KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA

Development of A Building Energy Efficiency Assessment Tool for Office Buildings in Ghana

by

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in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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DECLARATION

I hereby declare that this thesis submission is my own work towards the PhD Building Technology and that to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

The built environment is responsible for some of the most serious global and local environmental changes. This is exacerbated by increasing energy demands and decreasing resource availability. Building energy remains a critical criterion amongst both developed and developing nations and its availability cannot be overemphasized. In Ghana, more focus has been placed on the supply side, with measures taken to overcome the current supply deficit. In spite of the importance of improving the supply side, the demand side cannot also be overlooked. Interestingly, studies show that electricity demand is fast increasing, hence a need to relook at the strategy to curb this growing problem. In this thesis, the focus has been placed on demand side management. The thesis sought to answer one key question: how can one determine whether a building is energy efficient or not? A basic question, yet a critical starting point for energy efficiency studies in Ghana. Consequently, the overarching aim of the study was the development of a building energy assessment tool to be used in determining the energy efficiency of office buildings in Ghana. To achieve this aim, four main research objectives were formulated and a mixed methodology approach adopted. A combination of four different methods were used in this research: review of pertinent literature, Delphi survey, Delphic Hierarchy Process (DHP) and Simulation study. The first objective sought to examine methods used in building energy performance assessment towards the development of a conceptual framework. From the review of literature a conceptual framework was developed. The second objective sought to identify applicable criteria to form the dimensions of the building energy assessment method. A Delphi survey was conducted in two successive rounds following the literature review. Expert opinion from fields of academia, industry and government were assessed and consensus established showed that the international assessment methods are not fully applicable to the Ghanaian built environment. Five main blocks were established: the energy performance indices; calculation of energy performance; assessment of energy performance; setting of energy efficiency limit and energy performance labelling. Following this, the Delphic hierarchy process was used in achieving the third objective. This involved, the development of a customised weighting system for the Ghanaian environment. The resultant weighting system had building design having the highest weight followed by energy efficiency of building facilities. Use of renewable energy had the lowest weight. The findings reflect the current development of building energy data studies. It was noted that despite the huge role that renewable energy can play in reducing energy efficiency, current economic issues present an impediment to its investment and subsequent development. To achieve objective four, a simulation study was undertaken to test and validate the developed weighting

systems and further propose a grading system. Building energy data studies provided the required framework to properly develop the tool. It is important to state that the outstanding contribution of the study lies in the final tool developed for determining the energy efficiency of office buildings at the design stage. The development of a building energy assessment tool amongst many would contribute to energy security and economic stability. Such a tool can be adopted by energy planners, policy developers, building scientists, facility managers and designers in the planning, design and implementation of energy efficient building. Almost all well-known building assessment methods are updated and revised either annually or biannually. Therefore, it is recommended that the tool be subject to regular review which will inform required development and updating. Further developments should incorporate the developments of guidelines needed whilst using the tool. It is recommended that future studies explore building optimisation studies. This is necessitated by the dearth of study in this field in Ghana and a need for more direction to undergird the full utilisation of the developed tool. Also the interplay between cost and building energy efficiency is worthy of investigation in further research.

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LIST OF EQUATIONS

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LIST OF ABBREVIATIONS

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

AR - Asset Rating

ANP - Analytic Network Process

bEQ - Building Energy Quotient

BLAST - Building Loads Analysis and System Thermodynamics

BREEAM - British Research Establishment Environmental Assessment Method

BMS - Building Management System

BEEA - Building Energy Efficiency Assessment

BEE - Building Environmental Efficiency

CR - Consistency Ratio

CASBEE - Comprehensive Assessment System for Building Environmental Efficiency

CO2 - Carbon dioxide

DHP - Delphic Hierarchy Process

DOE - Department of Energy (US)

ELO - Energy Management of Large Buildings

EM - Energy Labelling of Small Buildings

EPBD - Energy Performance of Buildings Directive

EPC - Energy Performance Certificate

EAM	- Environmental Assessment Method
EPI	- Energy Performance Indicators
EUI	- Energy Use Intensity
EU	- European Union
GA	- Genetic Algorithms
GBTool	- Green Building Tool
GHG	- Greenhouse Gas
HVAC	- Heating Ventilation Air Conditioning
HK-BEAM	- Building Environmental Assessment Method in Hong Kong
IEA	- International Energy Agency
iiSBE	- International Initiative for a Sustainable Built Environment
IQD	- Interquartile Deviation
IQR	- Interquartile Range
LEED	- Leadership in Energy and Environmental Design
LI	- Label Index
MADM	- Multi-Attribute Decision Making
NCM	- National Calculation Method
OECD	- Organisation for Economic Co-operation and Development
PRM	- Performance Rating Method

RT - Ridge Tower

R&D - Research and Development

SAP - Standard Assessment Procedure

SBEM - Simplified Building Energy Model

SBTool - Sustainable Building Tool

TED - The Energy Detective

USGBC - United States Green Building Council

UNEP -

WEEE - Waste Electrical and Electronic Equipment

LIST OF PUBLICATIONS

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DEDICATION

Dedicated with the deepest love and gratitude to my family:

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For their support and love of erudition

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND TO THE RESEARCH

Presently most developing countries are faced with the gnawing need of raising their levels of energy production, whilst at the same time minimising energy related production and high energy costs, in an effort to ensure sustainable development. Top priority in any development must provide for sustainable growth including the increase of energy efficiency and renewable energy and the consequential reduction of energy production and its associated effect (UNHABITAT, 2010).

Energy consumption and economic development are highly related and linked to the expansion and growth level of a country. This association explains the uneven distribution of energy consumption across the globe. More than 50% of the world's main energy is consumed by developed economies (Sagar et al., 2006), but this proportion is likely to change with parts of emerging markets having relatively similar energy consumption patterns to those of developed countries (World Energy Outlook, 2006). Many reasons are put forward for this, notable amongst them is the substitution of traditional energy sources with fossil fuels (Terrapon-Pfaff et al., 2014). It is projected that energy consumption is set to continually increase as a result of growing population in developing countries and economic growth (Ding, 2008; European Union, 2009).

In Ghana, it is projected that consumption of electricity is rising by 10% per annum because of the surging population's requirement for energy (Essah, 2011). Despite this, as at 2011, only about 65% of the growing demand was met by the baseline production (Essah, 2011). The industrial and service sectors enjoy the bulk of the energy distribution, both having a total of 65% with the residential sector having about 30% of the total energy consumed (Essah, 2011).

According to the energy production and regulation bodies in Ghana (Energy Consumption Ghana, 2015), to eliminate the power cut experienced in the country within the past few years, a minimum generation of 16,398-17,350 GWh would be required. This translates into additional capacity requirement of 800 MW. One major challenge and critical developmental goal of most growing economies is the need to increase the energy capacity to meet its rising energy consumption base. A study by Ofosu-Ahenkorah (2007) estimates that by the year 2020, Ghana would require over 7 times the volume of electric power it used in 2007 based on the developmental path of becoming a middle-income country by 2020.

Kinney et al. (2003) reports that the release of greenhouse gas (GHG) emission related to building, rises sharply as a result of increase in urbanization and level of development in a country. As at 2010, Bertoldi et al. (2010) reports that the total number of people residing in urban locations increased by twofold its previous figure between 1970 and 1995. The resultant effect of this quickly expanding urbanization is a total increase in building energy.

In providing solutions to Africa's sustainable development, energy efficiency forms a major integral part. Energy efficiency provides opportunities for major improvement resulting in effective cost measures that possess the ability to contribute immensely to the socio-economic and environmental sustainability (Fall, 2010). In most emerging markets, the building sector is among the sectors increasing most rapidly; offering the biggest and most cost-effective opportunity for energy efficiency. Reports show that the marginal cost of increasing the energy efficiency of a building is at its minimum in the period of construction (Chew and Das, 2008). Consequently, new construction shows enormous occasion for integrating energy efficiency best practice from the onset. On the other hand, retrofit of existing buildings cost more and are even more grim and difficult to carry out. Fall (2010) asserts that more significant energy savings are brought in by key building characteristics such as architectural design, materials, building's locations and surroundings.

International Energy Agency (2006) in its assessment of technology aver that new building has the propensity to be 70% more efficient than already existing ones in most countries. Existing average standards and labour costs which are far lower in developing countries provide for immediate return on investment of energy efficiency than in Organisation for Economic Cooperation and Development (OECD) countries (World Energy Outlook, 2006). Analysis by the World Energy Outlook (2006) indicates that an extra $1 invested in programmes focusing on demand side management of electricity leads to $1.6 being avoided in OECD countries' supply costs and in non-OECD countries over US$3. In places like Africa where there are limitations on electricity generation capacity, improvements on energy efficiency measures will make energy more accessible. This will have the consequential effect of using the same electricity produced to supply more consumers than before and a further increase in energy security. Both scenarios provide faster ability to implement investments in energy security than supply and network options (Kushler, 2005). Due to these evidences, most developed countries are into the adoption and the usage of building energy standards and codes in order to ensure a cutback in energy consumption in buildings, towards the achievement of sustainable use of energy.

Extant literature shows that there are two major categories of building energy standards: prescriptive and performance based (Bagheri et al., 2013; Wang et al., 2012; Haapio and Viitaniemi, 2008). Prescriptive standards look at setting minimum requirements and performance levels such as envelope, equipment's components etc. Whiles performance base focuses on providing innovation by prescribing yearly energy consumption level or energy cost budget (Gann et al., 1998). Most commonly used performance based standards comprise Leadership in Energy and Environmental Design (LEED) - US, Building Research Establishment Environmental Assessment Method (BREEAM) - UK and Green Star-

Australia. Clearly, a robust building energy assessment tool will play a critical role in providing data and examination of the performance of buildings' energy use (Roderick et al., 2009). With the increase in building office construction in Ghana characterized by a general increase in demand for cooling these spaces, ensuring sustainable energy use represents a great challenge.

1.2 PROBLEM STATEMENT

Energy standard is instrumental in enhancing efficient energy design in buildings and overall energy efficient improvements (International Energy Agency, 2006). A report by the United Nations Environment Programme (2009a) shows that in the year 2000, building energy standards have contributed to energy reduction by about 16% in the United States. Estimates from the European Union (EU) also points to a similar effect, showing that new buildings use about 60% less energy as compared to existing buildings (EU, 2009). Considerable effort is made worldwide to achieve sustainable development in the construction industry with the focus on energy reduction both during the construction phase and the management of buildings. Studies show that energy efficiency standards for building exist in most developed countries with an increasing number of developing countries initiating regulations of this sort (United Nations Environment Programme, 2009b; Deringer et al., 2004). Iwaro and Mwasha (2010) unearthed in their study that more than 40% of emerging markets do not have a laid down energy benchmark, 20% have mandatory, 22% have mixed and 16% have proposed. They further showed that Ghana is among the countries lacking an energy standard. Energy efficiency processes are for the purpose of decreasing the quantity of energy consumed, at the same time, sustaining or bettering the quality of services delivered within the building.

An array of effects result from the lack of energy standard including, increased energy use for cooling and water heating; increased usage of electricity for lighting and appliances; higher maintenance requirements; lower quality of comfort and reduced property value. The inability to resolve the ultimate limitations related to demand through the identification of an equilibrium between lessening demand and heightening supply has resulted in power rationing in Ghana coupled with erratic electricity supply (Ackah et al., 2014). As a result, there is a huge demand for diesel or renewable energy-based backup/stand-by power generation from endusers. Growing power and energy requirements in buildings have the consequential effect of increasing capital outlay required, and the running costs of these stand-by systems. The incessant blackouts and lack of reliable energy supply has had a negative effect on the economy resulting in job cuts and lower productivity (Doe and Asamoah, 2014). The lack of a building energy assessment tool remains a critical challenge to energy security in Ghana.

1.3 AIM

The aim of this study is to develop a building energy efficiency assessment (BEEA) tool for assessing the energy efficiency of office buildings in Ghana.

1.4 OBJECTIVES

The following objectives were developed to meet the aim of the study;

1. To assess methods used in building energy efficiency assessment towards the development of a conceptual framework for developing a BEEA tool for Ghana
2. To identify applicable criteria to form the dimensions of the building energy efficiency assessment method
3. To propose a grading system underpinned by determined weighting coefficients for the building energy efficiency assessment method
4. To propose a tool for building energy efficiency assessment in office buildings in Ghana.

1.5 BRIEF METHODOLOGY

The research involved the use of both primary and secondary data. Secondary data collection was done through extensive and critical review of pertinent literature in the subject area. Due to the nature of the research, a mixed methodology approach was adopted. Four main methods were combined and used in this research: review of pertinent literature, Delphi survey, Delphic Hierarchy Process (DHP) and Simulation study. Each method was proposed towards achieving a specific objective in the study.

Primary data collection involved the use of structured questionnaires within two rounds as akin to the Delphi process (Rowe and Wright, 2011; Stitt-Gohdes and Crews, 2004). The literature review provided a profound opportunity for the identification of factors that impact energy consumption. The nature of the study was regarded as multidimensional and involving both sustainable and ecological contexts informed for a consensus based approach. The Delphi survey was used in the study in reaching consensus on the applicable criteria, thereafter a DHP was also adopted and utilized. The DHP aided in the development of an applicable weighting system to be used in the study. After the identification of these factors and their weights being established, a model was developed to predict the energy consumption. A simulation study was used to test and validate the building energy assessment tool. Building Simulation tools are today progressively used for assessment of energy performance of buildings and the thermal comfort of their inhabitants. Over the last two decades, simulation tools have played a pivotal role in the design and engineering of buildings. Building simulation could be used in the life cycle assessment of buildings, including design, construction, operation, maintenance and management (Ryan and Sanguist, 2012; Reddy, 2006).

1.6 SIGNIFICANCE

The research has both a theoretical and practical significance. The research contributes to closing the knowledge gap identified in building energy research by providing identification of key factors that affect the building envelope in relation to building energy. The developed tool would enable the reduction in the degree of energy expended while sustaining or bettering the quality of services delivered in the buildings.

A reduction in energy demand has the consequential effect of lowering energy costs. In view of the several prospects to significantly cutback buildings' energy needs, the possible savings from energy efficiency in the building sector will make momentous contributions to lessening of energy utilization within an entire society. The effect of this possible cutback ought not to be underrated, since the scale of energy efficiency in buildings is sufficiently huge to have an effect on security policy, climate preservation and public health on a nation-wide and worldwide scale.

Moderation of energy-end use in buildings would as well lessen greenhouse gas emissions and pollution generated by the combustion of fossil fuels. In view of the possible scale of energy savings across the building sector, a reduction in the requirement for energy and fossil fuels could significantly make contributions to a country's amenability with national or supranational objectives for the decrease of greenhouse gas emissions.

Particularly in Ghana, a reduction in requirements for energy necessitates lesser power plants, thus setting back or obviating the building of novel generation and grid capacity and facilitating government's ability to dedicate public funds somewhere else. Amongst these possible public advantages of energy efficiency in buildings, employment in the construction sector ought not to be overlooked such as creation of jobs for building energy assessors and low energy building designers. In addition to the above, there is the payback of energy efficient construction lessening fuel deficiency throughout society as they use lesser amount to maintain the required levels of thermal comfort within the indoor space.

Energy efficient buildings also have the advantage of being usually healthier as compared to traditional buildings. Compared to traditional buildings, energy efficient buildings provide an interior climate that is more stable. The development of a building energy assessment tool amongst many would contribute to energy security and economic stability. Such a tool can be adopted by energy planners, policy developers, building scientists and designers in the planning, design and implementation of energy efficient building.

1.7 SCOPE

The study focused on high rise office buildings within the Greater Accra Metropolis. Due to Accra being the capital city and the hub of most business activities, it consequently has a lot of office buildings located therein. The development of the tool is limited to the design stage of the building yet applicable to existing buildings. The scope of building energy assessment is vast and many variables inform the development of the tool. The design stage offers many options for consideration and thus represents a stage where decisions taken can impact the whole life cycle of the building.

1.8 LIMITATION

It was challenging to take account of additional case study buildings in the research due to the limitation of time. A major barrier was getting access to electricity bills; it was a herculean task being able to access utility bills from both the consumers of the electricity and the providers of electricity. This situation was exacerbated by the difficulty in obtaining as-built drawings, monitoring and observing usage of building energy. It should be stated that the decision taken earlier at the start of the study was to focus on office buildings of about three to four storeys high. However, because of the inability of electricity bills to accurately predict the energy consumed in the building, this approach was dropped. After months of trying to circumvent this challenge, a later decision to adopt the current case study was made due to the ease of getting access to data previously difficult to obtain. The case study adopted is a generic high rise building situated in the city of Accra. This came later in the study and as a result, time availability became a constraint and this led to the use of the current case study adopted.

Another limitation of the study is the failure to identify water conservation and efficiency as part of the indicators of building energy efficiency. The approach used in the study to identify the list of building energy efficiency indicators saw the exclusion of water conservation and efficiency. Water conservation and efficiency is a critical component in energy discussions due to the use of auxiliary pumps and the other energy dependent components in most high-rise office buildings in Ghana. The tool however does not capture this component and is recommended that further reviews of the tool should look at incorporating this important variable.

1.9 ORGANISATION

This study is divided into six main chapters following from the introduction to the conclusion. The introductory chapter, Chapter One, presents the backdrop of the study, the statement of problem, aim and objectives. The succeeding chapter gives an assessment of pertinent literature on the concept of energy performance and efficiency of buildings. Various energy performance assessment methods are also examined and presented. In the third chapter, the philosophical dimensions and research approach is explicated. Details on analysis adopted for the study is presented. The following chapter, presents the results from the primary data collection, analysis and the ensuing discussions. Chapter Five provides a validation work on the developed grading system based on a simulation based study. The concluding chapter, Chapter Six, provides a succinct presentation of the objectives and how each has been met. A synthesis of the recommendations and directions for future research is provided in this chapter.

CHAPTER TWO

2.0 LITERATURE REVIEW: BUILDING ENERGY ASSESSMENT METHOD

REVIEW

2.1 INTRODUCTION

The economic growth and development level of a country has strong linkages to its energy consumption due to its demand and uneven distribution across the globe. This chapter aims to orient the study in its appropriate perspective. The study involves a critical review analysis of the state of the art of building energy efficiency assessment procedures. It seeks to find out the current work done on building energy efficiency, challenges faced, solutions proposed and direction for future work. To achieve this, journal articles, conference proceedings, technical manuals and guides, books and a number of relevant literature sources were reviewed.

2.2 ENERGY CONSUMPTION IN GHANA

Ghana's population over the years has been on the increase with strides in economic growth; however, the same cannot be said of the energy situation (Essah, 2011). Statistics show that marginal increase has been seen in energy supply as compared to the burgeoning population growth (Essah, 2011). Currently it is estimated that 55% of Ghana's capacity to generate electricity is presently attributed to hydro-based sources; Akosombo (1,020 MW), Kpong (160 MW) and Bui (400MW) (Energy Commission Ghana, 2015). The remaining percentage of the energy supply is derived from thermal based plants in which the operation is based on using fuel sources such as natural gas and oil and converts energy stored in them into electrical energy (Energy Commission Ghana, 2015). The Navrongo Solar Farm a renewable source provides only 2.5 MW to the total supply (Energy Commission Ghana, 2015). It is reported that the total demand for electricity far exceeds the current available generation capacity. As at the year

2015, the current peak demand was about 2400MW, however only 1600MW of capacity was available at peak and 1400 MW at off-peak leaving a huge deficit of 800MW at peak (Energy Commission Ghana, 2015).

Key in energy supply increase is the addition of thermal sources to the nation-wide capacity to generate electricity. This comes with associated environmental hazards as this is linked with carbon emissions to the atmosphere. The Energy Commission Ghana (2007) has estimated that Ghana would require over 7 times its 2007 electrical power capacity by 2020 if it is to be successful in advancing its economy to a middle-income status.

Rapidly advancing, particularly in developing countries, the building sector provides the biggest, most economical prospects for energy efficiency and also provides the greatest cobenefits. The marginal cost of causing an upsurge in the energy efficiency of a building is minimum in the period of construction. Empirical data points to the fact that particular building elements and the appropriate management and control of such elements provides for considerable savings in energy (Fall, 2010). In a broad sense, building energy can be divided into embodied energy and operation energy. Embodied energy makes reference to the energy used in the manufacturing and conveyance of building supplies in the erection of building, whilst operation energy makes reference to the energy requisite for retaining cozy conditions within buildings, water usage as well as powering. The focus of this study is on the operation energy and the section that follows will centre on this aspect.

2.3 BUILDING ENERGY EFFICIENCY IN GHANA

The practice of energy efficiency within Ghana is not an entirely new concept. Records show that the first noticeable attempts came in 1975 after the first world oil price shock and in 1979 after supply disruptions occurred due to political activities taking place in Ghana then (Energy Commission, 2007). These attempts included policies that allowed consumers to produce more with less energy emphasizing more on industrial electrical energy and fuel. The Energy Commission (2007) provides that the early attempts were discontinued as a result of the normalization of the supply situation. Despite this, initial study results showed a lot of potential for energy saving in Ghana, especially in the industrial sector. Various reasons were advanced for the decline of energy efficiency methods. Notable amongst them were the lack of enforcement; lack of expertise for the failure and non-availability of energy saving technologies on the local market (Energy Commission, 2007).

Individual projects and case studies all confirm the huge potential existing in the demand side management. Some of the case studies include the various survey conducted on institutional buildings in Ghana to identify the level of electrical consumption and end-user patterns. However, this was not a critical issue then, due to low energy prices in the 1990's. This was particularly made evident by the donor agencies when GOG approached them for funding to increase the nation's power generation capacity (Energy Commission, 2007). The donor agencies proposed the option of demand side management rather than concentrating on the supply-side (Energy Commission Ghana, 2007). Focus on demand side management within the Ghanaian environment has pivoted on the appliance efficiency, particularly looking at the practices by Energy Foundation (Essah, 2011). This has resulted in the move to use Compact Fluorescent Lamps (CFL) and replacement of old refrigerators. The introduction of the Energy Efficiency Standards and Labelling Regulations, 2005 (LI1815) requires that a label is displayed which informs on the energy efficiency rating of the product (Energy Commission Ghana, 2016). The label is based on the star labelling principle or the energy star, with a maximum of five stars that can be awarded, thus the more the stars the higher the efficiency (Energy Commission Ghana, 2016). Currently, in Ghana importers and vendors of both air conditioners and CFL have been mandated by the Appliance Standards and Labelling regime to deal in products that meet the performance and efficiency requirements as postulated by the

Ghana Standard boards (Energy Commission Ghana, 2016).

It is also reported that import duties and VAT on Compact Fluorescent Lamps were removed by the Government in April 2003 (Energy Commission Ghana, 2016). This directive was to ensure this popularly known energy saving lamps were more accessible and affordable to the average Ghanaian in a move to ensure energy efficiency and reduce electricity cost. The Energy Foundation, the Energy Commission and the Ghana Standard Board have also introduced a Performance and Efficiency Standard for Compact Fluorescent Lamps in a bid to protect consumers from substandard and fake CFL which have penetrated into the Ghanaian market (Energy Commission Ghana, 2016).

Clearly, results emanating from such activities have had some impact on energy efficiency practices. Unfortunately, studies hardly exist in the assessment of the impact and the growing energy demands show more drive to look at the total energy consumption.

2.4 BUILDING ENERGY PERFORMANCE

This section first explores building energy performance quantification methods and the applications of energy quantification methods. This is necessary to help provide a complete understanding of both theoretical and practical knowledge underpinning the study of building energy efficiency. After this comes the development of the conceptual framework.

2.4.1 Building Energy and Building Performance Tools

A building is seen as a highly complex energy system especially when improving its energy performance. It is argued that taking advantage of energy analysis tools that provides rigorous examination of the operational energy implications of a variety of dissimilar design options should be advanced especially due to the weight attached to the building energy sector (Garcý´, 2006). Internationally, a plethora of building evaluation procedures and building environmental implements are in usage whilst others are being developed. Notable amongst them is the

Leadership in Energy and Environmental Design, LEED (United States Green Building Council, 2000) and the British Research Establishment Environmental Assessment Method (BREEAM). The orientation of these tools and others like these is titled towards the assessment of buildings and its impact from the perspective of their sustainability demands (Alyami et al., 2013). Reports also confirm that energy use reduction only, is not essentially the priority when exploring a sustainable energy building (Birt and Newsham, 2009). This brings to question their ability to provide appropriate assessment of building energy for other countries especially exploring both socio-economic and ecological factors. It therefore becomes imperative to prioritize the sustainable needs of a region when developing a building energy efficiency tool.

2.5 ENERGY PERFORMANCE ASSESSMENT

Energy performance is a phrase used to specify the quantity of energy utilized in actuality or projected to satisfy the differing demands connected to a homogenous usage of the buildings (Poel et al., 2007). This amount is mirrored in one or more numeric indicators referred to as Energy performance indicators (EPI). Most frequently used in many buildings and globally, is energy use intensities, i.e. kWh/m^2. The energy performance of a building is largely decided by six main variables: climate, building envelope, building services and energy systems, building operation and maintenance, occupants' activities and behaviour and indoor environmental quality provided, as placed in IEA Annex 53 project (IEA, 2000).

In the building sector, energy performance evaluation approaches can be placed in a two-fold categorization: performance-based and feature-specific approaches. These two approaches adopt different methods of assessing building energy. The performance based approach looks at comparing performance indicators (e.g. Energy Use Intensities or carbon dioxide emission) against yardsticks to inform on energy efficiency level. With the feature specific approach, examination is done to check whether certain specific features are met for credits to be awarded. The energy efficiency level is then determined by the total awarded credits (Lee and Burnett, 2008). These two have their advantages and their disadvantages. Wang et al. (2012) argues that the performance based approach is preferable as computations are easily quantifiable based on performance indicators. However, they aver that such an approach is cumbersome to develop as it includes firstly, the establishing of a suitable method of quantification and its associated criteria.

2.5.1 Objectives of Energy Performance Assessment

Different terms are provided to explain the objectives of energy performance assessment. Two major terms are employed in practices: performance diagnosis and energy classification. Energy classification seeks to provide information on the energy performance level, i.e., mostly efficiency level and carbon emission to building stakeholders including the users of building, owners and general public. Energy performance diagnosis goal is to determine the existence of faults and further find the cause of such faults and/or low related programmes in buildings (Haapio and Viitaniemi, 2008).

Wang et al. (2012) noted that energy categorization is a data supplying mechanism that furnishes building owners or the public with information pertaining to the energy performance of the evaluated buildings. They aver that the instruments provide information in a very simple to grasp format (1–100, or A–M, or poor–excellent), and they urge building owners to better improve the performance level of a building with regards to energy. Instruments used for energy classification are available in practice, mostly together with energy benchmarking, energy certification, and energy labeling. These tools possess varying specialties in the way energy performance is classified and displayed. Usage of these tools are not rigorously defined and most often have overlapping meanings (Perez-Lombard et al., 2009).

Building energy performance assessment methods can be differentiated according to their objectives, the details and issues concerned. According to the above differences, Wang et al.

(2012) classified the usage of energy performance evaluation into four classes comprising (1) building environment assessment schemes, (2) energy certification, (3) whole-building benchmarking tools and (4) hierarchical assessment and diagnosis tools.

2.5.2 Applications of Energy Performance Assessment

2.5.2.1 Building Environment Assessment Schemes

The most notable activity carried out by most building environment evaluation plans is the evaluation of energy efficiency. The schemes are generally driven by the market demands and their objective focuses on buildings that are for commercial use. Examples of these include the most popular LEED (Leadership in Energy and Environmental Design, USA (USGBC, 2008), BREEAM (Building Research Establishment Environmental Assessment Method) in UK (BREEAM, 2014), CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) in Japan, Green Star in Australia and HK-BEAM (Building Environmental Assessment Method) in Hong Kong (HK BEAM, 2014). Existing and freshly built buildings are both covered under the environmental assessments scheme. Simulation software is a frequently used method for buildings assessment in newly constructed buildings. For already existing buildings, measured energy data is common practice in building assessment. Most environmental assessment schemes have their specific procedures which are used for energy assessment. This is not always the case as others may take advantage of particular energy rating systems.

2.5.2.2 Energy Certification

A survey by Janda (2008) showed that Europe is currently the hub for the making of many energy efficiency policies in the building sector. This is engendered by law regulations such as the Energy Performance of Buildings Directive (EPBD). The EPBD sets out the compulsory assessment of building energy performance in Europe (Corrado et al., 2007). Examples include mandatory schemes focused on both new and existing buildings labeled Energy Management of Large Buildings (ELO) and Energy Labelling of Small Buildings (EM) Denmark. The EPBD-related assessment methods could be summarized to cover energy performance certification as setting up a common method for calculating the performance of building energy; establishing a requirement for the minimal performance of energy for both existing and new buildings; and a scheme to display the certification level of rated building energy performance. Various programmes have also been developed in the US. These consist of the American Society of Heating, Refrigerating and Air-conditioning Engineer's (ASHRAE) Building Energy Quotient (bEQ) program and the Department of Energy (DOE) energy asset rating (AR) program (Jarnagin, 2009). The AR program results in an energy certificate and created the resultant effect of commercial building owners being able to identify and implement specific actions towards the improvement of energy efficiency in the building.

2.5.2.3 Whole-building Benchmarking

Wang et al. (2012) explained that whole-building benchmarking uses a statistical standard to measure the energy performance index for a whole building. They aver that such benchmarks look at the whole assessment of existing buildings. This is done based on the comparison of the performance of energy of a building with reference to a standard. This is a simplified and very effective method. The key tool with performing a whole building benchmarking is the reference benchmark. Consequently, a suitable reference benchmark must be selected or an appropriate one must be developed. For this to be achieved, Wang et al. (2012) advances that benchmarks can be set up based on a statistical analysis of comparable and similar buildings referring to this as a statistical benchmark. However, in situations where there is no comprehensive energy performance data for a sample of buildings, benchmarks will have to be set up based on using hypothetical reference building for calculation.

2.5.2.4 Hierarchical Assessment and Diagnosis Tools

The hierarchical approach is used to acquire, identify and analyze specific systems' or facilities' performance (Wang et al., 2012). This approach uses assessment methods; it is normally combined with a comprehensive energy audit in present buildings. A case in point is the study of Lee et al. (2003) which advanced a procedure to provide assessment of energy performance of a complex commercial building based in Hong Kong. The procedure assesses energy performance of the space by combining a simulation exercise with an energy audit (Lee et al., 2003).

2.5.3 Energy Quantification Methods

Energy quantification involves steps taken to arrive at the total amount of energy used up or consumed in a building based on collated information from the said building. It is the first step and foundation for any quantitative energy performance assessment method. Common sources of quantifying building energy use include but are not limited to computer simulations, audited building data, utility bills and BMS monitoring system (Akbari, 1995). There are three main approaches for the quantification of an existing building's energy use: Calculation-based Approach, Measurement-based approach and Hybrid Approach (Bagheri et al., 2013; Wang et al., 2012; Pisello et al., 2012; Haapio and Viitaniemi, 2008;).

2.5.3.1 Calculation-Based Quantification

Any given energy calculation-based method comprises of three major components namely, inputs, calculation model/method and outputs (energy performance indicators). The determination of inputs required and subsequent output produced is based on the calculation model. For a particular building model, different calculation models employed handle the various dynamic effects different for any building modeling exercise. Generally, building quantification can be put under a dichotomy of either dynamic or steady state methods. Steady state methods employ correlation factors for simplification of dynamic effects or ignore such effects. This simplification process clearly decreases the complexity of computation. Dynamic methods adopt the use of detailed simulation tools to factor in building dynamics from thermal envelope analysis to system dynamics.

The use of dynamic simulation is now common place for analyzing a building energy performance. Dynamic simulation necessitates the usage of a simulation engine which is built upon a detailed mathematical model. Inputs collated from a building are fed into this simulation engine to produce various inputs. Generally, inputs used for such purposes can be grouped into four main parameters: weather data, building description, building systems and component description. The weather normally comprises outdoor air temperature (both wet and dry bulb temperature), wind speed and solar radiation intensity. Geographic location, construction materials, thermal zoning of building fall under building description. The description of building systems comprises the various control schedules (Ayres and Stamper, 1995). Component description comprises of the various heating, ventilation and air-conditioning systems employed in the building.

The fundamental workings of the simulation program are the engine which it is built upon. This is an algorithm describing a mathematical simulation. There are three main building blocks of this engine: thermal loads calculation, system simulation and central plant analysis

(Ayres and Stamper, 1995). The simulation of systems and equipment's performance is usually done using simplified and steady state methods. The output of such simulations results in information on the performance of energy. Such information may be communicated as the annual energy building use expressed normally as energy use intensity (EUI) or carbon dioxide (CO_2) emission. Other outputs are usually provided such as more specific and detailed energy performance indicators in the form of equipment efficiency of system and cooling/heat load of building. Steady state methods focus solely on simplification of energy calculation. This makes them less complex with a high speed calculation. Two major approaches popular with this method include; forward modeling and inverse modeling. An exemplary method for forward modeling is the Simplified Building Energy Model (SBEM). The SBEM is built as a steadystate model with the goal of implementing the EPBD. The degree-day method and whole building regression methods are examples of models adopting the inverse modelling. Another critical component of simulation study is the need for validation.

According to Ryan and Sanguist (2012), validation of energy efficiency models is principally of two types. These are the idealized and realistic studies. Idealized validation studies of building energy models aid in validating the combined physics of the models and the engineering hypothesis that comprise the models. In this instance, the idealized test cells are frequently modelled. Normally, the test cells entail one room adequately insulated against the environs on all walls with the exception of one (Loutzenhiser et al., 2007). Realistically, in validation research works, comparisons are made between the building energy models and metering. The data obtained from real residential and commercial buildings are audited.

2.5.3.2 Measurement-Based Quantification

Lee et al. (2003) advanced that the use of measured data for energy quantification is a better option when the focus is on existing buildings. However, for new building this cannot be used and calculation based method becomes the only option available. Measuring the actual building energy consumption can be done in a number of ways. This includes using energy bill and detailed end-use sub-metering.

The energy bill produces a high quality data and is a very cost effective method. The easy access to energy bill also makes it a very likely means of quantifying energy data. The drawback of the energy bill is in its inability to provide sufficient information for a more detailed energy performance assessment. The information on the energy bill is usually aggregated and this presents a difficult problem when doing multi-level diagnosis and assessment. One way of overcoming this difficulty is the disaggregating of energy bill. This involves the breakdown of the total energy use into the individual constituent end use with an acceptable degree of accuracy. Previous studies show the use of energy bill in energy quantification (Parker et al., 2006; Field et al., 1997). The study by Parker et al., (2006) provides the Energy Detective (TED). The TED is a metering system which captures the energy consumption of appliances in a house at the steady state level.

Use of sub-metering system is principally for research and in most cases, validation purposes due to relatively detailed energy data provided (Akbari, 1995). Case studies developed by the HARMONAC project show the capacity of BMS of being able to serve as a tool for monitoring energy performance (Masoero et al., 2010).

2.5.3.3 Hybrid Quantification Method

The hybrid quantification method involves the use of calculation analysis and supplemented with measurements to take care of any computation incongruities and use in the identification of model parameters. Two major methods are common in use with the hybrid quantification: calibrated simulation and dynamic inverse modelling. Calibrated simulation combines a simulation program and measured data by comparing the output of the simulation program using heuristics to ensure that predicted energy is close to data measured empirically (Reddy, 2006). An example is seen in the study by Claridge et al. (2004) in which a methodology was developed for calibration of energy use based on the disparity between measured and simulated performance.

Dynamic inverse models involve the use of in situ measurements for identifying the model aimed at computing a building's usage of energy. Advantages of dynamic models include the ability to capture dynamic effect. Haberl and Culp (2005) noted that such methods are not only complex but require a high level of information.

2.5.4 Review of Building Performance Assessment

A variety of review studies have been conducted to standardize the various building environmental schemes in usage currently (Lee and Burnett, 2008; Asdrubali et al., 2008; Hernandez et al., 2008). These research outcomes have been mutually qualitative and quantitative. Lee and Burnett (2008) for example, provided a comparison of the baseline buildings, performance criteria and simulation tools between the assessment methods of LEED, BREEAM and HK-BEAM (Hong Kong Building Environmental Assessment Method) premised on a statistical energy evaluation analysis. Lamberto et al. (2008) explored building energy regulations comparing that of Italy as well as Spain based on semidetached houses. Lamberto et al. (2008) focusing on single-family house in Italy, evaluated the energy performance centered on three differing reference benchmarks. Hernandez et al. (2008) scrutinized the energy performance benchmarks and building energy ratings through the employment of computed and assessed rating methods on a sample Irish school. Roderick et al. (2009) give an evaluation of three schemes - BREEAM, LEED and Green Star Scheme – premised on their valuation procedures, ranges, performance standards and energy rating scales. Results obtained from these researches demonstrate that the energy performance of a building and the equivalent energy rating attained are greatly contingent on the assessment scheme made use of.

Studies reviewing building energy certification have also been organized. Perez-Lombard et al. (2009) in their study, looked at the energy certification in buildings and explored the historic development and origins of energy certification schemes. Their study further looked at the definition and scope of a building energy certificate with the key issues of its implementation.

A seven step process which serves as a guide for the implementation of building energy certification is also proposed. Bertoldi et al. (2010) in their study provide a review of current white certificate (building energy savings) schemes in the European Union along with analysing the results of such schemes.

Dascalaki et al. (2012) provide an up-to-date outline of the advancement and present implementation EPBD phase, along with an initial evaluation of lessons garnered and experiences. Results obtained from such analyses indicate that the usage of certificates has a positive influence on building energy efficiency however, several past and prevailing difficulties faced encompass lags in execution of monitoring supervisory structures and little participation by shareholders. Other results indicate that building energy certificates also act as a behavioural modification tool that impacts positive improvement in public building energy performance as confirmed by Bull et al. (2012) in their study. Murphy et al. (2012) organizing research into building energy policy in the Netherlands discovered that existing apparatuses are improperly furnished to shape the future by providing a long-term saving strategy for energy usage in existing buildings.

Janda (2008) organized a worldwide survey of 80 countries of building energy criteria. They provided that the report on building energy efficiency assessment (BEEA) is very scant in most developing countries, particularly countries in Africa (Janda, 2008). Additionally, the effectual usage of BEEA apparatuses is based on the supposition of the presence of suitable substructures at a national or regional level (extensive databases, regulations, and statistics) (Sinou and Kyvelou, 2006).

2.6 ENERGY ASSESSMENT METHOD

One key tool in ensuring the sustainability of the environment is the use of energy assessment tool. These tools provide a means of diagnosing the built environment ensuring best practices.

These tools stress on the imperatives such as renewable energy, efficient energy design and energy conservation techniques. They provide many advantages accrued from the usage of such tools. The growing concern about global warming and other ecological threats give rise for the development and implementation of these tools (Lee and Burnett, 2008). Extant studies show the tremendous effort that has been invested in the development of such tools (Ali & Al Nsairat, 2009; Haapio & Viitaniemi, 2008; Grace, 2008; Chang et al., 2007; Cole, 2006; Cooper, 1999; Crawley & Aho, 1999).

Many of these tools that have been developed have been very successful (IEA, 2014; Cole, 2006; Todd et al., 2001). Research shows that BREEAM was a pioneer in developing a sustainable tool. This paved the way for the development of subsequent tools as Sustainable Building Tool (SBTool) and Comprehensive Assessment System for Building Environment Efficiency (CASBEE). The development of such tools also engineered the improvement in the standardization of issues related with sustainable building.

The development of assessment tools has been tailored for specific regions. Existing assessment tools are mostly not fully applicable for many regions (Cooper, 1999; Crawley et al., 1999). Alyami & Rezgui (2012) explain that environmental factors inhibit the full application and use of such tools. Some of these factors encompass climatic conditions; geographical physiognomies; prospect for renewable energy gain; resource consumption (for example water and energy); construction materials and techniques made use of; building stocks; government law and regulation; appreciation of historic value; population upsurge and public awareness.

BREEAM-UK has developed and evolved steadily during the last couple of decades. This evolutional progression has been critiqued on the basis of the absence of holistic transparency (Inbuilt, 2010). Mao et al. (2009) noted that there exist some similarities with BREEAM developed for the Middle East and that of BREEAM UK with very little changes in some criteria. They cite an example that watercourse pollution is a criterion used in Saudi Arabia however, it is uncommon to see a watercourse. The common phenomena there, is sand storm pollution and dust prevention but these do not have any criteria provided for them. BREEAM, UK, places large emphasis on CO_2 emission due to their source of power in the UK whilst some regions' source of power does not have CO_2 emissions generated as much as the UK hence, assessment of CO_2 is not critical. Additionally, BREEAM weighting system seems to have been initially developed for a single site. It is however in use in several additional sites observing strictly its initial classifications and standards context. These characteristics limit the regional application of building performance tools in places like Ghana. Therefore, the consensus of Ghanaian experts on applicable building energy criteria will be the optimum solution to form an appropriate calibration for local conditions, and at the same time taking into account what has been overlooked, such as vernacular architectural principles, cultural and social aspects and economic factors.

The primary objective of this study motivated the investigation of the most significant and internationally prevalent energy assessment methods, BREEAM, LEED, SBTool and CASBEE (Ali et al., 2009; Forsberg et al., 2004). Key similarities and differences were then established to provide a framework for the development of essential energy assessment method and criteria. Previous research work on building energy assessments methods and indicators were also explored to provide a background for development of the new tool.

These schemes were selected according to the following criteria: BREEAM and LEED are the foremost systems, and are equally run by renowned organisations (BRE and USgbc) with a proven track record in the area of building performance development. BREEAM has been used to certify over 200,000 buildings with more than a million registered for assessment (BREEAM, 2014). BREEAM has also been the template for the creation of numerous other tools across the globe, including tools such as GREENStar in Australia and the HK-BEAM in Hong Kong (Grace, 2008). According to USGBC (2014), the numbers of projects certified and registered under LEED increased twofold in 2008, from approximately 10,000 at the close of 2007 to over 20,000 by the close of January 2009.

A review of SBTool is presented here. This scheme was developed through an international effort to be an appropriate tool for over 20 countries, including South Africa (Gibberd, 2003), Denmark (Laustsen & Lorenzen, 2003), Hong Kong (Lee & Burnett, 2006), Taiwan and China (Chang et al., 2007). It is considered the most comprehensive of all environmental assessment methods (Cole & Larsson, 2014). The last system is CASBEE, which was established under the auspice of the Ministry of Land, Infrastructure and Transport provisions in Japan, for the purpose of evaluating building performance. This system has been chosen as its assessment system incorporates special features (particularly the weighting system), allowing for environmental issues to be prioritised in their given context (CASBEE, 2014).

2.6.1 LEED

With registered projects that cover 24 different countries, LEED is the most extensively acknowledged building environmental assessment scheme (Lee and Burnett, 2008). It is built on a set of conditions being met, leading to the award of credits. The award of credits is organized around a particular area. These areas include water efficiency, energy and atmosphere, sustainable sites, material and resources, indoor environmental quality and innovation and design process. A point is awarded based on requirements being fulfilled with the exception of the cases of energy performance and renewable energy. For these two categories, a number of points are awarded based on achievement of performance improvement. The sum of all the points awarded add up to the total scoring system. A total of 69 points can be awarded. LEED has a scoring system made up of four (4) hierarchy levels.

They are certified (26-32 points), Silver (33-38 points), Gold (39-51 points) and Platinum (5269 points).

LEED uses a twofold method to evaluate building energy performance recognised as Credit EA1- Optimize Energy Performance. The initial one is the Prescriptive Compliance Path, which permits particular projects to attain up to four points in the situation where they satisfy the measures prescribed by ASHRAE (Advanced Energy Design Guide for Small Buildings, 2004). The second method is the Whole Building Energy Simulation, which permits up to ten points in the situation where the building shows progress on energy cost as compared to a regularised building. For each method, the evaluated building is required to satisfy a performance level of at least two points.

The Whole Building Energy Simulation, which comprises 14.5% of the entire scheme points, necessitates the usage of a simulation program which can perform thermal analysis to the stipulations specified by ASHRAE Standard 90.1-2004 (ASHRAE, 2004) appendix G which is known as Performance Rating Method (PRM). The method stipulates that two kinds of building models are created. The initial one comprises the proposed building model and the subsequent one is the baseline building model. Observe that the baseline building necessitates a set up with orientations of 0, 90, 180 and 270 degrees respectively, so that the self-shading effect can be normalised. The energy rating is computed on the basis of the yearly energy cost of managing the proposed building relative to the average yearly cost of managing the baseline building through the usage of real rates for purchased energy or State average energy prices as shown below.

% of improvement = 100 x [1 – (Cost of Proposed/Average Cost of Baseline)]

2.6.2 BREEAM Scheme

BREEAM is a voluntary standard as well as the building rating environmental scheme with the most extensive usage in the UK. For energy performance assessment, the UK Building Regulations is adopted as a yardstick to measure the level of performance improvement. There is a new BREAAM International that has been developed specially for use in regions such as the Gulf and Holland (Stewart, 2014). The credit rating system in BREEAM offices 2008 is similar to that adopted by LEED. Credits are categorized into the building's environmental impact including energy, health & wellbeing, transport, water, waste, building management etc. Total credits available is up to 102. For an assessed building to be scored, firstly the total credits available is computed, then the number of credits attained in each category and finally a weighting factor. The overall performance of the building is scored according to the following categorises: Unclassified (<30%), Pass (≥30%), Good (≥45%), Very Good (≥55%), Excellent (≥70%) and Outstanding (≥85%). For each category, there are a minimum number of credits that must be achieved.

Credit Ene 1-Reduction of CO_2 emissions is the name given to the energy assessment in BREEAM. This permits up to fifteen credits to be attained in the situation where the building being evaluated shows an enhancement in the energy efficiency of the building fabric and building services. Totalling up to 14.7% of the total scheme credits. The energy performance of the building is shown as CO_2 based index. The number of credits attained is determined by relating the building's CO_2 index taken from the Energy Performance Certificate (EPC), with a table of benchmarks. The EPC is generated on the basis of the UK National Calculation Methodology (NCM) (Government, 2008). It supplies an energy rating for the building ranging from A to G where A is very efficient and G is least efficient. Two building models need to be created; actual building and the reference building, to be able to set up the asset rating. The asset rating is subsequently computed as the ratio of the CO_2 emissions from the actual building to the Standard Emission Rate that is decided through the application of a fixed improvement factor to the CO_2 emissions from the reference building.

2.6.3 SBTOOL

SBTool is regarded as the most flexible assessment tool. It has been adapted for over 20 different countries (Mao et al., 2009), located in their majority in Europe, Africa, Canada and the far east of Asia. Much of the focus of SBTool has been in for South Africa, with no customisation of SBTool as yet for the West African Continent. This might be attributed to the complex and unique environmental, economic, cultural and social aspects that characterise this region. SBTool is organized into four main levels, with the more advanced levels logically obtained from the weighted aggregation of the lower ones, using 1 goal, 7 issues and 29 categories (Chew & Das, 2008). It was formerly called GBTool and designed to facilitate the ability of those who use it to reflect the differing priorities, technologies, building traditions, and cultural values existing in the various regions and countries involved in the assessment process. For this reason, its benchmarks and weights are improved by national teams through various methods such as the analytic hierarchy process (AHP) (Chang et al., 2007; Lee and Burnett, 2008). The criteria and sub-criteria of each performance issue are scored using a linear scale from -2 to +5. SBTool has a different approach to the issue of energy efficiency evaluating the electrical peak demand for building operations (Cole & Larsson, 2014)

2.6.4 CASBEE

CASBEE is a joint governmental, academic and industrial sector approach used in Japan. The main four aspects of CASBEE included energy efficiency, resources efficiency, local environment and indoor environment which comprise a total of 80 sub-criteria which are further re-categories into two main groups: Q (Quality), and L (Loadings) (Horvat et al., 2005). In order to evaluate the sustainability of green building, CASBEE adopts the value of BEE (Building Environmental Efficiency), as illustrated by the equation below (Mao et al., 2009).

Building Environmental Efficiency Equation (IBEC, 2008);

$$\frac{Building\ environmental\ quality}{Building\ environmental\ loadings} = \text{BEE} \quad \text{- Equation 2.1}$$

One of the differential features of CASBEE is its unique approach to the completion of its final result. Rather than relying upon a simple additive approach, the CASBEE introduces the concept of Building Environmental Efficiency (BEE) with weighting coefficients for the assessment of different kinds of building (Chew & Das, 2008). These are developed from the results of a survey involving crucial stakeholders such as building operators, designers and owners and the outcome subsequently analysed by analytic hierarchy process (CASBEE, 2014). CASBEE is generally considered to be strong, in assessing Efficiency in Building Service System, whereas this area is not important in BREEAM, LEED or SBTool (Kawazu et al., 2005).

It should be noted that the calculation of CO_2 emissions and energy consumption under both BREEAM and LEED requires the use of other guides and additional tools such as Standard Assessment Procedure (SAP) and American Society of Heating, Refrigerating and Airconditioning Engineers (ASHRAE).

2.6.5 Critique of Selected Tools

Techniques for preparing sustainable and environmental assessment methods have an increasing role in the identification of human activities which will potentially affect ecological loading, economic elements, and social aspects (Wallhagen et al., 2013). Therefore, the initial direction taken during this research involved concentrating on classifications for sustainable assessment. However, it was observed at this stage that there are different categories of building assessment that are also commonly considered. Berardi (2012) explains different types including building lifecycle assessment, quality assessment, environmental assessment, etc.

Hence, following a critical review, the selection of a well-known EAM was made. This assisted in the study of the most relevant and matching domains that support the meeting and setting of research objectives. A critical review of renowned BEAM (BREEAM, LEED, SBTool and CASBEE) was conducted, and resulted in identification of principal deficiencies, which should be improved upon by any new assessment method (see Table 2.1).

Table 2.1 General Comparison

	CASBEE	**LEED**	**BREEAM**	**SBTool**
Scope of Assessment	Annual energy use Building envelope design Use of renewable energy	Energy-efficient design Annual energy cost	Annual CO_2 emissions Energy-efficient design	Electrical Peak demand Annual Energy Renewable Energy
Assessment method	Options of feature specific, criteria and energy budget Method	Options of featurespecific criteria and energy cost budget method	Mixture of performance-based and feature-specific criteria	Country Specific
Calculation Method	HASP/ACSS and BECS and BEST or Able to simulate the hour-by-hour energy	DOE-2 or BLAST or approved equivalent	No specific requirements. Actual consumption figures may be used where available	No specific requirement

It is a challenge for any single BEAM to be appropriate to all world regions, as every area has its own specific individual components related to geographical and environmental differences (Wong and Abe, 2014; Cole and Valdebenito, 2013; Kajikawa et al., 2011; Lee et al., 2003). Thus, a weighting system comprises a means to manage perspectives for credit distribution, which can be implemented by providing techniques and environmental assessment methods (Ali and Al-Nsairat, 2009; Lee and Burnett, 2006). The EAM systems employ various strategies for assessment, for instance, the BREEAM and SBTool employ a weighted system that prioritises environmental issues, while LEED employs a simple additive approach (1 for 1) which simplifies the process. However, making an assessment without weighting inevitably leads to criticism, because it is still the only approach approved to comprehensively evaluate and prioritise issues regarding the built environment (Lee, 2012). In consideration of this, CASBEE proposes weighting coefficients that can be modified to suit local conditions, such as climate, or that reflect the prioritisation of policies (CASBEE, 2011). Another important consideration is that due to the similarity of BEAM techniques in broad categories (energy, water, materials, etc.), certain sets of criteria are considered central assessment dimensions. For instance, LEED and BREEAM encompass around 70 criteria; CASBEE encompasses 80 criteria; and SBTool has over 150 criteria. This has resulted in complex structures, comprising large quantities of specific information that needs to be arranged and evaluated (Haapio and Viitaniemi, 2008).

Numerous schemes have tended toward generalisation to capture the majority of environmental assessment criteria inside their assessment structure. Embracing multiple criteria limits the accuracy of BEAMs, and does not lead to a specific reflection of performance in the built environment. Therefore, emphasis should instead be placed on a single common goal (e.g. efficiency of the built environment), consulting professionals about the most relevant criteria to pursue to meet that goal. Financial considerations are an important aspect of sustainability advancement and have a considerable impact on both developing and developed nations. Developed nations aim to decrease the ecological damage caused by maintaining living standards, while living standards are considerably lower in developing nations (Cole and Valdebenito, 2013) signifying that economic and social issues are more significant than ecological issues to these nations (Libovich, 2005). Thus, EAM should prioritise essential economic and social concerns (Gibberd, 2005). Nonetheless, LEED and BREEAM have both excluded the inspection of financial elements from their analytical structure. This opposes notions concerning the final value of sustainable development, as economic returns are crucial for all undertakings, and environmentally friendly actions remain costly to implement. One point to be considered in the CASBE and SBTool, as mentioned in this research, relates to its assessment of significant criteria in the quality service category, which was partially disregarded by LEED and BREEAM. The significance of this category is encompassed by sustainable activities, such as adaptability and flexibility in the construction of structures, and alteration of inhabitants needs. Instances of this could encompass the amenability of heating ventilation and air conditioning (HVAC) structures, and future alterations to a new fuel, or to technologies for renewable energy, as well as the supply of sufficient clearance and access points to permit imminent adjustment (iiSBE, 2011).

In addition, the complexity of structures often results in considerable ecological effects, rendering it challenging to approximate quantitatively the ecological effects of a structures environment, e.g. green plants, landscaping, pavements, parking lots, and infrastructure close to the structure (Lee and Burnett, 2006). Thus, each of the BEAMs chosen has made attempts to integrate these effects in various ways aimed at decreasing discharges and managing resources. LEED and BREEAM appraise plans for energy efficiency and the reduction of CO_2 discharges as chief ecological issues. The SBTool appraises matters of ecological effect within the operational phase, considering a variety of issues, several of which are beyond the influence of the designer, like greenhouse gas discharges, discharge of ozone-diminishing materials, acidifying discharges, and discharges resulting in photo-oxidants (Cole and Larsson, 2014).

The SBTool is regarded as the most customised assessment instrument available for enhancing regional green construction. As a result, it has been implemented in over 20 nations (Mao et al., 2009). Professional opinions (architects and experts, state authorities, intellectuals, and professors) relate to principal regional concerns and changes to local government that have been implemented; in particular, the AHP, which can offer suitable direction for SBTool implementation (Chang et al., 2007). Comparably, LEED and BREEAM modify structural assessment based on consensus, evaluating the views of professionals from various fields as a means to prioritise construction and accounting for ecological matters aimed at maintaining best practices. Nevertheless, it seems clear that most assessment systems play a significant role in reflecting sustainable development in the building sector with regard to building performance. However, their gradual evolution has the potential to enable such systems to surpass their roles as design tool. For example, by tackling issues such as financial returns, public awareness and willingness to cope with further development; these have the potential to make environmental assessment schemes more successful and to meet the overall objective of sustainability.

2.6.6 Rating Systems in Ghana: Green Building Council

The move to streamline and promote sustainable practices in both commercial and industrial buildings in South Africa led to the creation of a Green Building Council of South Africa (GBCSA) in 2007 (GBCSA, 2007). The Australian rating system which is the Green Star was customised for South Africa (GBCSA, 2007). In Ghana, the Green Building Council was established in the year 2009 to promote the up-take of green building and the general application of green building principles within the Ghanaian environment (GhGBC, 2010). Green building council in Ghana has also adopted the Green Star from South Africa (GhGBC, 2010). This rating system assesses the environmental impact of design and construction of nondomestic building types.

A report by the GhGBC in modification of the Green Star for Ghanaian purposes agree that the application of their rating system should be seen as only an interim tool (GhGBC, 2010). They argue that it would take time for GhGBC to develop its own rating tool or customize the Green Star specifically to Ghana (GhGBC, 2010). The Green Star rating system has six major components. Due to the focus of the research study attention is only paid to the energy rating component in the Green Star. The energy component of the Green Star focuses on encouraging and recongnising designs that minimize the greenhouse gas emission associated with operational energy consumption. The modified tool recommends the use of ASHRAE 90.12007 as a relevant standard due to the absence of energy efficiency requirements in either the Ghana Building code or by the Energy Commission (GhGBC, 2010). However due to different climatic conditions, different fuel factors and energy sources this approach does not provide an adequate assessment of the energy efficiency of the building. Consequently, the energy component applied within Ghana is not extensive enough and does not well capture the needed specifics for the particular environment.

2.7 ENERGY ASSESSMENT INDICATORS

To develop energy categories for energy assessment, key indicators need to be identified and weights assigned. Recent studies show that various works have been conducted in this area. A work by Wang (2006) proposed a list of indicators with a prime focus on building envelopes. Another indicator list proposed by Liu et al. (2006) focused on economics. A 17 indicator list proposed by Ding et al. (2003) focused on the blueprint criteria for energy efficiency of suburban buildings with a prime focus on building envelopes. Other works based on building energy indicators include: Cong et al. (2007); Entrop et al. (2007) and Brounen et al. (2009).

To ensure the establishment of an all-inclusive collection of indicators of the energy efficient assessment method, the four main environmental schemes were studied. The study also draws on previous academic research papers.

A procedure consisting of two steps has been organized in this study similar to that conducted by Yang et al. (2010) to arrive at an initial indicator list. In the initial stage, a complete scope of indicators connecting to the energy efficiency have been gathered. In this stage, on the basis of a review of the extant references, 83 indicators have been gathered (see Appendix 1). The references were obtained from the ensuing two principal resources: four of the most internationally pervasive environmental assessment methods: BREEAM, LEED, SBTOOL and CASBEE; and academic research papers. In the second stage, the 83 indicator list is refined and reduced down into five main categories. A study by Yang et al. (2010) refined an indicator list of 83 into five main categories based on four main regulations. This study adopts the use of the regulations to further reduce the list. The regulations include

1. Viability regulation: This regulation entails the prospect that an indicator could be evaluated at the present stage of technology or policy.
2. Holistic regulation: This regulation entails that the ascertained indicator list ought to encompass the primary facets of commercial building energy efficiency assessment.
3. Efficacy regulation: This regulation entails that the ascertained indicator list ought to overlook certain matters which have nominal effect on the residential building energy efficiency assessment.
4. Multi-attribute decision making (MADM) regulation: The MADM regulation entails certain conditions like rational number of mutually exclusive indicators. Mutually exclusive indicators will assist to avert unwanted 'double counting' when weighting them.

The second stage, produces a draft indicator list made of 21 indicators chosen out of the complete indicator list founded on the regulations provided above. Some indicators were filtered out. Within the scope of the first regulation, the following indicators were filtered out: "All year electricity consumption', 'Minimum energy sources consumption', 'Green power', 'CO_2 Emission'. This is as a result of the fact that presently, the authorities in Ghana do not give yardsticks for "all-year electricity consumption and 'Minimum energy sources consumption', neither the national nor local power grids labels the 'Green power'. Computing the CO_2 emission value of a building presents challenges at the current time as a result of the absence of a nation-wide computation method.

Table 2.2 Draft Indicator List

Building Categories	**Indicators**
Building Design	Orientation of building Outdoor Environment Use of shading devices Shape of building Glaze ratio of wall Advanced design and construction techniques Efficient use of Day lighting
Performance of Envelope	Airtightness of Envelope Insulation of building Thermal properties of building envelope
Energy efficiency of building facilities	HVAC facilities Efficiency of lighting systems Energy cost of operation of building Social Impact Optimisation of energy use
Building Operation and Management	Indoor thermal comfort Indoor lighting Acoustic Environment
Use of Renewable Energy	Proportion of renewable energy consumption Cost of renewable energy Use of local renewable energy sources

The following indicators were removed from the list as a result of regulation three; Decrease of lighting pollution', 'Dry space', 'Public transportation', 'Store space for bicycles', 'Work at home', 'Private space', 'Avoidance of the use of Freon and Halon, and Electromagnetic pollution. Yoon and Hwang (1995) specified that seven plus signifies the largest quantity, subtracting two signifies the smallest quantity of information which an onlooker could supply us concerning an object on the premise of an unequivocal judgment. Mutually exclusive indicators will assist to stop unwanted 'double-counting' when weighting them. Afterwards, the outstanding indicators are classified into five categories; Building Design, performance of envelope, energy efficiency of building facilities, building operation and management and use of renewable energy. The 21 indicators selected are presented in Table 2.2.

2.8 ECONOMIC, CULTURAL AND SOCIAL ASPECTS

One key deliverable of an assessment method is improved environmental performance. With increase in understanding of the concept of sustainability globally, future needs points to a more comprehensive sustainable method (Haapio and Viitaniemi, 2008; Sebake, 2009). Currently most assessment tools place more emphasis on environmental issues like energy landscape, resources, emissions and the indoor environment quality (Sinou and Kyvelou, 2006; Poston et al., 2010). Undeniably environmental issues are a global concern and attention ought to be paid to it. This goal most current tools perform excellently on (Mao et al., 2009; Poston et al., 2010). Nevertheless, other aspects of sustainability should not be neglected to the detriment of a delivering a wholistic sustainable method (Ding, 2008; Haapio and Viitaniemi, 2008).

Extant studies show key parameters in achieving sustainable performance include consideration of economic, social and cultural aspects (Forsberg and von Malmborg, 2004; Sinou and Kyvelou, 2006; Haapio and Viitaniemi, 2008; Mao et al., 2009). Todd et al., (2001) in a study provide that these parameters may present not only impediments but also opportunities for developing a rating system among developing countries. Moreover, Poston et al. (2010) cited that criticism is also levelled against assessment tool for focusing on environmental criteria at the cost of social and economic criteria despite shift towards more sustainable assessment. It is held that the local context is a major determinant of the significance of economic, social and cultural aspects. This is largely due to its variation across countries. Case in point Alyami (2015) argues that social and cultural aspects play a pivotal role in Arabic countries such as Saudi Arabia. This is supported by Cole (2005) who avers that for developing countries social and economic aspects rank high. Arguably environmental concern is largely at the forefronts in advanced countries. Hence, it is realised that Reed et al. (2006) regard economic, social and cultural dimensions as exclusive features which could stop a tool take-up. Significance of this sort could be inferred which consists of differing studies (Ali and Al Nsairat, 2009; Zuhairuse et al., 2009; Al-Sallal et al., 2013) that have created environmental evaluation tools for various developing countries. It is perceptible that some developing countries have commenced the development of domestic assessment methods with suitability for their milieu, and economic, social, cultural and historical circumstances (Todd et al., 2001).

Evidently, various studies have debated the inclusion or otherwise of economic, social and cultural aspects of a building assessment method. Moving forward these issues have a great potential of critically affecting existing environmental assessment methods such as BREEAM & LEED. For instance, the larger number of countries commence their assessment method instead, with the usage of accessible existing tools resulting from their lack for cultural aspects. Proof has been provided by a new generation of assessment methods springing up because of upsurges in the demand to take into account economic and cultural dimensions in assessment tools such as Estidama (Poston et al., 2010).

2.9 CONCEPTUAL FRAMEWORK

Drawing from the work of Perez-Lombard et al. (2009) a conceptual framework is developed (Figure 2.1). In their work, they aver that to develop an energy certificate certain key answers need to be provided. The answers stem from major questions; firstly, what ought to be computed for the assessment of building energy efficiency; next how should this be computed. The third and fourth question hinges on establishing an energy efficiency limit and a basis for comparison of building energy efficiency respectively. The next question deals with labelling of BEE. The seventh question deals with recommendation for energy efficiency and lastly the information that ought to be provided on the energy certificate. These questions are the building blocks for the development of a conceptual framework for this study. The following section outlines the major blocks.

2.9.1 Scope of Assessment and Assessment Method

Perez Lombard et al. (2009) provide that the first step in developing an energy assessment method is defining the performance indices of building energy. It has already been pointed out that energy performance is an amount indicating energy consumed and this amount is reflected in one or more numeric indicators referred to as Energy performance indicators (EPI). In energy analysis, both energy intensity and energy performance indicators may be used interchangeably due to complexity of assessing the quality and quantity of energy used per service. Most often used EPI in various applications of building typologies is energy use intensities (EUI), mostly in the form of kWh/m^2. Rey et al. (2007) in their study adopted the use of kWh/m^2 year as a quantitative indicator of the amount of energy required by the building. Roulet et al. (2002) considered the impact on the environment, indoor air quality as well as total energy consumed in the building to develop a multiple indices system as a way of defining energy performance. It should be noted that even when considering simpler applications of EUI i.e. kWh/m^2, decisions ought to be made on the quantum for energy use (exploring options such as energy delivered, CO_2 emissions and energy cost). A study by Eanga and Priyadarsinib (2008) developed a labelling system for Singapore engineered to be smart with energy and indoor environmental quality being the building blocks of its operation.

2.9.2 Energy Performance Quantification

The next stage is quantifying energy performance. As discussed earlier, the quantification of energy performance can mainly be classified under either dynamic methods or steady-state methods. Both methods have already been briefly explained along with the purposes for which they are carried out. The use of dynamic simulations requires the implementation of a computer based tool. Currently there is a large base of computer based tools available. Perez-Lombard et al. (2009) provided that the choice of any method requires considerations of issues such as accuracy, scope, reproducibility, complexity, sensitivity to energy parameters and user skills. These considerations are imperative as they have major influence on later software developments, final users' uptake, policy makers and stakeholders involved. It is argued that adopting a dynamic simulation method will not only make complex but posed difficulty in implementation, challenges in training and high cost in the purchase of simulation software or development (Perez-Lombard et al., 2009). Thus, the choice of the energy calculation tool largely determines the credibility and success of the certification scheme

2.9.3 Setting the Limit for Energy Efficiency

What follows next is the setting of limit of energy efficiency. This can be approached in two diverse ways; fixed and customized limits. Comparison of dissimilar building type is difficult using energy performance due to different services rendered by the buildings. The limit value for the building will be dependent of building type and also on climatic conditions. Various authors have approached this in varying ways for example Garcı´a-Casals (2005) are in support of an exclusive threshold value for each climate as a result of heating/cooling compensation and an excessive cost for small environmental profit, whilst others suggest a rising EPI limit with rising climate severity (Sa´nchez, et al., 2006). Additional boundaries purposed to attain discrimination could be building shape, energy source and ventilation rates.

Considering options for fixed limit setting, the lower limit values will largely depend on the variable impact that needs more reduction. Perez-Lombard et al. (2009) posits that building regulation is the first point for the setting of the minimum overall requirement for the energy performance index (EPI < EPIr). Using the self-reference approach a modified tailored limit may be acquired. This would be based on a reference building sharing common similarities such as location, common operational usage and geometry differentiated by dissimilar envelope and building system properties. The use of a reference approach is seen in the study of Bagheri et al. (2013), where they developed a performance label for office buildings in Iran. Also the Irish Building Regulations 2005 Technical Guidance Document Part L (6) was considered as the reference for new buildings constructed (Hernandez et al., 2008)

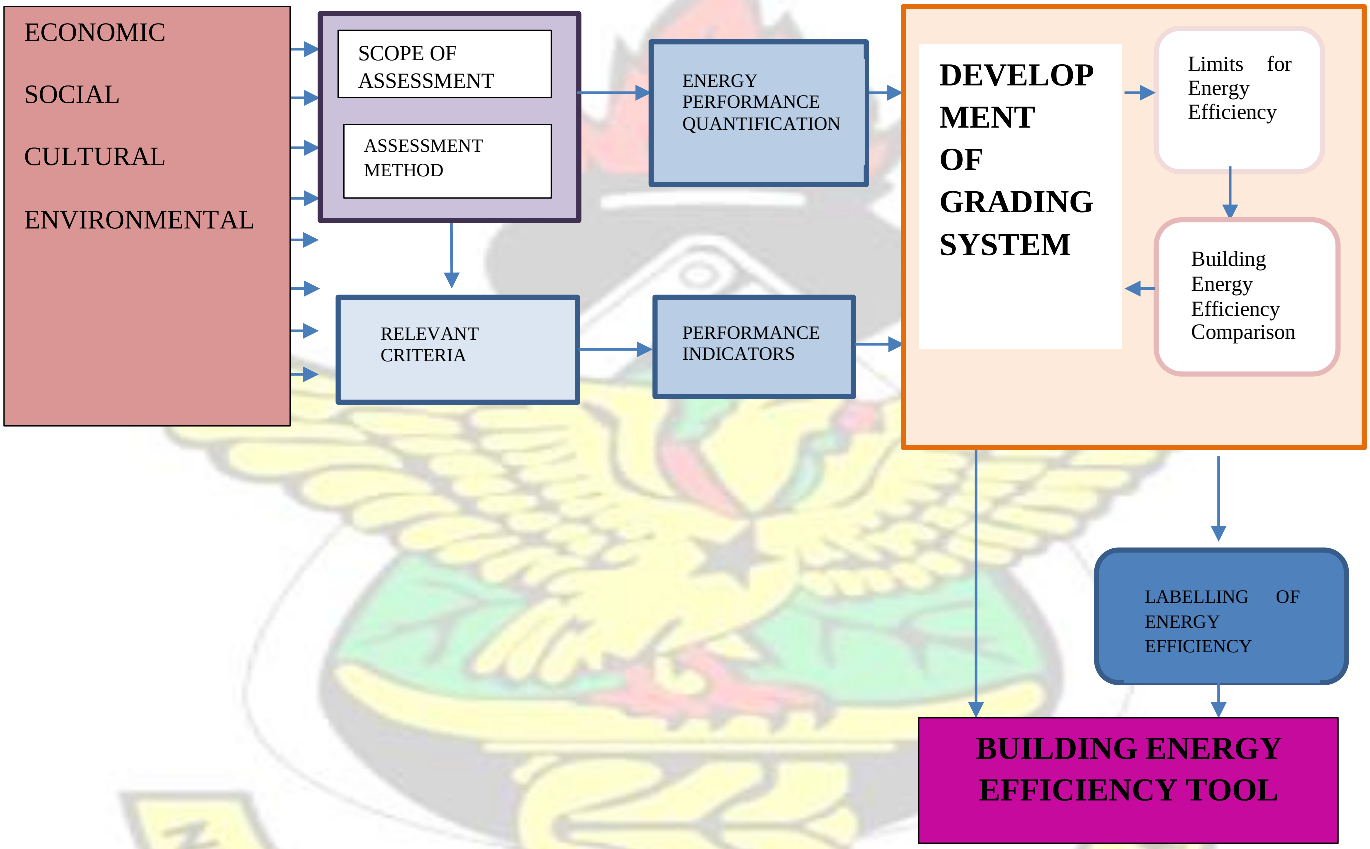

Figure 2.1 Conceptual Model for the Development of BEEA Tool.
Source: Author's Construct, 2015

2.9.4 The Building Energy Efficiency Comparison

Having computed the required EPI, the next step is the comparison of sample buildings. The objective of this is to provide for best practice whilst being cognisance of the average performance of buildings in the particular region. To achieve this existing building sharing similar features with the building must be selected and compared. Mostly similarities will be based on two main features; climate and building type whilst in other cases building energy sources may be considered. Situations exist where similar buildings may not exist for comparison. In scenarios as this a reference building is utilized. A reference building is described as a similar building for comparison developed with optimal energy consumption index (Bruner-Lienhart, 2005).

2.9.5 Labelling of Building Energy Efficiency

The initial step in this process is the definition of a label index (LI). Perez-Lombard et al. (2009) aver that this definition would be dependent on whether there is availability of sample buildings for comparison. If there are, LI would be defined as the ratio of the EPI of the building to the EPI average value of the sample, however if there are not, a self-reference approach must be used. For this approach, a reference building is used and the label index must show the saving percentage relative to the reference building performance.

The next step is to designate the parameters amid classes (definition of the scale) on the label index frequency curve if the comparison scenario is available or depending on the saving percentages of the reference building for the self-reference approach (Perez-Lombard et al., 2009). Two key benchmarks should be considered for the scale definition: scale sensitivity, the ability to improve the energy label of a given building, and scale credibility, buildings with better labels should save energy.

Three main concepts can be reviewed in the determination of the boundaries of grading for a building energy label (e.g. Grade A being the best and Grade G the worst) (Bagheri et al., 2013). Firstly providing enough space for the highest grades (A and B) with the intention of providing the opportunity for growth into this grades. The growth space should even apply for partially efficient existing buildings. Secondly the grades should be organized in such a way that a large percentage of existing buildings do not fail in even meeting the lowest grade. The last concept seeks to achieve a normal distribution of sample buildings in meeting the grades.

Evidently the first concept works on the principle of improving efficiency level of building with a push on building designers to be able to elevate the energy efficiency of buildings at the design stage. Based on this concept existent buildings would find it difficult to achieve the highest grades (A and B) to provide opportunities for more improved new buildings. This implies that in most cases the efficient existed buildings would at most achieve a grade C of the lable and may be improved to in certain situations to achieve a grade B when energy management considerations are put in place. On the other hand, moving to the highest grade avaliable will mean that thorough and comprehensive energy conservation opportunities need to be done.

The second concept seeks to avoid teething troubles in large portion of buildings not being able to meet the lowest grade which will clearly presents difficulties in the implementation process. That is, in situations where a lot of buildings are not able to even get the grade G invariabley will cause the effectiveness of implementing the labelling process to wane. With the third concept the results will be that most of the existing buildings (considering Grades A to G) would get the lower grades i.e. D, E and F and a smaller section achieving grace C and G. Consequently, this is desireable as it not only provides opportunities for growth but makes it more applicable in the implementation process.

The conceptual framework depicts the stages involved in the development of the tool. Firstly, for the tool to be developed the scope of assessment and the assessment method needs to be agreed on. Having established this premise, the next stage involves the energy performance quantification which would dovetail into the development of a grading system. The development of the grading system is also influenced by energy performance indicators which are also influenced by the establishment of relevant criteria. The development of the grading system will need to be done in cognizance of the limit for building energy efficiency and the energy efficiency comparison. For the tool to be properly useful, it should be underpinned by a labelling energy efficiency method. Consequently, this must be established for the final product to be ready. These stages represent critical steps in the development of a tool for a developing country like Ghana, bearing in mind the peculiar challenges faced such as the nonexistence of any standard on building energy and the paucity of literature addressing the peculiar nature of Ghana building energy. This provides a viable starting point for Delphi experts for brainstorming and carrying out deliberative measures. This consensus based approach will be based on an "open solicitation of ideas". The establishment of an applicable assessment method requires the consideration and prioritization of certain environmental, social and economic issues.

2.10 CONCLUSION

This chapter has reviewed pertinent literature in the area of building energy efficiency assessment. Four major tools including BREEAM and LEED have been assessed. Literature shows that most of the tools developed have focused primarily on environmental aspect of sustainability to the detriment of economic and socio-cultural issues. The prioritisation of economic and socio-cultural issues remains significant in developing countries. In this regard development of an energy assessment tool should be done in cognisance of these variables. Literature has shown a plethora of building energy indicators for efficiency assessment. Whilst this exist, not all indicators are relevant to a particular region. This is influenced by major region characteristics including level of technology, policy framework and differing climatic conditions. The chapter has also identified key building energy indicators for energy efficiency assessment. The lack of building energy standards is a critical limitation for the use and uptake of various building environment assessment tools. This is exacerbated by paucity of literature in building energy within most developing countries especially in Africa. As a result, a viable starting point need to be created for the development of a building energy assessment tool. To achieve this, a conceptual framework for the development of energy assessment tool has been presented. What follows next is the research design and approach adopted for the study.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 INTRODUCTION

The selection of a suitable research method is a major determinant in the success or otherwise of any research activity (Fellows and Liu, 2008). In this chapter, the research design and methodology chosen is presented. An overview of research paradigms and strongly related research approaches are provided. Explanation is provided of the chosen research instruments for data collection and analysis which includes the Delphi technique, the Delphic Hierarchy Process (DHP) and the Simulation study. Each stage is proposed towards achieving the overarching aim of the study.

3.2 RESEARCH PARADIGM

Yin (2009) encapsulates research design as the logical arrangement that links the collated empirical data to the initial objectives of a research and consequently to its conclusions. The multifaceted and multi-disciplinary nature of building energy assessment studies reflects its un-integrated theory. Thus, building energy assessment often draws on a wide range of theoretical bases from the social and natural sciences. Researchers are met with a difficult problem in clearly articulating an appropriate research design due to this multiplicity of diverse theoretical bases.

Many considerations come to play in the decision to select a suitable research methodology for a particular study. Most influential among those considerations is the defining aim of the research study and the kind of data type that have to be collected. The researcher is confronted with two broad research methodologies which must be deliberated upon in the subsequent selection of the appropriate one for the particular study. The research methodologies can be categorized as quantitative and qualitative. However, a use of either one or a combination of both is not uncommon in literature as far as the adopted approach is adequate in answering the research questions.

Research methodology is not developed in a vacuum. Various paradigms guide and inform a given research in the selection of the appropriate research methodology (Liu, 2008). Paradigms provide insights into the way researchers seek to comprehend and make sense of reality (Maguire, 1987). Paradigm shapes the way researchers perceive the research methodology adopted and the techniques to be used. Two main research paradigms dominate literature: positivism and interpretivism (Oates, 2006). In positivism, social phenomenon is assumed to follow natural laws and thus quantitative logic can be used. The scientific method employed avoids the inclusion of human influence in establishing the meaning of reality and as such, prevents researchers' bias (Guba, 1990). On the other hand, interpretivsim assumes that social phenomenon does not follow natural laws but it is constructed based on peoples' interaction with their environment (Walliman, 2001). This thus assumes the use of qualitative logic. The use of these paradigms is influenced by the ontological, epistemological and axiological assumptions underpinning the research (Keraminiyage et al., 2005)

Epistemology refers to the nature of knowledge and looks at how knowledge is created (Saunders et al., 2009; Pathirage et al., 2005). Epistemology provides the appropriate knowledge base that can be used to explore the research under study (Saunders et al., 2009; Pathirage et al., 2005). The ontological assumption looks at the nature of reality (Johnson and Duberly, 200) or idealism (Gummesson, 1991) influencing the phenomenon. Two views are seen through ontological study: realists view that research reality is a predetermined structure whereas idealists assume the view that different perceptions are perceived by different observers (Pathirage et al., 2005). Axiology is associated with value driven approach of the research and seeks to answer questions on whether the research philosophy surrounding the reality can be examined by an objective criteria or subjective criteria (Easterby-Smith et al., 2003). Consequently, the decision on the epistemology to use is greatly influenced by the ontological consideration and guided by the axiological positions of the research question. Therefore, the next section presents discussions on the ontological dimensions and its resultant effect on the chosen research methodology as well as the research epistemological considerations.

3.3 RESEARCH APPROACH

This sections stresses on the two main primary research approaches in relation to the above paradigms. Extant literature shows a clear difference between quantitative and qualitative research approaches (Yin, 2011; Liu, 2008). Kent (1999) averred that positivist's research is guided by principles such as; only phenomena that are observable are used to validate knowledge; use of systematic observation through the accumulation of verified facts to arrive at a scientific knowledge; and the process is judgment free. A positivist's research uses quantitative methodology to explore variable relationships. Quantitative methods are characteristically related with the natural science that explores natural phenomenon. Research findings are presented using approaches that stress on explicit, exact, scientific and formal procedures (Sarantakos, 2005). Quantitative researchers rely upon mathematical based approaches; numerical and statistical measurements to explain social science phenomenon.

Walliman (2001) explains that quantitative methodology employs a series of steps in the research process normally comprising postulating the research problem, positing research hypothesis, definition of variables involved, sample description, data collection and subsequent analysis of data and presenting findings arising from the process. In conducting a quantitative research, a number of steps have to be followed. These include firstly, identifying the research problem; generating hypothesis, variable definition, sampling and data collection using standardised approaches, data analysis, report of findings and examination of the set theory by either confirming or denying hypothesis (Henn et al., 2008; Walliman, 2001). The most commonly used quantitative research includes experimental studies, survey based studies, simulation studies.

In contrast subjectivists view reality with the involvement of people in the creation and modelling of fact and information (Jean, 1992). Subjectivist epistemology explores research with the object of study contributing less to the meaning of reality but more from the subject (Crotty, 1998). Research methodology associated with subjectivists is the qualitative approach which typically associated with social and cultural investigations. Social science phenomenon is studied systematically under the qualitative research process with the aim of understanding the various aspects associated with people, social and cultural problems (Myers and Avison, 1997). Examples of qualitative research include ethnography, grounded theory, case studies and action research.

Cases arise where the two methods may be employed to make up for the inherent weakness in each method (Amaratunga et al., 2002; Tashakkori & Teddlie, 1998). A combination of the above methods is known as a triangle method approach/triangulation also referred to as Mixed Method or pragmatism (Tashakkori and Teddlie, 2003).

Advocates for using the combined methods level arguments against the forced option of selecting between positivism and constructivism as certain circumstances may make using one particular method in isolation inappropriate and not adequate enough to provide a suitable answer (Tashakkori & Teddlie, 1998). Many advantages accrue from combining these methods; a multidimensional insight is provided on the research problem. This aids in having a deeper understanding and better analysis of the situation (Mangan et al., 2004), which as well is inclusive of the compelling points to be considered for contemporary research.

This methodological approach comprises a process which involves utilizing more than one research method to analyse a given data. Bryman (2006) explains that there are four basic techniques for this: (a) Triangulation which is used in parallel quantitative and qualitative methods; (b) Explanatory which involves sequential use with quantitative proceedings; (c) Exploratory sequential used in reverse order; (d) Embedding one type of method to supplement other techniques. This study in hand employs an exploratory mixed methodology approach due to the natural fluidity of the field of sustainable assessment methods as it includes a wide range of criteria from different ecological and economical dimensions (Ding, 2008)

3.4 JUSTIFICATION OF MIXED METHOD APPROACH

The two main research methods, quantitative and qualitative, both have inherent weaknesses and strengths. Critics of quantitative methods posits that such methods lack contextual realism whereas qualitative methods have a weakness of not being able to study with a level of accuracy and is criticized for inefficiency in providing accurate study of variable relationship (Sarantakos, 2005; Tashakkori & Teddlie 2003). Yin (2009) asserts that quantitative methods are tailored for addressing "what" and "how" questions, whereas qualitative methods are more appropriate for answering questions of "how" and why things occur. In developing an energy assessment tool for Ghana, the use of only one approach would be limiting. This is due to the non-existence of any energy assessment tool; a viable starting point needs to be created and this must be from previous energy assessment tools whilst incorporating expert opinion.

This requires the use of an approach that combines the strengths of both qualitative and quantitative methods, i.e., a mixed method approach. This approach provides the researcher with the advantage of discovering and justifying key components within a particular study. For example, the use of qualitative research provides the necessary realism and depth of information for hypothesis formulation and theory building due to its involvement of people (Tashakkori & Teddle, 2003). Qualitative study gives the researcher the information depth provided in detailed data rich for his interest. By using techniques such as the Delphi survey and data review, the contextual nature of the research question was captured. It is essential to take notice of the fact that in spite of the gathering of qualitative data in the first two stages of the research, the analytical approach adopted was skewed towards the positivist paradigm due to the research interest.

Further, the adoption of a Mixed Method Approach enabled answers to be provided to research problems that would not have been answered using just one single approach. The method built a stronger case for conclusion through convergence and verification of findings. It also made it possible for a holistic knowledge to be provided and this is necessary to inform both theory and practice. This approach provides answers which were of wide range and broad due to the multiplicity of research questions used. The study adopted a synthesis and analysis of building energy assessment methods with the Delphi Technique which was combined with both the DHP and a simulation based study in the current research. The use of these methods has been conducted by similar studies for example Alyami et al. (2014) in developing a tool for the Saudi Arabian environment.

3.5 RESEARCH DESIGN

It has already been shown that the research design links the collated empirical data to the primary research objectives (Yin, 2009). The next step after selecting a suitable method based on the necessary philosophical paradigm is to decide on the research design. The selected research design will consequently influence the selection of research instruments to be employed (Sarantakos, 2005). Guided by the aim and the research objectives, the decision on the research design has to be made. Nikolau et al. (2009) posited that the lack of building energy consumption detail is a critical impediment in analysing and drawing conclusions on the building stock with regards to their energy performance. The research objectives explores a sustainable and ecological context commonly regarded as multi-dimensional issue (Ding, 2008).

Following the discussion, three major issues need to be deliberated upon in choosing the appropriate research method to meet the research objectives raised in the study. Firstly, the research method must be able to provide a viable starting point and consequently identify key variables associated with energy assessment tool. Next, the research method should be able to ascertain the correlation between the variables identified and how energy efficiency is predicted by these variables. Lastly, they must allow for detail data to be collated and analysed showing how the identified variables can be used in determining energy efficiency.

Based on the above considerations, the study adopted the Mixed Methods research (quantitative and qualitative combined) approach as previously stated, discussed and justified. This method provides a robust procedure of meeting the research aim and objectives. Subsequently, to meet the stated objectives of the study as outlined at the outset of the research, the following strategies were adopted:

Objective one: To assess methods used in building energy performance assessment towards the development of a conceptual framework - Consolidated criteria from well-known tools: From the comparative study of the various assessment methods, areas of convergence and distinction are identified. Cole (2005) averred that this presents a viable starting point for the development of new assessment method. To well consolidate the criteria, it is imperative to identify regional variations due to the said unique regional characteristics.

Objective two: To identify applicable criteria to form the dimensions of the building energy assessment method - Appoint panel of experts; it is key that expert opinions be selected from different fields such as government, academia and industry (Chang et al., 2007). Conduct study with Delphi technique: previous studies have shown that the development of an effective building environmental assessment criteria usually requires a consensus basis approach (Chew et al., 2008). The Delphi technique is the most applicable approach in this respect, in light of its usage of a three-round system based on wide-ranging questionnaires so as to settle on the criteria that has the best applicability.

Objective three: To propose a grading system underpinned by determined weighting coefficients for the building energy efficiency assessment method - Conduct study with Delphic Hierarchy Process (DHP): The DHP will play a cardinal part in the development of a potential weighting system that is not only able to reflect local needs but also prioritise building energy aspects, government policy and both economic and social issues.

Objective Four: To propose and validate a tool for building energy efficiency assessment in office buildings in Ghana - Building energy data studies: various questions such as the average energy consumption need to be answered in the development of the new tool. In order to develop the tool a grading system underpinned by the weighting coefficients will have to be proposed. This can be answered through research work on building energy consumption profiles, the general characteristics of the building, data both on the weather and the environment (Lee and Kung, 2011). Building energy data studies such as a simulation based study will provide the required framework to properly develop the tool.

The following section gives explanations as to the details of the methodology adopted in meeting the stated objectives of the study.

3.6 STAGE ONE: COMPARISON OF WELL-KNOWN METHODS

Previous researches show that the comparison method has been used for the development of tools in various countries (Poston et al. 2010; Ali and Al-Nsairat, 2009; and Zuhairuse et al., 2009). Most environmental assessment methods have all been designed to fit a particular region and certain environmental factors might hamper the direct usage of any current environmental assessment tool or method (Cooper, 1999; Crawley et al., 1999). Cole (2005) opined that it is imperative that the initial stage of a new environmental tool development is a comparative analysis of establish methods. Hence, the first stage of BEEAT development was a comparative analysis of the most significant and internationally recognised environmental assessment methods (Alyami and Rezgui, 2012). Different tools are compared to identify gaps, parallels and differences that may exist between them. The comparisons orientation is skewed towards the development of the energy assessment tool for Ghana.

The objective for which differing tools are chosen is to investigate the impact on the countries from which they originated from. The presentation of every tool constitutes an aspect of a world leading to diversity in environmental, economic, social and cultural aspects.

So as to cover an extensive scope of system criteria, including the provision of an all-inclusive comparison, a number of tools have been selected on the basis of the number of criteria listed as follows:

- The dominant;
- An international utilized tool;
- The context of the chosen tool determined by the country it originated from.

The selection of these methods relied on the credibility of the organisations which launched and operated them and their success in the marketplace. Two main primary sources of information were used for the comparative analysis: related publications that analyse and compare their components and technical manuals of the selected methods. As indicated in the literature review, the selected methods were BREEAM, LEED, SBTool and CASBEE and their components were compared in order to determine key similarities and differences among their underlying approaches, thus establishing the possible classifications and criteria of a new assessment method. A number of areas were assessed and this included the scope of assessment, assessment method and the various ways in which calculation was computed for the tools.

The multiplicity of building assessment methods poses a difficult challenge in comparing different tools due to various aspects that have to be taken into consideration (Poston et al., 2010; Papadopoulos and Giama, 2009; Haapio and Viitaniemi, 2008a). Thus, to give the specific comparison of the designated assessment methods, the research categorises the criteria of every rating tool into three classifications based on the three dimensions of sustainability: environmental, economic and social.

3.7 STAGE TWO: DELPHI TECHNIQUE

The Delphi technique was developed in the early 1950's principally by Dalkey and Helmer (Miller, 2006) at the Rand Corporation, whilst undertaking a study for the US defence industry. The researchers conducted a structured survey for confidential military objectives in order to find the consensus of opinion of a group of experts which has the greatest reliability through a series of exhaustive questionnaires intermingled with controlled opinion feedback (Linstone et al., 1975). Since then, the Delphi technique has become a method with extensive usage and acceptability for the achievement of convergence of opinion regarding the real-world knowledge solicited from professionals within specific topic areas. The technique is designed as a group communication process which has the objective of organizing comprehensive examinations and discussions of a particular issue for the purpose of goal setting, policy investigation, or predicting the occurrence of future events (Ludwig, 1997; Turoff and Hiltz, 1996; Ulschak, 1983). Common surveys try to identify "what is," whereas the Delphi technique attempts to address "what could/should be" (Miller, 2006).

3.7.1 Delphi Characteristics

The Delphi technique is structured in a way to solicit the opinion of experts on complex issues by structuring the communication amongst them (Limestone et al., 1975). The structure in this technique helps to achieve consensus and brings about stability in the group judgment even with subjective issues. The technique in the Delphi is founded on four basic fundamental principles (Rowe and Wright, 1999; Alder and Ziglio, 1996; Linstone and Turoff, 1975);

Iteration: The Delphi method is characterized by participants taking part in more than one round of a questionnaire survey based on the principle of a multi-stage process. This multistage process of iteration allows participants to view the responses received from the rest of the experts. This provides the opportunity to rethink their previous judgements and if need be form new ones.

Anonymity: The Delphi process maintains the anonymity of the participants, eliminating any influence due to the position and/or social dominance of some experts taking part in the process. This affords participants the opportunity to make their opinions without any influence from other experts.

Controlled feedback: The Delphi method allows for the control of data collated and exchanged amongst the participants. After responses are received from the participants, they are subjected to the necessary analysis and this dovetails into the next round of the Delphi. This expedites the development of answers directed towards the particular study, eliminating any personal debates amongst participants.

Statistical group responses: Due to the complex nature of issues involved in the Delphi process there is the need for the use of an appropriate analytical tool not only to distil the intricate nature of the answers but to make sure it is a true reflection of the overall group judgment. Consequently, the Delphi process adopts a number of statistical indices including Mean, Median and Inter-Quartile Range (IQR) to achieve this purpose.

3.7.2 Justification for Using Delphi Technique

The focus of the study is towards the development of a building energy assessment tool. This focus involves different topics and necessitates the use of more than one research method. The initial step taken in the study has been to review existing methods with the aim of finding a basis to develop a novel tool. The next research method has been the adoption of a consensus based approach to create an applicable building assessment criteria. This approach was motivated due to the multi-dimensional nature of the research topic exploring both sustainable and ecological contextual areas (Ding, 2008). Chew and Das (2008) posit that the drive for scientific evidence within such subject requires the use of a consensus-based approach in arriving at a more appropriate building energy assessment method. This consequently led to the selection of the Delphi method.

3.7.3 Delphi Typologies

Already Loo (2002) has described the Delphi method as a prominent research instrument designed towards finding consensus on complex subjects. The Delphi method is characterised by a multi-phase survey in which group opinions are collected anonymously in rounds with the key objective of conducting more rounds until consensus is achieved on a criterion (Landeta and Barrutia, 2011; Dalkey, 1972; Dalkey, 1969). After the first use of the Delphi, the method has evolved. Many modifications have been created to handle particular inherent weaknesses and also provide for a tailored method for specific situations and goals. Currently, many versions of Delphi techniques exist, including Ranking Delphi, Decision Delphi and Classical Delphi.

Classical Delphi follows the line of the first developed Delphi and focus on gaining expert views to reach consensus on specific subjects. Through a succession of rounds, data is collated and outcomes fed back to experts in subsequent rounds. It is common to have two or more rounds in the procedure. The procedure comes to an end after consensus is achieved in a round. Experts complete questionnaire in their time with social pressure being eliminated due to anonymity used in the interaction procedure. Mostly, conventional post is used as a medium of communication (Linstone et al., 1975).

Decision Delphi is similar to the Classical Delphi but differs as it concentrates on informing future reality as against the classical method of merely forecasting it (Rowe and Wright, 2011). This focus influences the selection of participants who should be stakeholders and have a keen interest in resolving the particular problem. Hasson and Keeney (2001) argued that the decision Delphi is formed and does not border on definition or pre-arrangement. The nature of issues in this process necessitates the use of repetition and management of expert's response. Despite the fact that there may be variations in the number of rounds used, it is not a requirement that three rounds be used (Hasson and Keeney, 2011). The complex nature of questions investigated makes absolute confidentiality impossible and quasi-anonymity is used. Here, name of participant are included in the research however, responses of individuals are kept confidential (Linstone et al., 1975).

In **Policy Delphi** reaching consensus is not a key objective; however iterative rounds are utilized in gathering data from professionals. The goal here is the acquisition of varying views from professionals on a particular topic mostly policy oriented. Mode of communication may include group meeting and gathering members together which seems to contrast the classic Delphi approach however, the use of repetitions may be planned as compared to the Classic

Delphi. Usually, the first round would involve gathering data without meeting together as a group. This provides for confidentiality. The stages after that lead to absolving the confidentiality (Hasson and Keeney, 2011, Linstone et al., 1975).

In the **Ranking Delphi,** the prime objective is the identification and ranking of key issues using a panel of experts. The common principles used in other types of the Delphi are also used. However, it usually takes three rounds mostly comprising brainstorming in the first stage, narrowing down and finally ranking in the last stages. In answering the study questions this type of the Delphi seem most appropriate as it embroils the development and customisation of an energy assessment method. A further reason for selecting this type is that its goal is to identify and rank key issues using a panel of experts, unlike other versions that simply require the participation of any concerned individuals (decision makers or lobbyist). Schmidt (1997) and Okoli and Pawlowski (2004) provide a comprehensive explanation/guideline of how to carry out this type of Delphi technique.

Other categorisation of the Delphi technique includes the medium of time used in capturing answers from the participants. This may be in either real time or the conventional approach, i.e., answers are provided over a period of time afters questions have been delivered. The key features of conventional Delphi encompass assured anonymity through the distribution of questionnaires, which can be completed individually by professionals in the absence of social intrusion from group meetings. Features of the conventional Delphi are repetitive consultations depending on groups of professionals and the provision of maintained feedback, as summarised from previous rounds (Rowe and Wright, 2011; Hasson and Keeney, 2011; Linstone et al, 1975). Real time Delphi is not applicable in this study because it requires professionals to meet to resolve an issue. This is difficult for an individual PhD student to achieve, and it also shortens the time allocated to the consultation to one day, which does not meet the requirements of the ranking Delphi.

3.7.4 Delphi Technique in this study and Selection of the Delphi Panel

The Delphi type adopted for the study was the ranking Delphi technique. The four basic features of the Delphi survey- anonymity, iteration, controlled feedback and statistical group - is largely seen in the ranking technique, boosting its robustness (von der Gracht, 2012). The predominant aim of the Delphi study was to ascertain an appropriate method to form the dimensions of the building energy assessment method. Thus, the expected outcome of the Delphi study was to firstly come out with a suitable method for energy assessment and secondly produce a set of criteria that can be used for assessment of building energy. The Delphi technique was utilized in arriving at the various factors that influence energy efficiency standards in buildings. Organized in two rounds, key actors in the field of building energy were consulted in Ghana to arrive at an appropriate energy efficiency method. Rowe and Wright (2011) aver that the choice and selection of the Delphi panel is a critical step to achieving a successful Delphi study. Following in the steps of a successful Delphi, particular procedures have been adhered to in order to ensure panel suitability in relation to both size and composition
(Okoi and Pawlowski, 2004; Dalkey & Helmer, 1963). Panel members may vary from 10 to 50 members however the focus should be patterns of responses being clearly seen whilst avoiding complications arising from large panel size (Okoli and Pawlowski, 2004; Delbecq et al., 1975).

Concerning panel size, authors agree that the primary goal is to select participants with the requisite expert knowledge and experience in the field in question and not necessarily having a large panel size (Loo, 2002; Dalkey and Helmer, 1963). A similar study by Alyami (2015) selected 30 members for the panel in the development of a sustainable assessment tool for Saudi Arabia. Based on the foregoing the Delphi survey used in this research looked at a target number of 30 members for the panel. The panel comprised professionals from the academia, government and industry. The selection of the Delphi panel was directed by the recommended criteria used in the study by Alyami et al. (2013). These were;

- Academic specialists in the area of Building Energy;
- Decision-maker, manager, or practitioner in the field of sustainable and green building;
- Individual with practicable experience with adequate know-how concerning the Ghanaian energy built environment; and
- Professional with a degree of influence relating to the adoption of the consequent methodology.

3.7.5 Composition of Panel

The research panel comprised professionals from various sectors including experts from the public sector. The key objective of consulting this particular group of experts is to provide an up-to-date criterion that reflects construction industry trends, as well as the present and forthcoming policy of Ghana as regards building energy. Policy is of essential significance when establishing sustainable appraisal techniques. Professionals from the building sector constituting the main members of the Delphi panel, were identified within the area of construction and environmental development, and more significantly, have experience in sustainable assessment systems, such as LEED and/or BREEAM. It is important to note that it was necessary to encompass participants who are conscious and conversant with the tactical aims and operation of sustainable assessment techniques.

Experts from Ghanaian academic institutions also participated in the study. These included lecturers from the domain of sustainable development. The aim being to supply pertinent criteria to encourage the advancement of sustainability, based on their awareness of sustainable construction within the area. International professionals with experience concerning the strengths and weakness of the available techniques for appraisal and additionally, those who have worked closely with such structures were also included. Including such individuals brings to question their understanding and appreciation of the Ghanaian environment. It was imperative to provide such individuals with a background of the current situation within the contextual environment to aid them in making a suitable decision. Consequently, a brief summary of the main characteristics and peculiar environmental traits of the Ghanaian energy environment were furnished to these individuals. The raison d'etre of this international professionals' role was to address the general and specific limitations of established instruments. As a result, when viewing the profile of the panel and their collective experience, it is evident that the results from this research are proposed to meet the requirements of individuals from a variety of backgrounds. Their contribution was consequently instrumental in contributing to the existing body of knowledge.

3.7.6 Development of the Delphi Questionnaire

The questionnaire was intended to permit the professionals to give their judgments, with room given for them to make additions, removals, critique and justification for their answers. Also, a pre-test on the questionnaire was circulated among academics before embarking on the actual Delphi surveys. Three academics in the field of building energy were willing to partake in the pre-test and thus formed the main nucleus of the pre-test respondents. These three individuals were later engaged in the main Delphi survey. Their comments and suggestions were incorporated to further improve the questionnaire and ensure clarity of the questions asked. Initially there was no background provided for the international experts for the Delphi survey. From the pre-test is was deemed necessary to provide a brief backdrop of the study area to enable the targeted experts in responding to the questions posed. To begin with the Delphi survey, identified criteria from the literature review have been fused together from a comparative study of renowned schemes as adapted from Alyami and Rezgui (2012). These identified criteria from the literature review were then placed in the questionnaire for the target audience to rank starting from not applicable to very important (See Appendix 2). A seven point likert-type scale is adopted and used. The aim being to determine the applicability and suitability for the Ghana context.

3.7.7 Delphi Data Collection Process

The collection process comprised the use of both an online tool and physical data collection. Both approaches were adopted to complement each other's weakness. The online survey tool and the physical data collection proved to be enormously effective, facilitating the collection of the survey data within a period of six (6) months in two distinct Delphi rounds.

It should be stated here that many other decision making tools/multi criteria decision-making exist, each having their strengths and weakness and tailored for a specific purpose. Considering the purpose for the development of the tool, the choice of AHP became quite obvious.

3.7.8 Application of the Delphi Survey

Following a wide-range review of extant literature, the questionnaire was developed. Questions relating to various approaches exploring 5 major blocks of building energy assessment methods were designed. The questions were pieced together structurally and constructively to form the various rounds of the Delphi survey. In the principle of the ranking Delphi technique the first round was set as a brainstorming and narrowing down of the various approaches to energy assessment. This round adopted the use of both closed and opened ended questions. The questionnaire dealt with information on categories where respondents where tasked to rate based on a priority scale. Questions were based on proposed categories with various options provided to investigate participant's agreement or disagreement. The degree of consensus reached among the experts was measured using descriptive statistics. This form of statistics has been found to be the most suitable for the measurement of consensus among participants.

3.8 STAGE THREE: DELPHIC HIERARCHY PROCESS

Prior usage of the Delphi method and AHP to resolve complicated challenges underlines the probability of employing the both methods as systematic management tools (Kim et al., 2013). This helps in dealing with innovation planning in public R&D comprising complicated missions like organizing internal R&D, financing external R&D projects and providing support for scientific communities (Kim et al., 2013). The concept of the Delphi method has been extensively employed in additional complicated decision resolving issues associated with technological modification, economic and social pressure (Amer and Daim, 2011; Luque, 2011). An example is the assessment of the crucial factors relating to the new product enhancement, and choosing probable novelties for national system of innovation (Amer and Daim, 2011; Luque, 2011).

Though the Delphi method is a useful instrument for brainstorming and evaluating crucial factors, results from the Delphi may require additional research in managing moderate consensus among professionals. The AHP which was initially instituted by Saaty, can be the supplementary research for a Delphi study (Filtvedt, 2012). The AHP is an extensively used instrument in multi-criteria decision-making. The principle of the AHP is that a decision is broken down into a hierarchy structure to enhance decisions to be made more manageable and easier (Filtvedt et al., 2012). Additionally, the Delphi consultation may be implemented prior to the AHP to refine a set of factors. This increases the validity of the AHP as Joshi (2011) averred that in an AHP-compared set, the number of factors should be plus seven or minus two. It is very usual to use AHP to choose technologies in modern scientific research.

A number of studies abound in this direction. For example, a study by Joshi (2011) which focused on developing a based benchmarking framework using the AHP. The framework was for the purposes of evaluating the performance of a firm and further prioritize alternatives within the said firm. Another study by Kim et al. (2013) used the Delphi-AHP methods in choosing the primacies of a waste electrical and electrical equipment within the field of waste management. It must be reiterated that especially in the energy sector, numerous applications of the Delphi and AHP method exist. For the selection and prioritizing the choice of a renewable energy technology, Amer and Daim (2011) adopted the AHP model. This study was conducted in Pakistan. Further Daw et al. (2013), combined the Delphi and fuzzy AHP to select technology of late-starters in the energy-smart photovoltaic industry. The wider framework of this selection was to serve as a guide in industrial technologies procurement and resource allocation. Alessandro (2013) presented a framework that comprised a multi objective model for sustainable energy supply and evaluated four Combined Heat and Power (CHP) plants and two types of photovoltaic plant (mono-crystalline and poly-crystalline). The AHP method was made use of in the selection of the most appropriate alternative from amongst numerous efficacious solutions in the third stage of the proposed model.

In regard of this, the Delphi and AHP method are principally used to select the general direction of the technical route in the energy field or determine the optimal boundaries for experimentation. Albeit, it is essential to evaluate each particular technology which constitutes the industrial chain when choosing the best technical route, nevertheless limited efforts have been made on this front per the literature review. In this study a Delphi-AHP (DHP) based methodology is adopted to create a qualitative and quantitative measurement system, when choosing and prioritizing vital indicators for predicting building energy efficiency. To achieve this, the first round consists of question posed to identify the indicators of building energy efficiency. In the second round of the Delphi, feedback of the first round is given to the respondents and subsequently questions posed using Saaty's scale are provided. This enabled the comparison of the indicators using the analytic hierarchy process. What follows next is how the AHP was applied within the Delphi-AHP method.

3.8.1 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach permitting decision-makers to model a complicated challenge in a hierarchical structure. The initial step in AHP consists in subdividing a research problem into smaller interrelated components which are then composed into a comprehensive and coherent framework. The AHP framework or (model) is usually developed to breakdown complex problems into manageable elements. This in turn established different hierarchal levels. The first level of hierarchy model is the central issue that determines the scope of the subject matter. While the lower levels are the indicator by which the research problem can be evaluated. AHP however draws its strengths form converting the subjectivity of the research problem into mathematical form. In other words, the assessment of relative importance, likelihood or preference are analysed and then reflected in a set of priority ratio scale and overall weights. These processes are generated from conducting pair wise comparisons that estimate the relative importance of a certain parameter with respect to another parameter

3.8.2 Justification of using AHP

The character of building performance and associated ecological factors continue to result in dispute. To date, no single-dimensional technique has been accepted as offering precise outcomes upon which to measure the effect of a constructed area on ecology (Ding, 2008). Thus, the notion of sustainable development has to come to establish a basis for best suitable practice in human communication with ecology, inside multi-criteria techniques, ecological, social and economic viewpoints (Lee, 2012), building environmental assessment techniques appear to encourage the application of sustainability and establishment values (Cole and Jose Valdebenito, 2013). The identification and promotion of best practice in the construction industry is a key strength of sustainable and ecological appraisal programs (Berardi, 2012).

For a program to be well-developed, a dependable weighting structure should be planned to accept and institutionalize the significance of a wide variety of sustainable construction considerations (Ali and Al NAsirat, 2009). Thus there are several different evaluative methods created on the basis of available construction appraisal structures (Kajikwaw et al., 2011). These methods were impacted by numerous elements such as regional and geographic differences, climatic consideration, socio-cultural and economic elements. This is why every area requires its own structure, to assess whether the construction industry is implementing appropriate sustainability practices (Gou and Lau, 2014).

The AHP method is a well-known MCDM technique for providing applicable weighting systems in various scopes, it is an efficient technique for determining the weighting structure for construction appraisal programs in various nations. For example, a study was conducted with the intention to advance ecological appraisal instruments based on the local Jordanian context (Ali and Al Nsairat, 2009). Following analysis of global building assessment methods and recognising criteria appropriate to the Jordanian setting, AHP was used to order an appropriate weighting structure. The result of this endeavour was the SABA Green Building Rating System (Ali and Al Nsairat, 2009). An additional instance comprised the element of GBTool/SBTool, and was implemented in the Taiwan setting by Chang et al. (2007); cultural and regional elements were altered and prioritised to suit the Taiwan built environment. In this adaptation process AHP was a key tool resulting in the weighing system (Chang et al., 2007). A related instrument with similar application to the AHP method, is the Analytic Network Process (ANP) (Cheng and Li, 2007). AHP and ANP order means of quantifying immeasurable elements by employing pair wise comparisons with decisions that signify the prevalence of one aspect above another with regard to a shared feature (Chang et al., 2007). ANP is a simplification of AHP. Numerous resolution challenges cannot be arranged sequentially, as they concern communication and reliance on higher extent aspects in a sequence of lower extent aspects (Saaty, 2009). Although the AHP signifies a structure comprising a unidirectional sequential AHP association, the ANP permits intricate associations amid resolution extents and features (Saaty, 2006). However, AHP is one of the best approach to use in the development of a weighting system, as many publications substantiated (Ali and Al Nsairat, 2009, Chang et al., 2007, Chew and Das, 2008, Lee and Burnett, 2006, Berardi, 2012, Wong and Abe, 2014), this is because the dimensions are arranged hierarchically to meet a common goal (at the top of the hierarchy). They depend on meeting that goal, and do not implicate independent criteria that might be considered as multiple goals, such as are developed by ANP (Grener, 2012).

3.8.3 The Weighting System

The construction of a hierarchical structure is a key step in AHP that seeks to simplify the research problem. It provides different levels in which the research issue is decomposed into manageable elements. This, in turn, aids the decision makers, who carry out the AHP study, to understand, focus, communicate and organise the research issue. AHP model can be presented in different diagrams but all share one concept; the most common hierarchy form of the research problem. The model used in this study is divided into three levels: the highest level of the hierarchy represents the goal of the research problem; the second level represents evaluation categories or criteria; and the third level which represents the decision alternatives. According to Saaty (2006), the effectiveness of the hierarchical model is used to illustrate how changes in priority at the upper level influence the priority of elements in the lower level. Thus, a logical construction of such a model facilitates the identification of interrelationships and connections among the components of a research problem. As sustainable building assessment criteria are normally thought to be multi-dimensional criteria (Ding, 2008), scientific proof indicates that a consensus-based approach is most suitable for the development of all-inclusive and efficacious building environmental assessment categories and criteria (Chew and Das, 2008).

Furthermore, a reliable weighting system must be designed to acknowledge and formalise the degree of importance of these categories and criteria (Cole, 2005; Lee et al., 2003). Therefore, Analytic Hierarchy Process (AHP) is utilized to develop a suitable weighting system, for the approved categories that resulted from Delphi method.

3.8.4 Pair Wised Comparison (PCs)

The Pair wised comparison (PCs) method is a major stage of AHP. It involves a mathematical structure (Matrixes) that is built upon paired comparison of each category over another (Saaty, 1994). It utilises experts' judgment (intensity of importance), following Saaty's nine-point scale.

In order to achieve a pairwise comparison firstly two criteria are evaluated at a time in terms of their relative importance. Index values from 1 to 9 are used based on the Saaty's scale. If criterion A is exactly as important as criterion B, this pair receives an index of 1. If A is much more important than B, the index is 9. All gradations are possible in between. For a "less important" relationship, the fractions 1/1 to 1/9 are available: if A is much less important than B, the rating is 1/9. The values are entered row by row into a cross-matrix. The diagonal of the matrix contains only values of 1. The right upper half of the matrix is filled until each criterion has been compared to every other one. If A to B was rated with relative importance of n, B to A has to be rated with 1/n. The next step is to calculate the weights of the individual criteria. First, a normalized comparison matrix is created: each value in the matrix is divided by the sum of its column. To get the weights of the individual criteria, the mean of each row of this second matrix is determined. These weights are already normalized; their sum is 1. The last step is the calculation of the consistency resulting from the weights.

3.8.5 Analysis Stage (Synthesis and Consistency)

The extraction of the weighting system involves a number of calculations and analysis of the input data. It is also significant, in decision-making procedures, to know how reliable and valid those decisions are. In AHP, the overall consistency of judgment is measured by means of Consistency Ratio (CR). Consistency ratio is calculated to determine the degree of contradictions in the decision makers' judgments (Saaty, 1990). As Saaty states, a CR value less than 0.1 is acceptable; or else, a new pair-wise comparison matrix must be reconstructed, which will reflect reliable weight (Saaty, 1990). In order to carry out a reliable AHP analytical stage, Microsoft Excel was utilised as the main analytical software that apply AHP calculation and analysis.

Inconsistency exists in most assessments, which could lead to incorrect results. A typical example of inconsistency in a paired comparison is as follows: A is more important than B, B is more important than C; however, C is assessed more important than A when comparison of the importance between A and C is made. The AHP method estimates the consistency beyond the above inconsistency, because it covers the degree of inconsistency, for instance, A has double importance over B, B has triple importance over C, then A should have six time the importance over C, other assessments of the paired comparison between A and C lead to inconsistency in AHP.

The method to estimate the consistency in AHP can be shown as follows:

1. Calculating the consistency index (C.I.) by Eq. (1):

$$C.I = \frac{\gamma_{max} - n}{n - 1}$$

Gamma: The maximum eigenvalue of a comparison matrix;

n: There are n rows and n columns in a comparison matrix (i.e. there are n indicators needing to be weighted).

2. Identifying the random index (R.I) of consistency. Saaty provided the R..I in Table 6, for n =1 -11, the sample is 500, for n =12 -15, the sample is 100.
3. Calculating the consistency ration (C.R.).

The C.R. is calculated in terms of the following Eq. (2). Saaty stated that a C.R. less than 0.1 is accepted (Saaty, 1990): otherwise, a new comparison matrix needs to be reconstructed to weight the indicators.

3.8.6 Application of the Delphic Hierarchy Process

The round one question was developed out of the results stemming from the review of pertinent literature. Within the Delphic Hierarchy Process, round one was set for the identification of the key indicators. This round adopted the use of both closed and opened ended questions with options provided for participants to indicate the inclusion or otherwise of variables not specified. Questions were based on proposed criteria with options provided to investigate participant's agreement or disagreement. The degree of consensus reached among the experts was measured using statistics such as mean, median and interquartile range. The results from the first round fed into the round two. The AHP questionnaire was administered in the second round of the DHP study. This enable in the developments of various weights for the identified building energy indicators in the first round of the Delphic Hierarchy Process.

3.9 STAGE FOUR: SIMULATION STUDY

In order to achieve the last objective a simulation exercise based on a case study is conducted. Dynamic thermal modelling was used to simulate a generic office building in the hub of Accra, Ghana. The office building was then again simulated based on best practice to serve as a reference building for the bases of comparison. A single case study was used and involved the analysis of a high-rise office based on the various identified categories and criteria from the Delphi and DHP survey. The specific aim being to make practicable the proposed grading system, exploring both its strengths and weakness. The approach used was the initial analysis of the building design and construction fabric and materials. As-built drawings including plans were obtained for the identified office. In addition, annual electricity bills for the selected building were also obtained from the facilities' management office of the building. This was followed up with an interview of occupants of the offices in order to understand how the building is actually used.

3.9.1 Criteria for Case Study Selection

Many reasons informed the selection of the office building. Firstly, the selected building needed to be a generic building reflecting current trends in office buildings with respect to high rise office building in Ghana. Consequently, the selected building should mirror typical office building in terms of occupant density, size and area.

Figure 3.1 Exterior View of RT Building

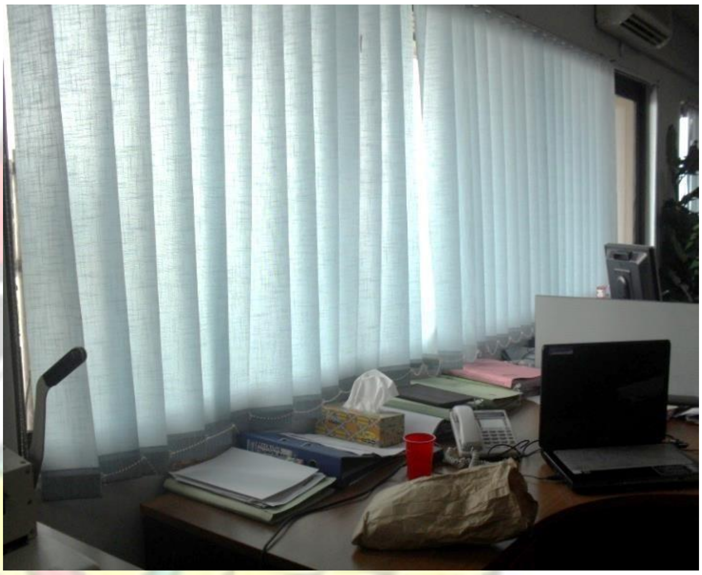

Figure 3.2 Interior View of RT Building

Source: Survey Data, 2015

Secondly, due to the inability to access data from the previous selected low rise office buildings, another requirement was the ability to obtain data with ease. This includes architectural drawings, construction details, occupant usage and if possible, electricity bills. Based on the above considerations, the selected case study was a high-rise office building located in the city centre of Accra known as the Ridge Towers (RT).

3.9.2 Case Study Description

The main reason driving the selection of Accra was due to its location, i.e., the hub of many business activities. As a result, many high-rise buildings are located in this region as compared to other regions in Ghana. The Ridge Tower building is selected and meets the above criteria stipulated located in the region. The RT building is host to varied multi-national organisations, having occupants with differing ages and educational levels. The orientation of the building is in the direction of the West-South East. The swastika symbol is the concept undergirding the design of the Ridge Tower. The total net area of each floor of the building is approximately 14.5 m² and is 15 storeys high. Figure 3.1 presents the glazing on the façade of the building. A recession is on the seventh floor which provides a protection for the glazing and also acts as a balcony. A section of this floor is occupied by the facility management company responsible for the whole building (Figure 3.3). The building is served by a centralized air-condition system. Thermostats are provided for the operation of the air-condition system. However, occupants are not able to access the thermostats as they are not allowed to change the settings by themselves. A typical office within the facility management company measures approximately 12.6m² in floor area. This office has no external shading devices provided. Occupants use internal blinds as a means of reducing the amount of solar entry into the spaces. It should be noted that these blinds are not automated and thus are manually operated by the users of the building. A typical office has a total of 40 watts of light used in the space (Field Survey, 2015). This may however differ depending on the size of the office space (Figure 3.2).

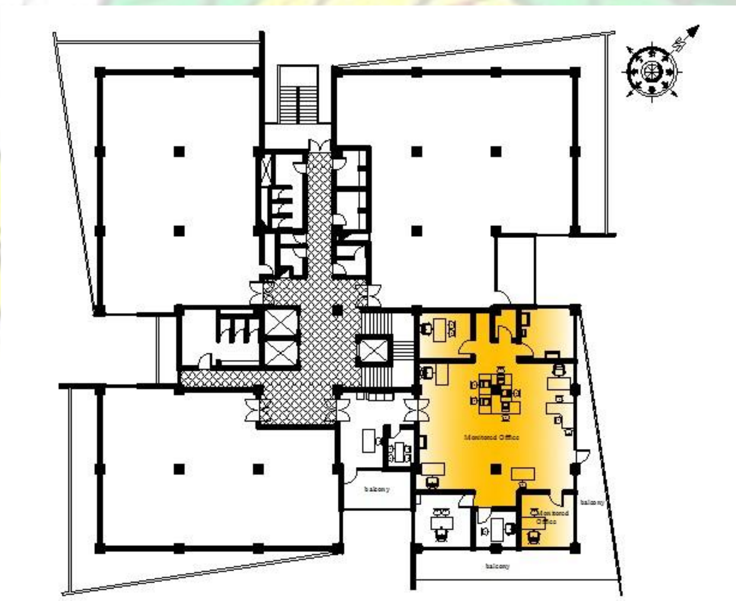

Figure 3.1 Schematic Plan of Offices on the 7th Floor in the R. T. Building.

Source: Survey Data, 2015

3.9.3 Data Collection

Three main sets of data were collated and this included the climatic data, information on the building parameter and how the building operates. Information on the building characteristics and parameters were collected between the period of about one year starting in May of 2012 and ended in April 2013. During this time the Accra Meteorological Department was successfully consulted for outdoor weather data. Due to lack of comprehensive data on outdoor weather information, segments of a synthetic weather file for Accra was identified and used. This approach has been used in previous studies within the Ghanaian context, see for example Amos-Abanyie (2012) and Koranteng et al. (2009).

Input data was drawn from the official architectural plans, knowledge of the building fabric as shown in the official construction plans and occupant usage data gathered from interviews regarding daily to weekly routines. In order to incorporate occupant behaviour into the model, it was necessary to create user profiles. The study further adopted data from a previous study conducted by Simons et al. (2015) on the RT building and used as a basis to create user profiles.

From this, it was possible to simulate hourly, daily, monthly and annual energy consumption figures. Further construction and thermal characteristics of the RT building are given in appendix 5.

Table 3.1 Base Parameters

Parameters	R.T.
Study Case Temperature(°C)	26
Occupancy Sensible (W/m²)	7
Occupancy Latent (W/m²)	1
Lighting loads (W/m²)	3

Infiltration-Air Change per Hour (h^{-1}) Day-Night	1/0.5
Equipment Sensible (W/m^2)	5
Window U_{value} ($W.m_{-2}.K_{-1}$)	2.8 (double glazing)
Window g_{value}	0,5
Thermal mass	Tiled Acoustic ceiling
Shading Options	Internal blinds

Source: Simons et al., 2015

3.9.4 Simulation Software Tool

To simulate and examine the energy consumption at the case study building, the DesignBuilder tool was employed. The tool provides advanced modelling tools in an easy-to-use interface. DesignBuilder has been checked and validated in accordance with the European Standard EN 15265 (DesignBuilder, 2012; EN ISO 13790, 2008). The software is user friendly and online support is easily available. Outputs from the DesignBuilder can easily be used in software like Microsoft Excel. The advantages mentioned above coupled with its integrated optimisation tool made the DesignBuilder the preferred software.

The DesignBuilder uses the EnergyPlus as its simulation engine. A major drawback of the EnergyPlus is the lack of a "friendly" graphical user interface and makes inputting data quite tedious and hectic. Designbuilder becomes useful here as the EnergyPlus has been incorporated within the DesignBuilder environment to allow for easy simulations. DesignBuilder has been specifically developed around EnergyPlus allowing most of the EnergyPlus fabric and glazing data to be fed into the software (Designbuilder).

3.9.5 Validation of the Simulation Model

Validating entails generating a model of the test component and performing simulations utilizing recorded climate data (Ryan and Sanguist, 2012). Furthermore, comparison is conducted against the test environment which has been measured to make sure that model predictions support data measured within an accurate range of operational conditions covering numerous days to many weeks (Strachan and Baker, 2008). When results from the comparison are almost the same, it generates confidence in the simulation program being correctly able to model the constituent features when incorporated into a one-to-one building. This procedure may be enriched by means of simulation for the design of experiments. Its purpose is to confirm that every influential factor is measured. A better realistic method is to express the evaluations to be conducted and equate the measurements with model predictions and adjust the model if required. When validation has been done, this implies the simulation package may be utilized to model component performance.

Comparing model results with empirical data permits for “absolute truth standard” in the experiment uncertainty. However, experimental data involves time demanding and costly experiments to be undertaken (Loutzenhiser et al., 2007). Utilization of empirical data provides a way for the comparison of model to real metering data and hence runs detailed robust validation. Hence, the building parameters (building materials and layout of architecture, heating, ventilation and air-condition systems) and behaviour of occupants (extra load of electricity because of appliances, volume of cooling used) need to be looked at (Ryan and Sanguist, 2012).

In this study, realistic validation process undertaken in ensuring the accuracy of the building energy modelling. A dimensional model was designed for the property using the DesignBuilder software, based on the design, the actual construction materials specified on the official construction plans, and the interview findings. The simulated results provided hourly climate data, hourly energy consumption, peak climate data, and energy consumption, including individual figures for each room in each property. Comparison is made between the simulated results and the real consumption of energy derived from the electricity bills for every facility. The approach used will provide many advantages. Whilst the electricity bills for the premises would reveal the exact quantity of electricity that run through the meters, the DesignBuilder modelling allows for identification of how much energy was consumed within the building. It further allows for the alteration of specified variables to simulate potential energy savings following modifications and subsequent optimisation.

To improve the reliability of the process of assessing likely methods which may enhance the thermal performance of office blocks in Ghana, there is the need for validating simulated models and hence had to match existing building. To this effect, comparison was made between billed electric energy and simulated electric energy and the difference was anticipated to be insignificant. If the results show a variation of more than 10% then the differences would be regarded as significant (Ryan and Sanguist, 2012).

3.10 CONCLUSION

This chapter encompassed the presentation of the methodology made use of in the study. The chapter discusses the numerous research models that existing literature provides. On the bases of the research agenda, an exploratory mixed methodology approach was adopted. It was identified that the adoption of the mixed method approach enabled answers to be provided to research problems that would not have been answered using just one single approach. Having selected the mixed methodology approach the following methods were chosen; a synthesis and analysis of building energy assessment methods, the Delphi Technique, the DHP and a simulation based study. The chapter showed that the synthesis and analysis of building energy assessment methods provided a profound opportunity for the identification of factors that impact energy consumption. Next, the Delphi survey was adopted to aid in reaching consensus on the applicable criteria whereas the choice of the DHP was to enable the development applicable weighting system. Having developed the weighting system, the chapter showed that a simulation based study will provide the required framework for the development of the tool. In the next chapter the results and analysis of the methods used are explicated.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter presents the analysis of data collated and the ensuing discussions. The chapter is divided into two main sections. Firstly, the Delphi survey results and discussion leading to the identification of the assessment categories is presented. This is then followed by the Delphic Hierarchy Process results and discussions which consequently leads to the identification of an applicable weighting system. As explicated in the previous chapter a consensus based approach is adopted and used in identifying applicable energy efficient building assessment categories for the Ghanaian built environment. The last section concludes with a discussion of the approved weighting system for the Ghanaian context, along with its distinguished aspects from international systems, and also discusses the future implementation and possible evolution into an international tool for similar regions.

4.2 SECTION ONE: DELPHI SURVEY RESULTS AND DISCUSSIONS

As discussed in the preceding chapter, the Delphi technique is selected and used. Two rounds of Delphi consultation are conducted with professionals within the wider field of sustainable and built environment assessment methods. The outcomes show that global assessment methods, wholly, are inapplicable to the built environment of Ghana. This section provides a review of the Delphi technique within the framework of the building sector. The purpose being to demonstrate the relevance of consensus-based approaches in this field of study, as well as to obtain a deeper understanding of the challenges involved, such as the complexity of construction criteria, the composition of the expert panel, and managing expected outcomes. The results of the Delphi stage of this particular study is then presented, including the approved building assessment categories, deemed applicable for the specific context of Ghana. These categories are discussed in terms of their relative importance after which the consensus measurement tool is provided. Finally, a discussion is offered on the resultant criteria and the importance of this assessment method for the Ghanaian built environment.

4.2.1 Background to the Delphi Survey

Out of the targeted thirty (30) experts, a total of twenty-two (22) experts responded. Consequently, twenty-two (22) experts were involved in the first round of the Delphi survey, out these twenty-two (22), only seventeen (17) responded in the second round. The panel pool was derived from experts across the academia, industry players and government officials. The non-probability sampling approach, i.e., snowball sampling was adopted in targeting a maximum of 10 experts identified from afore mentioned groups. The sampling approach was largely informed by informal interviews with experts in the field conducted prior to the start of the Delphi survey.

4.3 DELPHI SURVEY ROUND ONE

4.3.1 Analysis of Demographic Data

4.3.1.1 Area of Work

The initial question sought to find out the various areas of work in which the respondents worked. The questionnaire was targeted at three main areas: the ministries or governmental sectors, academia/research and industry. Using the Delphi survey approach, 10 questionnaires were sent out to each of the sectors, making a total of 30. Out of the 30 sent, 22 were retrieved. Table 4.1 sets out the distribution of the demographic data. The highest number of respondents were from industry with the lowest being from the governmental sector. The targeted respondents were personally introduced to the researcher due to the snowballing approach adopted. This enabled the use of various forms of communication to firstly establish contact and then also to follow up. The targeted groups were implored to respond to the questionnaires immediately they were given. Despite this approach, very few individuals completed the questionnaire in this way. Consequently, follow ups were made leading to the successful completion by 22 respondents. The international respondents made up a total of four out of 22 respondents; two being from academia and two being from industry. These respondents were based in the United Kingdom with a wealth of experience in building energy assessment methods.

Table 4.1 Demographic Data

	Frequency	Percent
AREA OF WORK		
Ministries/Other Governmental Sectors	5	22.7%
Academia/Research	8	36.4%
Industry	9	40.9%
Total	**22**	**100%**
EXPERIENCE		
Less than 5 years	7	31.8%
6-10 years	9	40.9%

11-15 years	6	27.3%
Greater than 5 years	-	-

Source: Survey Data, 2015

4.3.1.2 Experience

The next demographic question sought to find out the level of experience of the respondents. The results showed that majority, representing 41% of the respondents, were in the bracket range of 6-10 years of experience. The lowest age range respondents were 11-15 years. None of the respondents indicated that they had been in their place of work for more than 15 years. The panel consisted of individuals who had been practicing for more than five years. This provides enough basis to suggest that the respondents were individuals who had garnered experience over time in this particular field.

4.3.2 Energy Performance Indices Definition

It has already been averred that the first step in the development of an energy certification method is the definition of energy performance indices (Perez-Lombard et al., 2009). At this stage, the respondents were asked to rate the higher priority factors in terms of definition of energy performance indices for the Ghanaian context. The results show that annual energy use was most favoured amongst the Delphi subjects. In ranking, annual energy use was ranked first priority with energy efficient design and envelope performance ranked second and third respectively. Statistically, 21 out of the 22 experts prioritized as first, the use of the annual energy use; frequency showing a high level of consensus amongst the participants. The results are tabulated in Table 4.2.

Table 4.2 Results of Delphi Survey Round One

	Priority One	**Priority two**	**Priority three**
Energy Performance Indices			
Annual Energy Use	21	1	0
Energy efficient design	1	10	6

Envelope performance	0	7	9
Annual CO_2 emissions	0	4	4
Annual energy cost	0	0	2
Maximum electricity demand	0	0	1
Energy Performance Calculation			
Dynamic methods	22	0	0
Steady state method	0	22	0
Energy Performance Assessment			
Performance Based	22	0	0
Feature Specific	0	20	2
Energy Cost Budget method	0	2	20
Setting of energy efficiency limit			
Fixed Limit Option	11	10	0
Customised Option	10	11	0
Energy Performance Labelling			
Point Based System	9	12	0
Percentage Based System	12	9	0

Source: Survey Data, 2015

4.3.3 Calculation of Energy Performance

The next stage was the determination of the calculation method to be adopted. Two methods were advanced here: dynamic and steady state method. The use of dynamic simulations necessitates the implementation of a computer based tool. Lombard et al. (2009) provided that the choice of any method requires considerations of matters like accuracy, scope, reproducibility, complexity, sensitivity to energy parameters and user expertise. These considerations are imperative as they have major influence on later software developments, final users' uptake, policy makers and stakeholders involved. All the respondents pointed out that the dynamic method was the most preferred method for energy calculation.

4.3.4 Assessment of Energy Performance

The method of assessment of energy was inquired from the respondents. With three main methods identified from literature - performance based, feature specific and energy cost budget method - the respondents were asked to prioritize these three. The lead priority area was identified as performance based. All the respondents indicated this. The energy cost budget method was ranked as a third priority area.

4.3.5 Setting of Energy Efficiency Limit

One of the key questions in energy performance assessment is the setting of the limit of energy performance. Comparison of dissimilar building type is difficult using energy performance due to different services rendered by the buildings. The limit value for the building will be dependent on building type and also on climatic conditions. Two options were provided for the respondents to rank. The customised option was indicated as a lead priority having a frequency of 11 with the fixed limit option having a frequency of 10. It was difficult to establish consensus on this dimension as one of the respondents failed to respond to this. The frequency distribution showed no consensus.

4.3.6 Energy Performance Labelling

The last stage is the identification of the labelling method to be used in the assessment. This intends to classify the building energy performance related to the comparison scenario by assigning an energy label (Perez-Lombard et al., 2009). The respondents were asked to prioritise the labelling style most relevant for the Ghanaian context. The results for this bloc also showed no consensus. Table 4.2 shows the distribution of the answers of the respondents.

4.4 DISCUSSION

Results emanating from round one showed that the professionals were largely in agreement and that round two would effectively refine the discussion to the level that obvious points of accord or its absence, could be deciphered; hence, a third round was not required. Subsequently, the results from round one were evaluated and constituted the premise of the second round of the study. A third round was not necessitated and participants were educated in the second round of the Delphi. Despite the fact that the first was to allow participants to brainstorm and come up with other approaches, the first round produced interesting results with most of the participants generally agreeing with the areas that were produced from the literature with regards to the methods. The outcomes of this Delphi round were analysed and assembled by the researcher. The experts were furnished with the results of the first round.

In reality, achievement of consent is based on all participants being in agreement, however when 66.67% are in agreement, this is generally regarded as a common consent (Stitt-Gohdes & Crews, 2004). Additionally, researchers have made usage of frequency distribution to evaluate the agreement and the criterion of a minimum of 51% answering to any particular answer classification being used to ascertain consensus (McKenna, 1994). Additional studies, like one organized by Rayens and Hahn (2000), have made usage of means and standard deviations with a reduction in standard deviations between rounds signifying a rise in agreement. More so, Holey et al. (2007) utilized the ensuing criteria to ascertain consensus: percentage response; percentages for each level of agreement for each question to compensate for varying response rates; computation of median, standard deviation and their related group rankings. The studies above indicate that there is minimal concord on how to measure consensus in a Delphi Study. Albeit, it is agreeable that for the achievement of consensus, there ought to be a convergence of concepts and reasoning towards a subjective central tendency measure. For this work, the goal was to attain consensus on each question posed in the questionnaire, however common consent would be satisfactory. Common consent was gained when two-thirds of the experts came to agreement on a particular question. Each question was checked for consensus. For each question on the survey, a quantitative analysis was performed to check statistically if consensus had been achieved for each question asked. The results indicated three out of the five blocks questioned had consensus achieved.

4.5 DELPHI SURVEY ROUND TWO

Due to the response generated from the first round, the round two was a minor revision of the first round with panellists requested to answer through the usage of the provided rating scale. The statistical information computed from the first round was conveyed again to the panel members. It was projected that in round two, answers provided in response to the question would converge to show a consensus among the experts. The outcomes of the Delphi Study are hence given as relates to the particular Delphi objectives in the next section.

Table 4.3 Demographic Data from Round Two

	Frequency	Percent
AREA OF WORK		
Ministries/Other Governmental Sectors	4	22.7%
Academia/Research	7	36.4%
Industry	6	40.9%
Total	17	100%
EXPERIENCE		
Less than 5 years	7	31.8%
6-10 years	9	40.9%
11-15 years	6	27.3%

Source: Survey Data, 2015

From the synopsis of the all-inclusive analysis of literature outlining various methods and the comparison of well-known methods for building energy assessment, applicable categories are identified. In the second round, 17 out of the 22 participants responded in the second round.

Thus, five failed to respond. The distribution of the respondents is given in Table 4.3.

4.5.1 Energy Performance Definition

The three main sections that showed consensus was reported back to the panels. There were no changes in this result after the second round. Consequently, the analysis used for the first round is maintained. The outcomes are illustrated in Table 4.4.

Table 4.4 Results of Delphi Survey Round Two

	Priority One	Priority two	Priority three
Energy Performance Indices			
Annual Energy Use	21	1	0
Energy efficient design	1	10	6
Envelope performance	0	7	9
Annual CO_2 emissions	0	4	4
Annual energy cost	0	0	2
Maximum electricity demand	0	0	1
Energy Performance Calculation			
Dynamic methods	22	0	0
Steady state method	0	22	0
Energy Performance Assessment			
Performance Based	22	0	0
Feature Specific	0	20	0
Energy Cost Budget method	0	2	0
Setting of energy efficiency limit			
Fixed Limit Option	6	11	0
Customised Option	11	6	0
Energy Performance Labelling			
Point Based System	7	15	0
Percentage Based System	15	7	0

Source: Survey Data, 2015

4.5.2 Setting of Energy Efficiency Limit

The results from round one indicated no consensus on the setting of the limit of energy performance. One of the significant drawbacks of establishing building energy efficiency limit is the lack of energy data. The use of customised limit also affects the generalization of the efficiency limit hence becoming difficult to compare buildings in the same category. It is assumed that this dilemma may have caused the inability to reach consensus on the specific issue. After the second round, the panellist had more than 60% agreeing to the use of the customised option. The results are presented in Table 4.4.

4.5.3 Energy Performance Labelling

The last stage is the identification of the labelling method to be used in the assessment. This intends to group the building energy performance connected to the comparison scenario by assigning an energy label (Perez-Lombard et al., 2009). The respondents were asked to prioritise the labelling style most relevant for the Ghanaian context. The results for this bloc also showed consensus on the topic as evident in Table 4.4.

4.6 DISCUSSION

After analysing the responses from the second round, the categories and criteria that revolves into the development of energy assessment method, were systematized to generate a more holistic picture and to present the newly development energy assessment method. If there was a failure to reach a consensus at the second round, there would have been another analysis of the data from this second round which would be referred to the professionals to be considered in the response to a third round. The second round saw consensus achieved on all the various approaches and criteria put forward. On the basis of the results of the survey analysis of the Delphi rounds, new categories and criteria were developed for the Ghanaian context. As mentioned in the previous chapter, the levels of influence and impact of identified variables in predicting building energy efficiency within the Ghanaian context were then obtained as a product of the consensus achieved as detailed in this chapter.

In this section, a predominant premise has been established to satisfy this objective which is that the principal international sustainable assessment methods, such as BREEAM and LEED, are not applicable for the Ghanaian built environment. This premise was put to examination through the use of the Delphi technique, spanning a six-month period. Seventeen (17) Delphi panellists have reached a consensus on the categories and criteria which can be applied for a sustainable building assessment method in Ghana. The results of this consultation process indicates to a high degree that global methods such as BREEAM and LEED cannot be applied to the Ghanaian context. What follows is a discussion on the outcome of the Delphi survey.

4.6.1 Teething Problems

A strong knowledge base in building energy tools, building energy simulation is crucial in the use and implementation of an energy efficiency tool. The study results report interesting findings. Firstly, the consensus on annual energy use as the medium of energy performance indices is not surprising. This is largely due to the ease of measurement with this index. Also, other indices are difficult to define and invariably measure in the current Ghanaian context. For example, it would be difficult to define and measure CO_2 emissions related to buildings in Ghana. Lack of data is the primary source of this difficulty. This situation is exacerbated by lack of expertise. The Delphi findings also indicated the use of dynamic calculation methods over the steady state approach. Ideally, one would have thought that the use of steady state will be simpler due to the ease of implementing, however dynamic state was preferred. The argument here for this selection may be due to implementation problems. The challenges will be faced with the introduction of either method, i.e., dynamic or steady state. Nevertheless, implementing dynamic methods would definitely be more challenging. However, if the teething problems faced in steady state could be circumvented, then it is possible to overcome challenges inherent in using the dynamic methods. Also, transition from steady state to dynamic state method of calculation would pose another difficulty. With the changing and increase in understanding of building simulation methods, it is believed Ghana can make its initial step from the dynamic method of calculation instead of trying to play catch up all the time. In addition, in many countries, software tools are used to estimate the energy performance grade for an existing or designed (not built) building (Bagheri et al., 2013).

4.6.2 Need for Expertise

Moreover, the availability and accessibility of building energy professionals is crucial, as the procedure for the development of an instrument or its evaluation has the intended population to be building energy professional. This statement is reinforced Bagheri et al. (2013). In their work, they focused on energy professionals to do the evaluation. As well, Yang et al. (2010) utilized professionals in building energy to conclude their research. In Reilly et al. (2013) 159 buildings were surveyed by expert energy assessors. The use of performance based approach may provide a leeway within the Ghanaian context. Use of other methods, for example, the feature specific will require the build-up of consensus on what features should be assessed and the criteria for measuring such criteria. This would pose another difficulty due to other research questions that needs to be answered with the use of this approach. It can be seen from the ongoing that the panel agreed on certain issues due to the propensity of various debacles occurring if a particular approach is not taken.

4.6.3 Economic and Social Aspects

The consideration of finances is crucial in sustainability development and this issue is more persistent in developing countries than in developed countries. The concern of developed countries pertains to the lessening of environmental effects whilst upholding standards of living (Cole, 2005), whilst in developing countries, economic and social matters are usually as significant as environmental considerations (Libovich, 2005) or perhaps have more significance. Albeit, neither BREEAM nor LEED take into consideration the fiscal and social facets in their evaluative framework. This debatably contradicts the definitive principle of sustainable development, as monetary earnings are crucial for all projects, with environmentally friendly projects potentially being very costly to build (Ding, 2008). For example, the usage of renewable energy will be the easiest way to solve energy problem however, this variable requires the investment of capital and financing which at the moment will pose a difficult problem for the average Ghanaian.

4.6.4 Data Availability

The availability of data is a chief factor which determines the successfulness of energy efficiency implementation. This is primarily because of the fact that the research depends greatly on data including building energy consumption profiles, general building characteristics, weather data and the like (Lee and Kung, 2011). Bagheri et al. (2013) in their study posited that similar studies in the area of standard and labelling procedures for building worldwide mostly considered a sample society of buildings as the data bank for studies. Consequently, the panel's decision to go in for the customized approach in the setting of energy efficiency limit is not surprising. Concerns have been raised for inability to extract general conclusion on the energy performance of the building stock due to the lack of data (Nikolaou et al., 2009). With the customised approach, it provides a starting point for energy efficiency to be assessed. In addition to the above, the customized option not only provide a viable starting point but allow for the further development of a more efficient energy building.

This section gave synopsis of the outcomes as well as discussion of the outcomes from all the Delphi rounds, from the initial round to the second. Computation for each and every question element was made for the influence and impact of the criteria in predicting building energy efficiency within the Ghanaian context. Through the Delphi study, a consensus was reached on the identified criteria and categories for the Ghanaian environment. The section ended with a collective discussion of the outcomes based on the objectives of the Delphi study. As a result of the lack of a non-subjective approach for the development of new weighting systems for sustainable assessment methods, the usage of Analytical Hierarchy Process (AHP) considers a viable alternative (Ali and Al-Nsairat, 2009; Pohekar and Ramachandran, 2004). This follows in the next section which will provide a weighting system for the further development of the tool.

4.7 SECTION TWO: DELPHIC HIERARCHY PROCESS RESULTS AND DISCUSSIONS

Sustainability is a broad concept that draws on various dimensions in its measurement (Wong and Abe, 2014; Cooper, 1999; Crawley and Aho, 1999; Cole, 1998). Consequently, the use of a weighting system provides a viable approach to be able to prioritize the overlapping dimensions (Chew and Das, 2008; Chang et al., 2007). Several different methods rely on the use of a weighting system to prioritize and invariably produce an output for the sustainability of a building. The preceding section has looked at the various methods and through the Delphi survey, explored an adaptation of these methods for the Ghanaian environment. In this section, a weighting system is developed to prioritize building energy efficiency in Ghana. As discussed earlier, the use of Delphic Hierarchy Process is adopted for the purpose of this study. The research instrument involves participants from various fields including professionals and highly informed local experts from industry, academia and government. The section firstly introduces results of the first round of the Delphi Hierarchy Process together with the discussion of the results emanating from it. What follows next is a presentation on the resultant weighting system, including the weight of each category, the credit allocation strategy and the chosen rating formula.

4.8 DHP ROUND ONE

It must be stated that the administration of the Delphic hierarchy process was done concurrently with the first Delphi survey discussed in the previous chapter. Consequently, the demographics for both surveys were the same and therefore would not be repeated here. The next section only reports on the results derived from the Delphic Hierarchy Process.

4.8.1 Energy Efficiency Indicators

The first round of the Delphic Hierarchy Process elicited information with regards to the most important indicators as well as the need for the inclusion of any other indicator for the built environment in Ghana. A total number of 21 energy efficiency indicators were identified. Using the mean score and standard deviation, the indicators were ranked. From the analysis, Glazed ratio of wall was ranked as the most relevant, followed by the use of shading devices. Thermal properties and HVAC facility were both ranked third. The least ranked indicators were those in the renewable group. All renewable described indicators were ranked in the bottom three.

The results are displayed in Table 4.5.

Table 4.5 Energy Efficiency Indicators

	Mean	Median	Std. Deviation	Ranking	IQR
Glaze ratio of Wall	6.545	6.545	0.477	1	1.0
Thermal properties of building envelope	6.545	6.545	0.492	2	1.0
Use of Shading Devices	6.500	6.500	0.490	3	1.0
HVAC facilities	6.500	6.500	0.492	4	1.0
Airtightness of Envelope	6.364	6.364	0.510	5	1.0
Orientation of Building	6.318	6.318	0.510	6	1.0
Advanced design and construction technique	6.318	6.318	0.716	7	1.0
Insulation of Building	6.318	6.318	0.477	8	1.0
Social Impact	6.318	6.318	0.477	8	1.0
Optimisation of Energy use	6.318	6.318	0.477	8	1.0
Indoor Thermal Comfort	6.273	6.273	0.492	11	2.0
Efficiency of Lighting systems	6.227	6.227	0.476	12	1.0
Outdoor Environment	6.136	6.136	0.922	13	2.2
Efficient use of Day lighting	6.091	6.091	0.477	14	1.1

Indoor Lighting	6.000	6.000	0.816	15	2.0
Energy cost of operation of building	5.955	5.955	0.844	16	2.0
Shape of Building	5.864	5.864	0.468	17	0.0
Acoustic Environment	5.682	5.682	0.477	18	1.0
Proportion of renewable of energy in energy consumption	5.273	5.273	1.279	19	2.5
Cost of renewable energy	4.955	4.955	1.430	20	2.5
Use of local renewable energy sources	4.955	4.955	1.430	20	2.5

Source: Data Survey, 2015

4.9 DISCUSSION

There are a number of differing qualitative analysis methods in existence for determining consensus; the methodology selected is the interquartile range (IQR). The IQR is a descriptive statistical method which scrutinises every single mean of consensus (Gnatzy et al., 2011). The value of the IQR is reliant on the unit scales; for instance, for 5-unit Likert scales, consensus is shown by values of IQR between 0 and 1(0 IQR 1) (von der Gracht, 2012). Studies have adopted the use of the inter-quartile deviation (IQD) to ascertain consensus (Rayens & Hahn, 2000), which as well has been taken up for the current study. In their study, Rayens and Hahn (2000) incorporated an additional criterion to ascertain consensus along with the IQD so as to attain stability. The criterion to attain consensus was that the IQD ought to equal one (1) unit for which over 60% of respondents ought to have replied either generally positive or generally negative. Items which had an IQD ≠1 for which the percentage of generally positive or generally negative replies was between 40% and 60% were ascertained to show the absence of consensus or agreement. Also, Raskin (1994) recognised an IQD of 1.00 or less as an indicator of consensus. Spinelli (1983) deemed a variation of over 1.00 IQD point in every single consecutive stage as the criterion for meeting of opinion. It is agreeable that for consensus to have been attained, there has to be a meeting of ideas and reasoning towards a subjective central tendency measure. Thus, in the present study, consensus was ascertained to have been attained if the ensuing was realised:

- Over 60% of responses are generally positive or negative with certain questions;
- The IQD was less than 1.25. this implies that items with IQD = 0.00 were deemed to have reflected high consensus.

Thus, the consensus adapted for this research was median 5.5-7; and interquartile deviation (IQD) ≤1.25. Generally, the results indicate that there was high consensus achieved amongst the various indicators. The results show that renewable energy was ranked least. As indicated earlier the energy mix for Ghana is mainly made of three main sources; Hydro, Thermal and Renewables (Energy Commission Ghana, 2015). Renewables make up the lowest share with hydroelectricity making up the largest share of about 55% (Energy Commission Ghana, 2015). This has not always been the case. The contribution of Thermal sources has been on the increase evidenced by the reduction of the biggest contributor being Hydro. This raises question as to the impact on the environment due to the production of CO_2 by the thermal plants. The unique mix of Ghana's energy sources invariably affects its environmental impact and consequently, the level of policy or regarding its use. It should be noted that in Ghana, particular rural and isolated regions are so far not linked to the network, and linking them would necessitate an added upsurge in power generation. This will come with it consequential effect. Also, informed by the huge cost involved in the acquisition of renewable energy sources, this variable was ranked comparatively low. This lends credence to the fact that the economic variable is critical in the development of energy efficiency tools. However, the use of renewable energy at the demand level will go a long way to improve the energy situation in Ghana.

Improving government regulation is one primary means of tackling this matter. Germany's experience gives standing proof in this area; it has enforced a number of rules for reprocessing electronic waste (McDonald and Pearce, 2010). As well, there is the probability for alternate sources of renewable energy (other than PV) in Ghana. Alnatheer (2005) outlines several forms of environmentally and economically competitive energy sources, counting solar thermal, wind energy, and geothermal energy. This, has the possibility of enhancing clean energy generation in Ghana as the country faces great requirements for cooling, representative of a main source of overall energy consumption (Taleb and Sharples, 2011).

4.10 DHP ROUND TWO: DEVELOPMENT OF WEIGHTING SYSTEM

It is not only impractical but quite problematic to impose a single energy assessment method worldwide, given particular regional variations and existing socio-cultural issues. Grace (2008) debates that sustainable assessment methods include a range of criteria; making usage of a onedimension method is not the method with the highest practicability of achieving the projected objective of sustainable development principles. Instead, a multi-dimensional approach comprising the contribution of main stakeholders and decision-makers gives a more robust methodology, which would yield both quantitative and qualitative building assessment criteria (Ding, 2008). The development of recognized assessment methods was determined on the basis of consultation processes amongst a panel of experts, with the aim of reaching the most dependable consensus on applicable building assessment criteria (Sam, 2010). The study involved seventeen building energy experts from the fields of academia, industry and the government sector.

Building assessment categories and criteria are the basis of any assessment method. The development of a coherent and comprehensive framework was deemed to be complex issue, this, however, has been overcome by systematic consultation with informed experts. The illustration of the categories and criteria has comprehensively been presented in chapter two and here is the following part which is the proposed weighting system of that delivered categories and criteria. The weighting system is a viable strategy in which local environmental conditions may be prioritized; it is also considered the heart of any building assessment scheme (Cole, 2005). The identified categories were therefore subjected to the use of AHP. A hierarchy model was built relying on the consensus of 17 experts.

From the dissemination of the survey subjects (Table 4.1), it is evident that the survey is primarily focused on academics with practicable experiences. This could present a constraint per conventional survey method; albeit, this constraint can be made up for by the Group decision method. Group decision method is associated with the benefits of a fairer judgement and dealing with excessive persons (Robert and Ernest, 1992). Per the AHP method, the statistical value of an element in a comparison matrix is decided by the member's judgement under Saaty's nine-point scale. It is evident that there is mix-up in the comprehension of text descriptions that alike. To avert misapprehension of the text, a chart was used to assist the person doing the assessment to estimate the comparative significance of the indicators in the questionnaire design. A sample of the questionnaire on weighting indicators is provided in Appendix Three (3).

4.10.1 Weighting Indicators

A pair-wise comparison was carried out in order to rank these categories, premised on the domestic milieu of Ghana. Six matrix for comparison is provided for every questionnaire that was designated as completely filled. The matrices include one for comparison of categories (i.e. matrix 1), matrix 2 for indicators of 'building design', the comparison matrix of indicators of 'performance of envelope'(matrix3). The rest include comparison matrix of indicators of 'energy efficiency of building facilities', 'building operation and management' and 'renewable energy, respectively labelled matrix 4, matrix 5 and matrix 6. Out of the complete seventeen successfully filled questionnaires 102 matrices of comparison was totalled. Using group AHP, these 102 comparison matrices have been combined to form 6 group comparison matrices as:

‘G matrix one’, ‘G matrix two’, ‘G matrix three’, ‘G matrix four’, ‘G matrix five’, and ‘G matrix six’. Vectors relating to the maximum eigen value of the above 6 group matrices are calculated using Microsoft Excel. These 6 group matrices are listed in Tables 4.6 - 4.11 respectively. The weights of the indicators of building energy efficiency assessment in the Ghanaian context have been worked out and demonstrated in Figure 4.3.

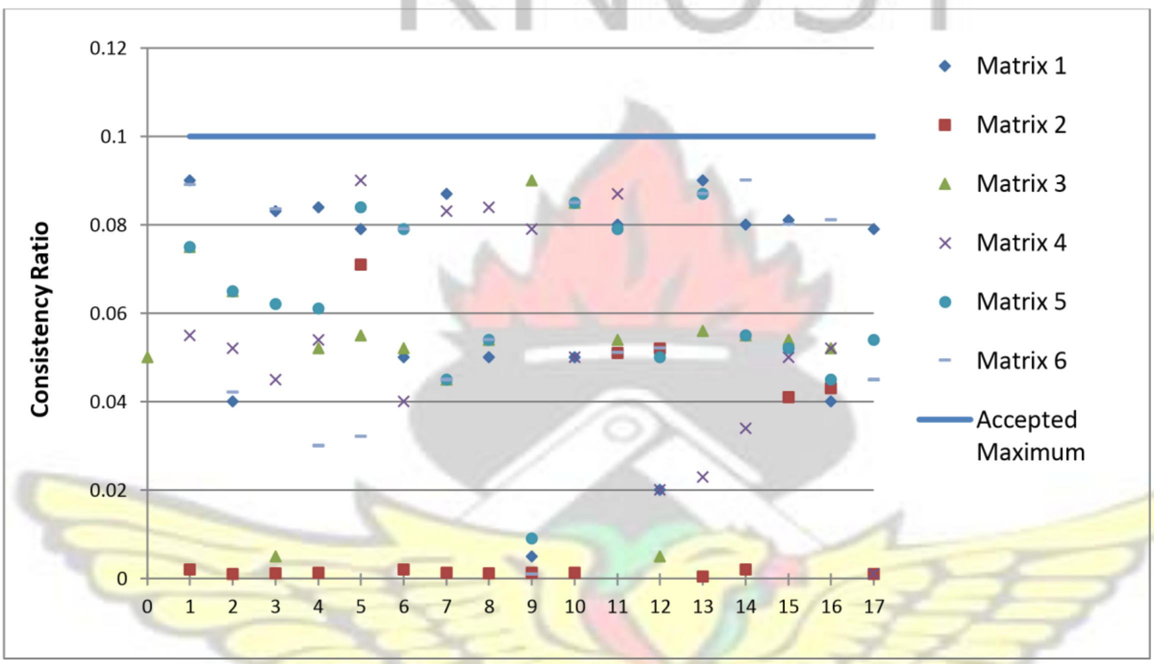

Figure 4.1 Consistency Ratio of Individual Comparison Matrices.
Source: Survey Data, 2015

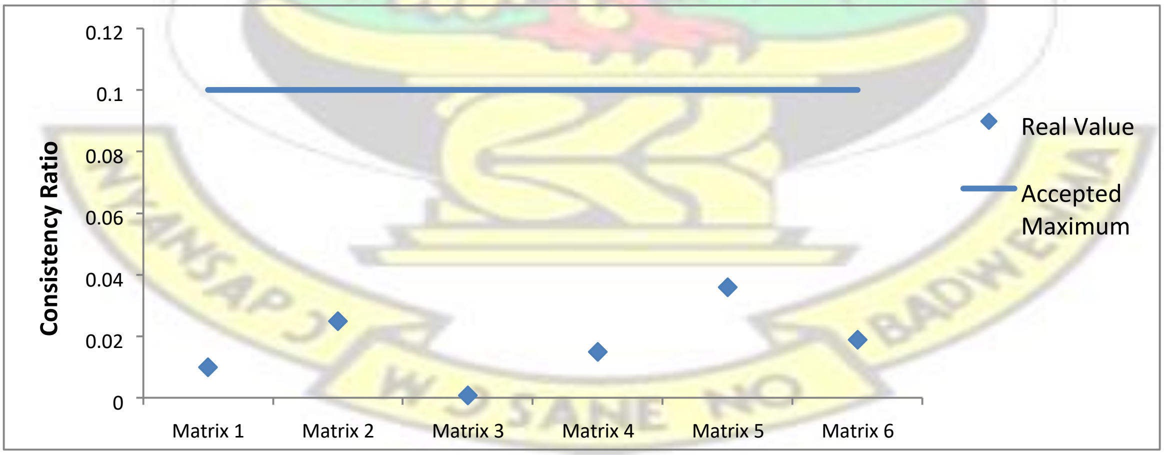

Figure 4.2 Consistency Ratio of Group Comparison Matrices.
Source: Survey Data, 2015

Conferring from the group AHP method, the consistency ratio (C.R.) signifies the consistency of judgments. The lesser the value of C.R., the greater the reliability of judgement. Figure 4.1 displays the C.R. of 102 comparison matrices by the separate judgement of professionals. From Figure 4.1, it is evident that the C.R. of every separate comparison matrix is less than 0.1. Hence, the consistency of separate judgement is satisfactory in this assessment procedure. Fig. 4.2 shows the C. R. of group comparison matrices. From Figure 4.2, it is evident the C.R. is far less than 0.10 in each group comparison matrix. This implies the consistency of group judgements is adequate in this survey. The size of the subjects is a determinant of the reliability of judgments and it is also a determinant of the consistency of judgment. The size of 17 subjects in this survey is adequate enough to guarantee the reliability of the judgement. Aside the number of the subjects, individual radical inclinations are avoidable through the group AHP method. Take the Indicator 'HVAC Facilities' as an example. The weightings by separate professionals have been established in Figure 4.3. From Figure 4.3, it is evident that the highest weighting is 0.35 voted by the professional no. 15, and the lowest weighting is 0.05 by professional nos. 2 and 8. Thus, it is apparent that there is huge variation amongst experts. Albeit, by implement of group AHP, the weighting of C1 is 0.13. Hence, it is evident that the group AHP provides a method to avert the radical inclinations of expert nos.1 and 9. The outcome calculations conducted show reliable judgments. This is clearly presented by the calculation of consistence ratio (which equals 0.037 in this study).

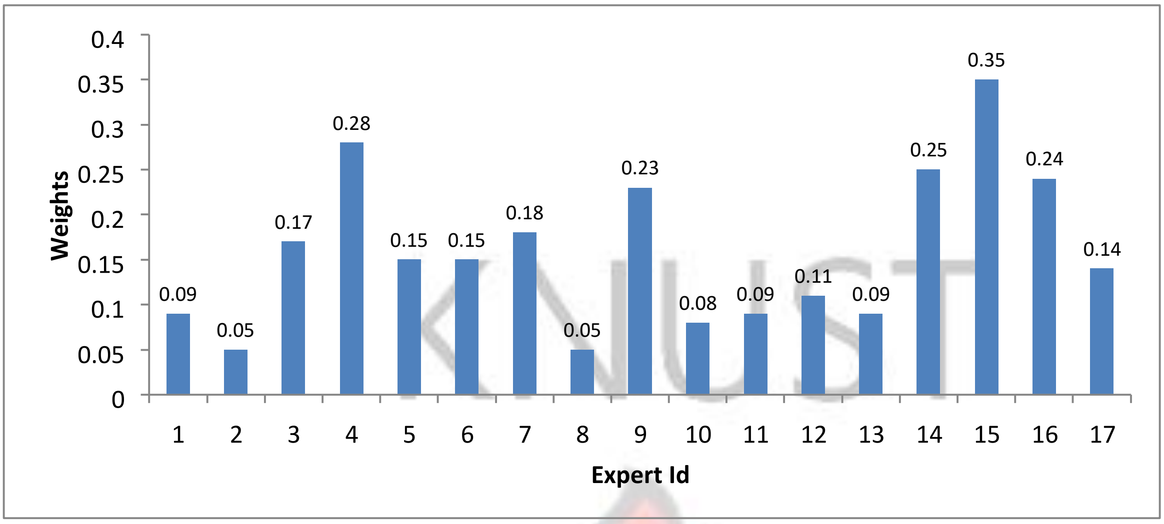

Figure 4.3 Weights of HVAC Facilities by Individual Experts.
Source: Survey Data, 2015

Table 4.6 Group Comparison Matrix of Categories

	Building Design	Performance of Envelope	Energy efficiency of building facilities	Building Operation & Management	Use of Renewable Energy	**WEIGHTS**
Building Design	1.000	1.619	2.506	1.611	3.786	0.44
Performance of Envelope	0.618	1.000	2.733	3.000	0.200	0.09
Energy efficiency of building facilities	0.399	0.366	1.000	1.133	2.704	0.28
Building Operation & Management	0.621	0.333	0.882	1.000	3.000	0.10
Use of Renewable Energy	0.264	5.000	0.370	0.333	1.000	0.08
G. C. I. =	**0.084**					
CR =	**0.037**					

Source: Survey Data, 2015

The synthesis of the pair-wise comparison revealed that "building design" and "energy efficiency of building facilities" are of top priority to the Ghanaian built environment (Table 4.6). In the same way, relative weights of indicators were computed under separate criterion and results are as follows:

Table 4.7 Group Comparison Matrix of Indicators of 'Building Design'

	Orientation of Building	Outdoor Env.	Use of Shading Devices	Shape of building	Glaze ratio of wall	Advanced design and construction technique	Efficient use of Daylighting	**WGTS**
Orientation of Building	1.00	3.83	2.29	3.15	1.85	2.42	1.53	0.27
Outdoor Environment	0.26	1.00	1.21	1.14	0.36	1.00	0.88	0.10
Use of Shading Devices	0.44	0.82	1.00	1.25	0.28	0.50	0.37	0.08
Shape of building	0.32	0.88	0.80	1.00	1.10	1.91	0.78	0.12
Glaze ratio of wall	0.54	2.81	3.56	0.91	1.00	1.08	1.00	0.17
Advanced design and construction technique	0.41	1.00	1.99	0.52	0.92	1.00	0.39	0.10
Efficient use of Daylighting	0.66	1.14	2.72	1.28	1.00	2.55	1.00	0.17

Source: Survey Data, 2015

4.10.2 Indicators of Building Design

Three indicators were related to Building Design and they include orientation of building to, use of shading devices and efficient use of daylighting. In all, a total of seven indicators were identified under the criteria building design. Table 4.7 shows that the Indicator: Orientation of building is the most important with 0.27 followed by the Indicators: Glaze ratio of wall and Efficient use of daylighting both with 0.17. Result ensuing from the analysis show that orientation of building was more significant in predicting energy efficiency than some other identified variables. It should be noted that some of the indicators invariably affect other indicators and thus, is not surprising that orientation had a more significant role. Despite the fact that some of the indicators overlap each other in interesting ways, the assessment of each individual indicator is needful as each indicator also plays a unique role in predicting energy efficiency. For example, orientation of building will affect how efficiently daylighting is utilized. However, daylighting utilization must be measured separately as the orientation alone cannot predict the efficiency of daylighting and consequently, its component on energy efficiency, though it informs on how daylighting is utilized. Subsequently, the separate measurement of this variable will inform the effects of daylighting.

Table 4.8 Comparison Matrix of Indicators of 'Performance of Envelope'

	Airtightness of Envelope	Insulation of Building	Thermal Properties of Building Envelope	**WEIGHTS**
Airtightness of Envelope	1.00	1.14	0.38	0.22
Insulation of Building	0.88	1.00	0.38	0.21
Thermal Properties of Building Envelope	2.66	2.62	1.00	0.57

Source: Survey Data, 2015

4.10.3 Indicators of Performance of Envelope

Three main indicators were identified under Performance of Envelope and they are *Airtightness of Envelope, Insulation of Building and Thermal Properties of Building Envelope*. Table 4.8 shows that thermal properties of building envelope yielded the highest weight, with airtightness of envelope being the second heaviest weight and insulation the least. The results indicate that the Ghanaian environment places more emphasis on thermal properties of building than insulation. This is not surprising as the Ghanaian industry is relatively new to the concept of insulating buildings. Literature shows a dearth of studies also in this regard (Amos-Abanyie, 2012).

4.10.4 Indicators of Energy Efficiency of Building Facilities

The category "Energy efficiency of Building Facilities" comprised of five main indicators (Table 4.9). From Table 4.9, HVAC facility was rated as the highest indicator with efficiency of lighting systems rated as the least. One variable introduced for the Ghanaian environment is

"Social Impact". This variable was rated as the third highest variable. It is important to mention here that the peculiar nature of the Ghanaian environment largely motivated the need for the inclusion of this variable. This is against the backdrop that the culture of the people largely influences the adoption of certain building facilities and thus the rating of this criterion will be incomplete without the inclusion of this variable.

Table 4.9 Comparison Matrix of Indicators of 'Energy Efficiency of Building Facilities'

	HVAC facilities	Efficiency of lighting systems	Energy cost of operation of building	Social Impact	Optimization of energy use	**WEIGHTS**
HVAC facilities	1.00	3.83	2.29	3.15	1.85	0.38
Efficiency of lighting systems	0.26	1.00	1.21	1.14	0.38	0.11
Energy cost of operation of building	0.44	0.82	1.00	1.25	0.30	0.12
Social Impact	0.32	0.88	0.80	1.00	1.07	0.14
Optimisation of energy use	0.54	2.64	3.35	0.93	1.00	0.25

Source: Survey Data, 2015

Table 4.10 Comparison Matrix of Indicators of 'Building Operation and Management'

	Indoor Thermal Comfort	Indoor Lighting	Acoustic Environment	**WEIGHTS**
Indoor Thermal Comfort	1.00	2.21	2.95	0.54
Indoor Lighting	0.45	1.00	2.93	0.32
Acoustic Environment	0.34	0.34	1.00	0.14

Source: Survey Data, 2015

4.10.5 Indicators of Building Operation & Management

This criterion had three main indicators under it. They include indoor thermal comfort, indoor lighting and acoustic environment. These variables represent the need to consider occupants' usage of the indoor built environment. It can be realised that certain variables represented in other environments are missing from this criterion. Various reasons are attributed for this. Very few studies exist in the Ghanaian environment describing this criterion and would thus be difficult to capture all these variables. The three indicators used describe in general, occupants' usage of the built environment and also able to predict energy efficiency with the Ghanaian environment. The results indicate that indoor thermal comfort is a greater predictor of energy efficiency than the other variables (Table 4.10).

4.10.6 Indicators of Use of Renewable Energy

Indicators identified under this criterion include proportion of renewable energy use, cost of renewable energy use and use of local renewable energy. Renewable energy cost was rated as the high predictor over all the other indicators, having a score of 0.74 as illustrated in Table 4.11.

Table 4.11 Comparison Matrix of Indicators of 'Use of Renewable Energy'

	Proportion of renewable energy consumption	Cost of renewable energy	Use of local renewable energy sources	**WEIGHTS**
Proportion of renewable energy consumption	1.00	0.91	0.94	0.09
Cost of renewable energy	1.10	1.00	1.12	0.74
Use of local renewable energy sources	1.07	0.89	1.00	0.17

Source: Survey Data, 2015

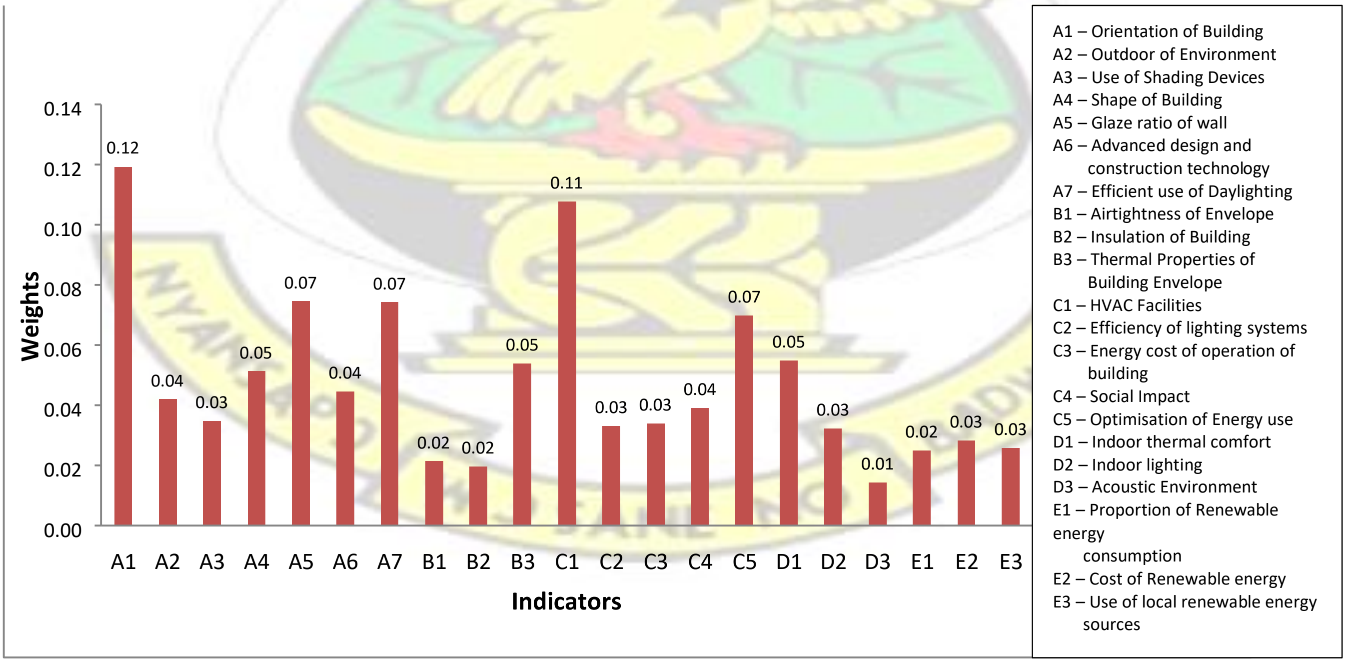

Figure 4.4. Weight of indicators of Building Energy Efficiency Assessment in Ghana. Source: Survey Data, 2015

From Figure 4.4, it can be seen that the highest rated indicator is A1, 'Orientation of Building with a maximum rating of 0.12. Orientation of building is the indicator of building energy efficiency assessment with the greatest significance in the Ghanaian Built Environment. The next rated indicator is C1, 'HVAC facilities with a maximum rating of 0.11. HVAC facilities play a very important role in predicting energy efficiency right up orientation. The least rated indicator was Acoustic Environment. Ergonomics is not at the forefront of most Ghanaian indoor environments, witnessed by the low ranking of acoustic environment and in effect, is a less predictor of building energy efficiency. The second least variables fall under the category of performance envelope, i.e., insulation and airtightness of Envelope. These are the indicators in building energy efficiency assessment in Ghana with relatively little significance.

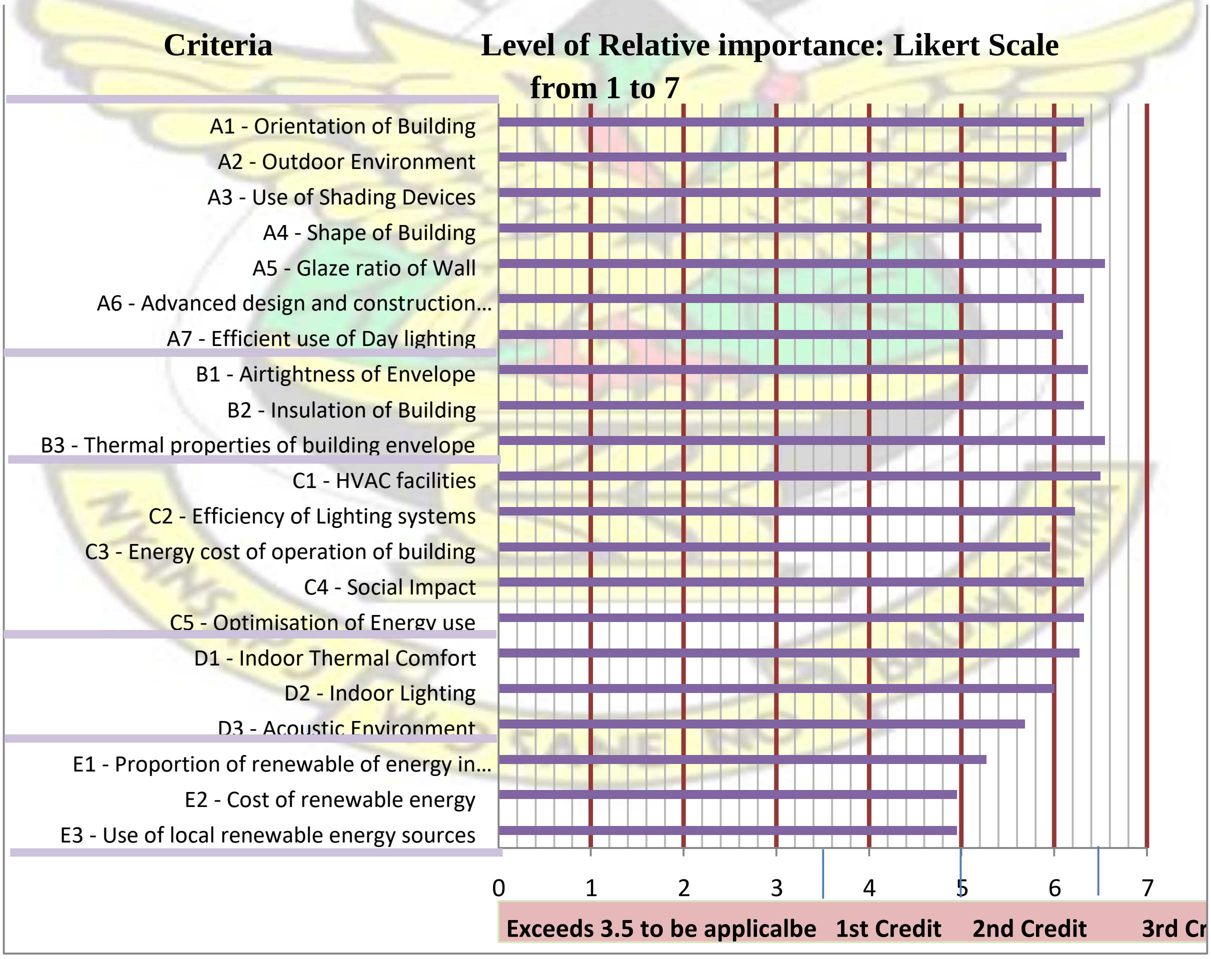

Figure 4.5. Credits Allocation Based on Intensity of Importance.

Source: Survey Data, 2015

4.11 PROPOSED WEIGHTING SYSTEMT

4.11.1 Credits Allocation

Given that the Delphi panel has reached consensus on the criteria's relative importance, credits developed will inform on ways to distinguish between these criteria. Table 4.12 illustrates the credits allocation system. Five main categories have been identified and allocated credits. Based on a similar study by Alyami (2015) in the development of a built environmental assessment tool, criteria that had a frequency rating of more than 50% was considered applicable to their context. This inferred that the criteria are important to that region. For this study, the same approach is used and criteria that exceed 50% or 3.5/7 in frequency rating are considered applicable to the Ghanaian built environment (Okoli and Pawlowski, 2004; Alyami, 2015). In order to differentiate between these criteria, therefore, a three-level credit allocation has been proposed. In other words, criteria rated more than 3.5/7 can award one credit; criteria rated more than 5.5/7 can award two credits; and criteria rated more than 6.5/7 can award three credits. This strategy will emphasize more compliance on higher rated criteria. Therefore, in Figure 4.4, three criteria are worth 3 credits; 14 criteria are worth 28 credits; and four criteria are worth 12 credits. The total available criteria are forty-three (43) credits, (which are presented in Table 4.12, the weight of the categories).

Table 4.12 The Weighting System

Categories	**Available Credits**	**Weights**
Building Design	**16**	0.44
Performance of Envelope	**7**	0.09
Energy Efficiency of Building Facilities	**11**	0.28
Building Operation and Management	**6**	0.10

Use of Renewable Energy	**3**	0.08

Source: Survey Data, 2015

4.11.2 Rating Formulas

From the system of weighting (Table 4.12) developed from AHP, the end product of the tool will be to produce a score that shows the energy efficiency level of a building within the Ghanaian environment. To achieve this a simple procedure needs to be followed. Firstly, the rate of each building indicator category needs to be determined (see Equation 5.1). This equation is proposed to enable the calculation of the specific weight of the category. As the principle of the grading system is developed around credits, the weights would be computed along the same. Thus, the grade would be based on the extent to which the category is able to achieve all the available credits. If a category achieves the total weights available that category earns the maximum weight available for it. Thereafter, all the categories are added up. Five differing rate scores will result as the tool has five distinct categories. Secondly, the differing five rating scores will be added up as depicted in Equation 5.2 to result in the final score that reflects the overall rating within a maximum of the forty-three (43) available credits.

$$BEAC = \frac{CA}{AC} \times W \times 100 \ - \text{Equation 5.1}$$

$$Building\ Rating = BEAC_1 + BEAC_2 + BEAC_3 + BEAC_4 + BEAC_5 - Equation\ 5.2$$

Where:

BEAC: Building Energy Assessment Category
CA: Credits Achieved
AC: Available Credits
W: Weighting Coefficient

4.11.3 Building Rating—Measured Energy Rating

Based on the cited concept on energy labelling in the review of literature in section 2.9.5, the grades are organized to meet the three main principles. As discussed earlier, the first concepts points to providing opportunity for growth and improvements in building energy, hence setting the bar higher for the highest grades. The second concept hinges on making a large percentage of existing buildings not failing on meeting the lowest grades. The last concept seeks to achieve a normal distribution of sample buildings in meeting the grades. These concepts are desireable as it not only provides opportunities for growth but makes it more applicable in the implementation process. Hence, a simple grading system is proposed here and applied:

Table 4.13 Grading System

SCORE	RATING	INTERPRETATION
100-80	A	Best Performance Level
79-70	B	Above Intermediate Performance Level
69-60	C	Intermediate Performance Level
59-40	D	Acceptable Performance
49-40	E	Minimum Acceptable Performance
39- under	F	Deficient

Source: Survey Data, 2015

4.12 DISCUSSION

The developed weighting system will play a major role in promoting energy efficiency within the Ghanaian built environment. It has therefore been subjected to a multi-stage process in order to obtain reliable customization. The derived assessment categories and criteria have resulted from two deliberative rounds; so as to enable key building stakeholders to evaluate the Ghanaian built environment in accordance with adapted building energy criteria. Each assessment category has been given a weight, by which the Ghanaian energy efficiency objectives may be prioritized. It is therefore important to discuss here the relevance of the customized weighting system for the Ghanaian context, and its divergence from the international system.

4.12.1 Envelope Performance and HVAC

In weather conditions with predominant cooling required, building envelope performance is often rated the highest weight amongst building assessment categories. For instance, Ali and Al-Nsaira, (2009) developed a rating system for Jordan and the result indicated that building envelope performance was ranked as the highest predictor of energy efficiency. Rattanongphisat & Rordprapat (2014) studied energy demand in a typical tropical climate of Thailand. They posit that the greatest influential factor affecting building energy consumption is the building envelope. A study by Aldossary et al. (2014) in the hot and arid Saudi Arabia region concluded that lack of optimal architectural design and construction materials has been the cause of high cooling. Studies within Ghana have yielded similar results however, results have not been conclusive.

On the other hand, HVAC facilities often has the dominant weight for many developed energy assessment methods (Roderick et al., 2009). Comparative studies conducted with international building environmental standards including LEED and BREEAM also support this assertion (Lee and Burnett, 2008). Chandratilake and Dias (2013) study found out that HVAC is the top ranked weighting in those surveyed systems. This results are corroborated by Roderick et al. (2009). Yang et al. (2010) developed building energy indicators for the hot summer and cold winter zone of China. Results ensuing from the study indicated that HVAC facilities are the indicator of residential building energy efficiency assessment with the highest importance. It can be seen that the regional climatic zone has an effect on the category that largely predicts energy efficiency.

4.12.2 Use of Renewable Energy

The uptake and usage of renewable energy sources has chalked success in some developing countries. A typical example is seen in Tunisia where the government encouraged the reduction of the country's reliance on oil and gas by promoting the use of renewable solar energy (UNEP, 2010). Through legal regulation and the development of a National fund for Energy management the Tunisian Government was able to save up to $1.1 billion in energy bills, from an initial investment of $200 million (UNEP, 2010). Nevertheless, Cobbinah et al. (2015) noted that despite the global acceptance of renewable energy as a viable sustainable option, many developing countries including India, China and Ghana have not been successful in developing renewable energy sources in spite of making strides in that particular direction. This they attributed to lack of policy direction, increasing poverty levels and rapid urbanisation, (Cobbinah et al., 2015). A case in point is China where policy efforts have been made through its Five-Year Plan (i.e. 2006-2010) towards achieving a low-carbon growth based on renewable energy sources. However, the country still remains one of the lead contributors of global carbon pollution resulting from their burgeoning urbanisation levels and economic development, which is unfavourable to sustainable development (UNEP, 2011). Though renewable energy has a great potential of reducing energy consumption by large amounts, it has been ranked very low. Following the ongoing discussion, it is not surprising. Basically, the required policy framework to address the peculiarities of the Ghanaian built environment is missing.

Consequently, at this level of development of the tool, “Renewables” play a relatively minor role in predicting building energy efficiency as compared to the other categories.

4.12.3 Energy Efficiency of Building Facilities

Building systems’ design and operating efficiency are fundamental to the overall energy efficiency of a building (Lee and Rajagopalan, 2008). This critical element largely influences the energy consumption factor in most buildings. For international assessment methods, this is often rated as the most important factor. However, the results indicate slightly different results. Despite this, this variable was ranked as the second highest (the indicator HVAC) and it still remains that this is not the highest predictor of energy efficiency in the Ghanaian environment.

It is argued here that many design variables can be explored to ensure energy efficiency which has not been fully done (Koranteng et al., 2009).

4.12.4 Potential Developments

Environmental assessment methods have been justifiably criticised for being used in widely differing climatic conditions without appropriate adjustment for local variation in conditions. This necessarily influences the accuracy of assessments being made (Ding, 2008, Haapio and Viitaniemi, 2008, Todd et al., 2001). Therefore, depending on where they are being utilised, the effectiveness of well-known environmental assessment methods may potentially be limited. The absence of adaptable assessment systems, that acknowledge the ways in which climatic conditions affect building performance, is causing severe criticism. Cobbinah et al. (2015) have also called for the need to relook at sustainable development in developing countries. Their argument was centred on the dearth of studies on poverty-urbanisation implications in developing countries. They opined that most studies in sustainability have overly focused on environmental aspects, neglecting other critical characteristics in developing countries' such as the experience of high urbanisation with persistent poverty levels.

One key element in the development of building energy tools is the existence of energy codes and data studies. Studies corroborate this element. For example in the development of energy label in Singapore, the basis for judgement was the code already existing (Lee and Rajagopalan, 2008). Countries that have adopted these tools have frameworks utilized in developing the tool (Bagheri et al., 2013; Batista et al., 2011). The situation in Ghana is stark different. Firstly, there are no existing energy efficiency codes for buildings. Secondly, lack of energy data poses a difficult challenge. Due to these impediments, the energy efficiency indicators will serve as a starting point in the prediction of energy efficiency. The use of standard practice is also adopted to serve as benchmarks in the use of the tool. This is further discussed in the succeeding chapter.

Moving forward, the study has unearthed interesting results with exciting findings ensuing from the work. The focus of the study area has been limited to the Ghanaian context. The peculiar nature of the African context - increasing urbanisation and grappling with poverty - presents a unique mix to the situation. This is exacerbated by the lack of energy codes and standards, lack of energy data and studies. Consequently, it should be noted that this is a first step towards developing the tool. It is seen that closing the knowledge gap in building energy efficiency studies in the Ghanaian environment will ultimately call for revisions to be made. As such, further revisions are expected based on empirical findings from studies. In addition to the above, the development of the model was based on the building energy experts in the field. This has its drawbacks and is expected that key stakeholders will be involved when revisions are necessitated.

4.12.5 Regional Variations and Weighting System

Energy efficiency is the driving force of implementing environmental assessment methods. This is due to the fact that the building industry worldwide is putting high pressure on natural resources, embodied in the tremendous demand for electricity. As mentioned earlier, electricity demand is increasing at a record level; and it is expected that the next 30 years will witness higher rates worldwide (World Energy Outlook, 2006). However, building environmental assessment methods are still evolving as a field of investigation. The existing assessment methods are heavily criticised for the absence of integrating regional variations (Haapio and Viitaniemi, 2008). Thus, it is of vital importance for policy makers and other building professionals (assessors) to detect how much environmental and economic benefits can be gained from the implementation of sustainability measures. It is exactly this degree of specificity that this study attempts to add to assessment methods by focusing on regional climate conditions. It can be argued that environmental assessment methods designed in the manner described above can bring about a new appreciation of climate influence on the built environment. They can provide decision makers with a robust strategy aiming to classify regional climates and in turn direct the growth and potential building boom to these areas. Again, the approach used does not eliminate the wider socio-economic environment but provides the recognition of variables necessary for the effective use of the tool.

4.13 SUMMARY

The need for stimulating the market demand for sustainable practices in the built environment requires the large-scale adoption of adapted environmental building assessment methods. While western countries have widely engaged in this avenue, developing economies such as Ghana are still trailing behind. Also, Ghana presents a great potential for renewable energy use. Hence, it becomes imperative to design and put into operation a benchmark scheme which will assess the principles of sustainable building energy consumption. This will foster the recognition of green building principles with the extensive adoption of sustainable energy practices. Therefore, the research objectives formulated earlier in this chapter is set to promote the adaptation of such a tool in Ghana. Using the AHP method, the input data was subjected to pair wise comparison. The results of the AHP study strongly suggest that the weighting system of well-known environmental assessment methods such as BREEAM and LEED are inapplicable for the Ghanaian context. New categories have been prioritized in this study, by means of AHP, with the aim of reflecting the most accurate sustainable measures of the Ghanaian built environment. As the strategy of an energy building assessment method is to provide a single score, this chapter combines AHP with Delphi to devise credits allocation for the new criteria and rating formula, and this, in turn, closes the circle of a completed weighting system. Having developed the weighting scheme together with the rating system, it is needful to subject this to further analysis to validate the results obtained. Building simulation tool (e.g. Designbuilder) is suggested to be used as research instrument to collect and analyse relevant data.

CHAPTER FIVE

5.0 DEVELOPMENT OF BUILDING ENERGY ASSESSMENT TOOL

5.1 INTRODUCTION

In this chapter, a case study is presented in which the developed grading system is used to assess the energy efficiency level. For this purpose, a simulation study (dynamic thermal modelling) was used. The DesignBuilder software was used to simulate a typical high rise office building in the city of Accra. Thereafter, a reference building is also modelled in DesignBuilder. The reference building modelled on best practice was used as a basis to measure the existing building. What follows next is discussions on the results of the simulation exercise, subsequent results generated and the application of the grading system.

In the preceding chapter a rating system has been developed following a Delphic hierarchy process. The Delphic hierarchy process provided the identification of various categories with available credits. A simple rating formula and grading system has also been proposed. Five main categories have been identified including building design, performance of envelope and use of renewable energy. Each of these categories have their own available credits and corresponding weights.

5.2 ANALYSIS AND RESULTS

Outcomes and results of the simulations for the facilities were assessed by way of the design of case study premises. These included the profiles of individual users and building fabric utilized. Simulations provided the real energy consumption. The simulated energy consumption data was compared against actual consumption of energy provided on the 2012 utility bills and analysed according to the type of building usage. The analyses provided were based on annual energy consumption and also monthly energy consumption.

5.2.1 Energy Consumption

The average annual electrical energy consumption (kWh/m2) for the property studied and simulated is illustrated in Table 5.2. The in-depth DesignBuilder analysis allowed an understanding of what the energy was consumed for in each case. Between 64% and 71% of the energy consumed was for air conditioning needs, which may be expected due to the very warm, humid climate (Field Survey, 2015). A comparable result has been presented in similar previous studies (Simons et al., 2015). Reducing this high electricity demand for air conditioning in hot, arid climates illustrates a sizeable challenge, and indicates a need to employ optimal insulation and architectural solutions. The lighting and other appliances consume the least amount of energy in all cases.

Table 5.1 presents the monthly energy consumption data based on both the simulation results and the utility bills. The season with the highest level of energy consumption is the hot dry season when the weather becomes extremely hot, necessitating a dramatic increase in the use of air conditioning facilities from December to May. As expected, the highest energy consumption is during this period, due to the requirement for air conditioning.

The energy consumption for offices in the warm humid climate of Ghana is up to 215 kWh/m2 per year (Simons et al., 2015). It is important to state that this high level of energy consumption (according to kWh/m2) does not necessarily reflect the total energy consumption (kWh) of the property, as the high electricity demand depends on the particular size of the property. The largest source of energy consumption is the cooling system (air conditioning), as illustrated by the data from the study.

Table 5.1 Simulation Results: Monthly Electrical Energy Consumption

MONTH	Electric Energy in kWh		
	Billed	**Simulated**	**Percent Difference**
Jan	4769	4599	3.56%
Feb	3991	4550	-14.01%
Mar	4227	4668	-10.43%
Apr	3952	4829	-22.19%
May	4330	4742	-9.52%
Jun	3847	3058	20.51%
Jul	3545	3107	12.36%
Aug	3592	2996	16.59%
Sep	3952	2947	25.43%
Oct	3904	3454	11.53%
Nov	2426	3658	-50.78%
Dec	3655	3674	-0.52%
Annual	**46,190.00**	**46,282.00**	**-0.20%**

Source: Survey Data, 2015

5.3 ENERGY PERFORMANCE CALCULATION

In accordance with the principles developed during the tool development, there is a need to build a reference building to use in assessing the case study building. In order to do this, the reference building needs to be highly optimised, representing an ideal building with an efficient energy consumption practice. Due to the lack of building energy codes and standards within the Ghanaian built environment, best practice was used (de Oliveira et al., 2006; Aldossary et al., 2014). Employing best practices, the reference building is optimised to ensure an efficient energy consumption profile.

Results for the performance of the building and even the rating obtained are strongly dependent on the tool used and particularly on the input parameters applied, which underlines the importance of developing robust methods. All the assumptions made and standard data used in developing the model for this study were based on the data gathered from the questionnaires.

Applying the standard activity data and the stock construction template to the building model and calculating the performance, and then re-calculating the building performance after assigning the reference building characteristics, the reference building performance was determined.

5.3.1 Optimisation Study

Many energy reducing measures are in place and various options arise which can be implemented in design. Some of this measure include proper orientation of the building use of shading devices. The building geometry, envelope and many building systems interact, thus requiring optimizing the combination of the building and systems rather than merely the systems on an individual. One way to achieve this is the use of automated mathematical building performance optimization paired with building performance simulation as a means to evaluating many different design options and obtain the optimal or near optimal while achieving fixed objectives (Attia et al., 2013).

The optimisation of low-carbon building design is a complex problem. If the designer is concerned only with a single performance objective, such as annual CO_2 emissions, and if the effect each design choice (each variable) has on the performance is independent of the values chosen for other variables, finding the optimum design may be relatively trivial. However, such a situation is rare. Even if there is only a single performance objective, the optimum specification for each variable often depends on the choices made for other variables, that is to say, the effect of each variable is epistatic (Attia et al., 2013). Furthermore, it is hard to imagine a situation in which the designer is concerned about improving energy performance or reducing

CO_2 emissions but is unconcerned about the cost of the resulting design (Attia et al., 2013). Therefore, in most low-carbon building design cases, there will be at least two performance objectives: cost and energy performance (Attia et al., 2013).

Methods for finding the optimum trade-off between competing objectives have been the subject of much recent research and numerous methods exist. These include particle swarm, gradientbased searches, pattern searches, neural networks, simulated annealing and genetic algorithms. A comparison of these different methods is beyond the scope of this thesis, which focuses on genetic algorithms as a well-established and robust method. Genetic algorithms attempt to mimic the natural processes of evolution by natural selection in order to improve the designs from an initial starting population. A state-of-the art study in 2013 by Attia et al. (2013) reveals a breakthrough in using evolutionary algorithms in solving highly constrained envelope, HVAC and renewable optimization problems. Also, they show that the simple genetic algorithm solved many design and operation problems and allowed measuring the improvements in the optimality of a solution against a base case.

In DesignBuilder Optimisation, Genetic Algorithms (GA) are used to search for optimal design solutions. In DesignBuilder, up to 10 design variables can be included in the analysis in combination with up to 2 objectives such as “minimise carbon emissions” and “minimising construction cost (Attia et al., 2013). The results are displayed graphically with operational carbon emissions on one axis and investment cost on the other and the performance of each design option that is tested as part of the procedure plotted on the graph. The designs with lowest combinations of cost and carbon form a “Pareto front” of optimal designs along the bottom-left edge of the data point “cloud”.

Already a study by Aldossary et al. (2014) has indicated the design options that have a huge impact on building energy consumption in warmer climates. The study has also revealed the key variables that predict the most energy efficient energy consumption. With this in mind and the limitation provided by the DesignBuilder software, only 10 options are studied here. It needs to be re-stated here that the focus of the study is not on optimisation but in order to achieve the efficient use of a tool, a simple optimisation study needs to be carried out. The results of the optimisation being applied to the reference building will provide the results intended, i.e., a highly optimised building serving as a benchmark to compare with the actual building. Table 5.2 presents an overview of the various options that were studied

Table 5.2 Summary Optimisation Options and Results

Design Parameter	Options Considered	Optimal Result (kWh.m-2.a-1)
Building Design		
Office Window Orientation	North-West windows at the R.T	174.58
Orientation of Building	From 0 degrees to 360 degrees	
Shading Option	External blinds	
	Internal blinds	
Glaze ratio to wall	From 10% to 90%	
Performance of Envelope		
Thermal Mass	Without carpet and acoustic ceiling (suspended ceiling)	184.17
Building Insulation		
Glazing type	Double glazing; g=0.5; U=1.7$W \cdot m^{-2} \cdot K^{-1}$	
	Double glazing; g=0.6; U=1.8$W \cdot m^{-2} \cdot K^{-1}$	
	Double glazing; g=0.6; U=2.8$W \cdot m^{-2} \cdot K^{-1}$	
	Single glazing; g=0.7; U=5.7$W \cdot m^{-2} \cdot K^{-1}$	
	Single glazing; g=0.8; U=5.7$W \cdot m^{-2} \cdot K^{-1}$	
	Single glazing; g=0.9; U=5.7$W \cdot m^{-2} \cdot K^{-1}$	
Energy Efficiency of Building Facilities		

HVAC	Coefficient of Performance 1.25 – 2.50	175.80
Efficient Lighting	2W.m^{-2}	

Source: Survey Data, 2015

Table 5.3 Weight and Grade Calculation for RT Building

Parameter	Case Building		Reference Building		Weights	CA/AC	BEAC
	Credits	EUI (kWh.m-2.a-1)	Credits	EUI (kWh.m-2.a-1)			
Building Design	10	– 214.87	16	174.58	0.44	0.63	0.28
Performance of Envelope	5	– 214.87	7	184.17	0.09	0.71	0.06
Energy Efficiency of Building Facilities	8	– 214.87	11	– 175.80	0.28	0.73	0.20
Building Operation and Management	4	– 214.87			0.10	0.50	0.05
Use of Renewable Energy	-		-		0.08	0.00	0.00
RATING FOR RT BUILDING							**0.60**

Source: Survey Data, 2015

5.4 GRADE CALCULATION

The grading developed in the previous chapter can be applied in a number of ways. Firstly, the use of the energy intensities in determining the level of grades. This means that the energy use intensity (KWhr/m2) of the building in question will be compared with the reference building. Ideally, with the existence of building energy codes and/or standards, it would have been relatively easy to determine the minimum requirement. If this was the case, then having determined the minimum requirement and the reference building acting as the maximum requirement, the levels in between the two will be used as a basis to determine the various grades. This represents a significant drawback. However, with the developed grading system, it provides a leeway in applying the levels. The grading system enables the buildings to be ranked over a 100%. Thus, for the categories identified, i.e., building design, renewable, etc., the building in question will be compared with the reference building. The reference building will be taken as the standard and probed to find out in relation to the levels identified how the base case building is able to meet it.

$$BEAC = \frac{CA}{AC} \times W \times 100 - Equation\ 5.1$$

Where:

BEAC: Building Energy Assessment Category

CA: Credits Achieved

AC: Available Credits

W: Weighting Coefficient

Table 5.3 provides the various calculation for the Building Energy Assessment Categories. It can be seen that the BEAC score for Building Design is 0.28. It has been already stated that a comparison will be done measuring the total energy consumption of the Reference building against the Case Building. The EUI for the reference building is 174.58 kWh.m-2.a-1 and that for the case building is 214.87 kWh.m-2.a-1. The available credits for the Building Design category is 16. The reference building is taken as the best-case scenario hence achieves all the 16 credits available. Based on the EUI score of the reference building achieved a total credit of 16, the case study achieved credits is calculated based on its EUI. Thus, a simple interpolation computation is done to find the total credits achieved for the case study building. Based on the final score the RT building, the building is awarded a rating of C which signifies that it operates at the Intermediate Performance Level.

Table 5.4 Grading System

SCORE	RATING	INTERPRETATION
100-80	A	Best Performance Level
79-70	B	Above Intermediate Performance Level
69-60	C	Intermediate Performance Level
59-40	D	Acceptable Performance
49-40	E	Minimum Acceptable Performance
39- under	F	Deficient

Source: Survey Data, 2015

5.5 DISCUSSION AND CONCLUSION

The operative rating as well as the standard shared characteristics put forward in this study are especially restricted in accurateness as well as applicability as a result of the reduction in the data collection exercise and the simple approaches and hypotheses made use of. Looking beyond those restrictions, a probable initial explanation of the grade C for computed rating is that the grade or standard of construction as well as the thermal energy performance features of the buildings sampled, is somewhere amid the building stock and building regulation reference buildings.

The ability to weigh a building with the representative building stock performance against rules constitutes a crucial measure for it to be certified. In the situation of computed ratings, the standard for determining similarities could be fixed as those building features which correspond to the rules and/or the building stock. The advancement of those reference building standards calls for certain hypotheses and gathering of data that could turn out to be a challenging undertaking. Whilst certain elements like activity, occupancy data, building area, , age of building, etcetera, could be obtained with ease through questionnaires, additional crucial statistics for evaluation for energy performance of the building, like particulars of the construction as well as efficacy of heating systems are usually unknown by respondents.

Putting questionnaires together with a quantity of building surveys to gather comprehensive statistics for reduced sample of buildings, as was carried out in this study, possibly will be the best in terms of useful answers for the advancement of reference building standards. The advancement of statistical standards of calculated energy could as well be a laborious job in states which do not have a custom of calculating and observing the usages of energy. Operative rating in this process which has been made simple demands a number of data inputs as well as measurements against standards to generate a label.

Successively, conclusions could be drawn concerning the possible energy performance of the building that might be beneficial for the end of selling or renting. The measured rating, in contrast, is associated with the advantage of signifying the real usage of the building, and generating a rating in accordance with this usage. This is mainly suitable to community buildings, since it evaluates the real performance, and usually, this element is of greater import for community buildings as compared to the ‘‘energy potential’’, since its selling or renting is seldom significant. A prevailing downside of the projected measured rating is the challenge of outlining suitable standards for drawing parallels, equally for the building stock for which performance data is unavailable within different states, as well as for the present practice buildings, which are parallel to novel buildings from which a certain amount of time would be needed for the collection of data. This study has given a simple and useful approach to gathering those energy utilization standards through questionnaires, assignment of the median value of the responses for building stock reference (Rs) as well as the upper quartile value for the prevailing practice regulation reference (Rr). Nonetheless, if a measured energy rating is approved and implemented in a state or province, the statistical yardsticks can be increasingly improved with the adding of data for all the measured and rated buildings.

As a concluding comment, it can be observed that giving regard to a computed rating as well as a measured rating jointly, might be a substantial merit in searching out enhancement of energy performance.

Developing ratings through the usage of the two approaches would necessitate substantial exertions in the gathering of data and data assessment in those states which do not have prior practical knowledge in this field. Additional efforts would be needed to permit the drawing of parallels between both ratings, in the nature of authenticating the computation as well as the simulation methods. These efforts would provide substantial additional worth in evaluating the performance of the building correctly, as well as determining if its performance is as a result of inherent features of the building, or to tenancy, activity and administration matters.

This research does not encompass indoor temperatures, aeration and indoor air quality assessment. Indoor temperatures and air change rates have been apportioned standard and approximated values in the computed rating, and not considered in the computed rating. Future development on the methods of rating ought to consider circumstances and matters associated with indoor setting to guarantee that energy efficacy does not ever complicate the quality of the indoor spaces. This is a first step in the right direction.

5.6 SUMMARY

In this chapter the developed grading system is use to further develop the tool for the assessment of building energy efficiency of office buildings in Ghana. Using a simulation study a generic office building has been modelled in dynamic thermal modelling software (DesignBuilder). Thereafter, the same building is modelled using best practice and used as a basis (reference case) to measure and compare the EUI of the actual building. The grading system is applied and the building is awarded a grade C. The various processes undertaken represents the various steps in the application of the proposed tool. The proposed tool is seen as creating a viable starting point for the implementation of a building energy efficiency assessment studies in Ghana.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 INTRODUCTION

The overarching aim of the study was the development of building energy efficiency tool for predicting energy efficiency of buildings at the design stage. The primary focus being the Ghanaian built environment. Congruent to this, a mixed methodology approach was adopted ranging from review of pertinent literature, Delphi study, a Delphi Hierarchy Process and a simulation study. In this chapter, the conclusions of the study and recommendations are presented. The recommendations have been generally categorised into two main groupings: one aimed at industry work and the other mainly academia and research. The chapter highlights key contributions resulting from the study.

6.2 RESEARCH CONCLUSIONS

The research conclusions are presented in congruence to the research objectives that were set and this follows below.

6.2.1 Objective One:

To Assess Methods Used in Building Energy Performance Assessment Towards the Development of a Conceptual Framework

As stated above, this objective was to steer towards the development of a conceptual framework to guide in coming out with the resultant tool. The main methodology used here was the review of pertinent literature. The review unearthed various approaches used firstly in building energy quantification. Subsequently, a review of various tools was conducted. A comparative study of the various tool was done. This aided in the identification of areas of convergence and distinction. This then led to the review of building energy indicators which later formed the basis for the grading system. From the review of literature and drawing upon the work of Lombard et al. (2009), a conceptual framework was developed. Literature also showed that authors have argued for the need to develop sustainability tools, stressing on the fact that seminal tools usually focus on the regional priorities and for most developed countries, it is usually geared towards environmental. However, the social and economic dimensions cannot be overlooked especially in developing countries faced with increasing urbanization and low standards of living.

6.2.2 Objective Two:

To Identify Applicable Criteria to Form the Dimensions of the Building Energy Assessment Method

To achieve this objective a Delphi survey was conducted. This was done in two successive rounds following the literature review. Expert opinion from fields of academia, industry and government were assessed and consensus established showed that the international assessment methods are not fully applicable to the Ghanaian built environment. Five main blocs were established: the energy performance indices; calculation of energy performance; assessment of energy performance; setting of energy efficiency limit and energy performance labelling.

The findings reveal that the experts came to a consensus of the use of annual energy as the medium of energy performance indices. This was largely attributed to the relative ease of measurement with this index. The Delphi findings also indicated the use of dynamic calculation method over the steady state approach. Ideally, one would have thought that the use of steady state will be simpler due to the ease of implementing however, dynamic state was preferred. It was advanced that increasing understanding and usage of building simulations may have proffered this option.

6.2.3 Objective Three:

To Propose a Grading System Underpinned by the Determined Weighting Coefficients for the Building Energy Efficiency Assessment Method

In cognisance of the research aim, the third objective was carved. Following the findings of the second objective, the Delphic hierarchy process was used to achieve the next objective. This involved the development of a customised weighting system for the Ghanaian environment. The Delphic hierarchy process combining the relative strengths of the Delphi method and the AHP was done in two successive rounds. The AHP in the second round played a key role in the development of a potential weighting system that is not only able to reflect local needs but also prioritise building energy aspects, government policy and both economic and social issues.

The resultant weighting system had building design having the highest weight followed by energy efficiency of building facilities. Use of renewable energy had the lowest weight. The findings reflect the current development of building energy data studies. It was noted that despite the huge potential that renewable energy can play in reducing energy efficiency, current economic issues presented an impediment to its investment and subsequent development. Also, the climatic conditions and the regional characteristics were reflected in the weighting system as evident by the highest weight attached to building design.

6.2.4 Objective Four:

To Propose and Validate a Tool for Building Energy Efficiency Assessment in Office Buildings in Ghana

To achieve objective four a simulation study was undertaken to test and validate the developed weighting systems and further propose a tool undergirded by the grading system. Research work on building energy consumption profiles, general building characteristics, weather data and the like were utilized. Building energy data studies provided the required framework to properly develop the tool.

6.3 VALUE AND CONTRIBUTION OF THE RESEARCH

The value and contribution of the current study is presented at three main levels: theory, methodology and practice. It is important to state that the outstanding contribution of study lies in the final tool developed for predicting energy efficiency of buildings at the design stage.

6.3.1 Theory

The study is significant because it closes the knowledge gap and dearth of theoretical information on key variables significant in predicting building energy efficiency in Ghana with a unique weighting system developed for the Ghanaian socio economic climate. Prior to this, three main studies focused in Ghana have been conducted, their locus exploring thermal performance of building. However, evidence of a similar study conducted within comparable regional context was not established. The study has created a viable starting point for mainline building energy studies in Ghana. This offers a base for other researchers to use for other follow-up studies within the field.

The study findings reveal that economic and policy framework plays a pivotal role in the determination of energy efficiency of buildings within that particular context. The findings enforced the argument that economic, social and cultural aspects are unique characteristics that prevent the use of international assessment methods. Apart from the study contributing to theoretical knowledge, it also contributed to methodological advancement in terms of the approach used in conducting the research.

6.3.2 Methodology

Similar studies across the globe have adopted the use of group consensus measurements such as the Delphi and AHP, while other have also adopted both the Delphi and AHP (Alaymi, 2015; Bagheri et al., 2013; Beradi, 2012). However, the current study due to peculiar issues within the region adopted the use of both the Delphi Method with the Delphic Hierarchy Process. The developed tool was later subjected to a simulation study. This unique methodology; the combination of the Delphi survey, the Delphic Hierarchy Process and the simulation study differentiates it from other similar studies conducted. Further, the approach afforded a bespoke tool fit for the peculiar region to be developed. Through this study, a robust methodology tailored for regions characterised by urbanization with a growing economy combined with lack of energy data studies have been developed and used. Contribution to practice, aside from its value to the body of knowledge in methodological terms, was also achieved.

6.3.3 Practice

Various literature points to the critical role played by building energy efficiency assessments tools (IEA, 2006). Internationally, usage of such tools has led to a reduction in total building energy consumption (UNEP, 2009a; EU, 2009). The development of a building energy assessment tool amongst many would contribute to energy security and economic stability. Such a tool can be adopted by energy planners, policy developers, building scientists and designers in the planning, design and implementation of energy efficient building.

Energy planners and Policy developer's usage

The findings from the study provides basis for the development of policy framework for building energy efficiency in Ghana. From the literature review, it was identified that currently, Ghana does not have any building energy efficiency program in place. Coupled with the rising demand and increasing energy cost, the study will serve as a building block for putting in place policy guidelines. The findings of the study, taking into cognisance the socio-economic environment, is a good basis for energy planners to use in measuring the efficiency of buildings.

Building scientist usage

The study unearthed key variables for usage by building scientist. It was realised that the building envelope and building energy facilities play a pivotal role in determining how energy efficient a building is. The developed assessment methods designed in the manner described in the study has brought about a better appreciation of climate influence on the built environment. They provide a robust strategy to building scientist aiming to classify regional climates and in turn direct the growth and potential building boom to these areas. Again, the approach used does not eliminate the wider socio-economic environment but provides the recognition of variables necessary for the effective use of the tool.

Building designers usage

For building designers, the tool can inform on how energy efficient various design options would be. This is very significant as it helps to better shape and further focus on the best design for a particular building. For regions of West Africa or of similar conditions, the tool can also serve as a springboard for designers and architects to use in designing energy efficient offices.

A reduction in building energy results in a reduction in environmental impact whilst improving energy security. For a country like Ghana, a reduction in energy will lead to a greater access to energy by the general populace which will ultimately have an impact on the economy.

6.4 RECOMMENDATIONS

Recommendations are proposed firstly for stakeholders including building designers, energy policy planners, etc., and secondly, for further research work on building energy efficiency.

6.4.1 Practical

The following recommendations for both public and private stakeholders in Ghana are made on the basis of the research work.

1. Almost all well-known building assessment methods are updated and revised either annually or biannually. Therefore, it is recommended that the tool be subject to regular review which will inform required development and updating. Further developments should incorporate the developments of guides needed whilst using the tool.
2. Well known building assessment methods are undertaken by trained building assessors. It is recommended that future developments of the tool should provide for potential assessors to take comprehensive courses. This will further make the evolving tool a process which is more reliable, reflecting the actual performance within the Ghanaian built environment
3. As the testing and simulation process of the developed tool, applicability has been limited. It is recommended that the tool be tested on more office buildings. It is also recommended that the creation of building energy consumption profiles for more buildings will be a plus.
4. Due to the lack of building energy standards within the Ghanaian environment, various variables had to be used, usually relying on best practice. It is recommended that building energy standards and codes be developed for the Ghanaian environment.

6.4.2 Policy

Stimulating the market demand for energy efficient buildings will be a positive direction for various policies to explore. It is explicated in the thesis the key role government plays in driving for energy efficient buildings. The introduction of incentives to encourage developers and building owners to invest in energy efficient design will be in the right direction. Government could look at reducing tariffs as an incentive for buildings that meet a particular grade when it comes to the payment of electricity.

6.4.3 Recommendations for Future Research

Based on the study findings and limitations, the following recommendations are made for further studies:

1. From the literature review and research findings, it is quite evident that there is a dearth of studies on building optimisation within the Ghanaian built environment. Most studies have adopted a parametric approach in analysing building design options. To further be able to use the tool appropriately, it is recommended that future studies explore building optimisation studies.
2. The current study has focused solely on office buildings within the Ghanaian context. It is recommended that further studies should explore other type of buildings including the different types of residential buildings and industrial buildings.
3. The focus of the study centred primarily on buildings at the design stage. Further studies looking at already built buildings and how to measure the energy efficiency would be very interesting. This would enable a continuing study on exploring retrofit options for the Ghanaian built environment.
4. Future studies could also explore building energy efficiency and cost. A research question focused on how much it costs for buildings to be energy efficient would be interesting. Cost could be looked at from different angles including life cycle cost and capital cost.
5. Further studies could also explore building energy management systems usage in Ghana.
6. Future studies could also look at other regional climates and possibly, even follow up to do a comparative study.

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APPENDICES

APPENDIX 1 – LIST OF BUILDING ENERGY INDICATORS

APPENDIX 2 - DELPHI SURVEY QUESTIONNAIRE – ROUND ONE

APPENDIX 3 – DELPHI SURVEY QUESTIONNAIRE – ROUND TWO

APPENDIX 4 – USERS OF RT BUILDING RESULTS

APPENDIX 5 – CONSTRUCTION TABLES

APPENDIX 1 – LIST OF BUILDING ENERGY INDICATORS

Indicators	Indicators	Indicators
Location of Building	Outdoor plant covering area	Reduction of lighting pollution
Water conservation	Co2 emission	Optimisation of energy use
Green power	Management of construction waste	Reuse of material resources
Recycle of building material	Monitoring of indoor CO_2	Improvement of ventilation efficiency
Management of indoor air quality	Control of air-conditioning system	Humidity of the indoor thermal environment

Natural lighting and outdoor scenery	Minimise the energy resource consumption	Thermal properties of building envelope
Dry Space	Environment-friendly labelling of building facilities	Indoor lighting
Outdoor lighting	Public transportation	Storage space for bicycles
Infrastructure of residential building	Artificial lighting facilities	Renewable and low-carbon energy sources
Work at home	Acoustic insulation	Private Space
Energy conservation guides for occupants	Considerate builders	Use of innovative techniques
Use of ground heat	Indoor acoustic environment	Indoor visual environment
Direct use of renewable energy sources	Lighting facilities	Hot water supply
Ventilation facilities	Energy-efficient building facilities	Management of building operation
Lift facilities	Reuse of resources	Project plan
Use of rain water	Reuse of building envelopes	Reuse of building materials
Use of green building materials	Orientation of building	Emission of greenhouse gases
Avoid the use of Freon and Halon gases	Refund of energy conservation investment	Use of industry waste water
Indoor air quality	Indirect use of renewable energy sources	Electromagnetic pollution
All-year electricity consumption	Social Impacts	Noise
Cost and economy	Awareness of energy conservation	Ventilation
Glaze ratio of wall	Shape of building	Density of commercial building area
Airtightness of external windows	Reduction of incoming solar radiation to residential area	Integrated part-load value (PLV)
Plant covering ratio of residential area	Distance between buildings	Shading coefficient of external windows
Colour of external building envelopes	Use of solar energy	Hourly cooling load calculation
Plant cover of roofs	Hourly heating load calculation	Energy efficiency of water supply system
Heat measurement of central heating systems	Energy efficiency of pumped central heating systems	Air-conditioning facilities

APPENDIX 2 - ROUND ONE SURVEY QUESTIONNAIRE

Kwame Nkrumah University of Science and Technology
Department of Building Technology
Kumasi

QUESTIONNAIRE

A Tool for Predicting the Energy Efficiency of Buildings at the Design Stage

Dear Sir/Madam,

This questionnaire forms part of a PhD research project which aims to develop a tool for building energy efficiency measurements. It is the first part of a Delphi survey and seeks to establish key parameters in the development of the tool. It is expected that this research will improve building energy efficiency designs.

I would like to invite you to participate in the above project. Completion of the questionnaire is completely voluntary and returning the completed questionnaire will be considered as your consent to participate in the survey. The questionnaire will take you less than 5 minutes to complete.

I appreciate that you are already busy and that participating in this survey will be another task to add to a busy schedule, but by contributing you will be providing important information. **All data held are purely for research purposes and will be treated as strictly confidential.**

If you wish to receive feedback on the research findings, a section is provided at the end of the questionnaire for you to indicate. In the event of questions or queries, please do not hesitate to contact me. Thank you for your time and valid contribution in advance.

Yours faithfully,

Mr. Michael Addy, PhD Student
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Mobile: 0506638122

DEMOGRAPHIC DATA

1. Please indicate that which best describes your area of work

    Ministries/Other Governmental Sectors [ ]

    Academia/Research [ ]

    Industry; Building Consultancy/Building construction [ ]

    Others Please specify ……………….

2. How long have you been working in this sector

Less than 5 years [ ] 6 – 10 years [ ]

11 – 15 years [ ] 16 – 20 years [ ]

21 years and above [ ]

3. What best describes your area of specialisation?

Electrical Engineering [ ]

Mechanical Engineering [ ]

Architecture/Architectural Engineering [ ] Construction Management [ ]

Others Please specify ……………….

BUILDING ENERGY EFFICIENCY TOOL DEVELOPMENT

Please rate the following options in response to the questions asked using the scale below

A – First Priority; B – Second Priority; C – Third Priority

You are required to choose the best three options. Where there are only two options provided you are required to rank the two

1. How should energy performance indices be defined in the assessment of building energy efficiency?

Annual energy use [ ] Maximum electricity demand [ ]

Energy efficient design [ ] Envelope performance [ ]

Annual energy cost [ ] Annual CO_2 emissions [ ]

2. How should energy performance be calculated?

Dynamic methods [ ] Steady state method [ ]

3. How should energy performance be assessed?

Performance Based [ ] Feature Specific [ ] Energy

Cost Budget method [ ]

4. How should the limit of energy efficiency be set?

Fixed limit option [ ]

Customised Option [ ]

5. How should building energy efficiency be labelled?

Point Based System [ ]

Percentage Based System [ ]

6. Please rate the degree of importance of these indicators in assessing the energy efficiency in office building in Accra, Ghana. The response scale is as follows from 1-7

Not at all important – (1); Low importance - (2); Slightly important – (3);

Neutral – (4); Moderately important – (5); Very important – (6);

Extremely important – (7);

Kindly tick the appropriate column

	1	2	3	4	5	6	7
Building Design & Construction							
Orientation of building							
Outdoor Environment							
Use of shading devices							
Shape of building							
Glaze ratio of wall							
Advanced design and construction technique							
Efficient use of Day lighting							
Other pleases specify; ………………………………							
………………………………………………………...							
………………………………………………………...							
Performance of Envelope							
Airtightness of Envelope							
Insulation of building							
Thermal properties of building envelope							
Other pleases specify; ………………………………							
………………………………………………………...							
………………………………………………………...							

Energy efficiency of building facilities							
HVAC facilities							
Efficiency of lighting systems							
Energy cost of operation of building							
Social impact (energy efficient facilities impact on sociocultural behaviour)							
Optimisation of energy use							
Other pleases specify; ………………………………							
………………………………………………………...							
………………………………………………………...							
Building Operation and management							
Indoor thermal comfort							
Indoor lighting							
Acoustic Environment							
Other pleases specify; ………………………………							
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………………………………………………………...							
Use of Renewable Energy							
Proportion of renewable energy in energy consumption							
Cost of renewable energy							
Use of local (city/town specific) renewable energy sources							
Other pleases specify; ………………………………							
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Any comments are warmly welcome

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THANK YOU!!!!

Kindly provide your contact details below if you would like to receive feedback on the research findings.

APPENDIX 3 - ROUND TWO SURVEY QUESTIONNAIRE

Kwame Nkrumah University of Science and Technology
Department of Building Technology
Kumasi

QUESTIONNAIRE - SECOND STAGE

A Tool for Predicting the Energy Efficiency of Buildings at the Design Stage

Dear Sir/Madam,

You are kindly invited to the second part of the Delphi survey. This questionnaire forms part of a PhD research project which aims to develop a tool for building energy efficiency measurements. It is expected that this research will improve building energy efficiency designs.

I would like to invite you to participate in the above project. Completion of the questionnaire is completely voluntary and returning the completed questionnaire will be considered as your consent to participate in the survey. The questionnaire will take you less than 5 minutes to complete.

I appreciate that you are already busy and that participating in this survey will be another task to add to a busy schedule, but by contributing you will be providing important information. **All data held are purely for research purposes and will be treated as strictly confidential.**

If you wish to receive feedback on the research findings, a section is provided at the end of the questionnaire for you to indicate. In the event of questions or queries, please do not hesitate to contact me. Thank you for your time and valid contribution in advance.

Yours faithfully,

Mr. Michael Addy, PhD Student
MSc, BSc, MIBPSA, MEI.
Kwame Nkrumah University of Science and Technology
Department of Building Technology
Email – mljaddy@yahoo.co.uk
Mobile: 0506638122

BUILDING ENERGY EFFICIENCY TOOL DEVELOPMENT

Please rate the following options in response to the questions asked using the scale below

A – First Priority;   B – Second Priority; C – Third Priority

You are required to choose the best three options. Where there are only two options provided you are required to rank the two

1. How should energy performance indices be defined in the assessment of building energy efficiency?

Annual energy use [ ]	Maximum electricity demand [ ]

Energy efficient design [ ]	Envelope performance [ ]

Annual energy cost [ ]	Annual Co2 emissions [ ]

2. How should energy performance be calculated?

Dynamic methods [ ]	Steady state method [ ]

3. How should energy performance be assessed?

Performance Based [ ] Feature Specific [ ] Energy Cost Budget method [ ]

4. How should the limit of energy efficiency be set?

Fixed limit option [ ]

Customised Option [ ]

5. How should building energy efficiency be labelled?

Point Based System [ ]

Percentage Based System [ ]

Building Energy Efficiency Indicators

Mark the relative importance of **the building energy indicators** for office buildings in Accra, Ghana using the following scoring pattern

SCORING PATTERN			
Relative Importance (More)	*Score*	*Relative Importance (Less)*	*Score*

Equal importance	1	Equal importance	1
Slightly more important	3	Slightly less important	1/3
Strongly more important	5	Strongly less important	1/5
Very Strongly more important	7	Very Strongly less important	1/7
Absolutely more important	9	Absolutely less important	1/9
Intermediate values	2,4,6,8		1/2,1/4,1/6,1/8

Please fill up the white space provided in the matrix on the next page

Any comments are warmly welcome

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THANK YOU!!!!

Kindly provide your contact details below if you would like to receive feedback on the research findings.

APPENDIX 4 - BUILDING USERS OF RT BUILDING

The table below summarises the results from the sets of questions distributed to the building occupants. The first section represents results on general questions and the remaining sections shows the response on specific topics.

Table A3: Summary of questionnaire response in terms of percentage of people

Nr.	Question	Category	R.T.
	GENERAL QUESTIONS		
1.1	Gender	Male	85.7
		Female	14.3
1.2	Age	<25	7.1
		25-35	64.3
		36-45	14.3

		46-55	7.1
		>56	7.1
1.3	Education	Elementary	7.1
		Junior High	-
		Senior High	-
		O level	7.1
		A level	-
		Undergraduate	42.9
		Postgraduate	42.9
1.4	How long have you been working in your current office	Under 1year	21.4
		1-5 years	57.1
		6-10 years	21.4
		>10 years	-
1.5	What percentage of your work do you perform on your computer	0-10	21.4
		11-20	-
		21-30	-
		31-40	-
		41-50	7.1
		51-60	28.6
		>60	42.9
1.6	How many hours in average do you work per week	0-30hrs	14.3
		30-40hrs	21.4
		41-50hrs	21.4
		51-60hrs	21.4
		>60hrs	21.4
1.7	Of these, how many hours do you spend at your workstation	0-30hrs	57.1
		30-40hrs	27.4
		41-50hrs	14.3
		51-60hrs	7.1
		>60hrs	-
2.0	What is your general feeling concerning the under listed parameter in your office?		

2.1	Temperature	Warm	4.8
		Neutral	21.4
		Cool	73.8
2.2	Relative Humidity	Very poor	-
		Poor	7.1
		Neutral	14.3
		Good	50
		Excellent	14.3
		Don’t Know	14.3
2.3	How would you prefer to feel during the Dry Season?	Cold	
		Cool	54

		Slightly cool	18
		Neutral	22
		Slightly warm	6
		Warm	-
		Hot	-
2.4	How is the average temperature in your office during the Rainy Season?	Cold	16
		Cool	54
		Slightly cool	12
		Neutral	18
		Slightly warm	-
		Warm	-
		Hot	-
2.5	How would you prefer to feel during the Rainy Season?	Cold	6
		Cool	42
		Slightly cool	6
		Neutral	24
		Slightly warm	6
		Warm	-
		Hot	-
		Ok	64.3
		Slightly dim	-
		Dim	-
3.0			
3.1	Can you open the windows of your office if required?	Very easily	14.3
		Easily	21.4
		It's ok	7.1
		complicated	21.4
		Not at all	35.7
3.2	Do you in the morning ventilate your office before switching on the airconditioner?	Yes, frequently	
		Occasionally	
		Rarely	
		Never	
3.3	Is the thermostat (air-conditioning regulator) easily accessible to you?	Very easily	7.1
		Easily	57.1
		It's ok	21.4
		Not at all	14.3
		Not applicable	-
3.4	Are there fans in your office?	yes	-
		no	100
3.5	Is the light switch easily accessible to you?	Very easily	7.1
		Easily	35.7
		It's ok	50
		Complicated	-

		Not at all	7.1
4.0			
4.1	Do you think that you can influence building energy consumption in the way you operate building systems?	yes	50
		Don’t know	28.6
		no	21.4
4.2	Do you think about energy conservation, when you operate building systems?	yes	64.3
		Don’t know	21.4
		no	14.3
4.3	What temperature range do you normally set your air-conditioner?	18-20^{o}C	87.1
		21-23^{o}C	12.9
		24-26^{o}C	-
		27-29^{o}C	-
4.4	Do you switch off your air-conditioner during short absence from the office?	yes	42.9
		no	57.1
4.5	If yes, choose the range of time that you would normally switch off the AC when you have to leave the office.	Under 20 mins	-
		21-40 mins	-
		41-60 mins	76.4
		1-2 hours	23.6
		2-3 hours	-
		Above 3 hours	-
4.6	How do you operate the air-conditioning system in your office?	Constant temperature	28.6
		Regulate with the thermostat	57.1
		Both a different times	14.3
4.7	How often do you use the lifts in this building?	All the time	94.1
		sometimes	1.6
		rarely	4.3
		Other, please state	-

APPENDIX 5 - CONSTRUCTION TABLES

RIDGE TOWER

Building Element	Material Layer	Width (mm)	Conductivity (W/m^2)	Density (kg/m^3)	Solar Absorptance Exterior	Solar Absorptance Interior	U-value (W/m$^{2.o}$C)

Wall	Plaster	10	1.73	1890	0.40	0.40	2.10
	Block	150	0.85	400			
	Plaster	10	1.73	1890			
Floor	Carpet	10	0.06	186	0.40	0.70	1.40
	Tile/13	15	1.75	2400			
	Concrete screed	25	1.83	2400			
	Concrete	150	1.4	2360			
Upper floor/ Ceiling	Tile/13	15	1.75	2400	0.65	0.50	1.40
	Concrete screed	25	1.83	2400			
	Concrete	150	1.4	2360			
	Soffit Plaster	20	1.73	1890			
Door Pane	Glass door	25	1	-	0.05	0.05	5.8
Door & Window Frames	Aluminium frame	50	204	2700	0.50	0.50	4.9
Window Pane	Opt-clear/4	12	1	-	0.29	0.19	2.8
	Cavity/1	10	-	-			
	Opt-clear/4	12	1	-			