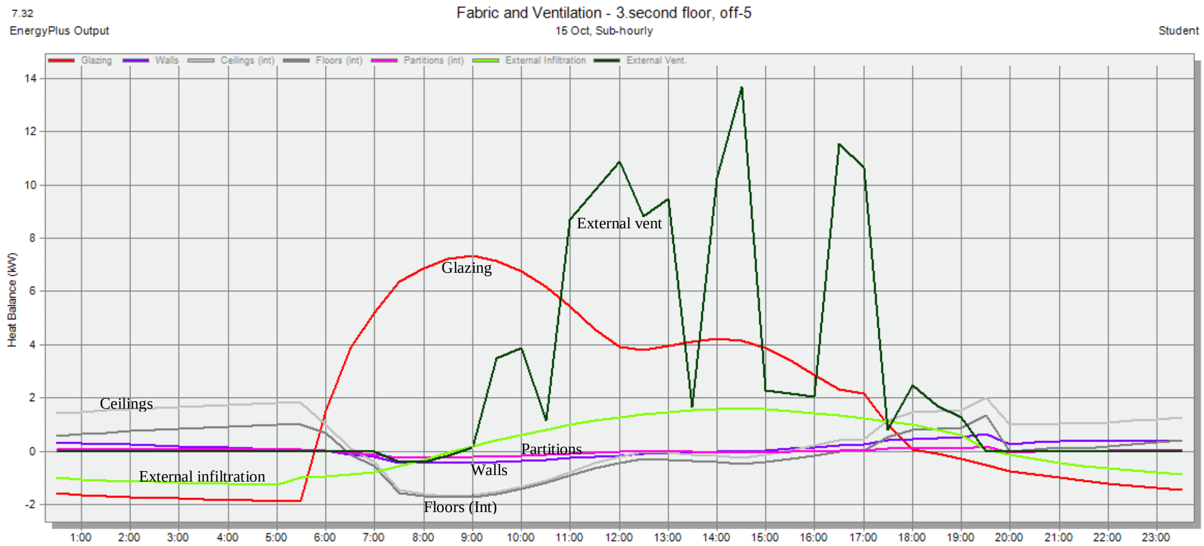


Figure 40: Reduced solar gains in afternoon 15:00 office 5 zone



Roof insulation

Based on a baseline cooling design simulation carried for a typical top floor zone (office 8), it was revealed that the roof presented a good opportunity to intervene in reducing the solar gains and reduce electricity consumption. Figures 41 and 42 below compare the baseline and optimised roof gains with a difference of 3.56kw –from 5.63kW to 1.8kW at 15:00. This intervention involved insulating the concrete roof covering an area of 1,452.24m^2 with an inverted expanded polystyrene layer on top of the asphalt water proofing element. This was the most viable, cost effective option considering that the dense concrete roof had already been cast, such that any intervention on the roof should be deemed to be a retrofit.

Figure 41: Gains through the roof before intervention (in brown). Office zone 8

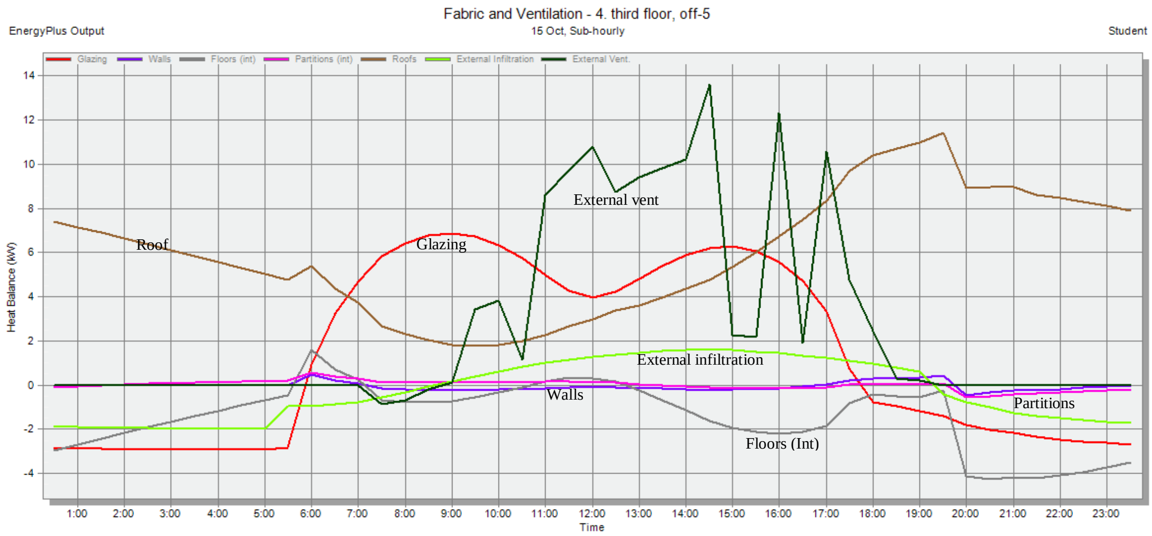
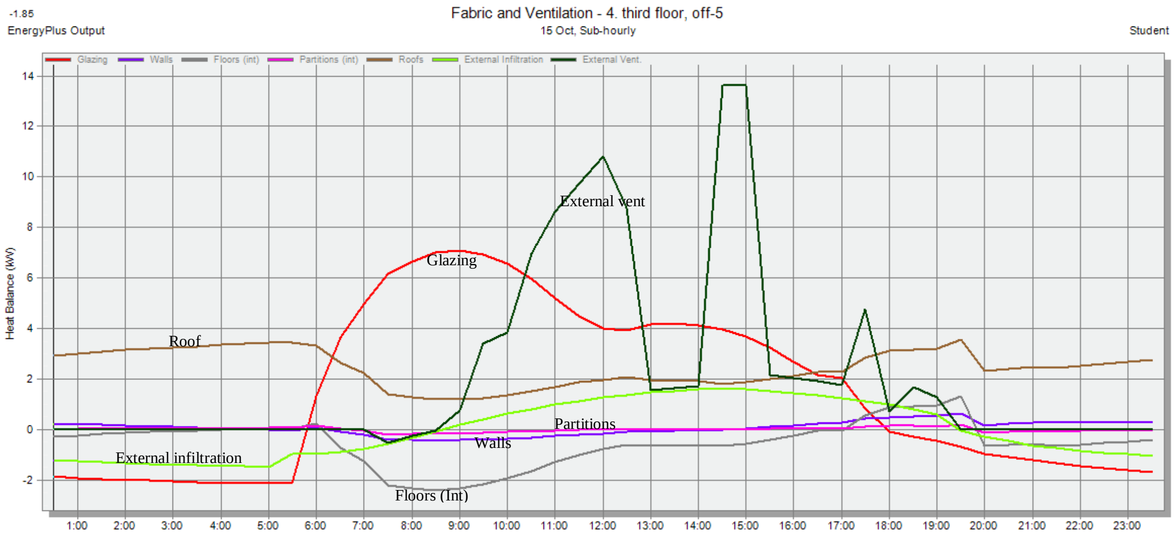


Figure 42: Optimised gains through the roof by insulation (in brown). Office zone 8



The resulting reduction of annual building energy consumption as a result of local shading and insulation of the roof was 235,564.5kWh (235.56MWh) as shown in Figure 43 and 44 below. These findings are summarised in Table 19.

Figure 43: Annual energy reduction as a result of shading and roof insulation

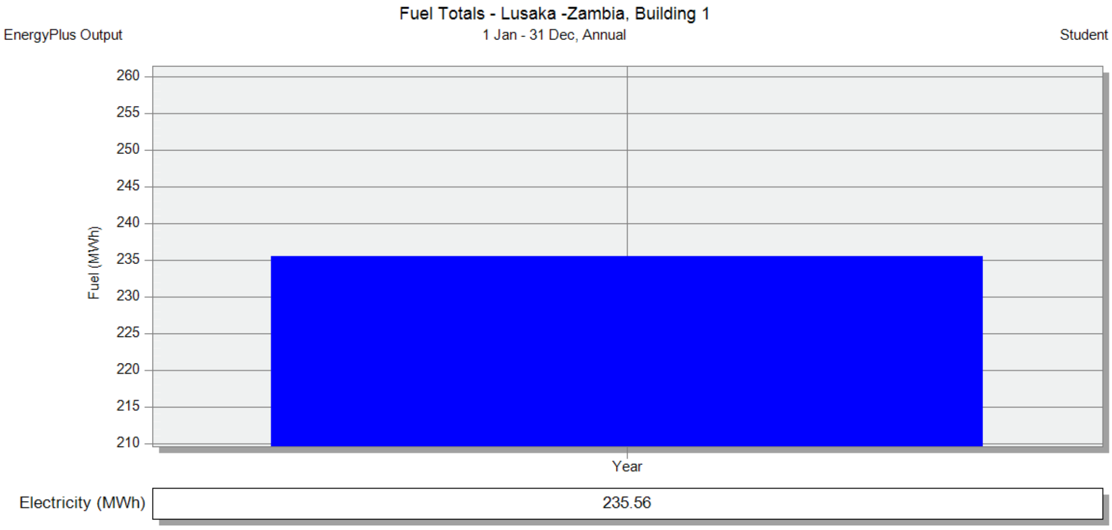


Figure 44: Significant reduction in internal gains due to solar gains from exterior windows

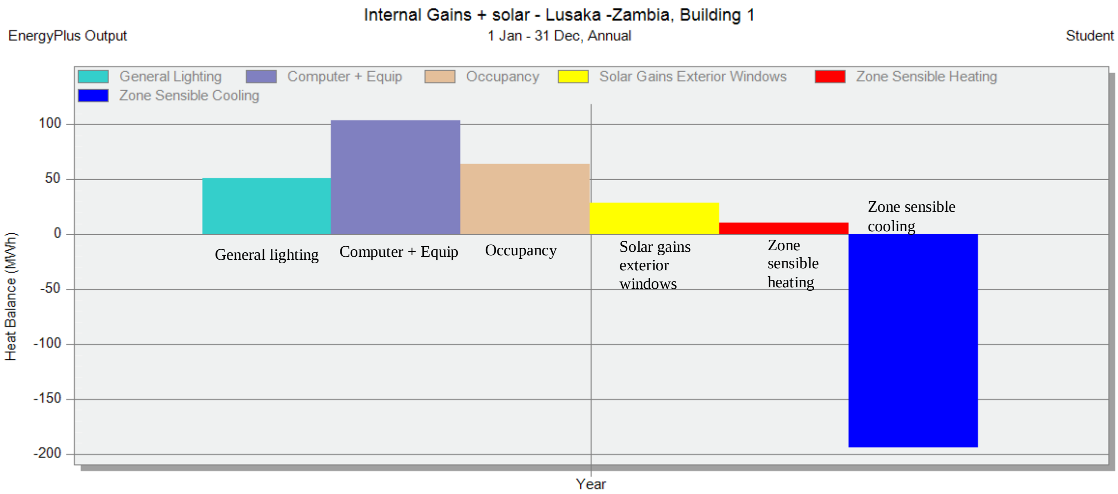


Table 19: Results after shading and roof insulation intervention.

Solar heat gain –exterior windows	Annual status quo	428, 560.00 kWh (428.56MWh)
	After shading and roof insulation intervention	28, 399.2 kWh (28.4MWh)
Sensible cooling	Annual status quo	-387, 070.00 kWh (-387.07MWh)
	After shading and roof insulation intervention	-194, 353.4 kWh (-194.35MWh)
		50% reduction
Annual energy consumption	Annual status quo	287, 706.7 kWh (287.71MWh)
	After shading and roof insulation intervention	235, 564.22kWh (235.56MWh)
		18% reduction

4.7.2 Active intervention

Lighting control

Lighting presented an opportunity for intervention because it accounted for the third highest electricity/fuel consumption after equipment and cooling loads. Although the design mainly specified LED lights which are ordinarily energy efficient, by introduction of lighting controls, a significant percentage of electricity was saved. Lighting controls enable the electric lights to operate in interaction with availability of natural day lighting. Design builder calculates luminance levels at every step during the simulation and determines how much electric lighting can be reduced. The factors that determine the daylight illuminance levels include sky condition, sun position, photocell sensor position and glass transmittance of windows. By default, all lights in a zone are controlled once the lighting control sensor is set to 100%. Some zones like office 4, 7 and 8 needed two sensors because they were larger zones. In addition, those which had facades in different orientations resulting in different illuminance requirements were also specified with two sensors. This gave a total of 25 daylight sensors. Applying day lighting controls resulted in a reduction in annual electricity/fuel consumption by 17% from 287,707kWh to 239,001kWh as shown in the Figure 45 and Table 20 below.

Figure 45: Reduction in annual electricity consumption as a result daylight lighting control intervention

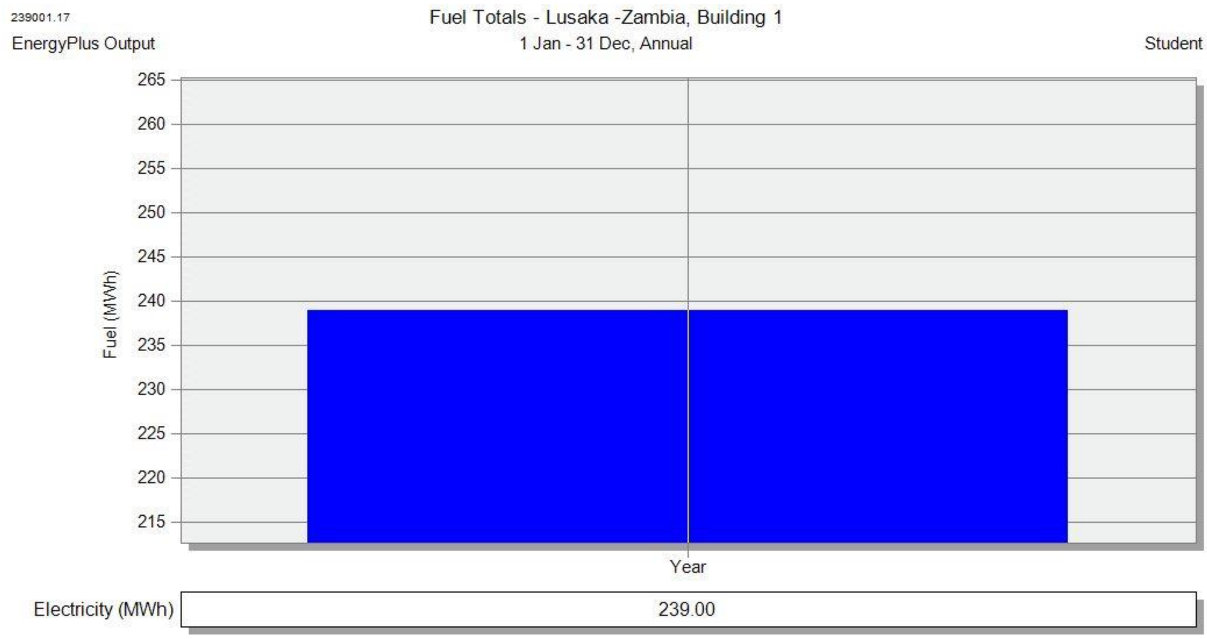


Figure 46: Reduction in annual lighting load from 52MWh to 36.86MWh

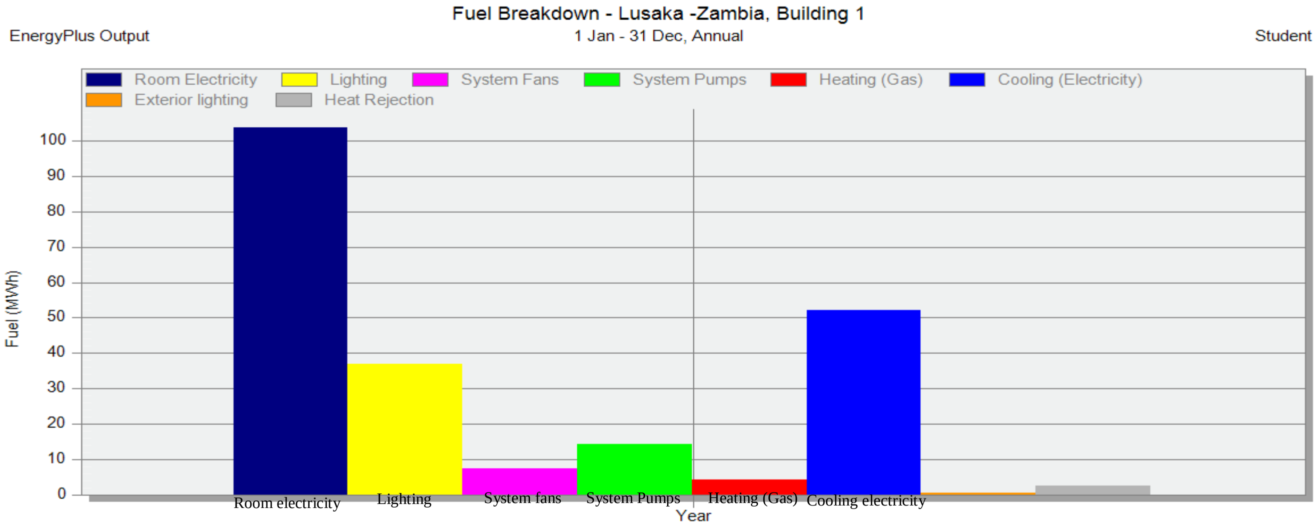


Table 20: Results after day lighting control intervention

Annual Lighting loads	Annual status quo	kWh (52MWh)
	After shading and roof insulation intervention	36863.2kWh (36.86MWh)
		29% reduction
Annual energy consumption	Annual status quo	287706.7 kWh (287.71MWh)
	After lighting control intervention	239,001kWh (239.00MWh)
		17% reduction

4.8 Preliminary results

The preceding analysis assumed the "full roof" solar PV module which approximated the maximum amount of PV that could be installed on the building and car park roof top. The system proposed 300W module array installed to the usable roof area deliberately intolerant of shading. After modelling and simulating the optimised building load profiles, it was determined that the available roof space as estimated in Section 4.1 had the capacity to net out the baseline annual electricity consumption and generate a surplus of 29kW (63,519kWh/year). Following this assessment, energy efficiency interventions to further reduce the baseline electricity consumption were simulated and the findings are presented in summary in Figures 47 and 48.

Figure 47: Comparison of results from three energy efficiency interventions

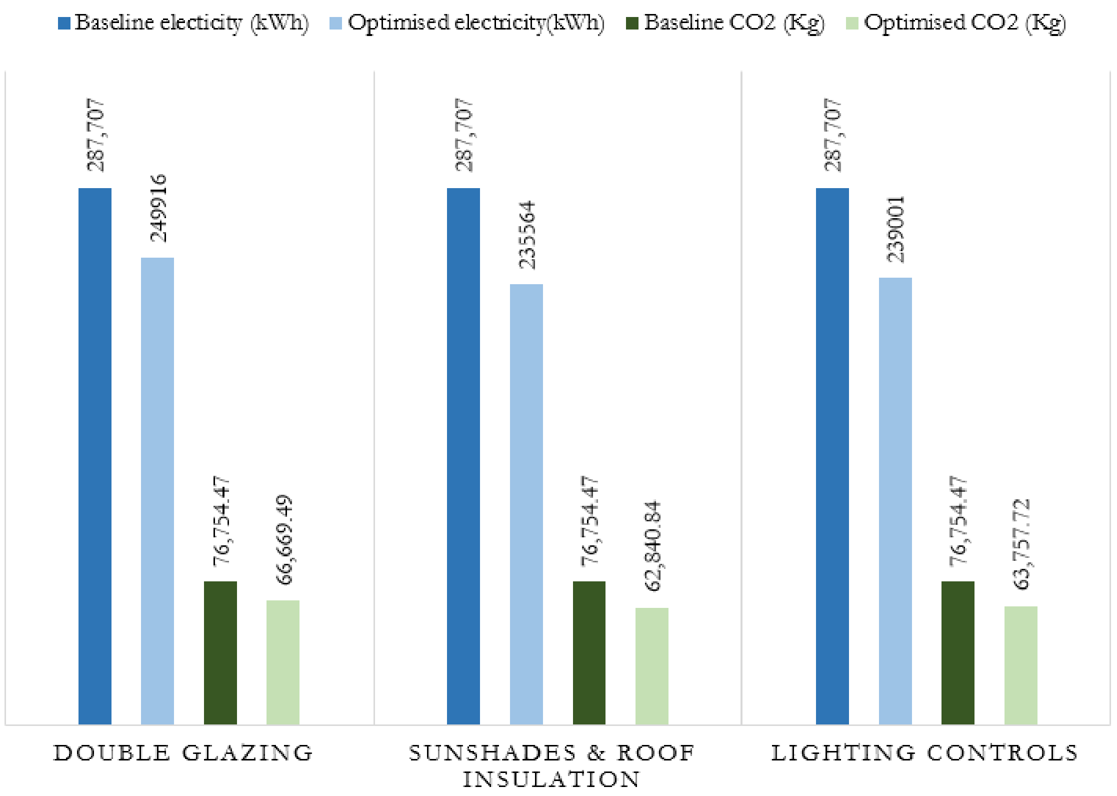
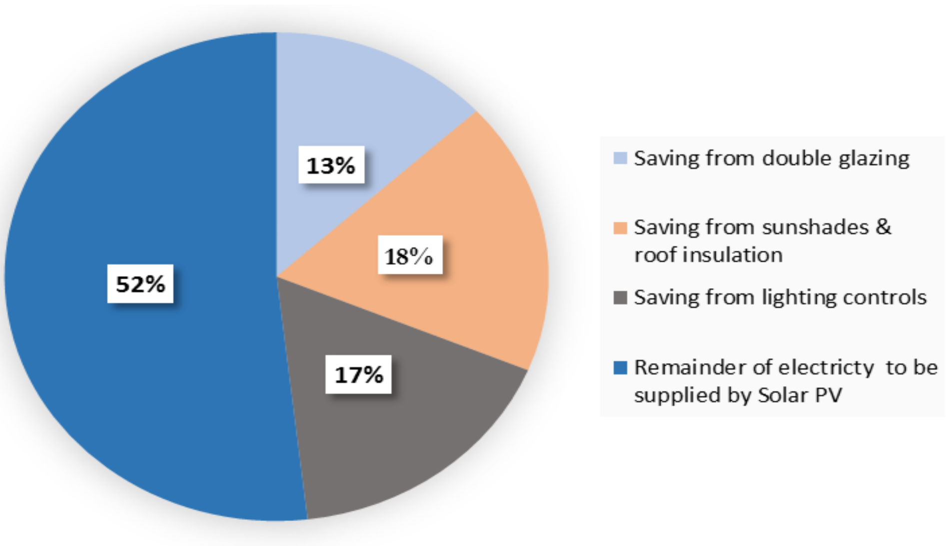


Figure 48: Comparison of savings from the three energy efficiency interventions



Chapter 5. General analysis of the solar PV investment environment in Zambia.

5.1 Introduction

The interview data gathered evidence on the solar PV investment environment in Zambia. This chapter provides insights on the general solar PV industry outlook. The chapter reviews the renewable energy feed-in tariff program as a key framework to explain the possibility of grid interaction. The chapter also looks at the involvement of the central utility in the development of decentralised solar PV systems. Data explaining the increased interest in solar PV systems among different consumer segments is also presented. Other data analysed is about the current regulations impacting on investment, the state of buildings integration of solar PV systems, existing financing mechanism and the technical and market scenarios in Zambia.

5.2 The Renewable Energy Feed-in Tariff (REFiT) program and grid interaction

Information obtained from interviewing various experts from the energy sector and secondary information from the latest policy documents all highlighted that there was an advancement in the development of feed-in tariffs and grid interaction mechanisms steered mainly through the REFiT policy program. This revealed that the National Energy Policy (NEP) of 2008 and the vision to harness the renewable energy-in order to drive economic growth through universal electricity access for all Zambians by 2030 were slowly being attained. This finding confirmed the literature review findings in Section 2.4.4 of Chapter 2 which stated that a dedicated policy framework on solar PV generation was either lacking or was still in the process of formulation. Notwithstanding this, policy on decentralised solar PV embedded generation regarding electricity tariffs, grid integration and licensing arrangements were embedded in two main programs namely; the renewable energy feed-in tariff (REFiT) policy of 2015/2016 and the scaling-up solar project which was being steered by the Industrial Development Corporation (IDC).

Developed by the Energy Regulation Board of Zambia (ERB-Z) with the help of the USAID Southern Africa Trade Hub/AECOM international development, the REFiT program is an internationally recognised mechanism to encourage private sector participation in electricity generation from renewable sources (USAID Southern Africa Trade Hub/AECOM International Development (a), 2016). A three-year phased framework to govern the implementation of this policy is already in place and subsequent REFiT program phases will be determined at the end of the first phase based on revised and updated mechanisms (*ibid*).

Much of the policy however leans towards the utility scale, grid-tied renewable energy generation with phase one of the implementation framework of the policy providing for a three-year REFiT generation allocation of an initial 150MW divided into 100MW hydropower and 50MW non-hydro power (solar photovoltaic and solar-thermal, geothermal, biomass and wind). Even though the REFiT policy outlined these allocations, latest literature and interviews undertaken with experts at CEEEZ and IDC revealed that the utility scale solar PV generation alone would exceed 100MW in the first round. A 600MW solar power program being implemented by the IDC, with support from IFC was commencing the first round which consists of two plants of 50MW each by using the World Bank group's scaling solar initiative. The second round which had already been launched targeted a further 200MW towards the 600MW solar PV allowed capacity (IDC, 2016). According to an expert interviewed at CEEEZ, the 600MW was the allowed solar PV capacity for the grid and if the World Bank moved quickly to install the whole of it in the coming years, then there will be no allowance for micro-generators unless the capacity was increased. Considering that the first phase was already under way, it is capped in generation capacity to 600MW in order to allow for the existing grid infrastructure to handle the solar power supply. This stride forward provided a good platform for future technology upgrades on the path towards decentralised PV systems.

Interestingly, the policy and allocation created an additional 10 MW grid capacity in order to provide the platform for the financing and development of 10 MW private sector micro-generation within the same phase period. This system would be based on net metering in such a way that the micro-generation served the owner's own consumption first with exporting the surplus generation to the grid, which would then be deducted from the overall consumption bill, but no positive earnings were guaranteed in the first phase of the REFiT program (USAID, Trade Hub southern Africa (b), 2016). In addition, the policy made it possible for the micro-generation projects to connect renewable energy power of maximum 300 kW size to the low-voltage electricity distribution side of the grid. The benefit for the micro-generation owner was that all produced energy could be utilized with no energy lost due to discrepancies between actual time of generation and consumption given that total generation was below total consumption. The micro-generation allocation would also introduce an incentive scheme to promote the generation of small-scale renewable energy with variation between different technologies and sizes in order to gain both a broader knowledge and serve as a demonstration in preparation of long-term goals.

Although the policy has provided for this small-scale allocation, information obtained from the utility company ZESCO expressed that the corresponding physical mechanism for such small capacities to interact with the grid were not yet in place. However, the equivalent for mini-grid solar systems were in place. To this effect, the utility built a substation in the South MFEZ to connect the 100MW power from solar under the IDC as a pilot.
Table 21 below shows the approved and published REFiT levels by the ERB-Z for solar PV.

Table 21: REFiT levels. (Source: USAID Southern Africa Trade Hub / AECOM International Development (a), 2016)

Solar PV Plant Size Range	Benchmark Tariff[1] (U.S. ¢/kWh)
500 kW but less than 1 MW	17.82
1 MW but less than 5 MW	16.76
5 MW but less than 10 MW	15.74
10 MW but less than or equal to 20 MW	14.25

Some of the key elements contained in the REFiT policy included: guaranteed purchase price for a fixed duration, access to transmission lines, a guide for qualifying renewable energy generators and obligations for the off-taker (ZESCO). Under the REFIT program, a grid code rules and compliance mechanisms/protocols had been developed with specific rules for the power generator and the off-taker (ZESCO). The requirements were designed to reinforce the existing electricity act, CAP 443 and the energy regulation act, CAP 436, with modifications to include contribution of the renewable project to grid stabilization and reduction in network losses and the technical and financial requirements for the network integration.

The development of the IDC utility scale solar PV project based on providing competitive priced clean power has formed the basis for a record low solar tariffs in sub-Saharan Africa to date (IDC, 2016). According to a respondent at CEEEZ, the high level of competition and the quality of tariff bids that were delivered by the scaling solar initiative led to the highly competitive solar tariffs. After running the tender process, two bidders from an initial 48 won the two 50MW projects with bid tariffs of 6.02US¢/kWh and 7.84US¢/kWh. These proposed tariff will remain fixed for 25 years (IDC, 2016). The formulation and implementation of the feed-in tariffs for different scales of electricity generation as well as and subjecting the utility-scale solar PV projects to tendering process means that the country should move to tariffs that are more reflective of global trends in response to ongoing innovations and diffusions in the market as reflected by escalating volumes.

5.3 The Central Utility's involvement

Apart from the need for reflective tariffs to steer private investment in solar PV generation, the private solar power generators need an off-taker. While ZESCO is still far from facilitating the off-taking of micro-generated solar electricity from both commercial and residential scale producers, the national utility has already put in place a mechanism to begin off-taking of the utility scale solar electricity generated through the round one IDC project. Information gathered through an interview with a respondent at ZESCO revealed that ZESCO is however very supportive of the bringing in of electricity at different levels including commercial, industrial as well as domestic level. Despite the utility being the sole provider of electricity, it has recognised the role and responsibilities of other players in the energy sector. Whereas other developing countries like South Africa are displaying a somewhat lack of intrinsic interest in decentralised solar solutions because of the current surplus in electricity and competition, ZESCO seems to take a lead role in promoting decentralised solar system, at least for the time being. Data gathered through interviews revealed that this support comes from the utility's recognition and utilization of the private sector involvement and its capacity to create a reserve in the case of excess electricity from private renewable energy generators.

From the utility's side (ZESCO), they have moved closer to ensuring that the planning for renewable energies, under which solar PV generation falls, is adequately handled, by dedicating one of its division to related consulting services, which was not the case previously when it all fell under one big umbrella. However, beyond that acknowledgement there is seemingly not much commitment to specifically narrowing down to policy on solar PV and the required structural framework as discussed in the literature under Sections 2.4.4 and 2.4.5.

Apart from this, ZESCO and the Zambia Bureau of Standards are currently working on a more detailed standard on solar products which has been necessitated by the wind of change towards solar PV systems. Whereas literature under Section 2.4.5 pointed out the lack of standards and coordination among allied stakeholders, the coming together of these two key institutions (as shown from the preliminary data collected) signifies positive strides towards the formulation of standards and studies in the solar PV industry. ZESCO takes a huge stake/role and has representatives on the board to guide the utility's direction regarding solar PV exploitation.

Limitations on grid integration infrastructure and studies underway

There are certain limitations to feeding solar generated electricity into the conventional grid. This is the major reason why many developing countries continue to lag behind in grid-interactive decentralised generation systems compared to developed countries, such as USA and Germany, which have moved to smart grids as part of their federal policy with well laid standards to support decentralised grid-interactive solar PV systems (Kempener *et al*, 2013). One of the imminent concerns that was revealed and identified as key priority concern towards integration of solar power electricity into the conventional grid, was the nature of its intermittency and variableness However, information obtained from the respondent from ZESCO revealed that notwithstanding this limitation, solar PV is receiving the most attention regarding how it can be integrated into the gird. The foremost background target was to determine what quantum of solar electricity could be accommodated without compromising the system. To this end, ZESCO has been carrying out independent studies through the transmission section in order to determine the most feasible solar PV connection points and install the necessary equipment that will take care of the intermittency. According to the respondent at ZESCO, the required studies are underway, and it is anticipated that the consumer will not feel any effect of the intermittency since the study will allow for more substations from which solar electricity can be fed into the grid. Although these policies have been included in the documentation, they have been lying idle for some time now. However, given the period in which the utility has had to adapt to accommodate the oncoming 100MW utility-scale solar plan goes to show that the utility could easily adapt with imminent changes. This could be taken to serve as a crucial precursor thus raising expectation that frameworks for other levels of solar electricity generation, including buildings, could be in place in the near future.

Another notable limitation pointed out by respondents from both CEEEZ and OPPPI was that currently, the set capacity of only 600MW for solar constitutes the cap in relation to what can be accommodated by the existing grid. This means that if the World Bank completes the utility-scale solar investment, any extra capacity will have to wait until major grid improvements are undertaken to handle more capacities. This will entail that the alternative feasible and viable options will be decentralised off-grid and isolated systems because it does not really matter where they are developed.

5.4 Motivation for the interest in solar PV systems

Data obtained from interviews corresponds with the information in Section 2.4.2 which states that the use of solar PV is on the rise in Zambia. Most literature has observed that this rise has been necessitated by the deficit of over 1000MW which has crippled many economic development activities (Mwila, 2016). As stated in the background of the study under Section 1.1, over eight hours of load shedding are being experienced across the whole country. According to a schedule obtained from ZESCO, the load shedding lasts 4 hours in a day for 3 days of the week in the case study location. This is only less because most of the surrounding area has commercial/office buildings. However, this disruption completely justifies the need for a decentralised solar PV system.

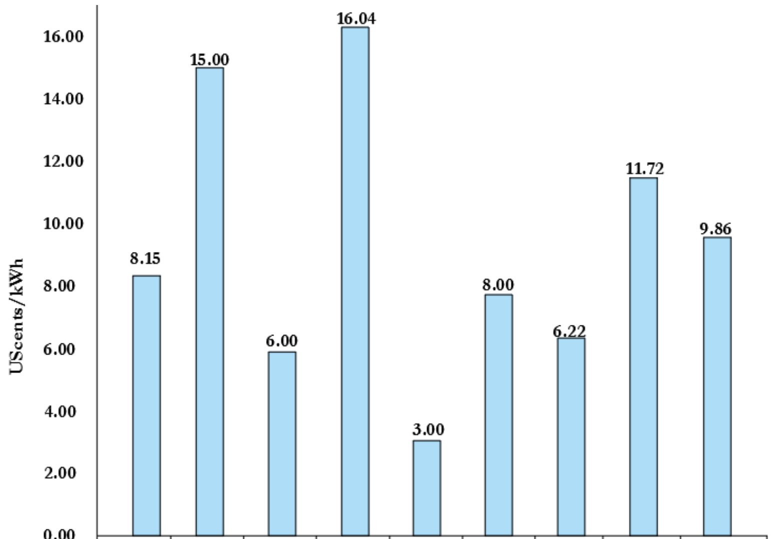
While the crisis has played its part in creating interest, data from the interviews revealed more reasons for this growing market. From the utility's perspective, work and support frameworks for solar PV integration had started some time back even before the onset of the crisis. Before a dedicated consultancy division was set up to oversee and enhance development of solar PV electricity generation, there were already units set up to work towards demand-side management and campaigns towards public use of solar home systems. A respondent from the utility noted that even if the country were to achieve full supply capacity, or did not have the deficit, working in a global world entails keeping up with advances in technology in the energy sector. Hence any energy source that is clean and brings down the cost of production would be worth exploring. Another driver which will further catalyse the interest is the projected increase in the electricity tariffs such that any investment in solar PV on the customer-side would translate into significant savings.

5.5 Towards cost reflective tariffs-economics around the technology

As stated in the earlier section, one of the biggest impediments of investment in private electricity generation in general has been attributed to the absence of reflective tariffs. Although data gathered through the interviews with respondents from ZESCO, ERB-Z and the department of energy revealed that efforts are being made to unify the tariffs and make them cost reflective. The tendency in the past has been a corresponding outcry from the consumers thus placing political pressure on the government to revert to subsidized tariffs. On two occasions (in December 2015 and October 2016), the country's power regulator rescinded a decision to increase electricity charges from 6 to 10.35 U.S cents/kWh following such an outcry (Mfula, 2016).

Arguably, for a long time now Zambia's electricity tariffs have remained to be among the lowest in the region, as shown in Figure 49, because the country had been sitting on a surplus (Sikwanda, 2016). Therefore, what the customer has become used to paying is not what it costs to generate, transmit and distribute the electricity. The respondent at ZESCO highlighted that the central utility is caught between the need to increase the cost and attract business and not undermine the essential part of its role to support the economy through low tariffs. The government, however, needs to balance the need to keep energy prices low due to existing poverty levels versus other competing socio-economic needs.

Figure 49: Average regional tariffs for end user -2015 (Source: Sikwanda, 2016)



	Mozamb-ique	Namibia	Zambia	Tanzania	Angola	Malawi	South Africa	Swaziland	Zimbabwe
Average electricity tariffs (UScents/kWh)	8.15	15.00	6.00	16.04	3.00	8.00	6.22	11.72	9.86

The view from a representative and solar PV expert at a leading local solar PV company revealed a similar concern over the current non-reflective tariffs affecting positive returns on solar business. He highlighted that ZESCO produces electricity at 10US¢/Kwh but sells it at a national average of 6US¢/Kwh. According to his experiences, the solar PV expert explained that this is the reason why despite the inconveniences arising from power cuts, most customers would favour to wait for the load shedding hour to elapse instead of investing in a decent solar PV system. However, with the REFiT program and selection of investors for the solar PV generation, the regulators realised the inevitable need to migrate to cost reflective tariffs in order to secure competitive bids and thus make business sense for the investors.

Despite these conditions, almost all the respondents expressed optimism that once the tariffs become cost reflective, more people will look to alternative electricity sources and solar PV, being a modular technology, offer a greater range of advantages above other competing alternatives. In this way, the economics would drive the market because once the cost of electricity is high there would be a huge saving from the substantial portion that would otherwise be going to electricity bills.

The ZESCO tariff plan prepared in 2012 already proposed an average of 26% tariff migration to cover the years 2012/13 to 2015/16 needed to generate revenue and operating profit for the utility (ERB-Z, 2012). Despite attempts to halt these escalations in prices (mainly due to political reasons), the tariffs have increased by an average of 4% within the same period. The table below shows the proposed tariff path for 2012 to 2015/16. From this it is possible to project that the electricity tariffs are expected to escalate by an average of at least 8.5 percent every year in the medium term.

Table 22: ZESCO's proposed tariff path 2012-2015 (Source: ERB-Z, 2012)

Average price - ZMK/kWh	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2014/15**	**2015/16**
Residential	353.08	347.53	458.73	635.75	850.78	948.50
% change			32%	39%	34%	11%
Large power	243.28	238.78	266.19	325.17	399.44	442.15
% change			11%	22%	23%	11%
Small power	237.51	232.06	288.47	343.91	482.33	554.89
% change			24%	19%	40%	15%
Commercial	343.23	339.44	420.04	508.01	654.23	730.08
% change			24%	21%	29%	12%
Services	260.08	259.98	307.33	396.24	541.91	616.55
% change			18%	29%	37%	14%
Weighted Average[2]		**280.72**	**353.37**	**463.61**	**620.49**	**700.97**
% change			**26%**	**31%**	**34%**	**13%**

Conversion rate Dollar to Zambian Kwacha: 1$ =10.125ZMK

According to the respondent from OPPPI, the country's energy sector environment could not attract any private sector participation because electricity was cheap. Private investment in electricity generation both at utility, mini-grid and decentralised micro-grid levels entail a need to contract Power Purchase Agreements (PPAs) at a higher tariff than what already exists in order to justify the investment. However, additional data obtained from the OPPPI respondent reveals that firstly, as a result of the crisis, demand has outstripped the supply as had been forecasted much earlier and so in order to move forward, governments in the region and in particular Zambia, need to bring in private-sector investment into the power sector and hence the urgency to migrate to cost reflective tariffs.

According to the respondent from OPPPI, as well as information highlighted in the literature, it is evident that in light of the several power generation projects expected to be implemented and in order to guarantee the supply and sale of power back to ZESCO, tariffs in the long term will have to increase to an average of 12US¢/kWh (Mukabe, 2015; Sikwanda, 2016). Most recently, in May 2017, the ERB-Z approved ZESCO's application to increase electricity tariffs for retail customers by 75% towards cost reflectivity (ERB-Z, 2017). This is to be effected in two phases of 50% in May 2017, and 25% to be effected in September 2017 (*ibid.*). One of the justifications for the hike was in order to attract a multi-billion US dollar portfolio of private generation projects which are important to diversify the generation mix to avoid the devastating effects of drought (*ibid.*).

5.6 Regulation and legislation

Regulation mechanisms are important in order to guarantee a bottleneck free, protection of the investor in independent electricity generation as well as the customers through creating a level playing field that does not lead to a disadvantage for any of the stakeholders. In Zambia the Energy Regulation Board of Zambia (ERB-Z) is the principle legislation enforcement agency and regulator of the sector. It has continued to play a facilitator role in the investment of electricity generation from all sources and in all magnitudes. Data gathered through an interview with a respondent from ERB-Z in charge of the department concerned with renewable energy, as well as a review of secondary data from the ERB-Z website, revealed that the regulator had developed a mechanism for renewable energy feed-in tariffs and a grid code to facilitate the sale of electricity generated from renewable energy. However, the complete documents are still in their draft form and yet to be released for implementation. According to the Energy Regulation Board of Zambia (ERB-Z) (2015), with the REFiT regulatory framework (stated in section 5.2) and secondary mechanisms on the way, it was envisaged that the REFiT program would be implemented by the first quarter to end of 2016 in order to accommodate the first phase of the scaling solar project.

Besides the electricity acts, the regulations provide terms for the grid code and licensing processes, and technical standards for the quality of electricity generated. Although it appeared largely generic, it provided a good basis for specific regulation on building scale electricity generation from rooftop solar PV. From the same interview data, it was evident that the general procedure that was followed during the registration process for applying for generation licences was very flexible compared to other countries like South Africa and Namibia. It was stressed by the same respondent that solar generated electricity had been prioritised and was being treated with preference. This led to the government introducing tax incentives on solar PV investments and formulation of easy procedures to attract more investments in the sector.

A positive motivation for investments for developers, companies and retailers is that there are various incentives available as was also discussed under Section 2.4.4. These included zero rating on solar technology imports which could have the potential to reduce the cost of products and ultimately the cost of investment. No-charge on licensing of companies setting up generation plants means that the market had been made more attractive for more players. However, data from the respondent at a leading solar PV company expressed disappointment that while these incentives were well outlined in documents, the actual situation on the ground revealed a lack of implementation and unwarranted misuse of the incentives by unlicensed companies and distributers to the detriment of the customers. The respondent highlighted that the industry had become too porous and this was affecting the genuine registered players where it hurts most, further adding that if this continued it would negatively affect investment since it was undermining the trust in the products among the potential adopters. On a positive note, the respondent observed that the tax rebates have had a powerful impact on the cost of the systems considering that modules and BOS (balance of systems) equipment were mainly imported from China and the USA.

5.7 State of buildings and solar PV electricity generation

Consistent with information highlighted in the literature appraisal especially under Section 2.4.3 in Chapter 2, there were no clear guidelines on building electricity use and generation. Although the utility was very supportive that the building scale electricity generation for decentralised self-use should overtake and mitigate the electricity deficit, the building industry had not updated the energy standards, and environmental performance ratings for regulating energy use in buildings were not yet in place. The respondent from ZESCO revealed that even though the policy on solar PV was being prepared for release, the utility had already gone ahead to coordinate decentralised rooftop solar PV electricity generation from buildings. This contradicted the actual situation on the ground which revealed a lack of dedicated framework for building scale electricity generation. The interview data collected confirmed literature appraisal findings under Section 2.4.3 that campaigns for energy efficiency are run frequently on different media to enhance solar PV adoption. Representatives from both the utility and the upcoming local Green Building Council stressed the need for designs that would allow for ease of adaptation to forms of clean energy through the provision of explicit building specifications.

The respondent from a leading solar PV company revealed that most solar PV companies do not undertake building energy modelling for load determination and energy efficiency propositions but would complete a status-quo/baseline load assessment. Sale of solar PV systems were usually preceded by load analysis in order to determine the customer requirements and consequently determine the associated system costs.. However, detailed energy calculations need to be adopted in order to guarantee cost effective systems and thus avoid oversizing or under sizing the installations. From a technology point of view, it was revealed that the utility had not yet put in place the upgrading to net metering and so for most installations, battery backups had to be installed.

5.8 Financing mechanisms, terms and conditions

The aspect of cost still remains one of the biggest impediments to the spread and implementation of solar PV projects at every level. Although many home systems are self-financed, for projects of this magnitude, partnerships in terms of loan financing from financial institutions are almost inevitable. Although banks like Barclays and Citi bank have started solar PV financing, Stanbic bank, one of the leading banks in the country had been keenly involved in financing solar projects both in Zambia and South Africa. Data obtained from an interview with a respondent (head of investment division) set up within the Stanbic bank revealed that the bank had been leading in solar financing for the past year.

After realising that there was a gap in the market beginning mid-2015, the bank positioned a product which initially started off as generator financing. This received a commendable gesture in the market. Realising that the bank needed to steer sustainability through promoting renewable clean energy, the institution decided to introduce solar PV financing. However, according to the respondent, this initiative is yet to gain momentum because of the current slow economic dynamics in the country.

The Bank had products that cut across personal as well as business and corporate market segments of the solar PV systems. The maximum finance period for solar PV for both individual and commercial entities was set at five years and depending on the customer profile, the bank could go up to 100 percent financing or part financing. The basic criteria involved the following process:

- The bank conducts the usual necessary credit checks and debt service coverage checks on the individual or company and whether they qualify for the financing.
- Determine the nature of business and company profile and the nature of business.

- Obtain a specification from recommended solar PV expert.

It came to light from the same interview as well as echoed by an experienced architect representing the upcoming Green Building Council of Zambia, that generally, commercial building owners in Zambia lack sufficient knowledge about the options available for financing solar PV systems. Therefore, even when building owners were keen to implement decentralised solar PV systems, they found it difficult to obtain, independent, objective, expert financial advice from financial entities. This was compounded by the fact that most financial institutions in Zambia did not have specific know-how on these technologies. To deal with this problem the bank introduced third party companies in a bid to close the knowledge and information gap thus demonstrating an innovative approach that could be replicated by other financial institutions in the country.

As a model to reduce the possibility of defaulting and ensure superior technical product specifications, the bank nominated over ten suppliers and solar PV companies with different products and skill sets in terms of their experience and track record. This step was essential to ensure trust and guarantee value of the products considering that so much money was dedicated to the initiative. Additionally, the companies could supply the equipment, and maintain the equipment for the duration of the financing. The objective was to have a double arrangement where the asset was provided as well as the after sale-service. It was revealed that one of the major impediments to borrowing for solar PV investment was the current downturn in the economy of the country. Although there was expressed optimism that the economy may stabilize, bank interest rates averaging 15.5% over the year increased the hurdle for upfront investment and discouraged customers from borrowing. (Lusaka Times, 2017).

According to a respondent at Keeper Zambia (an organisation overseeing the Power Africa initiative in Zambia), the predominant financing mechanisms from donor agencies targets off-grid systems. The main channel of this is through the Power Africa, which is an initiative started by the former US President Barack Obama and has extended to countries like Kenya, Nigeria and Ethiopia with the objective to bring lighting to over 50 million people. Under this initiative, Power Africa is working with individual start-ups who can bring in projects that are clean, green and smart. The financing offers a minimum of a $100,000 to boost the capital requirements of projects. There are possibilities for financing on-grid systems, but these will require sufficient motivation of scale and reach. Although this is the case for most donor funded initiatives, the Green Climate Fund, Smart Village and ongoing support from the Swedish embassy have a big pool and can finance projects of grid-interactive nature. One challenge is that there is limited awareness regarding the sources of funding amongst prospective entrepreneurs as stated by a representative interviewed at Keeper Zambia.

5.9 Technical and market scenario

As highlighted under Section 2.4.5 regarding the barriers of solar PV, in both the technical knowledge and skill development, these have not developed in tandem with the increase in solar PV installations. Despite general high-level learning being offered in renewable energy, the technical expertise in solar PVs and installation is limited to a few individuals in solar companies. On a positive note, in terms of solar PV installations, ZESCO is offering technical advice and consultancy to customers at different levels. Furthermore, the utility has facilitated private development by supporting investments in on-grid generation through renewable energy sources including solar by coming on board and being an obvious off-taker for credible solar PV developers. This market readiness assures the developer of sales of electricity and revenue generation.

According to a respondent from ZESCO, it is a promising time for renewable energy in Zambia partly steered by the deficit, but much more by the global interest in solar PV and renewable energies. The initial short-term expectations of 200MW from independent power companies from solar generation only, 50MW through the global energy transfer FIT, which is one of the large initiatives in solar PV has excited the market and encouraged many investors to come on board. Through the GET initiative, the utility expects units of 10MW and so the immediate technical challenge is to look at the appropriate areas where connectivity to the grid can be made in lieu of smart grid. This technical requirement has called for the close involvement of the utility company in the GET and has thus provided engineers to spearhead it. A good partnering model was revealed at Stanbic bank where technical partners are expected to be incorporated at the initial stages to give a technical perspective regarding specifications which clients may need. These partnerships are encouraged to assure a smooth procurement process of the solar PV systems.

As highlighted in the literature appraisal under Section 2.4.5, there are limited local skills, knowledge and expertise to install and operate solar PV technologies in Zambia. In addition, the capacity to manufacture and/or assemble solar technology components locally is also still unavailable (ZDA, 2014). Data from a respondent from a leading solar PV company revealed that most of the modules and associated solar PV components are sourced from China and the USA. Although the main imports come from China because of cheaper prices, many large installers prefer solar PV systems from the USA than from China, perhaps for the mere trust of the American brands.

5.10 Conclusion.

Addressing grid-integration barriers constituted a critical prerequisite for the long-term viability of the distributed RE industry in general, and the decentralised rooftop solar PV industry in particular. The development of the grid code and interconnection standards, formulation of feed-in tariffs and migration to cost reflective tariffs is just one positive step on the path towards increased deployment of decentralised electricity generation from rooftop solar PVs. It was evident that the Department of Energy, working with other stakeholders, are developing a research and development plan within the framework of the upcoming IDC utility-scale solar projects aimed at making the vision of viable solar PV industry for Zambia a reality. It is clear that plans for feed-in tariffs for small scale generation (as small as 500kW) are already underway. The utility-scale projects are already working as a precursor and foundation on which policies for small-scale generation can be developed.

Chapter 6: Conceptualizing the business model

6.1 Introduction

This chapter presents an analysis of the findings of Chapter 4 and 5 in order to address the sub-question on the responsive business model for decentralised electricity generation from rooftop solar PVs. The first section utilises findings about the energy efficiency interventions, solar PV generation capacities and prevailing electricity rates in order to make business justification for investment. The second section shows how the business model was conceptualised and synthesised. Thereafter, sections analysing the contribution of the findings to the energy goals and greenhouse emission reduction in Zambia are presented. This chapter ends with the consolidation of findings and key recommendations.

6.2 Business case and net present value

After answering the research sub question relating to the determination of the potential for solar PV electricity generation from the EIZ building as well as the support frameworks for solar PV investment in Zambia in the foregoing sections, the next step was to conceptualise a business model based on a profitable business case. In order for developers, commercial property owners (and long-term lessors) and even financiers to reap the economic potentials and benefits of decentralised electricity generation from rooftop solar PVs, business cases for any specific investment must be objectively evaluated and the projected return on investment be systematically tracked over time (Alta Energy, 2016).

Even though every successful business model that creates a profitable business case must address other non-financial aspects, in this study the criteria for the "go/no go" decision involved a somewhat strict financial approach to justify the benefit in terms of revenue and covering of upfront cost. This was done by comparing the status quo (baseline) situation, cost of investment with the net income and savings from not having to buy electricity from the utility ZESCO. In addition, a case was made based on an assumption of the sale of excess electricity to the grid in view of the feed in tariffs and upcoming grid interactive policies. According to Clean Energy Council (2014), making a business case for investing in solar PV system depends on what electricity tariffs the entity will be paying and how these might change during operation stage after the system has been installed.

6.2.1 Evaluation methods for the business case

Several ways can be used to determine the profitability of a project. For this economic evaluation for energy efficiency interventions, the methods used were the Simple payback (with inconsistent cash flows), Return on investment (ROI), and Net Present Value (NPV). According to Nikolaidis *et al* (2009), a progressive approach in applying these tools beginning with the simple payback to the Net Present Value reveals that each tool adds value to the decision making concerning the investment. The sub-sections which follow provide a brief description of each tool.

1. Simple payback period (with inconsistent cash flows)

This tool constitutes the analysis for determining the time period in which the investor will recover the initial outflow/investment (Ong and Thum, 2013). With all factors held constant, an investment with shorter payback period would considered a better project because an investor can recover the capital invested in a shorter period of time (*ibid.*). Besides, the simple payback also indicates the riskiness of a project since cash flows expected in the distant future are generally riskier than near-term cash flows. Although the simple payback is a simpler tool to establish recovery period, it does not consider important factors such as the time value of money.

Whereas for many simple payback calculations, the cash flow savings are taken as constant throughout the analysis period, this analysis assumed an inconsistent cash flow. The yearly fluctuations were as a result of the projected escalation in the electricity tariff from the grid. The simple payback with inconsistent cash flow was calculated by using a simple two column approach in MS Excel. The two columns contained values for the expected cash flows and the remaining cash flows needed to recover the initial investment. The successive cash flows for the years are subtracted from the previous remaining cash until the last period when the cash is recovered (shown by the negative values in the simple payback columns of tables 23, 24, 25, 27, 32, 35 and 38).

2. Return on Investment (ROI)

Return on investment is better than the simple payback because it takes into consideration the effective life of the project (Nikolaidis *et al*, 2009). With the ROI, the return on the project is measured as a percentage. A percentage return means that not only is the initial investment recovered but a percentage revenue accrues. The ROI for the life of a project is calculated as shown in Formula (2) below. The result is multiplied by 100 to get it into a percentage. In order to calculate the annual return on investment the result is simply divided by the period of the project analysis.

ROI = [(Total savings for the life of the project – Estimated Project Cost) / Estimated Project Cost] x 100% ....(2)

However, like the simple payback, the ROI does not take into account the time value of money. In addition it considers the cash flows that occur at the end of the project period instead of the steady stream. This way it could overstate the viability of the project.

3. Net present value

The NPV is used to assess the profitability of future cash flows to be yielded by a project and is the best tool to evaluate projects (Ong and Thum, 2013). It compares the present value of money and the value of the same in future terms by factoring in discount rate (*ibid*). The NPV is calculated by using Formula (3) given below.

$$NPV = -C_0 + \sum_{t=1}^{n} \frac{F_t}{(1+p)^t} \quad \text{.. (3)}$$

Where t is the specific period of time under consideration, usually a year, F_t is the net cash flow for the year t; C_0 is the initial cost of investment, p reflects the discount rate or cost of capital, and n represents the number of years under analysis.

If the NPV>0, an investment can be deemed to be profitable over the period assessed. On the other hand, if NPV<0, then the investment can be deemed to be unprofitable. In principle, where different investment alternatives are compared, the one with a higher NPV can be deemed to be the better option (Nikolaidis *et al*, 2009).

6.2.2 Making a business case for energy efficiency interventions

Cost analysis of energy efficiency interventions

Energy efficiency interventions involved both passive and active approaches. The passive interventions begun with changing glazing type to double glazing on a total calculated area of 908m^2. Considering that the material specifications could not be from local suppliers, the alternative was to identify an equivalent from China to correspond to the specification. Information obtained from a local construction company revealed that the estimated cost of the specified 6mm thick pane double glazing, with 13mm air gap (Dbl LoE-e2=1 clear 6mm) and associated aluminium works would cost between $150 and $185 (1,518.75 and 1,873.125ZMK)/m^2. Assuming the highest unit cost of $185, the total cost of the glazing over an area of 908m^2 was calculated as $16,7980.00 (1, 700798.00ZMK).

Similarly, the cost of the architectural aluminium sunshade louvers from China (Foshan Dexone building materials) ranging from $150 to $200 (1518.75 to 2025 ZMK) per square meter were selected. Assuming the highest cost of the shading ($200), the total cost of the shading applied on a total window area of 345m2 (see Section 4.7.1) was calculated as $69,000 (698,625.00 ZMK). The price of the 100mm expanded polystyrene obtained from energyweb.com in South Africa was $4.81(48.10ZMK)/$m^2$. The total cost calculated by multiplying the total roof area (1,452.25 m^2) was $6,989.32 (70,726.39ZMK). The combined cost of sunshades and roof insulation works out to $75989.32 (76, 9351.39 ZMK).

Assuming the use of DFR ambient light sensor Arduino (DFR0026) from South Africa which costs $4.65 (46.57ZMK) with a life of over 25 years (Sustainable.co.za, 2016), the total cost of investing in day lighting control to minimise electricity consumption was calculated as $116.25 (1,117ZMK).

Economic evaluation parameters

Some parameters needed for the evaluation included the time period, electricity tariff in 2016 tariff escalation rate, and the discount rate. These are given below.

- Analysis period: **25 years** (PV system useful years).
- Electricity tariff (2016): **0.6ZMK ($0.06)/kWh**.
- Conversion rate Dollar to Zambian Kwacha**: 1$ =10.125ZMK**
- Energy escalation: **8.5%** (Estimate based on ZESCO's proposed tariff path 2012-2015- see Section 5.2.4.).
- Discount rate (p): **8.5 percent** Assumed guaranteed investment rate (Estimated Bank of Zambia rate).

Table 21: Simple payback, ROI and NPV calculation for intervention 1 (Introduction of double glazing)

Year (t)	**Present value factor:** **A** = $1/(1+p)^t$	**Electricity rate** (ZMK) **B**	**Baseline energy use** (kWh) **C**	**Baseline energy cost** (ZMK) **D** = (B x C)	**Design energy use** (kWh) **E**	**Design energy cost** (ZMK) **F** = (B x E)	**Energy saving/Cash flow** (**F_t**) (ZMK) **G** = (D-F)	**Simple pay back** **H** = (Initial investment (C_t) - G)	**NPV_t** (ZMK) ($1/(1+p)^t \times F_t$) **I** = (A x G)
1	0.92	0.60	287707	172624	249916	149950	22675	1678123	20898
2	0.85	0.65	287707	187010	249916	162445	24564	1653559	20866
3	0.78	0.71	287707	204272	249916	177440	26832	1626727	21007
4	0.72	0.77	287707	221534	249916	192435	29099	1597628	20997
5	0.67	0.83	287707	238797	249916	207430	31367	1566262	20860
6	0.61	0.90	287707	258936	249916	224924	34012	1532250	20847
7	0.56	0.98	287707	281953	249916	244918	37035	1495214	20922
8	0.52	1.06	287707	304969	249916	264911	40058	1455156	20857
9	0.48	1.15	287707	330863	249916	287403	43460	1411696	20855
10	0.44	1.25	287707	359634	249916	312395	47239	1364458	20893
11	0.41	1.36	287707	391282	249916	339886	51396	1313062	20951
12	0.38	1.47	287707	422929	249916	367377	55553	1257509	20871
13	0.35	1.60	287707	460331	249916	399866	60466	1197043	20937
14	0.32	1.73	287707	497733	249916	432355	65378	1131665	20865
15	0.29	1.88	287707	540889	249916	469842	71047	1060618	20898
16	0.27	2.04	287707	586922	249916	509829	77094	983524	20900
17	0.25	2.21	287707	635832	249916	552314	83518	900006	20868
18	0.23	2.40	287707	690497	249916	599798	90698	809308	20886
19	0.21	2.61	287707	750915	249916	652281	98635	710673	20935
20	0.20	2.83	287707	814211	249916	707262	106949	603725	20921
21	0.18	3.07	287707	883260	249916	767242	116018	487706	20917
22	0.17	3.33	287707	958064	249916	832220	125844	361862	20911
23	0.15	3.61	287707	1038622	249916	902197	136426	225437	20894
24	0.14	3.92	287707	1127811	249916	979671	148141	77296	20910
25	0.13	4.25	287707	1222755	249916	1062143	160612	-83316	20895
							1,784,113		**522,562**

Energy escalation: 8.5%, Discount rate (p): 8.5%, F_t=net cash flow for year t, C_t =Initial investment for year t (e.g. 1st year 1, 700798 (C_0) - 22,675 =1, 678123)

Table 22: Simple payback, ROI and NPV calculation for intervention 2 (Introduction of sunshades and roof insulation)

Year (t)	**Present value factor:** **A** = $1/(1+p)^t$	**Electricity rate** (ZMK) **B**	**Baseline energy use** (kWh) **C**	**Baseline energy cost** (ZMK) **D** = (B x C)	**Design energy use** (kWh) **E**	**Design energy cost** (ZMK) **F =** (B x E)	**Energy saving/Cash flow (**F_t) (ZMK) **G =** (D-F)	**Simple pay back** **H =** (Initial investment (C_t) - G)	**NPV$_t$** (ZMK) ($1/(1+p)^t$ x F_t) **I =** (A x G)
1	0.92	0.60	287707	172624	235564	141338	31286	738065	28835
2	0.85	0.65	287707	187010	235564	153117	33893	704172	28791
3	0.78	0.71	287707	204272	235564	167250	37022	667151	28984
4	0.72	0.77	287707	221534	235564	181384	40150	627001	28971
5	0.67	0.83	287707	238797	235564	195518	43279	583722	28782
6	0.61	0.90	287707	258936	235564	212008	46929	536793	28765
7	0.56	0.98	287707	281953	235564	230853	51100	485693	28868
8	0.52	1.06	287707	304969	235564	249698	55272	430422	28778
9	0.48	1.15	287707	330863	235564	270899	59964	370457	28776
10	0.44	1.25	287707	359634	235564	294455	65179	305278	28828
11	0.41	1.36	287707	391282	235564	320367	70914	234364	28907
12	0.38	1.47	287707	422929	235564	346279	76650	157714	28798
13	0.35	1.60	287707	460331	235564	376902	83429	74285	28889
14	0.32	1.73	287707	497733	235564	407526	90207	-15923	28789
15	0.29	1.88	287707	540889	235564	442860	98029		28834
16	0.27	2.04	287707	586922	235564	480551	106372		28837
17	0.25	2.21	287707	635832	235564	520596	115236		28793
18	0.23	2.40	287707	690497	235564	565354	125143		28819
19	0.21	2.61	287707	750915	235564	614822	136093		28885
20	0.20	2.83	287707	814211	235564	666646	147565		28866
21	0.18	3.07	287707	883260	235564	723181	160079		28861
22	0.17	3.33	287707	958064	235564	784428	173636		28853
23	0.15	3.61	287707	1038622	235564	850386	188236		28828
24	0.14	3.92	287707	1127811	235564	923411	204401		28851
25	0.13	4.25	287707	1222755	235564	1001147	221608		28830
							2,461,671		**721,017**

Energy escalation: 8.5%, Discount rate (p): 8.5%, F_t=net cash flow for year t, C_t =Initial investment for year t (e.g. 1st year 76, 99351.39 (C_0) – 31,286 =73, 8065)

Table 23: Simple payback, ROI and NPV calculation for intervention 3 (Introduction of Lighting controls)

Year (t)	**Present value factor:** **A** = $1/(1+p)^t$	**Electricity rate** (ZMK) **B**	**Baseline energy use** (kWh) **C**	**Baseline energy cost** (ZMK) **D** = (B x C)	**Design energy use** (kWh) **E**	**Design energy cost** (ZMK) **F =** (B x E)	**Energy saving/Cash flow (F_t)** (ZMK) **G =** (D-F)	**Simple pay back** **H =** (Initial investment (C_t) - G)	**NPV_t** (ZMK) ($1/(1+p)^t$ x F_t) **I =** (A x G)
1	0.92	0.60	287707	172624	239001	143400.60	29224	-28047	26934
2	0.85	0.65	287707	187010	239001	155351	31659		26893
3	0.78	0.71	287707	204272	239001	169691	34581		27074
4	0.72	0.77	287707	221534	239001	184031	37504		27062
5	0.67	0.83	287707	238797	239001	198371	40426		26885
6	0.61	0.90	287707	258936	239001	215101	43835		26869
7	0.56	0.98	287707	281953	239001	234221	47732		26965
8	0.52	1.06	287707	304969	239001	253341	51628		26881
9	0.48	1.15	287707	330863	239001	274851	56012		26879
10	0.44	1.25	287707	359634	239001	298751	60883		26927
11	0.41	1.36	287707	391282	239001	325041	66240		27002
12	0.38	1.47	287707	422929	239001	351331	71598		26899
13	0.35	1.60	287707	460331	239001	382402	77930		26985
14	0.32	1.73	287707	497733	239001	413472	84261		26891
15	0.29	1.88	287707	540889	239001	449322	91567		26934
16	0.27	2.04	287707	586922	239001	487562	99360		26936
17	0.25	2.21	287707	635832	239001	528192	107640		26895
18	0.23	2.40	287707	690497	239001	573602	116894		26919
19	0.21	2.61	287707	750915	239001	623793	127123		26981
20	0.20	2.83	287707	814211	239001	676373	137838		26963
21	0.18	3.07	287707	883260	239001	733733	149527		26959
22	0.17	3.33	287707	958064	239001	795873	162191		26951
23	0.15	3.61	287707	1038622	239001	862794	175829		26928
24	0.14	3.92	287707	1127811	239001	936884	190928		26950
25	0.13	4.25	287707	1222755	239001	1015754	207001		26929
							2,299,410		**673,491**

Energy escalation: 8.5%, Discount rate (p): 8.5%, F_t=net cash flow for year t, C_t =Initial investment for year t (e.g. 1st year 1,117(C_0) – 29,224 = -28047).

Table 24: Cost and benefits of energy efficiency interventions.

	Intervention 1	**Intervention 2**	**Intervention 3**
Description	Introduction of double glazing	Introduction of sunshades and roof insulation	Introduction of lighting controls
Annual baseline electricity use (kWh) *(Column C)	287,707	287,707	287,707
Annual baseline electricity cost for Year 1 (ZMK) *(Column D)	172,198.00	172,198.00	172,198.00
Optimised annual electricity use (kWh) *(Column E)	249,916	235,564	239,001
Optimised annual electricity cost (ZMK) *(Column F)	149,950.00	141,338.00	143,401.00
Annual electricity cost savings Year 1 (ZMK) *(Column G)	22,675.00	31,286.00	29,224.00
Percentage savings in electricity use costs Year 1 (%)	13%	18%	17%
Total electricity cost savings for 25years (ZMK) *(Column G)	1,784,113.00	2,461,671.00	2,299,410.00
Sum of Net Present Value electricity cost savings for 25years (ZMK) *(Column I)	522,562.00	721,017.00	673,491.00
Initial cost of investment in energy efficiency intervention(ZMK) *(C_0)	1,700798.00	76,9351.00	1,177.00
Simple payback(Years) *(Column H)	**24.5**	**13.8**	**Less than a year**
Return on investment over 25 year period (%) *Refer to formula (2)	**5%**	**220%**	**195262%**
Net Present value (p=8.5%, t=25) *Refer to formula (3)	**-7,178,235.50**	**-48,334.00**	**672,314.00**

As shown in Table 26, the Simple Payback, Return on Investment and Net Present Value revealed that the lighting control intervention was the most economically viable intervention. The payback was within a year of investment, yielding a return on investment of 7810% for each year. The introduction of sunshades and roof insulation even though a bit more expensive had a much lower payback period, greater return on investment and NPV compared to the intervention involving replacement of glazing.

It was obvious that the intervention involving change of glazing had the biggest payback period (24.5 years) and constituted the lowest return on investment (5%) and gave a greater negative NPV (-7,178235.50). This is deemed to guide the decision towards excluding double glazing as a viable intervention.

Combining options

According to Short *et al* (2005), combining energy efficiency interventions is good for producing more cost effective investments. Going for the lowest cost intervention alone would most likely amount to "cream skimming "and a quick fix". Therefore, a fresh simulation and analysis which combined two cost effective options (intervention 2 and 3) was done and yielded a more financially viable saving as shown in Tables 27 and 28.

Table 25: Simple payback, ROI and NPV calculation for adopted interventions 2 and 3.

Year (t)	Present value factor: **A** = $1/(1+p)^t$	Electricity rate (ZMK) **B**	Baseline energy use (kWh) **C**	Baseline energy cost (ZMK) **D** = (B x C)	Design energy use (kWh) **E**	Design energy cost (ZMK) **F =** (B x E)	Energy saving/Cash flow (F_t) (ZMK) **G =** (D-F)	Simple pay back **H =** (Initial investment (C_t) - G)	NPV_t (ZMK) ($1/(1+p)^t$ x F_t) **I =** (A x G)
1	0.92	0.60	287707	172624	186904	112142	60482	710046	55744
2	0.85	0.65	287707	187010	186904	121488	65522	644524	55658
3	0.78	0.71	287707	204272	186904	132702	71570	572954	56033
4	0.72	0.77	287707	221534	186904	143916	77618	495336	56007
5	0.67	0.83	287707	238797	186904	155130	83666	411669	55642
6	0.61	0.90	287707	258936	186904	168214	90723	320947	55608
7	0.56	0.98	287707	281953	186904	183166	98787	222160	55807
8	0.52	1.06	287707	304969	186904	198118	106851	115309	55634
9	0.48	1.15	287707	330863	186904	214940	115923	-615	55629
10	0.44	1.25	287707	359634	186904	233630	126004		55730
11	0.41	1.36	287707	391282	186904	254189	137092		55884
12	0.38	1.47	287707	422929	186904	274749	148180		55672
13	0.35	1.60	287707	460331	186904	299046	161285		55848
14	0.32	1.73	287707	497733	186904	323344	174389		55655
15	0.29	1.88	287707	540889	186904	351380	189510		55742
16	0.27	2.04	287707	586922	186904	381284	205638		55748
17	0.25	2.21	287707	635832	186904	413058	222775		55662
18	0.23	2.40	287707	690497	186904	448570	241927		55712
19	0.21	2.61	287707	750915	186904	487819	263096		55840
20	0.20	2.83	287707	814211	186904	528938	285272		55804
21	0.18	3.07	287707	883260	186904	573795	309465		55794
22	0.17	3.33	287707	958064	186904	622390	335674		55778
23	0.15	3.61	287707	1038622	186904	674723	363899		55731
24	0.14	3.92	287707	1127811	186904	732664	395148		55776
25	0.13	4.25	287707	1222755	186904	794342	428413		55734
							4,758,910		**1,393,872**

Energy escalation: 8.5%, Discount rate (p): 8.5%, F_t=net cash flow for year t, C_t =Initial investment for year t (e.g. 1st year 77, 0528(C_0) – 60428 = 71, 0046).

Table 26: Cost and benefits of adopted combined energy efficiency interventions 2 and 3.

	Combined Intervention 2 & 3
Description	Introduction of sunshades and roof insulation, and lighting controls
Annual baseline electricity use(kWh) *(Column C)	287,707
Annual baseline electricity cost(ZMK) *(Column D)	172,198.00
Optimised annual electricity use as a result of combining interventions(kWh) *(Column E)	186,904
Optimised annual electricity cost as a result of combining interventions (ZMK) *(Column F)	112,142.00
Annual electricity cost savings for year 1(ZMK) *(Column G)	60,482.00
Percentage savings in electricity use/costs (%)	35%
Total electricity cost saving for 25years (ZMK) *(Column G)	4,758,910.00
Sum of Net Present Value electricity cost savings over 25years (ZMK) *(Column I)	1,393,872.00
Initial cost of investment for combined energy efficiency interventions (ZMK) *(C_0)	77,0528.00
Simple payback(Years) *(Column H)	**9**
Return on investment for 25 year period (%) *Refer to formula (2)	**518%**
Net Present value (p=8.5%, t=25) *Refer to formula (3)	**623,344.00**

Simulated results for adopted combined interventions

A fresh EnergyPlus simulation of the adopted financially viable interventions 2 and 3 resulted in an optimised annual electricity use intensity of (186,904kWh) as presented in Table 28 and Figure 50 and 51. In addition, a corresponding reduction of CO_2 emission from 76,754.47Kg to 49,847.66Kg was attained as shown in Figure 51. A summary of figures comparing the baseline electricity consumption and CO_2 emission to the optimised situation were presented in Figure 51 while Figure 52 shows the overall percentage reduction in the baseline electricity intensity achieved by combining interventions 2 and 3.

The simulation also revealed the optimised peak load power demand for the EIZ building to aid in the sizing of the solar PV system to offset remainder of the electricity demand. After simulation, October month was revealed as the highest intensity month which became a somewhat slight contrast to that of the month of March in the baseline simulation as presented in Section 4.6.1. Therefore simulation for October month was carried out after optimisation using the adopted interventions. The results depicted in the monthly peak load profile in Figure 53 revealed a maximum daily peak load of 869.63kWh on the 13th day of October. By following the same procedure used to determine the baseline peak load presented in Section 4.6.4, the optimised peak load was calculated as 145kW. A summary of the estimated solar PV output of the "full roof" carried out in Section 4.4, the baseline peak power demand derived from Section 4.6.4 and the optimised peak power demand were compared as shown in Figure 54.

Figure 50: Simulated optimised annual electricity consumption by applying interventions 2 and 3

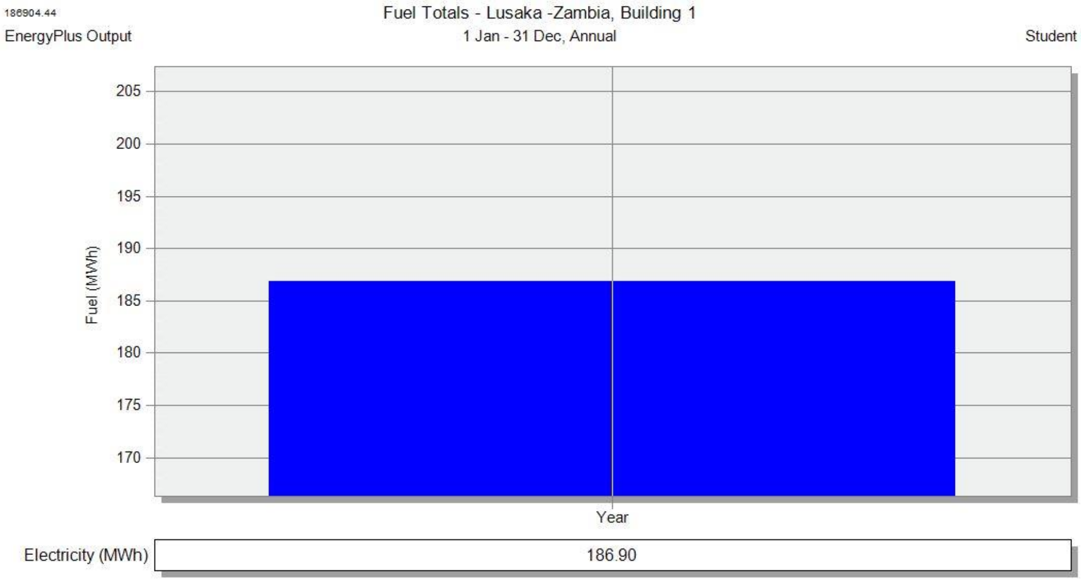


Figure 51: Comparison of baseline case and after adoption of combined interventions 2 and 3

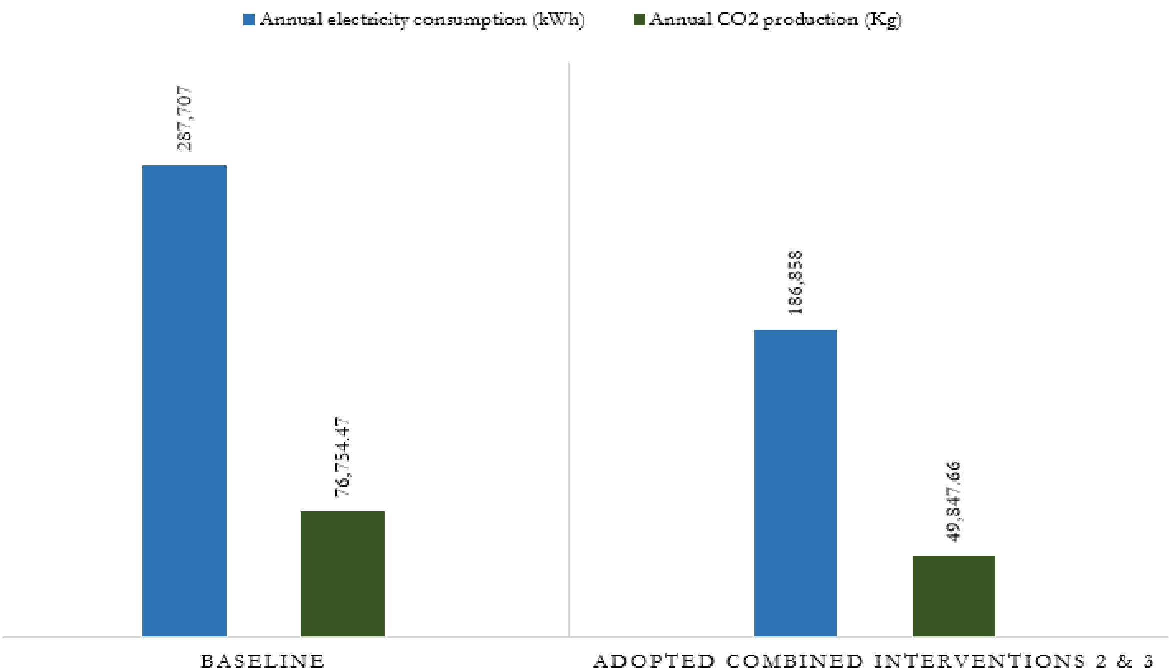


Figure 52: Percentage savings from adopted combined interventions 2&3

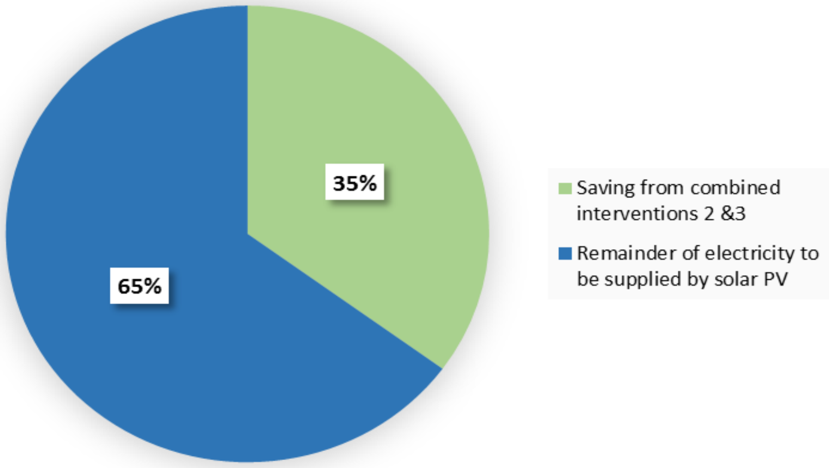


Figure 53: Peak month power load profile and optimised daily peak load (869.63kWh) by applying interventions 2 and 3

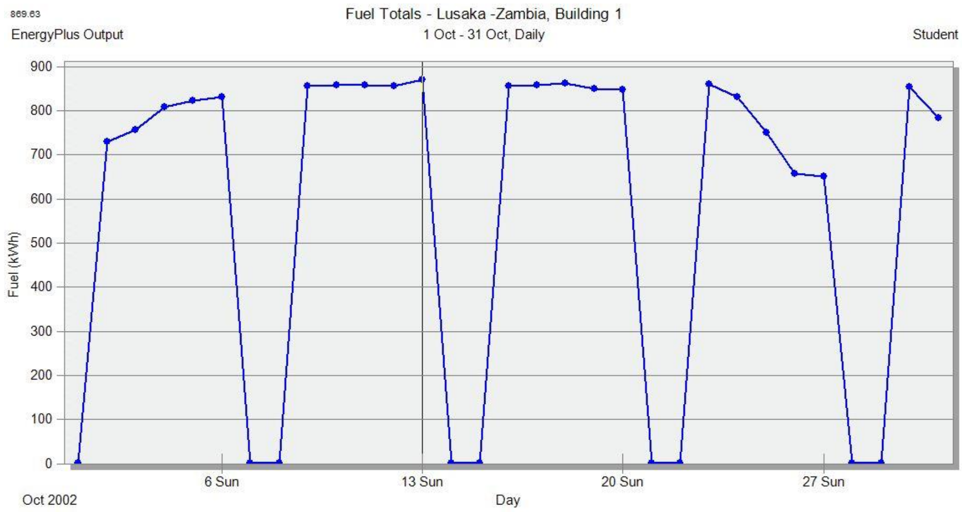
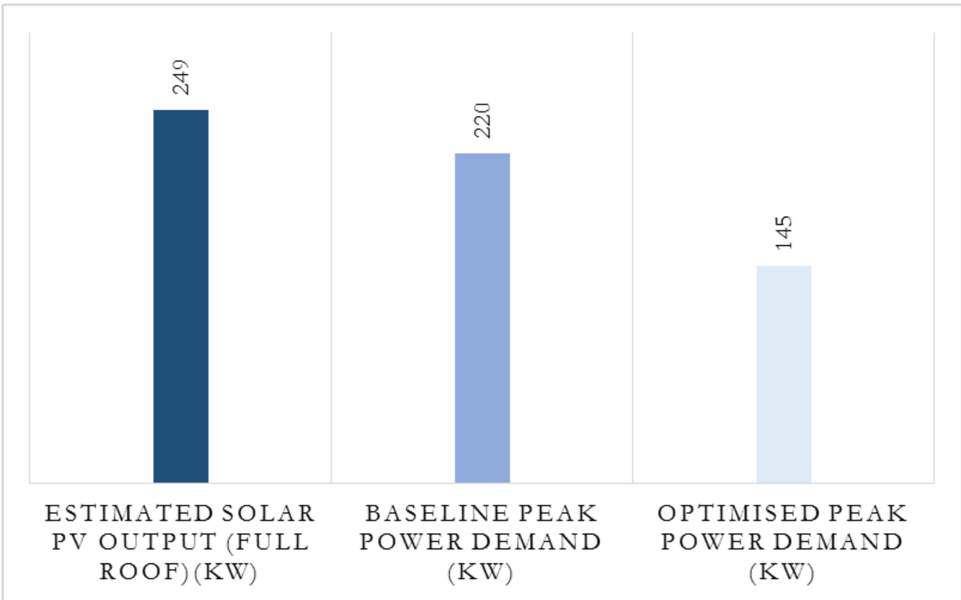


Figure 54: Comparison of full roof peak output (see Table 16), baseline peak (see Table 16) demand and optimised peak demand.



6.2.3 Making a business case for solar PV system

Procedure in sizing the solar PV modules

The initial step in sizing the solar PV modules, inverter and the backup system is to ascertain the peak electricity demand which should be met by the solar PV system (Saleh *et al*, 2015). For this instance, the peak electricity demand for the building is presented in Figure 68 as 145kW. Usually the norm is to adjust this figure by multiplying it with a factor for the energy lost in the system (*ibid.*). For this analysis, the factor was taken as 1.3 based on the advice from the local solar PV company. Therefore to calculate the required number of PV panels for a system, the peak electricity demand of the building is divided by the rated output Watt-peak of the PV module as shown below.

$$\text{Number of panels} = \frac{\text{Peak electricity demand (kW)}}{\text{Rated output Watt-peak of PV module}} \quad \text{--------------------------------(4)}$$

It is a norm to round off the result to the whole number to get the PV minimum number of PV modules required (Saleh *et al,* 2015).

Cost analysis of the PV system

To select the appropriate solar PV panels for analysis, a leading Zambian solar PV company was contacted and the main technical specifications were drawn. Although the "full roof" estimation in Section 4.1 and 5.2 assumed the LG LG300N1 (300W) module solar grid tied solar system for the estimator, an exact specification, Suntech (STP300-24/Ve-300Watt polycrystalline solar module) from China with the exact efficiency was used for this cost analysis. This was done in order to ensure that the cost analysis reflected as close as possible the actual product specifications currently being imported into the Zambian market.

As revealed by the interview findings from a solar PV expert representing one of the leading solar PV companies in Zambia, the majority of solar products are imported from China followed by the USA (see Section 5.2.4). This module was recommended as one of the best modules for the commercial setup and was available both from China and the USA. For the sake of economy, this analysis assumed the modules to be sourced from China. That being the case, the sale price of the Suntech (STP300-24/Ve-300Watt polycrystalline solar module) obtained from an online source (solarsystems usa .com) as $268.28 (2,716.335ZMK). As earlier stated in Section 5.2, this cost was assumed to be without any import duty as per existing policy.

Table 27: Solar PV specifications-Suntech (STP300-24/Ve-300Watt polycrystalline solar module)

Electrical characteristics (STC)	
Maximum Power at STC (Pmax)	300 W
Optimum Operating Voltage (Vmp)	35.9 V
Optimum Operating Current (Imp)	8.36 A
Open Circuit Voltage (Voc)	44.5 V
Short Circuit Current (Isc)	8.83 A
Module Efficiency	15.5%
Operating Module Temperature	-40°C to +85°C
Maximum System Voltage	1000 V DC (IEC)
Maximum Series Fuse Rating	20 A
Power Tolerance	0/+5 %
Mechanical characteristics	
Solar Cells	Polycrystalline silicon 156 × 156 mm (6 inches)
No. of Cells	72 (6 × 12)
Dimensions	1956 × 992 × 40mm (77.0 × 39.1 × 1.6 inches)

Determining the capacity of the inverter

The inverter was chosen according to the required capacity and proposed efficiency. Inverters convert the low voltage DC electricity created by the solar panels to the AC since most of the applications in the building require AC power (Haruna & Onuigbo, 2015). Inverters are rated in many ways. For the selection of the inverter, the same local solar company recommended the trending models in Zambia. Some of the models included: the Schneider Conext, the XW+, magnum and Victron inverters. After appraising the different models, capacities and outputs, the Schneider electric 25kW 3-PH grid-tied inverter (PVSCL25NA301) was selected as the most appropriate for the study. In comparison to others, the Conext CL series is made up of a line of three phase string inverters for greater efficiency, high flexibility, easy connection and service (solaris-shop.com, 2016). In addition this inverter also had an inbuilt MPPT charge controller which serves better for the grid tied assumption.

The sale price of this unit inverter obtained from Solaris-shop. Com from the USA was $6,885.00 (69,710.625ZMK). In order for the inverter to be of the right size, its watts rating must be approximately equal to or slightly more, but not too much than the solar systems output watts rating (Solar choice, 2014).

Table 28: Schneider Electric 25kW 3-PH Grid-Tied Inverter - PVSCL25NA301

Full power MPPT voltage range	500-800 volts
Operating voltage range	250-1000 volts
Max. Input voltage , open circuit	1000 volts
Number of MPPT/strings per MPPT	2/4
Rated output power	25.0kW
Max. apparent power	25.0kVA
Nominal output voltage	277/480
AC voltage range	244-305V/422-528V
Frequency	60Hz
Max. output current	33.0A
Nominal continuous output current	30.1A
Total harmonic distortion	<3%
Power factor(adjustable)	0.8 lead to 0.8 lag
Peak efficiency	98.4%
CEC efficiency	98%

Determining the size of the battery system

According to the brief obtained from the EIZ, the solar PV system was supposed to include battery backup system for periods when the solar PV could not supply electricity. The formula below could be used to determine the battery capacity.

$$\text{Battery capacity} = \frac{\text{Total watt-hours day (kWh)} \times \text{Days of autonomy}}{[(\text{Battery loss factor}) \times (\text{Depth of discharge}) \times (\text{Nominal battery voltage})]} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

The battery loss factor was assumed to be 0.85 (assuming an 85% efficient inverter). The depth of discharge or simply the percentage below which the battery should not discharge further was assumed to be 60%. The days of autonomy which represents the period when the battery should operate without the solar power was assumed to be one day because the existence of the grid was deemed to be an extra backup. Although this procedure was included in the study, the battery was omitted in the subsequent analyses for simplicity. This was so because firstly, the study assumed a grid tied system (with grid as back-up) and secondly was taken that the inclusion or exclusion of it would have a concurrent effect on the cost of the system.

Scenario 1: A net-zero electricity building scenario (no export)

Under this scenario, it was assumed that the solar PV system would just be meant to net out the optimised consumption/demand of the building. So this scenario's energy/cost saving was compared with the benefit of not paying bills to the utility for a period of 25 years which is the analysis period (Life of solar PV system).

Table 29: Calculated cost of the solar PV system of Scenario 1

	Description	**Rate (ZMK)**	**Quantity***	**Cost (ZMK)**
1	Suntech (STP300-24/Ve-300Watt polycrystalline solar module)	2,716	483 (Formula 4)	1,311,828.00
2	Schneider Electric 25kW 3-PH Grid-Tied Inverter - PVSCL25NA301	69,711	6	418,266.00
3	Cost of system without battery			1,730,094.00
4	20% of the total cost of PV system (1, 730,094.00) as the total cost of labour, installation and miscellaneous.			346,018.00
5	**Total cost (without battery)** *(C_0)			**2,076,112.00**
6	Cost of high capacity battery			Omitted

* Quantity of panels: 145kWp/0.3=483 (Formula 4). Quantity of inverters: 145kW/25kW=5.8=6.

Table 30: Simple payback, ROI and NPV calculation for the solar PV system-Scenario 1.

Year (t)	**Present value factor:** **A** = 1/(1+p)^t	**Electricity rate** (ZMK) **B**	**Optimised annual energy use** (kWh) **C**	**Optimised annual energy cost** (ZMK) **D** = (B x C)	**Cash flow/savings as a result of PV system** (F_t) (ZMK) **E** = D	**Simple payback** **F =** (Initial investment (C_t) - D)	**NPV$_t$** (ZMK) (1/(1+p)^t x F_t) **G =** (A x E)
1	0.92	0.60	186904	112142	112142	1963970	103357
2	0.85	0.65	186904	121488	121488	1842482	103198
3	0.78	0.71	186904	132702	132702	1709780	103893
4	0.72	0.77	186904	143916	143916	1565864	103846
5	0.67	0.83	186904	155130	155130	1410734	103169
6	0.61	0.90	186904	168214	168214	1242520	103106
7	0.56	0.98	186904	183166	183166	1059354	103475
8	0.52	1.06	186904	198118	198118	861236	103154
9	0.48	1.15	186904	214940	214940	646296	103145
10	0.44	1.25	186904	233630	233630	412666	103331
11	0.41	1.36	186904	254189	254189	158477	103617
12	0.38	1.47	186904	274749	274749	-116272	103224
13	0.35	1.60	186904	299046	299046		103550
14	0.32	1.73	186904	323344	323344		103193
15	0.29	1.88	186904	351380	-66886 *		-19674
16	0.27	2.04	186904	381284	381284		103365
17	0.25	2.21	186904	413058	413058		103206
18	0.23	2.40	186904	448570	448570		103299
19	0.21	2.61	186904	487819	487819		103537
20	0.20	2.83	186904	528938	528938		103469
21	0.18	3.07	186904	573795	573795		103450
22	0.17	3.33	186904	622390	622390		103421
23	0.15	3.61	186904	674723	674723		103334
24	0.14	3.92	186904	732664	732664		103417
25	0.13	4.25	186904	794342	794342		103339
					8,405,472		**2,461,421**

Energy escalation: 8.5%, Discount rate (p): 8.5%. PV age loss: 1% per year. * Negative cash flow due to replacement of inverters in 15th year. F_t=net cash flow for year t, C_t =Initial investment for year t (e.g. 1st year 2,076,112 (C_0) – 112,142 = 1963970).

Table 31: Cost and benefits of solar PV system-Scenario 1.

Optimised annual electricity demand (65%) (kWh) *(Column C)	186,904
Optimised annual electricity cost (ZMK) *(Column D)	112,142.00
Annual electricity savings (resulting from solar PV generation (ZMK)-Year 1. *(Column E)	112,142.00
Total electricity cost savings for 25 years (ZMK) *(Column E)	8,405,472.00
Sum of Net Present Value electricity cost savings for 25years (ZMK) * (Column G)	2,461,421.00
Investment cost of solar PV system (without battery)*(C_0) Refer to Table 31.	2,076,112.00
Simple payback (years) * Column F	**11.6**
Return on investment for 25 year period (%) * Refer to formula 2.	**243%**
Net Present Value (p=8.5%, t=25) ZMK * Refer to formula 3.	**385,309.00**

Scenario 2: Export the excess to the grid when building is not in use

Under this scenario, a business case was made with the assumption that the excess generated on weekends was exported to the grid on a feed-in tariff of 0.78ZMK (based on the winning tariff from the scaling solar IDC project). An assumption was also made on the appropriate mechanisms of net metering and grid integration. It was also assumed that the solar PV system generated electricity for 365 days in a year. Table 34 shows the total investment cost of the PV system while Table 35 shows the calculations of the payback, ROI and NPV. Table 36 presents the costs and benefits of scenario 2.

Table 32: Calculated cost of the solar PV system of Scenario 2.

	Description	Rate (ZMK)	Quantity	Cost(ZMK)
1	Suntech (STP300-24/Ve-300Watt polycrystalline solar module)	2,716	483 (Formula 4)	1,311,828.00
2	Schneider Electric 25kW 3-PH Grid-Tied Inverter - PVSCL25NA301	69,711	6	418,266.00
3	Cost of system without battery			1,730,094.00
4	20% of the total cost of PV system (1, 730094.00) as the total cost of labour, installation and miscellaneous.			346,018.00
5	**Total cost (without battery)** *(C_0)			**2,076,112.00**
6	Cost of high capacity battery			Omitted

* Quantity of panels: 145kWp/0.3=483 (Formula 4). Quantity of inverters: 145kW/25kW=5.8=6.

Table 33: Simple payback, ROI and NPV calculation for the solar PV system-Scenario 2.

Year (t)	**Present value factor:** **A** = 1/ $(1+p)^t$	**Electricity rate** (ZMK) **B**	**Optimised annual energy use** (kWh) **C**	**Optimised annual energy cost** (ZMK) **D** = (B x C)	**Cash flow/saving as a result of PV system** (ZMK) **E** = D	**PV generation 365 days** (kWh) (1% age loss) **F**	**Net annual PV surplus** (kWh) **G**=F-C	**Feed in tariff** (ZMK) **H**	**Net annual PV surplus export revenue** (ZMK) **I**	**Total cash flow** (ZMK) (F_t) **J**=E+I	**Simple payback** **K = (**C_t - J)	**NPV$_t$** (ZMK) $(1/(1+p)^t$ x $F_t)$ **L =** (A x J)
1	0.92	0.60	186904	112142	112142	313200	126296	0.78	98511	210653	1865459	194150
2	0.85	0.65	186904	121488	121488	310068	123164	0.78	96068	217556	1647903	184804
3	0.78	0.71	186904	132702	132702	306967	120063	0.78	93649	226351	1421552	177212
4	0.72	0.77	186904	143916	143916	303898	116994	0.78	91255	235171	1186381	169693
5	0.67	0.83	186904	155130	155130	300859	113955	0.78	88885	244015	942366	162281
6	0.61	0.90	186904	168214	168214	297850	110946	0.78	86538	254752	687614	156149
7	0.56	0.98	186904	183166	183166	294872	107968	0.78	84215	267381	420234	151050
8	0.52	1.06	186904	198118	198118	291923	105019	0.78	81915	280033	140201	145805
9	0.48	1.15	186904	214940	214940	289004	102100	0.78	79638	294577	-154377	141362
10	0.44	1.25	186904	233630	233630	286114	99210	0.78	77383	311013		137557
11	0.41	1.36	186904	254189	254189	283252	96348	0.78	75152	329341		134251
12	0.38	1.47	186904	274749	274749	280420	93516	0.78	72942	347691		130628
13	0.35	1.60	186904	299046	299046	277616	90712	0.78	70755	369802		128051
14	0.32	1.73	186904	323344	323344	274840	87936	0.78	68590	391934		125082
15	0.29	1.88	186904	351380	-66886 *	272091	85187	0.78	66446	-440		-129
16	0.27	2.04	186904	381284	381284	269370	82466	0.78	64324	445608		120803
17	0.25	2.21	186904	413058	413058	266677	79773	0.78	62223	475280		118753
18	0.23	2.40	186904	448570	448570	264010	77106	0.78	60143	508712		117149
19	0.21	2.61	186904	487819	487819	261370	74466	0.78	58083	545903		115864
20	0.20	2.83	186904	528938	528938	258756	71852	0.78	56045	584983		114432
21	0.18	3.07	186904	573795	573795	256168	69264	0.78	54026	627822		113191
22	0.17	3.33	186904	622390	622390	253607	66703	0.78	52028	674418		112066
23	0.15	3.61	186904	674723	674723	251071	64167	0.78	50050	724773		110999
24	0.14	3.92	186904	732664	732664	248560	61656	0.78	48092	780755		110205
25	0.13	4.25	186904	794342	794342	246074	59170	0.78	46153	840495		109343
										10,188,580		**3,280,752**

Energy escalation: 8.5%, Discount rate (p): 8.5%. Feed-in tariff: 0.78ZMK. PV age loss: 1% per year. * Negative cash flow due to replacement of inverters in 15th year. F_t=net cash flow for year t, C_t =Initial investment for year t (e.g. 1st year 2,076,112 (C_0) – 210653 = 1).

Table 34: Cost and benefits of solar PV system-Scenario 2.

Solar PV annual electricity generation 365 days (kWh)	313,200
Optimised annual electricity demand (65%) (kWh)	186,904
Optimised annual electricity cost(ZMK)	112,142.00
Annual electricity savings (resulting from solar PV generation (ZMK)-Year 1	112,142.00
Total electricity cost savings + revenue from sales to the grid for 25 years(ZMK)	10,188,580.00
Sum of Present Value electricity cost savings + revenue from sale to the grid for 25years (ZMK)	3,280,752.00
Initial investment cost of solar PV system (without battery) *(C_0) Refer to Table 34.	2,076,112.00
Simple payback (years) *Column K	**8.5**
Return on investment for 25 year period (%)* Refer to formula 2.	**391%**
Net Present Value (p=8.5%, t=25) ZMK * Refer to formula 3.	**1,204,640.00**

Scenario 3- Positive net-zero electricity generation (full roof)

Under this scenario, an assumption was made that the building's rooftop solar PV produces more electricity than it consumes. The concept of positive net zero means that each year the building generates surplus from its "full roof" solar PV system to supply to the grid. This scenario analysed a business case for the 25 year analysis period assuming that the supportive mechanism to facilitate export to the grid and interaction was fully materialised. Based on the feed-in tariff of 0.78ZMK (the winning tariff for the scaling solar IDC project), an analysis of the costs and benefits of the system was made. Table 37 shows the total investment cost of the system while Table 38 shows the calculations of the payback, ROI and NPV. Table 39 presents the costs and benefits of Scenario 3.

Table 35: Calculated cost of the solar PV system of Scenario 3.

	Description	Rate (ZMK)	Quantity*	Cost (ZMK)
1	Suntech (STP300-24/Ve-300Watt polycrystalline solar module)	2,716	830 (Formula 4)	2,254,280.00
2	Schneider Electric 25kW 3-PH Grid-Tied Inverter - PVSCL25NA301	69,711	10	697,110.00
3	Cost of system without battery			2,951,390
4	20% of the total cost of PV system (1, 730094.00) as the total cost of labour, installation and miscellaneous.			590,278.00
5	**Total cost (without battery)** *(C_0)			**3,541,668.00**
6	Cost of high capacity battery			Omitted

* Quantity of panels: 249kWp/0.3=830 (Formula 4). Quantity of inverters: 249kW/25kW=9.96=10

Table 36: Simple payback, ROI and NPV calculation for the solar PV system-Scenario 3.

Year (t)	**Present value factor:** **A** = 1/ $(1+p)^t$	**Electricity rate** (ZMK) **B**	**Optimised annual energy use** (kWh) **C**	**Optimised annual energy cost** (ZMK) **D** = (B x C)	**Cash flow/saving as a result of PV system** (ZMK) **E** = D	**PV generation –Full roof-365 days** (kWh) (1% age loss) **F**	**Net annual PV surplus** (kWh) **G**=F-C	**Feed in tariff** (ZMK) **H**	**Net annual PV surplus export revenue** (ZMK) **I**	**Total cash flow** (ZMK) (F_t) **J**=E+I	**Simple payback** **K = (**C_t - J)	**NPV$_t$** (ZMK) ($1/(1+p)^t$ x F_t) **L =** (A x J)
1	0.92	0.60	186904	112142	112142	537840	350936	0.78	273730	385872	3155796	355643
2	0.85	0.65	186904	121488	121488	532462	345558	0.78	269535	391023	2764773	332156
3	0.78	0.71	186904	132702	132702	527137	340233	0.78	265382	398084	2366689	311663
4	0.72	0.77	186904	143916	143916	521866	334962	0.78	261270	405186	1961503	292372
5	0.67	0.83	186904	155130	155130	516647	329743	0.78	257200	412330	1549173	274218
6	0.61	0.90	186904	168214	168214	511480	324576	0.78	253170	421383	1127790	258285
7	0.56	0.98	186904	183166	183166	506366	319462	0.78	249180	432346	695444	244244
8	0.52	1.06	186904	198118	198118	501302	314398	0.78	245230	443349	252095	230838
9	0.48	1.15	186904	214940	214940	496289	309385	0.78	241320	456260	-204164	218950
10	0.44	1.25	186904	233630	233630	491326	304422	0.78	237449	471079		208351
11	0.41	1.36	186904	254189	254189	486413	299509	0.78	233617	487806		198848
12	0.38	1.47	186904	274749	274749	481549	294645	0.78	229823	504572		189568
13	0.35	1.60	186904	299046	299046	476733	289829	0.78	226067	525113		181830
14	0.32	1.73	186904	323344	323344	471966	285062	0.78	222348	545692		174153
15	0.29	1.88	186904	351380	-345730 *	467246	280342	0.78	218667	-127063		-37374
16	0.27	2.04	186904	381284	381284	462574	275670	0.78	215022	596307		161657
17	0.25	2.21	186904	413058	413058	457948	271044	0.78	211414	624472		156030
18	0.23	2.40	186904	448570	448570	453369	266465	0.78	207842	656412		151162
19	0.21	2.61	186904	487819	487819	448835	261931	0.78	204306	692126		146899
20	0.20	2.83	186904	528938	528938	444347	257443	0.78	200805	729743		142750
21	0.18	3.07	186904	573795	573795	439903	252999	0.78	197339	771135		139029
22	0.17	3.33	186904	622390	622390	435504	248600	0.78	193908	816298		135642
23	0.15	3.61	186904	674723	674723	431149	244245	0.78	190511	865235		132510
24	0.14	3.92	186904	732664	732664	426838	239934	0.78	187148	919812		129833
25	0.13	4.25	186904	794342	794342	422569	235665	0.78	183819	978161		127253
										13,802,732		**4,856,509**

Energy escalation: 8.5%, Discount rate (p): 8.5%. Feed-in tariff: 0.78ZMK. PV age loss: 1% per year. * Negative cash flow due to replacement of inverters in 15th year. F_t=net cash flow for year t, C_t =Initial investment for year t (e.g. 1st year 3,541,666(C_0)-385,872= 3, 155,796).

Table 37: Cost and benefits of solar PV system-scenario 3.

Solar PV annual electricity generation 365 days (full roof) (kWh)* Column F-Refer to Table 5 and Figure 68 (249kWp converted to kWh for 365days)	537,840
Optimised annual electricity demand (65%) (kWh)*Column C	186,904
Optimised annual electricity cost(ZMK) *Column D	112,142.00
Annual electricity savings (resulting from solar PV generation (ZMK)-Year. *Column E	112,142.00
Total electricity cost savings + revenue from sales to the grid for 25 years(ZMK) (F_t) *Column J	13,802,732.00
Sum of Net Present Value electricity cost savings +revenue from sale to the grid for 25years (ZMK) * Column L	4,856,509.00
Investment cost of 'full roof "solar PV system (without battery) *(C_0) Refer to Table 37.	3,541,668.00
Simple payback (years) *Column K	**8.5**
Return on investment for 25 year period (%)* Refer to formula 2.	**290%**
Net Present Value (p=8.5%, t=25) ZMK * Refer to formula 3.	**1,314,841.00**

6.2.4 Summary of findings.

Table 38: Cost and benefits of solar PV system-scenario 3.

Scenario	**Scenario 1**	**Scenario 2**	**Scenario 3**
Brief description	Generate enough to net out the demand only.	Export excess generated when building is not in use to the grid at 0.78ZMK/kWh	Generate from "full roof" and export excess to the grid at 0.78 ZMK/kWh
Payback period (Years)	**11.6**	**8.5**	**8.5**
ROI (25 years)%	**243%**	**391%**	**290%**
NPV (ZMK)	**385,309.00**	**1,204,640.00**	**1,314,841.00**

From Table 40 it was shown that all the options yielded positive returns on investment. Going by the scenario 1, it still makes financial sense to invest in the system even without the need to export the surplus. Assuming that the net-metering and grid integration policies are implemented, the findings reveal that Scenario 2 could be the most financially viable option compared to Scenario 3. This is because of a lower cost of investment for Scenario 2 which yielded the same payback period as Scenario 3 and thus shows a higher return on investment while the difference in the net present value was relatively marginal (110,201ZMK). This could not justify the adoption of Scenario 3.

6.3 Appropriate business model

After analysing the existing framework for solar PV electricity generation in Zambia and then making the business case for energy efficiency interventions and the solar PV system for the case study building, this section presents the conceptualisation of a viable business model. The model is also guided on explanation of the potential to increase the deployment of decentralised rooftop solar PV technologies within the context of the commercial building sub-sector in Zambia and in view of upcoming policy and regulatory support mechanisms.

Even though the addressing of financial barriers to beat the upfront costs has been viewed by many scholars as the most crucial aspect from a business case point of view, understanding business models from the primary objective of value creation entails that there are many other non-financial aspects worth consideration (Würtenberger, Bleyl, Menkveld, Vethman and Tilburg, 2012). Therefore in developing a business model for value creation, other aspects that could be factored include: the market segments in which the model would be best suited (for example whether the model suited existing or new buildings, rented or owner occupied buildings, commercial or residential buildings), the supporting role of policy including actors such as the utility, government, developers, architects, engineers, energy service companies, contractors and so on (*ibid.*). For this study, the most ideal model was to endeavour to be responsive to the prevailing barriers, and especially those identified in Section 2.4.5 and gaps and opportunities presented in Section 5.2. On the other hand, the model was expected to leverage on the support mechanisms and structures which are already in existence. Even though most business models are evaluated in light of which market segment to which they are most likely to apply best, this study narrowed down to the commercial building segment as represented the case study building (EIZ).

In their comprehensive write up on business models for the built environment (which is based on the earlier work of Wuestenhagen (2005), COWI (2008) and Osterwalder (2004)), Würtenberger *et al* (2012) endeavour to distinguish between ten different business models of varying complexity by classifying them into three categories based on the drivers of value creation. The three categorisies are: models based on service products, models based on new revenue models and models based on new financing schemes (*ibid.*). However this simplification seemed to create a challenge in conceptualizing a model because of the several interdependent components within these categories which cross the boundaries of specific business models.

Despite this, the categorisation approach created a very good template for weaving a responsive business model in respect to the study context.

6.3.1 Methodology for conceptualising the business model

Since there are a plethora of existing and emerging business models which are defined at different levels, the first stage adopted for this study in conceptualising a model was to primarily single out (prioritise) the most applicable/feasible models as guided by both literature, ground observation and interviews. This initial sampling of the most feasible models was based on their applicability to the context area, their popularity as highlighted in various literature as appraised under Section 2.5 and their potential to increase the penetration of the decentralised rooftop solar PV technology within the study context.

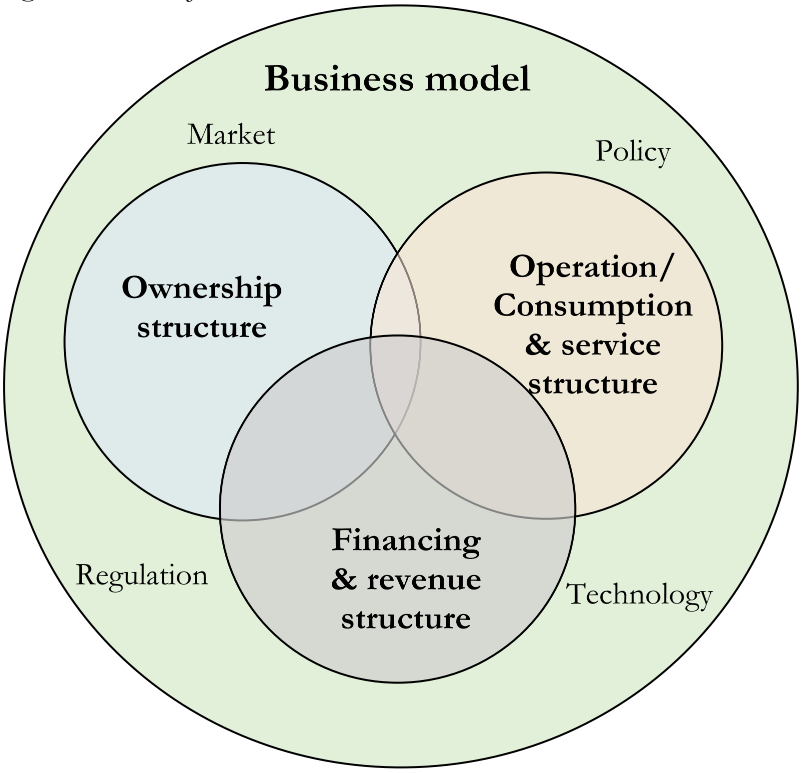
Following this preliminary identification of business models, an evaluation of each model subject to three main models/structures was done (see Figure 55). These models/structures are: ownership/control (who has the rights over the facility?), operation/consumption/service (the intended use of the electricity generated, the type of energy service package and aspects of O+M) and financing/revenue (including investment and revenue streams). The study evaluated the identified general business models based on a general template adopted from the work of Würtenberger *et al* (2012) to ensure compatibility to the selected commercial segment and the supportive environment. As highlighted in Chapter 2, owing to the infancy of solar PV business models in Zambia, the models identified for analysis from other regions were also evaluated for their ability to be scaled and replicated to suit the local scenario.

The template to evaluate the selected models contained a Strength, Weakness, Opportunity and Threat (SWOT) analysis of each model in order to synthesize the most suitable option. This was discussed and presented in a schematic/graphical format with highlights of the most important elements that must be addressed by each model/structure in order to warrant its adoption for the case study (Refer to Tables 41, 42 and 43).

Some sub-models within the three categorised structures were further differentiated. As an example, the variants of ESCOs within third party models and various types of consumption were appraised in more detail.

The paramount questions for this analysis were largely based on the findings of Chapter 2 in relation to policy environment, the findings of the business case undertaken in the forgoing Section 6.2, and the market scenario identified in Zambia as discussed in Chapter 5. More specifically, questions relating to the effectiveness, efficiency, usefulness, vulnerability and viability of the models were considered to give guidance towards the analysis of strengths and weaknesses, opportunities and threats.

Figure 55: Three categories used to define the most viable solar PV business model



6.3.2 Ownership and control structure

The aspect of who owns the solar PV facilities, the rights as well as the related cash flows and benefits, is crucial to determining the potential viability of any business model (Frantzis *et al*, 2008). Although most documents intertwine aspects of operation and financing structures when discussing the ownership of solar PV systems, in this study these have been evaluated separately under the other two structures for the sake of simplicity. In light of the case study segment under consideration (that of new commercial building, to be occupied partly by the owner while the remainder of the building is rented out) and the reviewed policy environment under Chapter 5, the ownership structure was deemed to endeavour to address a number of aspects to warrant its adoption.

The appropriate ownership model was supposed to be able to leverage incentives provided by policy and regulatory environment to the maximum. As observed from the findings, the central utility is somewhat unpredictable episodic and volatile regarding prices and general policy mainly influenced by political forces. Even though Zambia's central utility (ZESCO) appeared to be currently supportive of the ideas of decentralised solar PV electricity generation, it is uncertain for how long this support can be expected to last. The experiences from a country like South Africa showed that there is a lack or weak intrinsic interest by central utility entities in dealing with small scale solar PV and RE electricity generating companies as indicated by the reluctance to commit to power purchase agreements (PPAs) and related grid integration. An innovative ownership structure was therefore expected to critically address the level of utility involvement as a crucial stakeholder in order to drive the required levels of market penetration. As the market penetration of solar PV systems gains momentum (as evidenced from the growing interest in solar PV technologies), the central utility (ZESCO) seems to tread cautiously to safeguard its interests with particular concerns over safety, grid stability and revenue erosion.

Given the relatively immature decentralised solar PV systems in Zambia as discussed earlier, an ideal model of ownership was deemed to present more departure from dependency on utility control/involvement. The model was expected to have the ability to lessen cumbersome, restrictive procedures but at the same time to be adaptive and flexible enough in order to respond to future changes in policy and technology.

Another aspect that the desired ownership model was expected to address was the application of the building. The ownership model of the system was supposed to factor in the fact that the case study building was a commercial building to be occupied by both the client and leasing tenants and so change in use and electricity loads would vary from time to time. The fact that the building was a new building and not an existing one also had some bearing on the ownership and operation options.

The desirable ownership model should also be able to easily integrate aspects pertaining to energy performance and future energy and system upgrades. It should address the question of whether it is more likely to bolster more interest in energy investments for the future against other alternative investments to the building such as merely improving aesthetics.

Furthermore, it should address the hassle factor and perceived troubles that come with dealing with transactions, procurement, information gathering and obtaining competences for installation, and eventual maintenance.

Some selected ownership scenarios with several interdependent components are discussed below. Most literature categorises solar PV installations into two broad models based on ownership; direct and third party or more generally utility driven and customer-driven models (Garg *et al*, 2014; Alta Energy, 2016; Tanţă *et al*, 2014). However, given the emergence of new innovative models and maturation of legislative frameworks, and natural markets, hybrid of models making use of greater intermediaries and permutations have developed. Based on the work of Frantzis *et al* (2008), Barrett (2015) and others, this study identified three broad ownership models for discussion namely: Customer owned or owner-owned, third party ownership and a relatively new model of community ownership.

Case A: Owner/customer owned – (The EIZ owns the facility)

In this scenario the EIZ funds, constructs and operates the solar PV project, which generates electricity on site and behind the meter (demand-side) (Frantzis, 2008; Barrett, 2015). Assuming the existence of net metering policies in future, excess electricity generated is sold to the utility ZESCO. In this scenario, an electric (smart) meter, tracks the electricity flow debiting the EIZ account for electricity drawn from the grid and crediting the account for excess electricity sold back to ZESCO (*ibid*). The amount payable for the used electricity varies and is defined by the net metering policies. Seeing that the mechanism to ascertain the difference between what is bought and sold to constitute the EIZ bill is still not yet in place, the excess generation capacity risks being a liability rather.

Case B: Third party owned (The EIZ outsources a third party)

Rooftop solar PV systems owned by third parties have been categorised in the second generation of the evolution of solar PV business models towards more integration of decentralised systems with the utilities (Garg *et al*, 2014; Frantzis *et al*, 2008). In the USA, third parties are becoming widespread while in African developing countries they are becoming common in decentralised rural setups through ESCOs (Huijben and Verbong, 2013; Frantzis *et al*, 2008). Included within this category is an analysis of energy contracting models as these are frequently discussed as an important third party approach to energy service provision and subsequent increase in the deployment of solar PV technology systems and energy efficiency (Würtenberger *et al*, 2012).

Some of the notable advantages of the third party ownership model in general are that developers or third party companies are typically specialised solar industry players with greater understanding of the solar PV systems (Garg *et al*, 2014). The EIZ case would leverage and eliminate some hurdles by adopting this model. Additionally the EIZ can access specialised financing at lower costs, better manage technical risks and make use of economies of scale to take advantage of the government incentives more efficiently than if the EIZ owned it themselves. There are several sub-ownership models depending on who hosts the system and who controls it. Some of the control and ownership scenarios for consideration are discussed below.

Option 1: The EIZ as host only

In this scenario, the EIZ or any particular client/owner leases out the roof to a private developer or company who installs, owns and operates the solar PV system under a long term lease agreement. The developer simply pays the EIZ an annual lease for the roof and the right to operate the facility and sells the green electricity to an off-site customer. In the case study location where there is sufficient land and bigger roof spaces, there is no particular motivation for simply renting the EIZ roof unless with a view to supply the nearby precinct. Even if this was to be the case, the EIZ building roof is constrained in size compared to other buildings in the area. Therefore this model is not favourable and can only work well in areas where the demand for electricity is very high, electricity tariffs are high while the available roof space is limited as in the case of dense built up areas. This is primarily applicable to large commercial/ institutional consumers with adequate rooftop space.

Option 2: The EIZ as the power purchaser

In this variant scenario, not only does the EIZ agree to a long term lease with a private solar PV developer/company to construct own and operate the system, but also executes a power purchase agreement (PPA) to purchase all the power produced for a long term period of say 25 years at a specified annual rate. In the Zambian case with a seemingly strong upcoming solar PV market as well as many local and foreign commercial entities looking for power purchasers from among commercial building owners such as the EIZ, this becomes a very attractive option. In return the EIZ benefits from lower prices especially if they subject the leasing to a competitive bid. Given the importance of a PPA towards the projecting of financing, such clients committing to purchase electricity are very attractive because of strong credit rating. The primary benefit to the (EIZ) is that its cost of electricity will remain stable and predictable against the grid-supplied price volatility.

Case C: Collectively owned solar model (EIZ and other building owners own the facility collectively)

Collectively owned solar is a relatively new mechanism for developing solar systems which has the potential of being applicable to the building under study assuming that the surrounding context which has a shopping mall and upcoming commercial buildings can collaborate (Refer to Figure 13 section 4.3.1). The concept is that the solar project is developed at a single site and the subscribers or shareholders pay for the electricity produced based on how much they consume (Huijben and Verbong, 2013; Barrett, 2015). This can work well through areas with adequate property and sites as is the case study area. However some disadvantages in respect to the EIZ case are that currently the surrounding buildings are widely spaced. Moreover the minimum connection standards for such an arrangement are not yet in place. In addition this model will require that all the objectives and electricity demands of the other entities or would be parties be unified which can be a time consuming undertaking.

Table 39: SWOT analysis of different ownership models.

	A. OWNER/CUSTOMER (EIZ) OWNED FACILITY.	B. THIRD PARTY OWNED (INCLUDING ESCOS,ESC)	C. COLLECTIVELY OWNED SOLAR
STRENGTHS	•The owner (EIZ) retains the renewable energy credits and rights. •The model is applicable to commercial segments such as the case under study. •Total control of the facility and subsequent upgrades. •The owner (EIZ) promote a green image and with appropriate polices may charge a higher rental. •Guaranteed energy security	• Proven market based model in Zambia and applicable to large property investors such as EIZ. • Could focus on integrating other energy sources apart from solar as well as energy efficiency projects. • The EIZ benefits from out-sourcing extra incentives and lessened hustle factor. • ESCOs concept induces an intrinsic interest to increase efficiency and to reduce final energy demand. • ESCOs/third parties can leverage maximum government incentives. • Most projects are market-based with relatively little dependence on supporting policy measures and may easily negotiate policy and institutional barriers which is a benefit for both the customer and third party. • Guaranteed energy security	• New model gaining momentum (can be replicated from working rural models). • Can be applicable for the context area given the typology of buildings (offices, shopping mall, and sports complex) • The surplus from the full roof scenario could supply a considerable number of buildings. • Shared capital cost and associated maintenance • Guaranteed energy security
WEAKNESSES	•The owner does not retain the benefits from outsourcing energy services •Relinquishes any credits from solar PV electricity generation. •Absence of net metering policies means the facility will be a liability when generating excess. • Higher hassle in coupling the system supply to the variable tenant load demand. • Not core to their business. • Utility more keen to deal with larger players and established companies in terms of grid interaction. •The changing roles of technical personnel and specialization will make it difficult to have in house personnel and specific energy experts.	•Requires mutual long-term dependencies and a long-term business perspective of the ESCO/third party and the client. •Requires strong contract agreements relating to premature contract termination, buy out clauses and it may place too many caveats on the third party to their disadvantage. •Some models are complex which combine both electricity supply and energy efficiency. They sometimes cover the entire project life cycle in one contract and require technical, economical, financial, legal and organisational know-how.	•Buildings are too spread out •Minimum connection standards not yet in place •Different organisational priorities •Management of the system, guaranteed supply is difficult. •Hosting of facility may give undue advantage.

SWOT analysis of different ownership models continued…

	A. OWNER/CUSTOMER (EIZ) OWNED FACILITY.	B. THIRD PARTY OWNED (INCLUDING ESCOS,ESC)	C. COLLECTIVELY OWNED SOLAR
OPPORTUNITIES	•The owner buildings will build a green image which can attract tenants and increase rentals when marketed on that basis. •Upcoming green building codes and ratings will promote the building. •Could build internal capacity and expertise and increases knowledge and understanding on energy related issues. •Gain the advantage of incorporating energy efficiency at building procurement stage (design & construction stage). Leverage viable input from consultants at the design and construction phase •Linkages with multiple industry actors.	•Suitable for any project size and the market potential in Zambia is attractive given that customers want to hedge against power interruptions. •International energy companies with good credit portfolios and technology could form joint ventures with local companies. •The hype in demand for solar PV products, progressive supportive policy measures (i.e. tax incentives), partnerships, developing standards and codes, and training will lead the growth of this ownership model. •More new buildings coming up indicate an opportunity for owners to engage third parties to guarantee confidence in the products and external technology.	•Great opportunity for upcoming office/business parks and large clustered developments
THREATS	•Growing trend towards third party models. •Vulnerability to low product standards. •Slow development of supporting feed in policies. •Potential problems with managing/control load structure from tenant equipment and usage and resulting pressure to effectively deliver the required captive demand.	•Unpredictable policies and political influence affects the market. •Slow adoption of supportive policies. • Could be viewed as source of competition with the utility. •Threatens existing jobs in the organisation, its energy plans and routines. •Threats of performance defaulting and failure to meet supply baselines due low system performance could lead to problems with customer. •Relies to a certain extent on the supportive legislative and policy support to eliminate barriers such as unfair competition and standards, compliance. •Threats of addressing split incentives of building owner and tenants/occupants.	•Relatively in infancy. •Heavily reliant on policy support and connection standards and contractual agreements. •Challenges of owning common facility. •A way back to central systems.

6.3.3 Operation/consumption and service structure

Apart from the question of who should control the rights over the system, other aspects relate to who takes charge of ensuring that the system operates to the required standards and who ultimately consumes the electricity generated from the rooftop PV system. Moreover, this type of service apart from mere electricity provision must be streamlined in order to holistically define a business model.

Service and operation

Apart from the renewable energy system, there are other energy efficiency services, system upgrades and technologies that are required. In addition there are operational expenses such as maintenance. Once again the broad options are whether these service provisions and O+M can be borne by the EIZ exclusively or by a third party company. Third-party developers typically manage all aspects related to installation of the systems and are responsible for their long-term operation and maintenance. The EIZ's involvement as the rooftop owner is limited to providing roof space and perhaps also purchasing of all electricity to offset the demand or part thereof.

Third party models like ESCOs may offer other energy related product services beyond supply of electricity such as energy saving and emission saving which the EIZ may not prioritise and so it's an added benefit and building of a green image (Würtenberger *et al*, 2012).

In terms of the consumption of the electricity generated, three options were considered as discussed here below.

Captive generation and consumption (no grid feed)

Under this sub model classification, it is assumed that the EIZ consumes all the electricity generated from the roof top solar PV system which would be just enough to meet the optimised demand. The system is designed not to feed any electricity into the grid, but instead they may continue to buy electricity from the grid as billed by the utility (ZESCO). Considering that this system is for captive use, it is quite common for many consumer segments who want to hedge against the inconveniences of the unreliable grid supply and power cuts. In the case study area which experiences six hours of power cuts, this captive generation is feasible as an alternative. A business case presented in Section 6.2.3 proved that this option is financially viable for the case study. Another motivation for this consumption model is that given the slow development of policy on feed in mechanisms, investors can go ahead and generate electricity without having to worry about the grid. Under this option the EIZ can use solar electricity for specific loads such as lighting while the remainder is met by the grid supply. However, with the unreliable grid supply, the best option is to net out the whole electricity demand of the building. The weak side of this option without the grid interactive mechanism is that the excess electricity generated from periods when the building is not in use, has to be curtailed otherwise costly storage systems and charge controllers need to be installed.

Captive generation with excess power fed into the grid (net metering).

The electricity generated from the rooftop solar PV system is first used to service the captive loads of the EIZ building. The excess electricity is then fed into the grid through a bi-directional meter. Given that Zambia has not yet formulated the net metering policies, this option is only under future scenarios. A business case analysis for the case study building presented in Section 6.2.3 revealed positive financial benefits for this alternative assuming the existence of supportive structures. In some instances this option could have a variant where the excess generation is capped and excess injection is not compensated (Garg *et al*, 2014). Either way it translates into profit for the EIZ as opposed to wasting the excess or investing in expensive storage systems. Given the progressive policy on feed-in tariffs for the upcoming utility scale solar projects, this option could guarantee good returns on investment. Whereas this option is very attractive to consumers who pay high tariffs such as commercial and industrial users, with low non-reflective tariffs in Zambia, the returns are too marginal to attract investment from developers.

Excess generation grid fed (Gross-metering)

Having determined that the EIZ roof space is sufficient to generate surplus electricity within the acceptable scale limits of what can be sold to the grid, in view of the progressive mechanisms and feed-in tariffs this option is lucrative for both the EIZ and the private developer. However this model is very sensitive to conducive policy environment hence it can only be viewed as prospective.

Table 40: SWOT analysis of different operation/ service and consumption models.

	A. OWNER/CUSTOMER OPERATED/SINGLE ENERGY SERVICE (SOLAR ELECTRICITY)/ SELF-CONSUMPTION.	B. THIRD PARTY OPERATED/MULTIPLE SERVICES (ENERGY CONTRACTING)/SELF AND FEED IN GENERATION.
STRENGTHS	• The main focus is on generation for self-consumption and they concentrate on their core business. • Offsets the electricity bills. • Increases the property value. • Energy efficiency is embedded as part of the solar project. • Can make the solar PV system part of the overall procurement process. • Captive generation means it can handle certain loads of the building while the grid is still available to meet the remainder. • Arguably applicable to smaller sizes, easier to handle and manage. • Can use cheaper in-house expertise and personnel	• Performance guarantee to the building owner (EIZ) reduces risk of the system not generating the expected benefits. • O &M borne by the third party or ESCO so it is less responsibility for the owner. • Offers front-end evaluations to ascertain cost-saving opportunities and estimate system yields. • Poses expertise, and highly knowledgeable to provide scope and assessments about suitability of technology (eliminating information barriers). • The EIZ pays for the results and outputs (Services) instead of the inputs and components (the solar PV system and associated technology) • The EIZ benefits by leveraging the third party's networks and partnerships. • The services are packaged in a modular and customised manner according to the specifications so the EIZ could have a choice which one to implement.
WEAKNESSES	• The customer (EIZ) misses out on O+M • The facility becomes a liability when generating excess electricity for the captive model. • Possibility of oversizing or under sizing the system. • Provision of the deficit electricity not guaranteed given grid unreliability and standards. • May need to invest in expensive back up batteries. • Parts of the roof are underutilised. • The owner may still need to protect the facility at their premises. • Not easy to get license exemptions.	• Caveats can be restrictive regarding access to the facility for O +M of the system • Formal contractual agreements too procedural and time consuming. • Third party/ESCO could be business oriented and bent on profit maximisation at every turn. • Not easy to quantify savings and baseline service targets for remuneration.

SWOT analysis of different operation/ service and consumption models continued….

	A. OWNER/CUSTOMER OPERATED/SINGLE ENERGY SERVICE (SOLAR ELECTRICITY)/ SELF-CONSUMPTION.	B. THIRD PARTY OPERATED/MULTIPLE SERVICES (ENERGY CONTRACTING)/SELF AND FEED IN GENERATION.
OPPORTUNITIES	•The owner could interface directly with the occupants. •The owner could affect the user consumption patterns and behavioural change in energy efficiency. Influence user habits and behaviours as they interface with users directly. •Opportunities for partnerships with intermediaries for operation and services (during procurement stage)	• The building owner may benefits from other energy services such as consultancy, training staff and emissions reduction which the owner may not prioritise at a time. • The third party company can assist the owner to transition to upgrades that are more complicated and less familiar technologies. • The implementation of feed in tariffs will be a good basis for developing third party energy companies. • Upfront evaluations are a good business development activity for the third party company. •Many public and private building rooftops could be offered for PPPs.
THREATS	•Fear of losing control •Management incapacity to handle operations. System deterioration. •Split incentives between the owner and the tenants. •May fall victim to poor technology in given weak standards. •Competitive environment with presumes rapidly emerging without enabling policies.	• Delayed uncertain policies on feed in tariffs and net metering standards. • Restrictive purchase limits from off taker (ZESCO). • Reliance on the willingness of the building owner to outsource energy packages. • Complex contracts running for long periods. • Split incentives with tenants and building owner. • Inexperience market • Tenancy change and corresponding change of electric loads

6.3.4 Financing/ revenue and investment model

Regardless of the ownership structure, financing of the rooftop solar PV system is an interrelated consideration that is equally critical in order to reduce the high upfront costs which act as one of the major barriers to an increased deployment of solar PV technologies. This Section focuses on the characteristics of the main financing and revenue streams and their likely applicability to the case situation. Some are new innovative financing models that can create good frameworks, which do not overburden the government and negotiate the hurdles associated with accessing financing.

For easy distinction, the analysis of the models were largely classified into owner finance and third party finance. Other sub models have been discussed primarily regarding sources of funding and revenue streams.

Owner financing model

Here the owner (EIZ) of the property finances the solar PVs project. Some examples of the sources of funding could be from internal revenue in the form of corporate finance, where the corporation finances all costs and there are no other financiers or lenders involved. The benefit to the EIZ is that it will reap all the revenues associated with the investment including renewable energy credits and green image if implemented in future. In as much as it is possible for a big entity like the EIZ to self-finance given their strong credit ratings, it is very rare for solar PV systems of such magnitude to be financed solely by the owner of the building (Green Rhino energy, 2013), the EIZ could therefore benefit and ease the initial capital burden by getting a soft loan while leveraging on the incentives. As stated in Section 5.8 financing is available for personal, business and corporate market segments.

Where a soft loan is obtained, one of the revenue for repayment options would be through electricity savings. In this case if the EIZ decided to go with the Net-Zero option presented in Section 6.2.3, the resulting savings from the offset bills can be used directly to repay the debt and thereafter retain system and the revenue to itself.

Third party financing model

Third party solar financing is a common financing option and has emerged in the recent past as one of the most popular solar financing methods to beat initial cost and to help customers realise the benefits of solar (Garg *et al*, 2014; Frantzis *et al* 2008). For simplicity two primary models through which financing are accessed are considered: a solar power purchase agreement and a traditional lease.

Solar PPAs

A common model is characterised by the third party using a power purchase agreement. This scenario, whose ownership structure is highlighted under Section 6.3.2, would allow the developer or ESCO to install the system on the host (EIZ) rooftop and sell the electricity to EIZ (customer) through a signed contract for a period of time. The property owner has the option to extend the contract or even buy the solar PV system from the developer at the end of the PPA contract. This option makes it attractive to the customer as a potential solution in order to avoid upfront cost as well as offset their electric utility bill in addition to avoiding responsibilities related to operation and maintenance, both of which would typically be transferred to the developer or ESCO. The developer uses this PPA to source the required funding from financial institutions. At the end of contract, they could acquire enough internal capacity to handle operations. In the case of Zambia's low tariffs, this may be difficult for the developer, but in view of higher tariffs and desire to hedge the inconvenient power cuts, reliability is guaranteed. According to (Kollins, Speer and Cory, 2010), these advantages appeal to the owners of the buildings (both commercial and residential) who may seek to acquire a solar PV system.

Solar leases

In this model of solar leases, the customer signs a contract with the developer/ESCO/installer and then pays for the system, rather than the electricity generated for a period of time. In this arrangement it is possible to either pay no upfront cost, pay part of some money, or pay for the system before the end of term which makes it very flexible. However it is stated that experiences from the US indicate that challenges are created with tax credits and accelerated depreciation (Kollins, Speer and Cory, 2010).

Table 41: SWOT analysis of different financing models.

	A. OWNER/CUSTOMER (EIZ) FINANCED MODEL.	B. THIRD PARTY FINANCED & REVENUE MODEL (PPAs and SOLAR LEASES)
STRENGTHS	•Use of internal revenue means no need to service lenders. •Less administrative huddles since the scale is manageable. •All financial benefits and revenue accrue o the owner (EIZ) from saved electricity bills. •The EIZ could source a soft loan which could be re-paid directly using the electricity savings •Little use of and dependency on government funds.	•Secure, common, repayment method to beat upfront cost used applicable and tested for this market segment. •The third party or developer can use a PPA to source for funding and finance the solar PV. •Through a PPA, the EIZ could enjoy fixed tariffs from the third party for at least 25 years. •The EIZ benefits because the cost of installation, O+M and related responsibilities are transferred to the third party. •With a solar lease, the EIZ could buy the system and equipment flexibly structured in a way that makes optimal use of incentives.
WEAKNESS	•Insecure repayment •Difficult to beat upfront costs. •Intolerant to projects with longer payback periods in terms of business. •Hard to overcome bureaucratic huddles on their own.	• Difficult to quantify performance for payment. • Multi players (actors) split incentives • Reduced focus on maximising return on investment because interest is on performance. • Need for periodic revision of contractual terms in relation to changing economic conditions. • Usually the PPA tariff is lower than market tariff.

SWOT analysis of different financing models continued…..

	A. OWNER/CUSTOMER (EIZ) FINANCED MODEL.	B. THIRD PARTY FINANCED & REVENUE MODEL (PPAs and SOLAR LEASES)
OPPORTUNITIES	• Possibility to sale electricity to the grid and others. • Government and utility support for prosumers. • Opportunity for business case through savings and financial capital-dual aspect, no much portfolio. • Owning assists feed excess • Competition among building owners, presumes energy with enabling mechanism	• Options exist for shared savings with third party or guaranteed savings. • Third party companies can secure financing by bringing investors that are formula with the project to the table. • Access to foreign capital, environmental green finance (emissions trading) and public private partnerships. • The owner may benefit from lower prices from a competitive bid. • Tolerance for long payback a benefit to building owner. • Could access green finance. • Government promotion of grid scale utility size alternatives is an opportunity to increase capacity • Partnerships and joint ventures with international companies.
THREATS	• High interest rates • Failure to meet credit checks set by financial institutions. • Financial institution lack of knowledge on technology • Financial institutions requiring proof of involvement of experts and associated actors. • Hard to access green finance as corporate entities. • Insurance risks • Minimum incentives. • Slow policy permitting interconnection • Non reflective tariffs de-motivator. • Government promotion of grid scale utility size alternatives	• Non reflective tariffs are a hindrance. • Shared savings • Unfair competition. • Policy shifts and unstable political interference. • Financial institution lack of knowledge on technology. • Slow policy permitting interconnection. • Slow formulation of standard forms of contract for building scale rooftop solar PV systems.

6.3.5 Synthesis of the business model

Following the SWOT analysis of the selected business models and their respective sub-models, this section synthesises an appropriate business model based on the broader findings of SWOT analysis. In arriving at the business model, the different model categories are presented in tabular form together with the key barriers they best addressed (see Table 44). In this way, the research question about the appropriate responsive business model to address the barriers particular to the study segment and stimulate an increased deployment of the technology was answered. The barriers are presented in a generic form and some could be addressed by more than one model.

Generally, from the table findings, the barriers of high upfront cost and lack of access to capital are better addressed by outsourcing investment to a third party. Assuming the support policy on grid interaction, net metering and feed-in-tariffs is quickly implemented, this model will accelerate deployment of decentralised rooftop solar PV systems. More effectively, these barriers would be addressed by energy service contracting with viable power purchase agreements with the building owners. The PPAs will assist the ESCOs to spread the cost on system investment over a lifetime of the project. Through a strong business case and lifecycle approach of dealing with the third party, the building owner with limited investment would be provided with an opportunity to kick off the project because the ESCO bears less capital cost constraint. This is possible because most ESCOs have strong credit ratings, their own capital, could access green finance and could also use the PPAs as guarantees to borrow money. In addition the owner will benefit from a low cost project as a result of a competitive bid process to select the best ESCO. Furthermore, the findings show that under the financing models of leasing and PPAs, the owner is cushioned from financial hassles of providing sureties and collateral as the financial institutions could deal directly with the company. If the ESCO does not provide financing itself, it can still take on the role of a facilitator supporting the building owner to get access to third party financing solutions.

Considering that there are not many such building that have rooftop solar PV systems of this magnitude in Zambia (if at all any exists), the EIZ arguably the first such big project, one imminent barrier to increased uptake would be the owners'/customers'and financial institutions' aversion to the risk of new solar PV technologies and the routes of service delivery. The third party model of ownership, consumption/service and financing eliminate the risk from the owner who at most is inexperienced to deal with implementation, operation and maintenance. The ESCO would take on the economic and technical risk and is paid for both the output delivered (both the electricity supplied from the system as well as the energy saving). Given the relative slow maturity of such technologies in the Zambian market, there are several competing technology options in the market globally. The building owners are therefore better off outsourcing the third party (ESCOs) who can provide credible, proven technology about which they have more experience. Foreign and local ventures of ESCOs are even better placed and can easily take in the risk of introducing new piloted technologies.

As reviewed from the interview data, one hindrance to the deployment of solar PV systems is the hassle factor. The owner has to deal with inexperienced consultants, poor standards, import procedures, negotiating product prices and incentives amid having to manage actors and interfaces. Although the procedures required when acquiring licenses for grid scale electricity generation are a bit flexible, they still remain cumbersome for the building owners to negotiate on their own while still undertaking their core businesses. The scaling up of solar project by the IDC as highlighted under Section 5.2 substantiated on the lengthy process involving stakeholders, regulation agencies, central utility and financiers that had to be followed to secure the first company for the project. The EIZ rooftop solar PV project is itself another example having taken over a year to secure solar PV contractor and will possibly require longer time to have the system in place. During an interview with the project architect, it was revealed that the client (EIZ) and the consultants had not agreed as yet regarding whether the exact specifications of the PV system would be sufficient to meet the building loads. By outsourcing this project to a third party (ESCO), energy contracting would sometimes offer a service package that includes several other services such as planning, installation, financing, operation and maintenance.

Problems related to knowledge barriers about product technical specification, trending efficiencies and cost effective technologies from international sources can be dealt with by including specialised companies to operate and service the systems. Within third-party models, split incentives are dealt with by binding agreements between the parties. Stable agreements mean that both the owner and the third party company will hedge against unstable political policies, unreliable central utility services because of the mutually established performance guarantees.

Barriers relating to the general lack of interest and prioritising the use of rooftop solar PV systems and undertaking energy efficiency projects among building owners is very much dependent on policy environment and cannot be attributed to any one model. However, the owner-based models could play a huge role through building their green image, documenting and publicizing the benefits and savings arising from the adoption of solar PV systems and energy efficiency interventions. However, that this will not drive the significant transformation required on its own without strong policy support.

Although regulatory barriers as well as non-existent or slow policy frameworks are difficult to deal with under the business models because they highly depend on the Zambian government and decision makers, the third party models are more capable of avoiding and navigating around such barriers. In addition, third party as well as building owners who move quickly may take advantage of weak or non-existent of certain restrictive policies and accelerate deployment before formal, strictures are enforced.

Table 42: Barriers addressed by business models. (Adapted from Weisterberger, 2012)

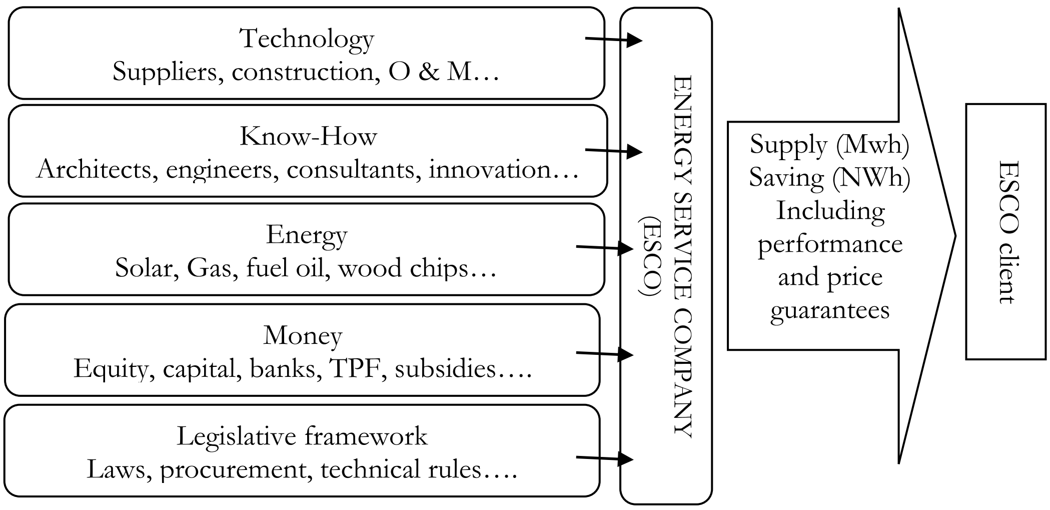
	Ownership and control model				Service/consumption and operation model					Financing/ revenue and investment model		
	Owner owned (EIZ)	Third party owned (ESCO)	Utility owned	Community owned	Owner operated solar PV system only	Third party (ESCO) operated (+Other energy services)	Captive generation and consumption (no grid feed)	Captive generation with excess power fed into the grid (net metering).	Excess generation grid fed (Gross-metering)	Owner financing model.	Solar PPA	Solar leasing
Market barriers												
Price distortion												
Lack of trust/ for solar systems		O				O						
Hustle factor		O	O			O					O	
Split incentives												
Low priority of energy issues in building industry	O				O							
Information and technological barriers												
Poor standards and product categorisation		O				O						
Lack of awareness						O						
Limited information on financing options						O					O	O
Limited competence of technicians.		O	O			O						
Limited information on emerging technology		O	O			O						
Regulatory and policy barriers												
Restrictive procurement rules/red tape		O	O			O						
Cumbersome licencing process		O	O			O						
Limited policy on interconnection and grid feed	O	O			O	O	O					
Dependence on the utility involvement						O	O					
Economic and financial barriers												
High upfront cost/operation cost		O	O			O		O			O	O
Low or no return on investment		O				O		O	O			
Difficult in accessing capital		O				O					O	O
High risk of solar PV investment		O				O						O

Conceptualizing the model by building on the energy contracting (ESCO) framework

Based on the information revealed from literature in Chapter 2 and the analysis of the different models in the foregoing sections of this chapter, it was apparent that the solar PV industry was moving away from the first generation business models in which the customer/owner not only operated and financed the system, but also managed most aspects (Frantziz *et al*, 2008). The direction is more towards third party models.

Streamlining the third party model further, this study identified the energy service contracting (ESCO) framework as the appropriate basis to weave an innovative business model. This selection was backed by the fact that the (ESCO) models are already applicable in Zambia with great potential to be adapted for commercial building rooftop solar PV technologies as highlighted under Section 2.4.4. Energy contracting is a wide-ranging energy service model to implement energy efficiency projects at minimalized project cycle costs (Weisterberger *et al*, 2012). ESCOs fall within this model. Normally an Energy Service Company (ESCO) operates as a general contractor, implementing a tailored service package (consisting of services such as design, installation, (co-)financing, user-motivation, optimization, and O+M). As key features, the ESCO's payment is based on performance. The ESCO also guarantees for the product and comprehensive costs of the services and takes over risks associated with commercial as well as operational and technical aspects for the project tenure. As a product service system, energy service companies or energy service contracting is widely applicable in the field of renewable energy.

Figure 56: IEC-model: Schematic standard scope of services (Weisterberger et al, 2012)



Although there could be several varieties in practice, the ESCO models are mainly distinguished as providing either useful electricity (in this case solar electricity supply) or energy saving services (energy performance contracting) to the end user/customer (Weisterberger *et al*, 2012). In the context of the building under study where energy efficiency interventions precede electricity generation from rooftop solar PVs, a more integrated energy contracting model was deemed as the most ideal.

The Integrated Energy Contracting (IEC) model combines both electricity supply and energy saving measures in a building. Moreover, the IEC model has the capability of extending the range of services and thus the energy and emissions savings potential to the whole building. It is innovative, and for new buildings it could be included in the energy service package. The conceptual framework of the integrated energy service contracting model is shown in Figure 57 below.

Figure 57: Energy-Contracting: A modular energy service package with guaranteed results for the client. (Note: The added value for the client of energy contracting compared to in-house implementation is displayed in red.) (Source: Weisterberger et al, 2012)

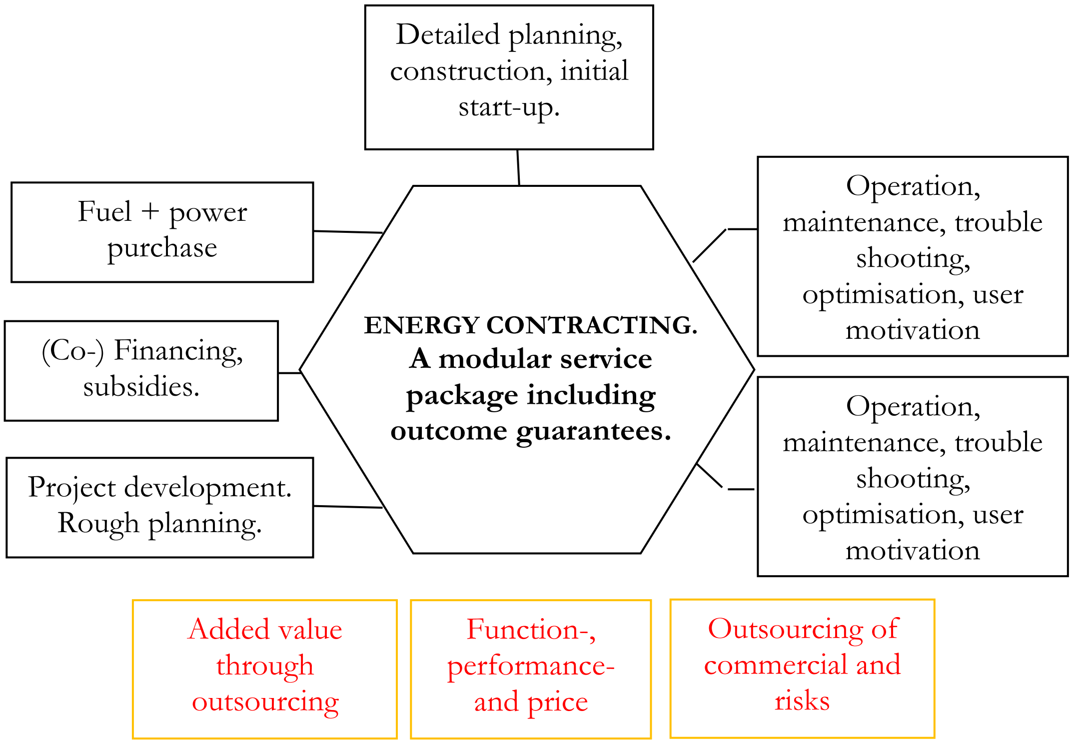


Figure 58: Concept for business model based on the IEC-model framework.

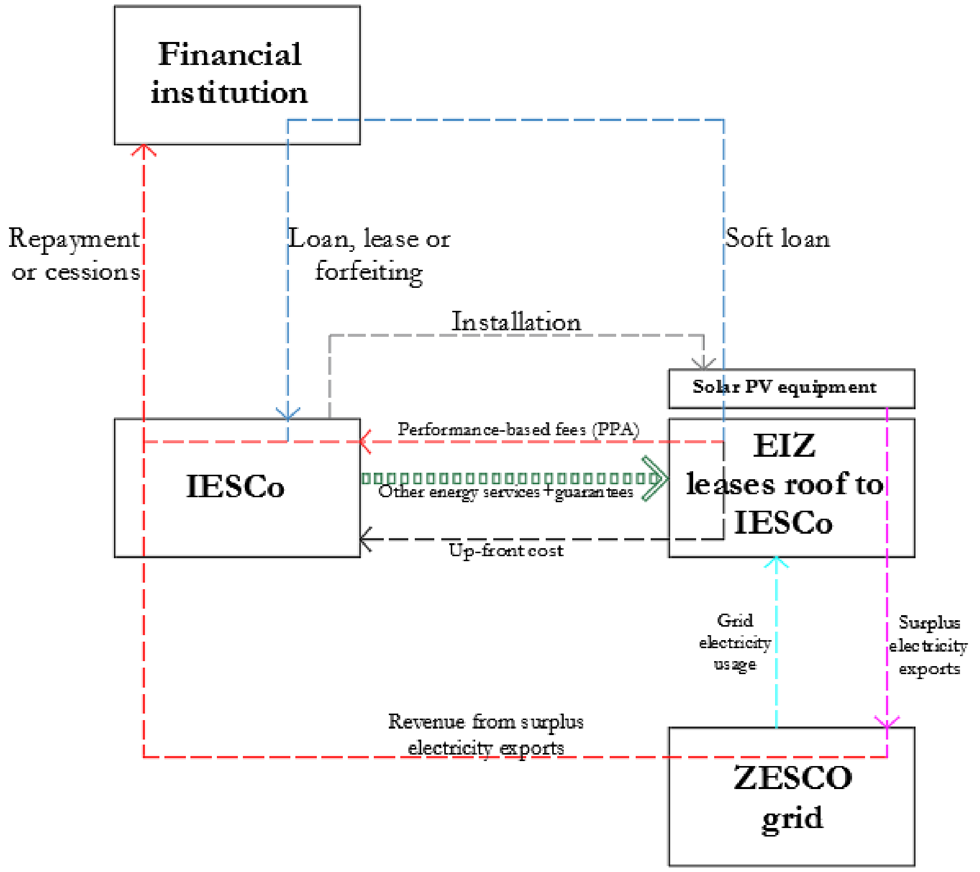
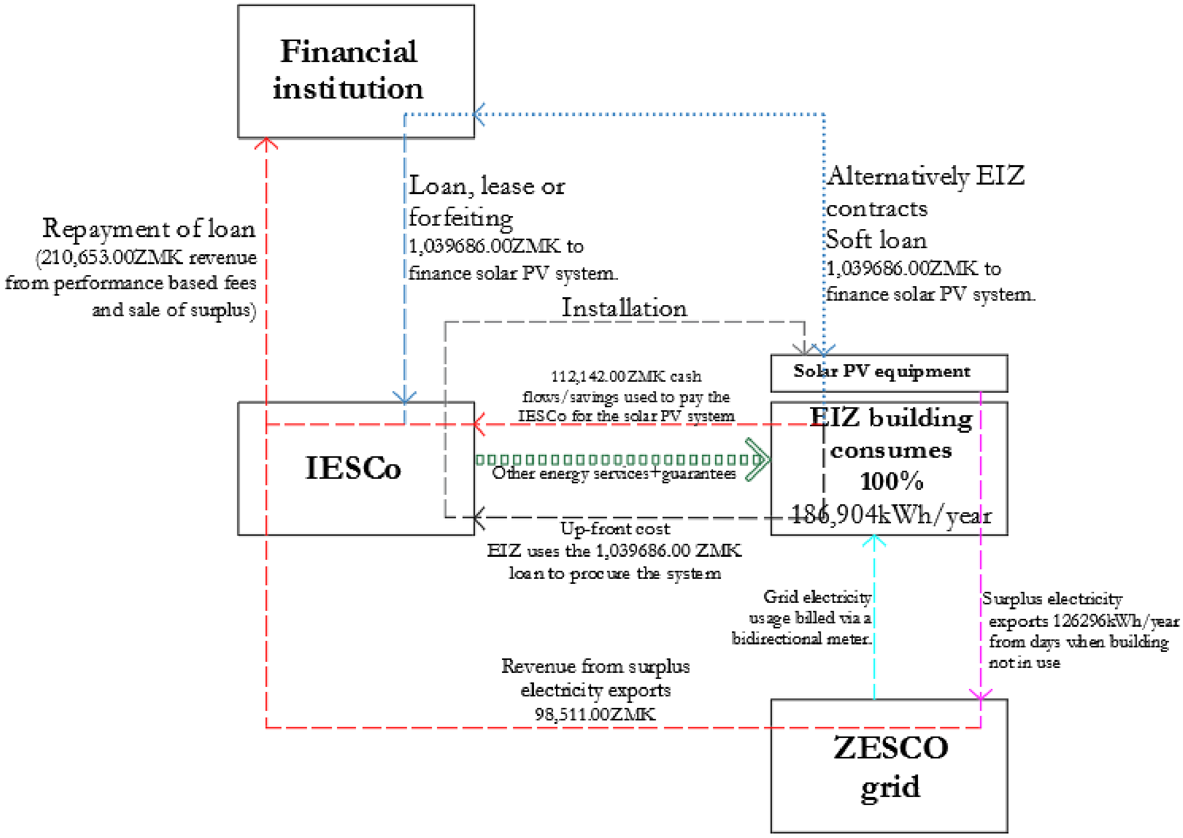


Figure 59: Adopted business model assuming supportive mechanism are implemented



Derivation of key findings

Under the assumption that the prerequisite progressive policy on net metering, and feed-in mechanisms are quickly implemented, the following findings were derived. The chapter used the template from the work of *Weisterberger et al, (2012)* to analyse the various identified models of ownership, operation and financing which could guide the conceptualisation of a business model. A SWOT analysis of these models was presented in Tables 41, 42 and 43. Table 44 summarised and discussed which particular barriers were best addressed by specific models so that the appropriate business model could be synthesised. Both analyses demonstrated that the third party models were more favourable for the case study. More specifically, the integrated energy service contracting framework was identified as the basis upon which the responsive business model could be developed. The study demonstrated that this model could provide opportunities for the EIZ to finance apparent costs and outsource risks while leveraging the supporting role of government through legislation. It was also demonstrated that an integrated energy service company (IESCo) framework would be ideal for the case study because of its minimal direct dependence on policy and financial support but was instead more market driven. This meant that it was less sensitive to the lack of supportive policies and volatile policies from the government.

With reference to the favourable business case evaluations presented under Section 6.2, the study conceptualised a business model as shown in Figures 58 and 59 which could lead to a significant increase in the deployment of decentralised rooftop solar PV technologies in commercial buildings for Zambia. The model proposed an IESCo acting at the centre of the model. The IESCo secures financing from the financial institution and supplies various services to the owner (EIZ) (including solar PV system installation, energy efficiency services and operations and maintenance). The owner (EIZ) has an option to contract a soft loan from a financial institution and pay for the upfront cost of the system to the IESCo while the IESCo also suppliers other services besides installation of the system. In the case that the IESCo contracts a loan from the financial institution, the EIZ pays the IESCo based on performance based fees (and the power purchase agreement) which the IESCo in turn uses to service the loan from the financiers. An additional revenue stream from the export of electricity (assuming the fast implementation of the feed-in-policy and supportive mechanism) could be used by the IESCo to repay the loan. After the loan is repaid, the IESCo and the owner (EIZ) could then agree on new contract terms to share savings from the facility for a specified period of time. This model was deemed appropriate because it could bring key actors in the sector including

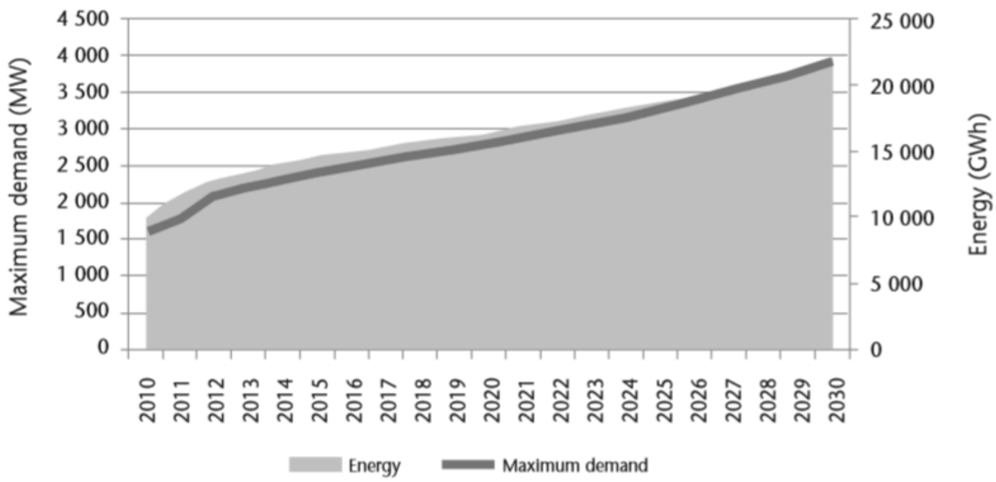
ZESCO, building industry experts (architects, engineers), financial institutions, building owners, developers and policy makers.

To address the weaknesses and threats of the model as analysed in the Tables 41-43 and thus enhance the role of third party (IESCo) models in the increased deployment of decentralised rooftop solar PV systems, the Zambian government could support the IESCos through the establishment of agencies to serve as facilitators between the potential clients and the IESCos. In addition, model contracts (documents and procedures), monitoring, evaluation and procurement rules and standards need to be formulated. On the other hand, independent consultancies such as architects (building professionals) need to be empowered to prepare detailed energy and financial models and put out calls for proposals from energy service companies.

6.4 Contribution to Zambia's electricity generation goals

As expected of a lower-middle income developing country which is characterised by an increase in urbanisation and a growing number of new buildings, the demand for electricity is expected to grow exponentially compared to supply. A load forecast prepared by Kapika and Eberhard (2013) revealed that the demand is expected to reach a maximum average of 4.5 and 3.9% per year from the period 2010 to 2030 (see Figure 60). The targets set for electricity generation from mainly hydro power plants (under construction) showed that ZESCO intends to increase electricity generation by around 39% by 2020 from the current installed capacity of 2500MW (ERB-Z, 2016). In addition, following the electricity crisis that hit Tanzania and Kenya, ZESCO started feasibility studies to construct a 697 kilometre electricity transmission line to these countries in a bid to export electricity (*ibid.*). This entails that the generation capacity will have to be increased to guarantee enough electricity for export while closing the gap in electrification of more than 70% for both urban and rural consumers.

Figure 60: Load forecast, Zambia, 2010-2030 (Source: Kapika and Eberhard, 2013)



If the projected demand materialises, the level of hydro generation is insufficient to meet the demand. It is also noteworthy that the deficit is also expected to be higher given the susceptibility of the hydro based generation system to droughts. Since, the majority of the expansion projects are hydro based, the capital cost, non-modularity of the systems and their susceptibility to droughts makes this target all the more difficult to reach and match up with the soaring demand. A history of droughts in the past is enough evidence that Zambia's energy security will not be guaranteed in the projected target years. For example during a drought that occurred in the period of 1991 and 1992 the gross generation output was decreased by almost 30% (Kapika and Eberhard, 2013). Intermittent droughts also occurred during the first five years of the millennium (Nyambe & Feilberg, 2009 cited in Kapika and Eberhard (2013). The latest was the drought that occurred from 2011 to 2015 which hit the electricity generation by over 40%. If this means anything for Zambia electricity generation, it is the fact that it needs to build resilience through use of energy efficiency (end use demand reduction) and decentralised renewable energy generation systems among other strategies.

Although it cannot be specifically said that rooftop solar PVs decentralised electricity generation from buildings has been recognised to contribute to the transformation of the electricity sector, the efforts observed from the upcoming utility scale solar projects indicate that solar PV electricity generation is favoured and has great potential to enhance energy security. The upcoming utility grid scale solar PV systems are a great precursor to rooftop solar PVs which have shown great potential from the study findings. The integrated resource plan shows that solar PV solutions can contribute 600MW to the current generation capacity. According to interview with a respondent from CEEEZ, the two upcoming solar projects being implemented by the IDC will meet the allocated capacity of 600MW in record time. Therefore the capacity will have to be increased while the grid also has to be upgraded in order to accommodate the upcoming decentralised rooftop solar PV initiatives such as the EIZ case.

A significant finding from this study indicated that firstly, the building energy usage can be optimised by cost efficient energy efficient interventions and also produce electricity via rooftop solar PVs to offset the consumption from ZESCO grid electricity but more so to generate surplus which can be supplied to the grid. Even though the study focussed on a single case study a new commercial building under construction, the findings that the electricity consumption could be reduced by 35% by simply introducing technically and financially viable energy efficient interventions are very positive. In addition the finding that the annual demand of 186,904kWh can be netted out by the rooftop solar PV system and export a further 350,936kWh surplus to the grid (assuming supportive mechanisms are brought to effect) is also very positive.

Given that this case study is indicative of similar electricity consumption patterns in Zambia, and similar potential for electricity generation, the results in this study can be transferable to similar buildings under similar contexts. The domestic segment accounts for the second largest consumption of electricity with mining as the largest one. Although the specific statistics for commercial buildings are not available, it can be assumed that their consumption falls within the range of the residential category. However, even greater consideration should be made for the increased deployment of these systems in the residential sub-sector which is expected to have much greater building stock. The overall findings of this report and the building case study specifically, reveal that this technology presents a great opportunity to reduce electricity consumption in buildings, enhance self-sufficiency, hedge against the grids' unreliability and power cuts, improve resilience and enhance Zambia's electricity generation goals. The co-benefits relating to revenue have been demonstrated in the business case scenarios.

6.5 Significance to Zambia's GHG emission reduction

Apart from the contribution to the enhancement of the energy security and other economic and social benefits of decentralised electricity generation from rooftop solar PVs, this section discusses the contribution of the related interventions to Zambia's greenhouse gas reduction in response to climate change mitigation. Generally Zambia is classified as a non –Annex 1 country to the UNFCCC. This implies that it is not particularly subject to the binding GHG emission reduction requirements under the COP 21 agreement. This is partly due to the low contribution of the energy sector to the GHG emission. Compared to countries like South Africa whose electricity is 70% coal based, Zambia's low GHG emissions are primarily due to the fact that over 70% of the electricity is hydro based renewable generation. Although the country is not bound to this compulsory mandate, it nonetheless has its own responsibility to reduce it GHG emission especially given the country's vulnerability to the impacts of climate change with hydro-electricity as one of the most significant casualties. Therefore despite the low contribution on average, the country needs to identify the mitigation and adaptation strategies as well as track the technologies, skills and equipment to strategically mitigate GHG emissions and reduce vulnerability of all social and economic actors to the impacts of climate change (CEEEZ, 2013). Equally, Zambia's green image should be preserved, and in view of green credits, the country must aspire to maintain its prevailing low GHG emission record as it achieves improved human-development gains.

Zambia's formulation of policies on climate change, and human development, and the works of various actors on the ground, depict a committed, progressive approach towards tackling climate change at local, regional and international level. Some of the policies include the general policy on environment whose main objective is to minimize the impacts of climate change by reducing air pollution and GHG emissions (NEP, 2007 in CEEEZ, 2013). In addition, during the preparation of the Sixth National Development Plan (SNDP 2011-2025), the government identified climate change as an important influencing factor. In both policy documents, one of the strategies relevant to the attainment of these targets to cut across economic, service and social sectors was the development and promotion of renewable energy in place of fossil fuel and wood-fuel based energy.

More specifically, a mitigation analysis undertaken during the preparation of the Second National Communication (SNC) identified energy, agriculture, land-use change and forestry, and waste as the key priority sectors for strategic reduction of GHG and climate change mitigation. Statistics from the technology needs assessment report compiled in 2013 indicated that the largest contribution of indirect greenhouse gas emissions of CO_2 came from agriculture, followed by land use change and forestry and then energy (CEEEZ, 2013).
Under the IPCC inventory guidelines, CO_2 emissions are counted under land use and forestry and the household sector accounts for the greatest contribution to emissions because of combustion of firewood and charcoal. With this consideration the overall greenhouse gas emissions are projected to increase from 2.8 million tonnes in 2000 to 8.1 million tonnes equivalent in 2030 with the largest contributor being the household sector (CEEEZ, 2013).
The scale up contribution of this case study to the reduction of GHG emissions was discussed in terms of its ability to reduce the electricity intensity and displace the need for a fuel based generator. The brief obtained from the EIZ proposed a stand-by generator set. Although this one is stand-by, to compensate for low solar PV production power interruptions, many commercial buildings and residential households use fossil fuel generators to supply electricity as an alternative to solar PV. An interview with the financial institution reviewed that they had been giving out loans for diesel generators before they introduced solar PV financing. Against this back drop, the findings from the case study that over 76,000kg of CO2 emissions can be offset by reducing the demand and netting the electricity which would have been supplied by the fossil fuel generator is positive for GHG emission reduction. The correlation between generation from

solar PV electricity and the CO_2 reduction shows that these results can be transferred to similar building types in the same context.

6.6 Consolidation of finding and overall conclusion

The question that this study set out to answer was: what is the potential of rooftop solar photovoltaic (PV) in grid interactive distributed generation as an intervention towards enhanced energy security and climate change mitigation for Zambia, and what would be the responsive business model as well as policy and regulatory support mechanisms? Through simulation, the study determined the potential of the EIZ building to generate electricity from rooftop solar PVs. Thereafter the study provided an analysis of the existing policy, regulatory and market environment around decentralized solar PV electricity generation including frameworks on grid interaction. This was based on the interviews conducted with various stakeholders in the solar PV industry in Zambia.

The study went ahead to make a business case for the prioritized energy efficiency interventions that were applied to the case study building namely: changing of glazing type, introduction of sunshades and roof insulation, and introduction of lighting controls. Another business case was done for the solar PV system considering three scenarios. In the first scenario, it was assumed that the solar PV system only netted out the optimized electricity demand of the building without exporting the excess. In the second scenario, it was assumed that the solar PV system generated enough electricity to net out the building demand and then exports the surplus generated on sunny non-business days to the grid with payment from the utility company at a feed in rate. The last scenario assumed that the system produced excess electricity from the full extent of the roof to export to the grid at a feed-in tariff rate.

A business model was then conceptualized that would best address the gaps in the existing solar PV policy, regulatory and market framework in Zambia and increase the deployment of such technologies to required levels. This was also conceptualized based on the assumption that some prerequisite policy is quickly implemented. A SWOT analysis of certain models based on the three structures of ownership, control and financing preceded the synthesis of the appropriate business model. The significance of the findings relating to building energy efficiency and electricity generation from rooftop solar PVs regarding enhancing Zambia's electricity generation goals and greenhouse gas reduction were highlighted in Section 6.5 above.

Based on the simulation undertaken in Chapter 4, the estimated entire roof total rooftop solar PV power output was 249kW which translates to a net annual electricity generation of 537,840 kWh. On the other hand, the simulated annual baseline electricity consumption of the building was found to be 287,707kWh. From this finding, it was certain that the roof space was not a constraining factor given a surplus of 87%. Considering that the study sought to find out the opportunities for building energy efficiency intervention to optimise the baseline consumption, three technically viable options were selected. The first option was the replacement of the default glazing in selected potions of the building with double glazing (6 mm thick double pane, with 13mm air-Dbl LoE-e2=1 clear 6mm) which yielded a reduction in the baseline annual electricity consumption to 249,916kWh representing a 13% reduction. In the second option, sunshades in vulnerable window sections and roof insulation were introduced which yielded a reduction in the baseline annual electricity consumption to 235,564kWh representing an 18% reduction. The third option involved the introduction of lighting controls in selected zones of the building which yielded a reduction in the baseline annual electricity consumption to 239,001kWh representing a 17% reduction. Through this analysis the sub-questions relating to the determination of the baseline consumption and opportunities for energy efficiency as well as the question on comparison of the baseline and optimised consumption were addressed. By optimising the baseline consumption through viable interventions and simulating for the capacity of "full roof" electricity generation, the sub-question relating to the opportunity for surplus generation was addressed as shown by the percentage reductions above.

A business case analysis revealed that a combination of two interventions (sunshades and roof and lighting controls) was the most financially viable option with a payback period of nine years, a ROI of 518% over the 25 year period (21%/year), and a positive NPV of 623,344.00ZMK. After adopting this combined intervention, a new simulation revealed a reduction in the baseline annual electricity consumption to 186,904kWh representing a 35% overall reduction. This responded to the question on the comparison of the baseline consumption and the optimized consumption. Following this, a separate business case for the solar PV system which assumed a net zero scenario, only without export of surplus demonstrated a payback period of 11.6 years, a ROI of 243% over the 25 year period (9.72%/year), and a positive NPV of 385,309.00ZMK. Comparing this saving from having to pay the bill to the utility indicated that this option is financially viable. Two other scenarios, one assuming export of surplus to the grid as a result of generation on sunny days when the building was not in use and a scenario where the full roof generated excess for sale to the grid at 0.78ZMK rate were analyzed. The findings revealed that the second scenario had a payback period of 8.5 years, a ROI of 39%(15.63%/year) and a positive NPV of 1,204640.00ZMK while the third scenario had a payback period of 8.5%, a ROI of 290% (11.6%/year) and a positive NPV of 1,314841.00ZMK. Therefore, assuming the existence of grid interactive mechanisms and off taking of electricity generated from the system by ZESCO, Scenario 2 was deemed as the better option than Scenario 3. This was so because for a lower cost of investment for Scenario 2, it yielded the same payback period as scenario 3, had higher return on investment, while the difference in the net present value was relatively marginal (110,201ZMK).

In relation to the sub-question on what would be the responsive business model required to scale-up such opportunities, the findings revealed that the IESCo model was the ideal responsive business model to catalyze the increased deployment of decentralized rooftop solar PV systems building on some of the support policy and regulatory structures. However, to make this a reality, considerable transformation of the industry market need to be considered. The findings from Chapter 5 about the general environment in Zambia revealed that progressive policies and support mechanism are coming up. To address the question on what would be the supportive policy frameworks for grid-interactive distributed generation some recommendations on expediting policy have been given based on the gaps identified in Chapter 5. For example, for the identified responsive model to flourish, commercial banks must be encouraged to lend out money to IESCos who are better placed to offer guaranteed schemes that share the risk of default. Through the formulation of IESCo facilitating or agencies and associations, guaranteed funds could be given. Furthermore, the government must address quality concerns through involving policy makers, industry associations, current retailers and manufacturers in the establishment of a rating system for inverters, modules and installations in order to build more trust in the infant solar PV market in the country.

In as much as there is a need to migrate to cost reflective tariffs to guarantee good business, this in itself, is not a panacea towards the increased uptake of rooftop solar PV systems. This notion is disproved by the Tanzanian example, where tariffs are high but new private investment in rooftop solar PV still remains difficult to attract (Kapika and Eberhard, 2013). Instead, tariffs must be seen in the context of a package of regulatory measures.

The Zambian electricity sector is in an exciting phase of its historical and future development where the private sector has an increasingly important role to play in the exploitation of renewable energy and solar PV in particular, and Zambian government has already put in place a range of progressive economic incentives to encourage investment. These include fiscal incentives (tax incentives that include income tax, value-added tax, and customs duty incentives) as well as non-fiscal incentives. With all the challenges of centralised electricity generation systems, high solar irradiation, given the viable business cases and models as highlighted in the study findings, entrepreneurs who act quickly (especially before more restrictive policies are implemented) can expect to lead this industry with significant returns. In particular the growth of the building industry and other large commercial buildings present a significant opportunity for investments in decentralised rooftop solar PV systems.

While few projects in decentralised roof top solar PV generation have to date been successfully developed, financed and constructed, projects such as the EIZ case and those at utility scale (100MW scaling solar project) and mini-grid systems in rural areas run by ESCOs are enough reason to be optimistic that this industry will leapfrog into a stable contributor to the energy needs of Zambia.

6.7 Recommendations and further investigation

Policy is one of the areas that need to be considered for both future research and improvement. With a wide range of policy instruments emerging in Zambia (given the increased interest in solar PV technologies), it is difficult to analyse all of them in this report. The opportunities for decentralised electricity generation from rooftop solar PVs must be looked at in view of interface with the grid. Therefore the implementation of the feed-in mechanisms and related policy must be accelerated. Another recommendation is that, as opposed to short-term and broad scale policies on renewable energy, government and stakeholders in the energy sector must aim at targeting long-term technologies with specific, achievable applications. For instance the upcoming policy on solar PV integration should include small building-scale electricity generation from rooftop solar PVs and not only focus on utility-scale generation. To this end, there should be a clear consideration of all categories of technology and scale of generation including decentralised generation for self-consumption, off-grid technologies, and mini-grids, grid interactive and net metered systems. These should be carefully assessed for their contribution and impact on the grid and electricity generation targets. Another policy recommendation relates to incentives. Even though Zambia has put in place some incentives as highlighted in Chapter 5 of the report, care should be taken that these incentives should be effective, cost-efficient, transitional, reducing over time and must target the most needed actors. They must also be tractable and foster innovation and technology improvement in the market.

Considering the maturation of the rooftop solar PV into the mainstream technologies in Zambia, ZESCO as the grid operator, together with the other regulatory bodies must look ahead and expedite the mechanisms for grid integration, storage mechanisms, net metering and develop new technologies to integrate varying amounts of electricity into a flexible, efficient and smart grid. Coupled to this, there is need for increased research and development into solar PV technologies in order to match the rapid growing demand in the world. Research institutions must incorporate this in their curricula beyond what is currently being offered at tertiary institutions like the University of Zambia. Identifying development/training needs for crucial areas like system installations and grid connection need to be effected while the government must allocate funding for such research to achieve critical longer-term technology breakthroughs. Trade schools must be particularly active in training technicians in this field. In addition, to avoid duplication, there is a need to encourage international collaboration and joint ventures between local and foreign research projects and firms for capacity building and financing. Multilateral and bilateral donor agencies and green organisations should extend financing to such private decentralised technologies in terms of green financing for low carbon and economic development as an appropriate financing scheme. If carbon credits can be expedited and monetized, these can generate an additional revenue stream and make investment viable and become a business model in their own capacity.

Another recommendation is that NGOs and ZESCO could monitor progress and policy milestones and statistics of net zero buildings and publish results to keep government and industry on tack. Policy should also define contract templates and standard terms for the power purchasers and the sales models, open up the market and set up agencies for solar PV companies to initiate contact with target clients and industry associations.

Lessons for Architects and the building industry

There is a need to entrench energy efficiency and net zero building design in Zambia and particularly among Architects. From the study, it was demonstrated that not only is a net-zero building viable in commercial buildings and residential sector as well but adds unique value to them. However, it is difficult to develop these net zero buildings with the current gaps in the building industry and the conventional delivery processes. There is a need for architects to assume a leadership role in order to transform the building industry as professionals with a unique role in making net zero energy buildings a reality. As a profession, architects in Zambia must make some changes, taking ownership of the problems associated with energy design inherent in building projects, rather than relating them to the engineers and energy modellers and the clients. As designers, they have a major role to play in advising clients. The building industry, through the upcoming Green Building Council of Zambia should expedite the development and strengthening of building codes, provision of guidelines to encourage designers and builders as well as building owners to select net-zero energy technologies and to operate and maintain them properly. The Green Building Council should step up as a certification body and with support from allied building and energy stakeholders must develop not only voluntary but mandatory standards for energy efficiency design and environmental performance ratings as obligations are stronger instruments to overcome the barriers of low priority energy issues. The removal of the use of incandescent bulbs is just one aspect. In addition, they should provide building certification and develop the desired skills as in the case of South Africa.

Based on the analysis that this report investigated, several questions arose and topics for further research on decentralised electricity generation and role of policy and business models were identified. There is need for further research on market segments, technical aspects of integrating into the grid, economics and incentives, green building certification schemes, the role of energy suppliers, green trading, value of energy certified buildings to non-certified buildings, innovative financing schemes and how the financial institutions can be better involved.
There is a need for synergies and partnerships between market actors with complementary expertise and resources. Bringing together key actors in the sector including ZESCO, commercial banks, suppliers, building owners and occupiers will assist in scaling up such technologies as presented in this study.

References

Abd El-Basit, W., Abdel-Maksooud, A.M., and Soliman, F.A.S. (2015). New investigation on the applications and computer simulation of photovoltaic cells and storage systems, *International journal of engineering sciences & research technology*, 4(10), 2277-9655.

Autodesk sustainability workshop. (2015). Equipment and lighting loads. INTERNET: https://sustainabilityworksop.autodesk.com/buildings/equipment-and-lighting loads. Accessed: 27th November 2016.

Attia, S., Gratia, E., De Herde, A. and Hensen, J.L. (2012). Simulation-based decision support tool for early stages of zero-energy building design. *Energy and buildings*, 49:.2-15.

Avastthi, J. (2014). Energy modelling inputs and engineering assumptions-energy efficiency analysis and building design. INTERNET: https//greenmodelling.Com/sustainability guide. Accessed: 10th December 2016.

Centre for Energy, Environment and Engineering Zambia (CEEEZ). (2013). Technology needs assessment and technology action plans for climate change mitigation-part IV: Project ideas. INTERNET: https//unfcc.int/ttclear/misc_/staticfiles/gnwoerk_static/TNR_CRE/e9067c. Accessed: 23rd February 2017.

CIA World Factbook. (2017). INTERNET: https://www.cia.gov/library/publications/the-world-factbook/geo/za. Accessed: 10th December 2016.

Clean Energy Council. (2014). Guide to installing solar PV for business and industry. Clean Energy Australia report 2014.

Climatetemps.com. (2016). INTERNET: http://www.Lusaka.climatemps.com/.Accessed 21 December 2016.

Cooke, P. (2016). Shopping clean – Retailers and renewable energy, Greenspace, South Africa.

Crawley, D. (2009). Getting to net zero, *ASHRAE Journal*, 18-25.

Creswell. J. (2009). *Research design: Qualitative, Quantitative, and Mixed methods Approaches*. Third Edition, SAGE publications, Thousand Oaks, California.

Dali. M., Belhadj, J., Roboam, X. (2010). Hybrid solar-wind system with battery storage operating in grid connected and stand-alone mode control and energy management-Experimental investigation. *Energy* (35) 2587-2595.

Dike, V.N., Chineke, T.C., Nwofor, O.K. and Okoro, U.K., (2012). Optimal angles for harvesting solar electricity in some African cities. *Renewable energy*, 39(1), pp.433-439.

Energy Research Centre. (2012). Personal carbon footprint calculator for developing countries. UCT. Capetown.

ERB-Z. (2012). Invitation to submit/comment on ZESCO's application to revise electricity tariffs for the financial year 2012/2013. Energy Regulation Board of Zambia. Lusaka.

ERB-Z. (2015). Overview of the energy sector in Zambia: Case of renewable energy. Presentation to the promoters of renewable energy technologies. Energy Regulation Board of Zambia. Lusaka.

ERB-Z. (2016).Energy Sector Report 2016. Energy Regulation Board: Lusaka, Zambia.

ERB-Z. (2017). Energy Regulation Board announces its decision on ZESCO's tariff application. Press statement. INTERNET: https//:www.erb.org.zm/content.php. Accessed 5th August 2017.

Frantzis, L., Graham, S., Katofsky, R. and Sawyer, H. (2008). Photovoltaics business models. Golden, Colorado: National Renewable Energy Laboratory.

GBCSA. (2013). Green Building Council, INTERNET: https://www.gbcsa.org.za/.Accessed 8th December 2016.

Global Environment Facility (GEF). (2013). Renewable energy based electricity generation for isolated mini-grids. Project document. Zambia.

Harford, J., R., J. (1998). BP solar and photovoltaic projects - A case study of health centre rehabilitation project in Zambia, *Renewable Energy*, I5, 491-495.

Hootman, T., 2013. *Net zero energy design: A guide for commercial architecture*. John Wileys and Sons, Inc. USA.

Hou, X., (2014). Comperative analysis of solar PV business models. Unpublished master's thesis in Environmental Energy Technology. Faculty of Technology. Lappeenranta University of Technology.

Hu, G and Agarwal, R. (2016). Accented Models: Evaluating their effectiveness in building energy simulation. Mechanical Engineering and Materials Science Independent Study. Paper 2.pdf. INTERNET:http://openscholarship.wustl.edu/mems500/2.Accessed 01st December 2016.

Huijben J, C, C., M, Verbong, G, P, J. (2013). Breakthrough with subsidies? PV business model experiments in the Netherland, *Energy policy*, 3(2): 362-370.

Ibarra, D and Reinhart, C. (2009). Building performance simulation for designers-DesignBuilder//EnergyPlus 'Tutorial #1' Getting started. Harvard Graduate School of Design.INTERNET:https://www.mit.edu/tito/www/tutorials/energy/modelling_getting started.pdf.Ibara/-.Accessed 03rd December 2016.

Industrial Development Corporation (IDC). (2016). First 'Scaling Solar' auctions in Zambia yield record low tariffs amid electricity shortages. IDC, Zambia. INTERNET: http//www.idc.co.zm.Accessed: 04th January 2017.

International Renewable Energy Agency (IRENA). (2013). Zambia renewable energy readiness assessment report, IRENA.

International Renewable Energy Agency (IRENA). (2015). renewable energy technologies: cost analysis series, IRENA.

Jelle,P, B & Breivik, C.(2012). State-of-the-art building integrated photovotaics. *Energy procedia*, 20: 68-77.

Kahu, R. (2014). Evaluating Energy Efficiency in the Design of large scale office building in hot –dry climate of Nigeria. Unpublished research report, Msc Environmental design, Department of Architecture, Ahmadu Bello University, Zaria, Nigeria.

Kapambwe,E. (2011). Economic feasibility of photovoltaic/diesel/battery hybrid power system to replace Stand-Alone diesel generators in off-grid remote areas of Zambia. Master of Science thesis. KTH School of Industrial Engineering and Management Energy Technology EGI, Division of Heat and Power Technology, Stockholm.

Kapika, J and Eberhard, A. (2013*). Power-sector reform and regulation in Africa. Lessons from Kenya, Tanzania, Uganda, Zambia, Namibia and Ghana.* HRSC press. Cape Town, South Africa.

Karaekezi, S., Kithyoma, W. 2002. Renewable energy strategies for rural Africa: Is pv–led renewable energy strategy the right approach for providing modern energy to the rural poor of sub Saharan Africa? *Energy policy* 30(11): 1071-1086.

Kempener, R., Komor, P. and Hoke, A., 2013. Smart Grids and Renewables. A Guide for Effective Deployment. International Renewable Energy Agency (IRENA). November. IRENAWorkingPaperINTERNET:http://www.irenaorg/DocumentDownloads/Publications/smart_grids. Pdf .Accessed: 22nd December 2016.

Kollins, K., Speer, B. and Cory, K.S. (2010). Solar PV project financing: Regulatory and legislative challenges for third-party PPA system owners. National Renewable Energy Laboratory.

Landau, R.C. (2015). Optimum tilt of solar panels. INTERNET:http://www.solarpaneltilt.com-Accessed: 20th December 2016.

Lusaka times. (2017). Banks urged to lower interest rates following drastic drop in inflation. *Lusaka times*. INTERNET:https://lusakatimes.com.Accessed: 10th January 2017.

Marko, W.A., 2014. Small-scale, big impact–utilities' new business models for "Energiewende". *Die Unternehmung*, 68(3):201-220.

Martin, J. (2009). Distributed vs. centralized electricity generation: Are we witnessing a change of paradigm? *An introduction to distributed generation*. Research paper submitted to HEC, Paris.

McCrone, A., Usher, E., Moslener, U., dÉstals, F., Usher, E., and Grüning, C. (2016). Global trends in renewable energy investment 2016 (Frankfurt School UNEP Collaborating Centre for Climate & Sustainable Energy Finance).*http://www.fs-unep-centre.org (Frankfurt am Main) 2016*.

McNabb, N. (2013). Strategies to achieve Net-Zero energy homes: A framework for future guidelines, Workshop summary Report. *Special Publication NIST Special Publication, 1140.*

Mfula, C. (2016). Zambia to diversify generation mix as drought hits hydropower, *The Lusaka times.* INTERNET: http://www.luskatimes.com. Accessed on 10th may, 2016.

Mfune, O and Broon, E. (2008). Promoting renewable energy technology for rural development in Africa: Experience of Zambia, *Journal of Human ecology*, 24(3) 175-189.

Ministry of Energy and Water Development. (2008). *National Energy Policy*, Ministry of Energy and Water Development. Lusaka.

Mukabe, Y. (2015). Zambia power tariff must increase drastically to become cost reflective, *Mining review Africa.* INTERNET:http//www.miningreview.com/news/Zambia-.Accessed: 23rd January 2017.

Mulenga, C., L. (2003). Urban slums reports: The case of Lusaka, Zambia. Understanding slums: Case studies for the Global Report on Human Settlements 2003.

Mwila,A.,M. (2015).Renewable Energy Feed-in-Tariff Stakeholder Workshop Objectives, Lusaka, Zambia, September 22, 2015, Energy Regulation Board.

Nikolaidis, Y., Pilavachi, P.A. and Chletsis, A. (2009). Economic evaluation of energy saving measures in a common type of Greek building. *Applied Energy*, 86(12): 2550-2559.

Ong, T. S. and Thum, C. H. (2013). Net present value and payback period for building integrated photovoltaic projects in Malaysia*, International Journal of Academic Research in Business and Social Sciences,* vol. 3(2):153-171.

Orb, A., Eisenhaur, l., Wynaden, D. (2000) Ethics in qualitative research. *Journal of Nursing Scholarship* 33(1): 93-96.

Paradis, R. (2012). Retrofitting existing buildings to improve sustainability and energy performance. *Whole Building Design Guide* (WBDG).

Pepermans, G., Driesen, J., Haeseldinckx, D, Belmans, D'haeseleer, W. (2005). Distributed generation: definition, benefits and issues. *Energy policy*, 33(6): 787-789.

Rallapalli, H., S. (2010). A Comparison of EnergyPlus and eQUEST whole building energy simulation results for a medium sized office building. Unpublished thesis, Master of Science, Arizona State University. USA.

REN. (2015). Renewables 2015 global status report. REN21 Secretariat. Paris. France

Saleh, A., Haruna, Y., Onuigbo, F. (2015). Design and procedure for stand-alone photovoltaic power system for Ozone Monitor Laboratory at Anyigba, North Central Nigeria. *International Journal of Engineering Science and Innovative Technology*, 4(6): 41-52.

Sarantakos, S. (2005). *Social research principles*, Macmillan, London.

Scott, M.J., Wrench, L.E. and Hadley, D.L. (1994). Effects of climate change on commercial building energy demand. *Energy sources*, 16(3): 317-332.

Short, W., Packey, D.J. and Holt, T. (2005). *A manual for the economic evaluation of energy efficiency and renewable energy technologies*. Hawaii: University Press of the Pacific.

Shubha,S., Kori., A.K. (2013). Centralized And Decentralized Distributed Power generation In Today's Scenario. *IOSR Journal of Electrical and Electronics Engineering*.4 (5):40-45.

Sladoje, M. (2016). Lights out: Zambia's electricity crisis. International Growth Centre (IGC). INTERNET:https://www.theigc.org/blog/lights-out-zambia-electricy-crisis./.Accessed: 01st May 2016.

Solar Choice. (2014). Sizing your inverter for optimum system. *Solar choice*. INTERNET:https://solarchoice.net.au/blog/optimizing-solar-panel-system. Accessed: 8th January 2017.

South African National Standard (2011) SANS 10400-XA: 2011. Edition 1.

South African National Standard (2011). SANS 204:2011. Energy efficiency in buildings. Edition 1.

Tanţău, A.D., Nichifor, M.A., Regneala, H. (2014). The current context and future trends of the photovoltaic business models in Central and Eastern Europe: Case study—Romania. *Smart Grid and Renewable Energy*, (5): 43-51.

Tembo, B., Marven, B. (2013). Policy options for the sustainable development of Zambia's electricity sector. *Journal of energy in southern Africa*, 24(2):16-27.

United Nations Environment Programme (UNEP). (2009). Sustainable Buildings & Climate Initiative SBCI. Buildings and climate change: summary for decision-makers.

United Nations Economic Commission for Africa (UNECA). (2014). United Nations Development Account Project. Promoting energy efficiency investments for climate change mitigation and sustainable development. Case study- Morocco, South Africa and Zambia. Policy reforms and regulatory frameworks.

United Nations Environment Program (UNEP), (2016) Environment for development. INTERNET: http//www.unep.org/sbci/aboutsbci.sp. Accessed on 15th Jun, 2016.

United States Foreign Commercial Service and Department of State. (2011). Doing business in Zambia, country commercial guide for U.S. Companies.

USAID Southern Africa Trade Hub/AECOM International Development (a). (2016). Renewable Feed-in Tariff (REFIT) Program- Zambia Renewable Feed-in Tariff Rules. Submitted to: USAID/Southern Africa and Energy Regulation Board of Zambia. Energy regulation board of Zambia. Lusaka.

USAID Southern Africa Trade Hub/AECOM International Development (b). (2016). Zambia Renewable Feed-in Tariff (REFIT) Program- Grid Connection Guidelines. Submitted to: USAID/Southern Africa and Energy Regulation Board of Zambia. Energy regulation board of Zambia. Lusaka.

Utilink (2015) Technical and commercial requirements for solar Photovoltaic power supply system for the proposed EIZ Headquarters

Walimpi, H. (2013). Investment incentives for renewable energy in southern Africa: Case study of Zambia. Policy brief submitted to the International Institute for Sustainable Development (IISD).

Weather spark (2012). INTERNET:https://www.weatherspark/Zambia/-.Accessed 20th December 2016.

World Bank. (2017). World DataBank. INTERNET: https://data.Worldbank.org/country/ Zambia. Accessed: 12th March, 2017.

World Bank. (2015). Zambia - Electricity Access for Low-income Households in Zambia Project.Washington,D.C.

Würtenberger, J.W., Bleyl, M., Menkveld, P., Vethman, X., Tilburg, V. (2012). Business models for renewable energy in the built environment, IEA Implementing Agreement for Renewable Energy Technology Deployment (IEA-RETD). Energy research centre of the Netherlands.

Yin, R. (1994). *Case study research design and methods*. 2nd Ed. SAGE, Thousand oaks.

Zambia Development Agency. (2014). Energy sector profile. Lusaka.

Appendices

Appendix A-Ethics clearance certificate

SCHOOL OF ARCHITECTURE AND PLANNING
HUMAN RESERCH ETHICS COMMITTEE

SCHOOL OF ARCHITECTURE & PLANNING

CLEARANCE CERTIFICATE
PROTOCOL NUMBER: SOAP55/24/06/2016

PROJECT TITLE:	Decentralised electricity generation through building integrated solar photovotaics (PV) in Zambia - A case study of the Engineering Institute of Zambia (EIZ) office building project, Lusaka
INVESTIGATOR/S:	Joseph Samunete (Student No. 1537615)
SCHOOL:	Architecture and Planning
DEGREE PROGRAMME:	MArch in Sustainable and Energy Efficient Cities (March SEEC)
DATE CONSIDERED:	19 September 2016
DECISION OF THE COMMITTEE:	APPROVED
EXPIRY DATE:	19 September 2017

CHAIRPERSON ______________________
(Professor Daniel Irurah)

DATE: 16 · 09 · 2016

cc: Supervisor/s: Gerald Chungu

DECLARATION OF INVESTIGATORS

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to endure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee.

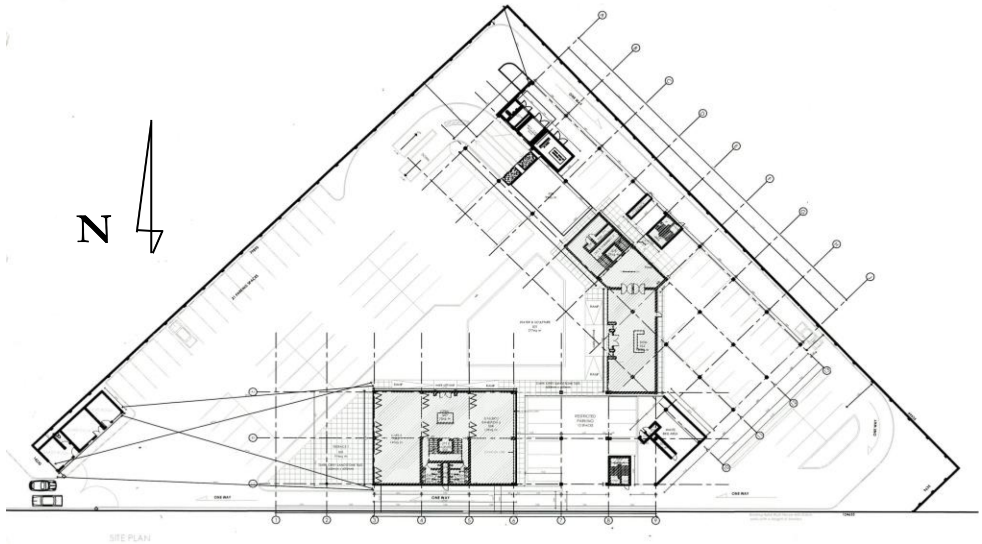
Signature ______________________ **Date** 17/10/16

School of Architecture & Planning
University of the Witwatersrand
Private Bag 3 Wits 2050
Johannesburg South Africa
www.wits.ac.za

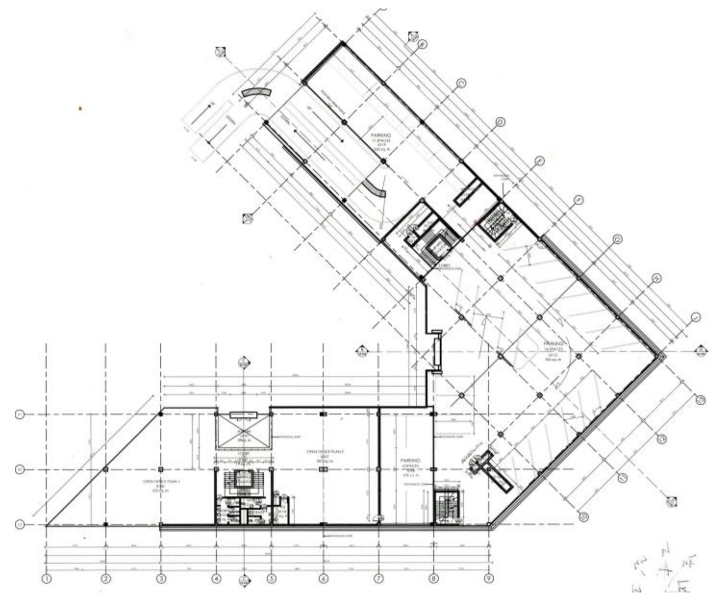
T + 27 11 717 7623
F + 27 11 717 7649

Appendix B –EIZ building drawings.

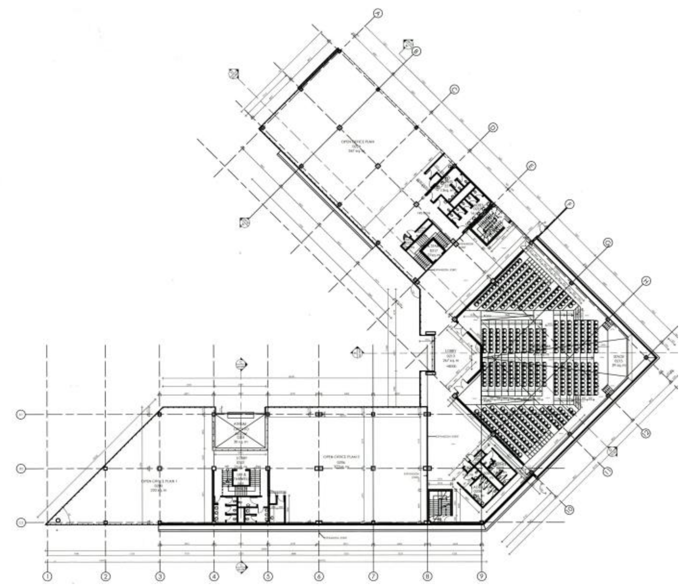
Site and ground floor plan and site (Source: A+ urban technics)



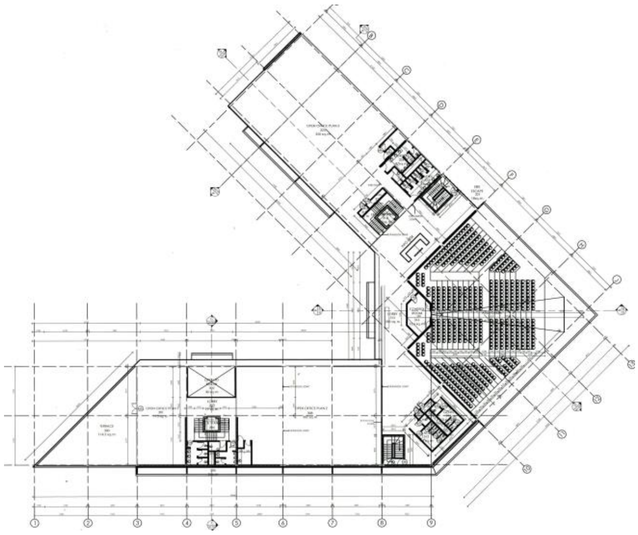
First floor plan (Source: A+ urban technics)



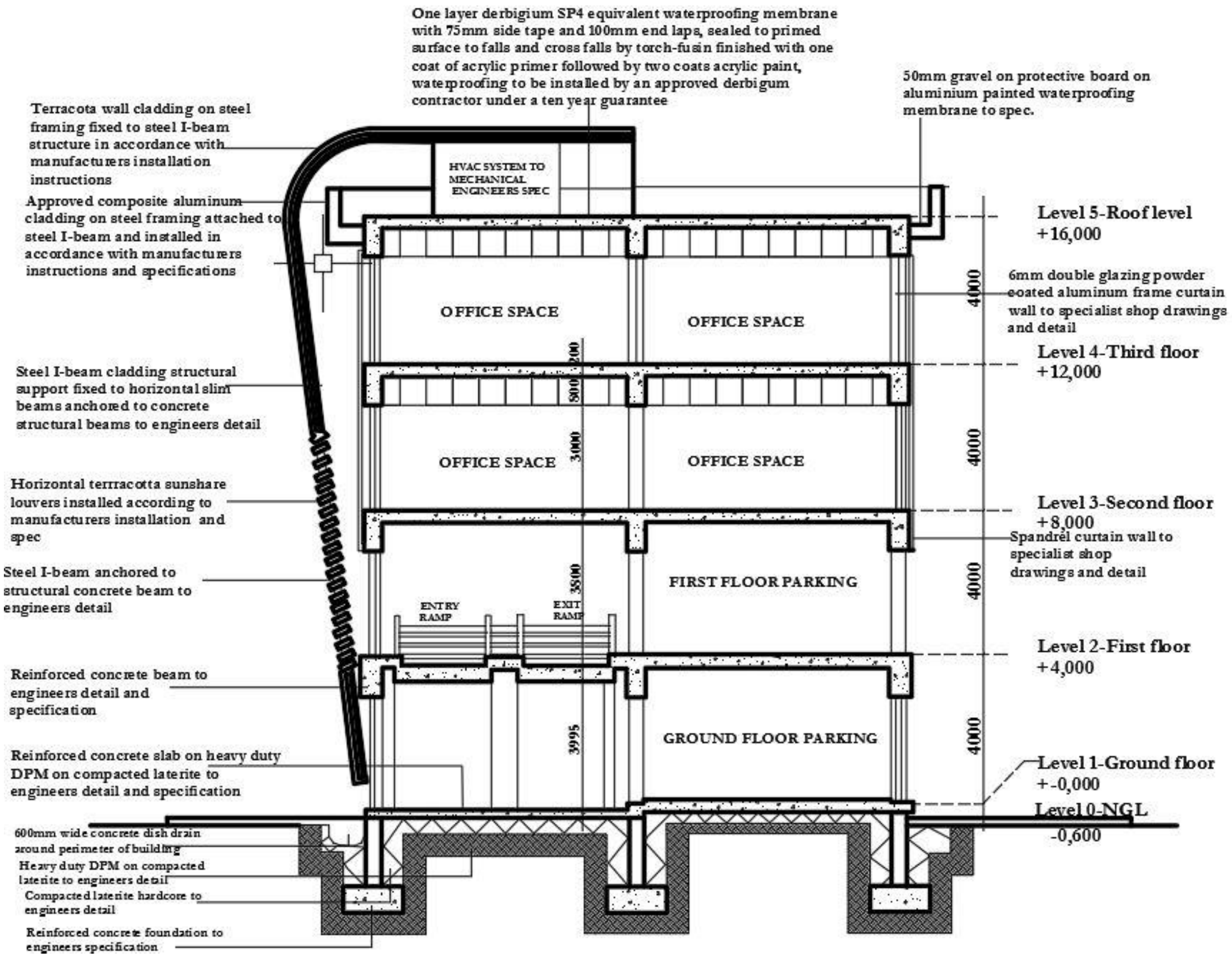
Second floor plan (Source: A+ urban technics)



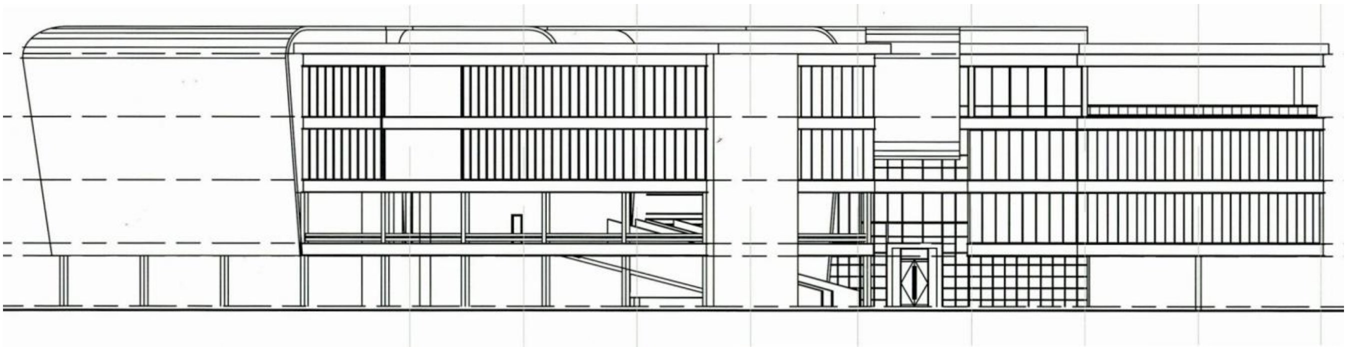
Third floor plan (Source: A+ urban technics)



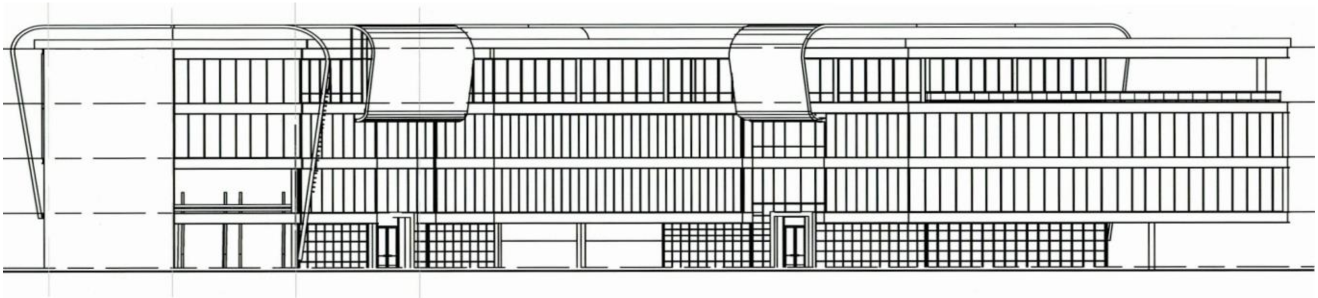
Section through eastern wing showing heights, envelope materials and glazing to opaque surface relationship (Source: A+ urban technics)



Northern elevation (Source: A+ urban technics)



North-western elevation (Source: A+ urban technics)



Western elevation (Source: A+ urban technics)

Southern elevation (Source: A+ urban technics)

Appendix C- Interview questions

National energy expert at CEEEZ and the Department of Energy-Ministry of Mines, Energy and Water Development

1. What are your perceptions about the economic feasibility and private investment outlook including the life-cycle benefit and potential of building efficiency and self- generation of electricity from rooftop solar PVs for urban residential and commercial buildings? Has this potential been exploited?
2. How is the current structure of the energy sector; policy and regulatory support mechanisms that govern decentralised electricity generation from rooftop solar PVs including measures of tax, other political, social, economic factors and their impacts? Is the environment supportive? Are there any deliberate policies for decentralised solar PV systems? Is the country ready given the growing interest in renewable energy?
3. Despite the crisis, growing interest in solar electricity generation, fall in prices of solar PV systems globally, why is there a seemingly lack of diffusion of solar PV systems among different consumer segments (slow market penetration). Why would one maintain a status quo or buy a generator over a solar PV system?
4. What are some of the investment hurdles in solar PV electricity generation and related PV products in Zambia?
5. What are some of the existing sources of funding/financing for solar PV based investments in Zambia?
6. How do you describe the current market environment in Zambia for distributed PV electricity generation from solar PVs?
7. What are the existing market segments and business models for solar PV based investments in Zambia?
8. Can you explain to me the current solar PV supply chain?
9. What are Zambia's carbon goals and how can decentralised electricity generation from buildings via rooftop solar PVs mitigate climate change? How can the positive contribution be measured?
10. To what extent has the building industry and policy makers in Zambia embraced net zero energy building concept as a key strategy for meeting carbon goals as well as archiving energy security?
11. With regards to Solar PV investment, what would you like to recommend for the purpose of this research and the future?

Expert from the Zambia Electricity Supply Corporation (ZESCO)

1. What are your guidelines and policies regarding grid-interactive solar PV electricity generation by private producers, in relation to net metering, interconnection standards and purchase of the electricity generated from buildings?
2. What pricing mechanisms are in place for private solar PV electricity producers and what opportunities exist for feed-in tariffs?
3. To what level can solar PV electricity generation from building rooftops reduce the demand for conventional power in Zambia?
4. What is the severity of the electricity crisis and what are ZESCO plans for renewable/solar PV decentralised electricity generation.

Solar PV experts (Solar PV companies, manufacturers, distributors)

1. What are the different types of solar PV systems trending the market in respect to their capacities, cost, lifespan, maintenance and so on?
2. What is your reliability analysis of solar PV electricity compared to conventional supply, and what have been your experience with customers in respect to satisfaction with your services?
3. Do you undertake energy model and optimise for energy efficiency before recommending the system?
4. What possibilities exist for the manufacturing and assembling of solar PV components locally?
5. What are the available payment terms used by different segments of customers of solar PV systems and products?
6. What market distribution channels are available in the solar PV market to reach the different customer segments?
7. Who are the main customers of the solar PV systems?
8. How price sensitive are customers of solar PV systems?
9. Can you please describe the level of competition existing among solar PV companies?
10. Is the policy and regulatory environment favourable for business?

Informant from a financial institution and Keeper Zambia

1. What specific financial and fiscal measures are in place to support investment in solar PV, and what are the terms and conditions associated?

2. What are the procedures to be followed when considering financing for investment in solar PV electricity generation?
3. What are some of the risks associated with investment in solar PV electricity generation?
4. Can you highlight examples of successful business investments in solar PV electricity projects that you have financed and what you experienced has been?
5. What is the market share of solar PV investments and what entrepreneur opportunities exist?
6. What are some of the partnerships between different players like buildings trade, developers, suppliers and distributers can be formed to provide best solar energy investments in Zambia?

Expert from the upcoming Zambian green building council

1. To what extent has the Zambian construction industry embraced green building and design, and how would you compare this with other countries like South Africa.
2. What is the mandate of the Zambian green building council?
3. Do you have any ratings and incentives for green construction and energy efficiency in buildings?
4. To what extent are buildings in Zambia energy efficient and how can they be improved?
5. Are there any guidelines for Net-zero energy buildings?
6. What are your thoughts about the future of Zambian buildings in regard to electricity generation via rooftop PVs?
7. In your view what kind of business models could work to scale up investments in rooftop solar PV electricity generation with regard to policy, financing etc?

Architect and Project Manager for the Engineering Institute of Zambia Headquarters (EIZ-HQ) building project

1. What procedures have you had to go through to gain approval for a building of this sort to undertake an energy project?
2. What energy efficient design features have been incorporated in the design?
3. What opportunities are there to replace elements in the building envelope to enhance energy efficiency?
4. How does the design address the forecast whole building and end-use electricity consumption (E.g. - Lighting, HVAC, IT services, elevators, water heating, etc)?