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BAHCESEHIR UNIVERSITY

GRADUATE SCHOOL

THE DEPARTMENT OF ARCHITECTURE

I. LAWWAL

ENERGY EFFICIENCY FOR RESIDENTIAL BUILDINGS IN NIGERIA: REGULATIONS' SUFFICIENCY AND STAKEHOLDERS' KNOWLEDGE

MASTER'S THESIS

IBRAHIM AMINU LAWWAL

BAU 2024

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ABSTRACT

ENERGY EFFICIENCY FOR RESIDENTIAL BUILDINGS IN NIGERIA: REGULATIONS' SUFFICIENCY AND STAKEHOLDERS' KNOWLEDGE

Ibrahim Aminu, Lawwal

Architecture Master's Program

Thesis Advisor: Asst. Prof. Dr. Sinem Kültür

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Energy efficiency in buildings is the use of less energy for lighting, heating, ventilating and air conditioning (HVAC) in buildings. Energy-efficient buildings are at the forefront of global innovations and stakeholders are continually tasked with the role of providing measures that will continue to enhance energy efficiency in buildings. This thesis is on energy efficiency for residential buildings in Nigeria, regulations' sufficiency and stakeholders' knowledge. Nigeria is a West African country and its capital Abuja, a fast growing urban city with a mix of existing and new buildings, is currently experiencing high demand for energy consumption as a result of the rapid urbanization and continuous increase in the influx of people into the city. The quest to accommodate this rapid urbanization has resulted in the design of poorly planned buildings which are often not energy efficient due to the lack of adherence/compliance to the building regulation code of the country during construction. Studies have shown that the majority of the buildings in Abuja are residential buildings and most of these residential buildings especially the new ones are designed without adhering to the National Building Energy Efficiency Code of the country. This results in poorly planned buildings that are not energy efficient.

This thesis uses a comparison and survey methodology to first check the sufficiency of the Nigeria Building Energy Efficiency Code and then to assess stakeholders' knowledge on energy efficiency. Findings from the comparison of the Nigeria Building Energy Efficiency Code which is the principal legislation for energy efficiency in Nigeria with the selected global codes – the US and EU energy efficiency codes reveal that the Nigeria Building Energy Efficiency Code is sufficient because it contains all the minimum requirements for energy and compliance mechanism for energy efficiency captured in the US and EU energy codes. However, the implementation and compliance to the Nigeria Energy Efficiency Code is weak. This is due to the voluntary nature of the stringency for enforcement of the code compared to US and EU energy codes that are mandatory.

The major finding on stakeholders' knowledge of energy efficiency reveals that architects/engineers and contractors have good energy efficiency knowledge, while the energy efficiency knowledge of users is poor. Therefore, as a measure to improve the knowledge of users, the government needs to raise more public awareness policies to educate users on the benefit of having an energy-efficient building. As a future projection to curtail poor implementation of the Nigeria Building Energy Efficiency Code, the stringency of the Nigeria Building Energy Efficiency Code needs to be made mandatory just like the US and EU energy efficiency codes. The study recommends that renewable energy sources and greener buildings designed with a good blend of passive and active design techniques need to be adopted for residential buildings to mitigate the likely problems associated with lack of energy efficiency in residential buildings in Nigeria.

Keywords: Energy Efficiency, Residential Buildings, Regulations, Stakeholders, Awareness, Nigeria.

ÖZ

NİJERYA'DA KONUT BİNALARI İÇİN ENERJİ VERİMLİLİĞİ: YÖNETMELİKLERİN YETERLİLİĞİ VE PAYDAŞLARIN BİLGİSİ

Ibrahim Aminu, Lawwal
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Binalarda enerji verimliliği, binalarda aydınlatma, ısıtma, havalandırma ve klima (HVAC) için daha az enerji kullanımıdır. Enerji verimli binalar küresel yeniliklerin ön saflarında yer alır ve paydaşlar binalarda enerji verimliliğini artırmaya devam edecek önlemler sağlama rolüyle sürekli olarak görevlendirilir. Bu tez, Nijerya'daki konut binaları için enerji verimliliği, düzenlemelerin yeterliliği ve paydaşların bilgisi üzerinedir. Nijerya bir Batı Afrika ülkesidir ve başkenti Abuja, mevcut ve yeni binaların bir karışımı olan hızla büyüyen bir kentsel şehirdir ve şu anda hızlı kentleşme ve şehre sürekli artan insan akınının bir sonucu olarak yüksek enerji tüketimi talebi yaşamaktadır. Bu hızlı kentleşmeye uyum sağlama arayışı, inşaat sırasında ülkenin bina yönetmeliği koduna uyulmaması/uyumluluk eksikliği nedeniyle genellikle enerji verimli olmayan kötü planlanmış binaların tasarımıyla sonuçlanmıştır. Çalışmalar, Abuja'daki binaların çoğunun konut binaları olduğunu ve bu konut binalarının çoğunun, özellikle yeni olanların, ülkenin Ulusal Bina Enerji Verimliliği Koduna uyulmadan tasarlandığını göstermiştir. Bu, enerji açısından verimli olmayan, kötü planlanmış binalarla sonuçlanır.

Bu tez, önce Nijerya Bina Enerji Verimliliği Kanunu'nun yeterliliğini kontrol etmek ve ardından paydaşların enerji verimliliği konusundaki bilgilerini değerlendirmek için bir karşılaştırma ve anket metodolojisi kullanır. Nijerya'da enerji verimliliği için temel mevzuat olan Nijerya Bina Enerji Verimliliği Kanunu'nun, seçilen küresel kanunlarla - ABD ve AB enerji verimliliği kanunlarıyla - karşılaştırılmasından elde edilen bulgular, Nijerya Bina Enerji Verimliliği Kanunu'nun, ABD ve AB enerji kanunlarında yer alan enerji ve enerji verimliliği için uyum mekanizması için tüm asgari gereklilikleri içerdiği için yeterli olduğunu ortaya koymaktadır. Ancak, Nijerya Enerji Verimliliği Kanunu'nun uygulanması ve uyumu zayıftır. Bunun nedeni, ABD ve AB enerji kanunlarının zorunlu olduğu kanunlara kıyasla kanunun uygulanması için sıkılığın gönüllü nitelikte olmasıdır.

Paydaşların enerji verimliliği konusundaki bilgisine ilişkin önemli bulgu, mimarların/mühendislerin ve müteahhitlerin iyi enerji verimliliği bilgisine sahip olduğunu, kullanıcıların enerji verimliliği bilgisinin ise zayıf olduğunu ortaya koymaktadır. Bu nedenle, kullanıcıların bilgisini geliştirmek için bir önlem olarak, hükümetin kullanıcıları enerji açısından verimli bir binaya sahip olmanın faydaları konusunda eğitmek için daha fazla kamuoyu farkındalığı politikası oluşturması gerekir. Nijerya Bina Enerji Verimliliği Kanunu'nun kötü uygulanmasını azaltmak için bir gelecek projeksiyonu olarak, Nijerya Bina Enerji Verimliliği Kanunu'nun katılığının ABD ve AB enerji verimliliği kanunları gibi zorunlu hale getirilmesi gerekir. Çalışma, Nijerya'daki konut binalarında enerji verimliliği eksikliğiyle ilişkili olası sorunları azaltmak için yenilenebilir enerji kaynakları ve pasif ve aktif tasarım tekniklerinin iyi bir karışımıyla tasarlanmış daha yeşil binaların konut binaları için benimsenmesi gerektiğini önermektedir.

Anahtar Sözcükler: Enerji Verimliliği, Konut Binaları, Yönetmelikler, Paydaşlar, Farkındalık, Nijerya.

To My Well-wishers

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A special thanks to my friends and colleagues, who inadvertently have consistently pushed me to be competitive, inspiring me to achieve more than I thought possible. Their camaraderie and encouragement have made this academic journey both fulfilling and enjoyable.

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LIST OF SYMBOLS/ABBREVIATIONS

AEDC	Abuja Electricity Distribution Company
ASHAE	American Society of Heating and Air-Conditioning Engineers
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASRE	American Society of Refrigerating Engineers
BEEC	Building Energy Efficiency Code
BEEG	Building Energy Efficiency Guide
BREEAM	Building Research Establishment Environmental Assessment Methodology
CE	Commercial Provision
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen
DOE	Department of Energy
EED	Energy Efficiency Directive
EPBD	Energy Performance of Building Directive
EPC	Energy Performance Certificate
EPD	Equipment Power Density
EPB	Energy Performance of Buildings
ESSI	Environmental and Energy Study Institute
FCT	Federal Capital Territory
GHG	Green House Gases
HVAC	Heating, Ventilating, and Air-conditioning
ICC	International Code Council
IECC	International Energy Conversion Code
LCA	Life Cycle Assessment
LPD	Lighting Power Density
NEEAP	National Energy Efficiency Action Plan
NBS	National Bureau of Statistics
NZEB	Nearly Zero-Energy Buildings
RE	Residential Provisions
RED	Renewable Energy Directive
SERPA	Sustainable Energy Regulation and Policymaking for Africa

TSPR	Total System Performance Ratio
UNDP	United Nations Development Programme
USGBC	United States Green Building Council

Chapter 1

Introduction

Globally, with the way the world is built, energy plays a critical role in every aspect of life, and buildings are known to be important fields in the world's energy consumption. It is a known fact that all activities that keep a building comfortable consume and emit energy. These activities are needed to provide comfort via lighting, heating, ventilating, and air-conditioning (HVAC) in buildings (Ochedi and Taki, 2021). Therefore, there is a need to regulate the energy required for carrying out these activities in buildings efficiently.

According to United Nations Development Programme, (UNDP, 2010), "the amount of energy a building will need to purchase and consume in order to attain the required indoor comfort/energy efficiency is dependent on":

1. The building properties in relation to its passive and active design;
2. How well does the delivered energy used in the building meet its net energy demand;
3. How efficiently do occupants use the energy in buildings and how do those responsible for operating buildings effectively apply existing energy efficiency imperatives;
4. The percentage of the buildings' energy requirement that is supplied by renewable energy.

The Environmental and Energy Study Institute (ESSI, 2022) stated that "creating an energy-efficient building starts with the right design approach, which entails considering specific microclimate conditions of the site, building orientation, and shaping of the building form, conscious selection of building materials and envelope systems". The proper implementation and knowledge of energy codes of regions where the building is to be constructed is also important in creating an energy-efficient building. However, it is important to know that different countries have their own specific building energy efficiency codes often geared towards regulating energy usage in buildings when effectively utilized.

The Nigerian National Building Energy Efficiency Code is aimed at setting standards/minimum requirements for the design and construction of buildings for efficient energy usage. The code is also aimed at providing guidelines that will give a blueprint for implementing, controlling, and enforcing the code's requirements (FRN, 2017). According to the Federal Republic of Nigeria National Building Energy Efficiency Codes Handbook (2017), building energy efficiency codes have a similar advantage to conservation, waste reduction and increasing supply of energy as a result of efficient energy use, stabilizing power supply and ensuring unfailing supply in energy. However, this is only achievable when the code is effectively utilized for planning, designing and construction of buildings.

Therefore, the importance of energy efficiency codes is enormous. The codes save up to 40% of energy usage in buildings when properly implemented (Nwoji, 2017). They contribute to enhancing and improving thermal comfort in buildings; they set standards for developing new buildings and also maintain existing buildings with the main drive of reducing energy consumption in these buildings; they also reduce pollution by limiting the amount of greenhouse gases emissions. All these benefits of energy efficiency improve the quality of life of users and also save users huge amounts of money expended on energy costs. Hence, all stakeholders who are responsible for designing and constructing the built environment and users who occupy this built environment ought to have proper knowledge of these codes so as to maximize an eco-friendly environment of more energy efficient buildings.

The thesis is centered on energy efficiency for residential buildings in Nigeria. Its scope is limited to the capital city, Abuja. The study will be detailed on the sufficiency of the existing energy efficiency regulation in Abuja, Nigeria; and the knowledge of stakeholders' in respect to energy efficiency.

Thus, the study is believed to be significant, on the one hand, for understanding the level of knowledge of the stakeholders, which can be enhanced in the future by the government or other initiatives; on the other hand, for learning the sufficiency of the existing Nigerian energy efficiency regulation in terms of technical aspects and the enforcement mechanisms. The study will also highlight the benefits accrued from energy efficient buildings/environment and the need adhere to energy efficiency regulations/building energy codes.

1.1 Background

Numerous studies by different scholars have shown that rapid urbanization in developing countries has a direct impact on the building and energy sectors of these countries (MeetMED, 2019; Ochedi, *et al.*, 2021). According to MeetMED (2019), Africa's urbanization rate of 3.5 percent per year is the highest in the world. This has resulted in the development of more urban areas with bigger populations and expansions in existing urban areas in Africa.

Nigeria, as a developing country, has its own fair share of this rapid urbanization effect. Abuja, its capital city is amongst the rapidly growing urban cities in the world which is currently witnessing a significant rise in population and increase in building development. The city's population is estimated to be over 3,000,000 people (FCT, 2021). The city experienced an annual growth of 35% in 2015, making it one of Africa's fastest-growing cities (Abuja, 2020). This enormous increase in the influx of people into Abuja has directly affected its building sector and has triggered a substantial rise in the level of the demand for energy consumption in Abuja as evident in Figure 1, which presents the projected electricity demand in Abuja.

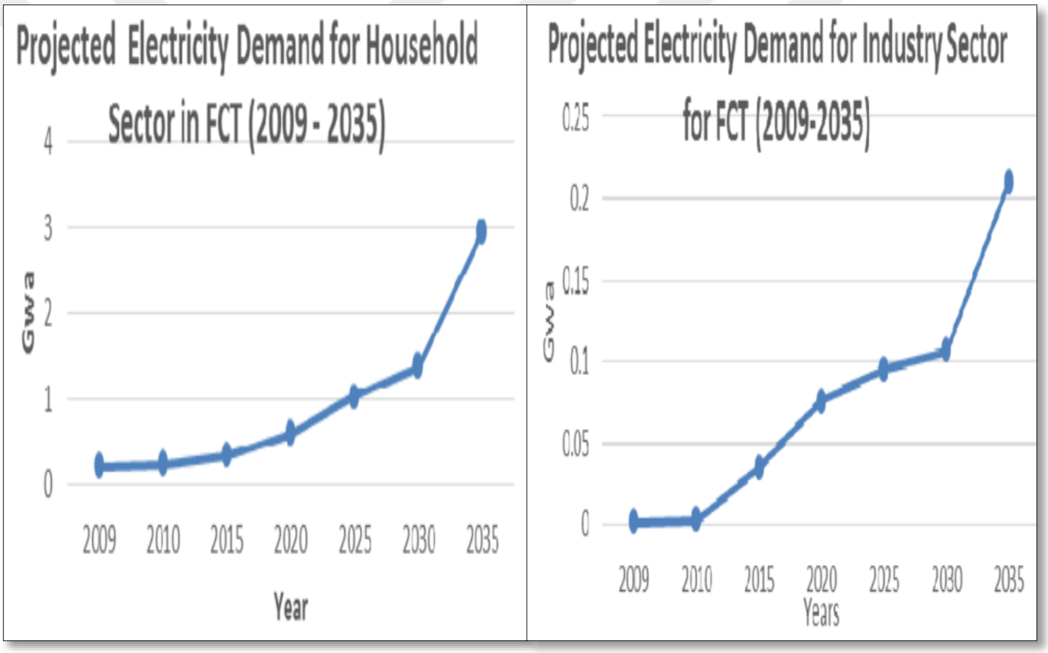


Figure 1. Projected electricity demand for households and the industry sector in Abuja (Energy Commission of Nigeria, 2009)

Today, in most urban regions of the world, energy has become one of the primary necessities for livelihood for every human, along with the basic needs for existence. Studies have shown that the building sector consumes more of the world's global energy than any other sector (US Department of Energy, 2015). Kevin, *et al.*, (2005) recorded that the building sector consumes about 42% more energy than any other sector. This is true due to the fact that most humans spend more time (about 90%) in buildings than in any other place.

In addition, the US Department of Energy (2015) elaborated that, “the major areas of energy consumption in buildings are lighting, heating, ventilation, and air conditioning (HVAC). Out of the total building energy, it is estimated that lighting consumes 11%; major appliances (water heating, refrigerators, freezers, dryers) consume 18%, while the remaining 36% are consumed in miscellaneous areas, including electronics”, totaling 65%. However, it is important to understand that in each of these activities, there are tendencies of improving the performance of systems used for carrying out these home activities by opting for more energy efficient ones.

Hence, as a result of all of this, building designs and construction are anticipated to be smart, with less negative environmental impacts, even in the face of climate change and thermal distress among urban populations. So, the development of energy-efficient buildings in today’s world is inevitable. Thus, this explains why it is becoming a global phenomenon that energy-efficient design strategies in building developments are becoming the mainstream for achieving sustainability in buildings and also achieving a humane and responsive environment.

According to Meier and Thomas (2002) “energy efficiency regulations are more effective if implemented during the early stages of the building project” because these regulations are geared towards enhancing comfort in buildings using less energy. Thus, there is a need for the government and relevant stakeholders to enforce these regulations and ensure adherence to the standards / minimum requirements for designing, constructing, renovating, maintaining, and retrofitting buildings for energy efficiency.

According to MeetMED (2019) “it is estimated that by 2030, the amount of energy used in buildings could be cut by more than 20% with the aid of advancement in technologies known to be energy efficient”. MeetMED (2019) added: “If this is achieved, much higher savings will be technically possible in terms of global energy consumption by more than 35%”. To this end, relevant stakeholders have a responsibility to ensure that the buildings developed are energy efficient, and as such, they need to become acquainted with a vast knowledge of energy efficiency regulations/measures. This explains why this thesis is centered on the energy efficiency for residential buildings in Abuja, Nigeria; so as to examine the sufficiency of Nigeria’s existing energy efficiency regulation and also the knowledge of relevant stakeholders’ in Abuja, Nigeria.

1.2 Problem Statement

Globally, there have been advancements made in achieving energy-efficient buildings. It is a known fact that as rapid urbanization increases the demand for energy use also increases. Abuja, Nigeria, being a fast-rising developing city, is experiencing its own fair share of this hullabaloo. The continuous increase in urbanization and rapid influx of people into the city also means an increase in electricity demand and consumption in the city.

As the influx of people increases, there is a higher per capita living area and a significant increase in the number of new buildings and the appliances in these buildings. Most of these new buildings are being designed without adhering to the National Building Energy Efficiency Code of the country (Fadera and Olaniyi, 2022). This has led to buildings being poorly planned, with most buildings in Abuja not adopting passive design strategies, hence hampering the delivery of energy-efficient buildings in Abuja. In some cases, some buildings do not have enough natural daylight to function throughout the day and must rely on artificial lighting, while some are not properly naturally ventilated. Also, most of the appliances that are used for lighting, heating, ventilation, or air conditioning (HVAC) have become obsolete and, as such, tend to consume more energy to run. Due to the poor nature of the power supply in the state and the hot climatic conditions, most residential buildings rely on alternative energy sources, especially those that are nonrenewable, e.g., generators for lighting and ventilation. These generators use fossil fuels and as such, could contribute to the rise of greenhouse gases (GHG) emissions and global warming. Again, the ignorance on energy efficiency by most users has made them stick to the use of old appliances without opting for retrofitting to appliances that consume less energy.

Hence, this thesis on the energy efficiency for residential buildings in Nigeria focuses on residential buildings in Abuja. The study will check the sufficiency of existing building energy efficiency regulations in Nigeria by comparing its national building energy efficiency code to some global building energy efficiency codes. The selected global codes are the US and EU codes. These two codes are selected for comparison because of their great importance in enhancing energy efficiency globally. It will also seek to check stakeholders' knowledge of energy efficiency so as to proffer proper recommendations that will enhance energy efficiency in residential buildings in Abuja from the information that will be gleaned from the research outcome.

1.3 Objectives

The main objective of the thesis is to focus on the energy efficiency in residential buildings in Nigeria. The sub-objectives are:

1. To check the sufficiency of existing energy efficiency regulations in Nigeria by comparing existing national building energy efficiency codes to global building energy efficiency codes.
2. To assess stakeholders' knowledge on building energy efficiency.

1.4 Scope and Limitations

The selected city for the scope of this research is Abuja, Nigeria. The study will cover the sufficiency of the existing regulation on building energy efficiency in Abuja, Nigeria; and the knowledge of stakeholders on energy efficiency in Abuja, Nigeria. However, the thesis is limited to only residential building types in Abuja as its scope due to the fact this building type (residential building) makes up for most of the building types available in Nigeria. In an article titled "Impact of Inflation on Residential Property Value in Abuja" it was recorded that about 70% of total buildings in Abuja are residential buildings (Umoh, 2022).

Numerous studies have shown that building energy code framework is categorized into four categories namely; (a) Prescriptive codes (b) Simple trade-off codes (c) Performance codes and (d) Outcome-based codes (VanGeem, 2016; IEA, 2018).

a. *Prescriptive codes:* These are codes that recommend guidelines for designs, construction, materials, and equipment/systems. They provide the minimum requirements that must be adhered to in terms of the construction of buildings for energy efficiency. Prescriptive codes are rigid because of their stringency. They require that the minimum needs for the construction of buildings must be adhered to. In terms of energy efficiency, prescriptive codes set the minimum requirements for insulation, windows, HVAC systems, lighting systems and other building components. In energy efficiency code documents, the minimum requirements of prescriptive codes are often organized in quantified tables. These tables often contain the list of the requirements from the minimum to maximum permissible (R- and U-values of materials) according to climate and region. (VanGeem, 2016). In other words, this code dictates the specific requirements that must be met in assembling building materials, but it does not account for potentially nontechnology energy-saving features like window orientation. The IEA (2018) noted that compliance with these codes is commonly assessed by checking project designs and specifications against the list of prescribed requirements. The IEA (2018) added that prescriptive code specifies requirements for key elements such as wall and ceiling insulation, windows and doors, roofs, foundations, heating, ventilation, air-conditioning, equipment efficiency, water heating, lighting fixtures, and controls.

b. *Simple trade-off codes:* “Simple trade-off energy efficiency codes are energy codes that balance the energy efficiency requirements with other components such as; cost-effectiveness, environmental impact and implementation ease. They are aimed at regulating energy usage in buildings and greenhouse gas emissions to the minimum level with a key interest in building design as a whole and materials and systems. They allow for trade-offs between similar building components. For example, they allow the trade-off of less efficient insulation for more efficient windows in the building envelope.

c. *Performance codes:* “Performance codes are building regulation codes that focus on the measurable performance of a building rather than specific design or construction methods” (IEA, 2018). They are aimed at achieving specific results, rather than meeting prescribed requirements for individual building components (VanGeem, 2016). The IEA (2018) stated that “these codes set criteria for the desired performance outcomes of a building in terms of energy efficiency, environmental impact, safety, or other factors, allowing flexibility in how those outcomes are achieved”. These codes require that energy modeling should be conducted at the design stage and as such energy simulation and modeling tools are used in conjunction with this code so as to ascertain the expected performance of a building in terms of energy consumption at the design phase. This aids in demonstrating compliance with the requirements of the code. The compliance of this code is commonly checked by comparing the modeled energy performance of the design with a reference building of the same type (IEA 2018).

d. *Outcome-based codes*: “Outcome-based codes represent a shift in building regulation from prescriptive requirements to performance-based standards” (IEA, 2018). These codes focus on ensuring that a building achieves a specific outcome for energy efficiency, environmental sustainability and safety in design elements, construction methods, materials, etc. These codes ensure that buildings perform at an established level already determined (VanGeem, 2016). These already determined levels are regarded as the target of the code requirements for the building. Hence, the code allows developers, architects and owners to be flexible in meeting the targets. According to IEA, (2018) "the compliance to this code is typically possible through energy performance certificates or with energy disclosure policies". Outcome-based code encourages innovations. It allows inventing creative ways in building design and construction while still maintaining design performance standards.

It is worthy to mention that all these energy efficiency code frameworks are vital in the quest to attain energy efficiency in buildings; however, this research will be limited to *performance based codes* which are more flexible and allow for creative innovations in the quest to achieve energy efficiency in buildings. They also allow designers and architects to choose the best technological advancement as solutions for energy efficiency in specific construction projects depending on the site conditions. This explains their importance in solar energy, photovoltaic and other technologies for energy efficiency.

Within the scope of the thesis, the sufficiency of the National Building Energy Efficiency Code of Nigeria and the knowledge of relevant stakeholders' in the building and construction sector in Nigeria. The sufficiency of the National Building Energy Efficiency Code of Nigeria will be checked by comparing the code with global codes. The US and EU codes are the selected global codes for this comparison because they are vital to enhancing energy efficiency in buildings and also because they contain performance based energy efficiency requirements which will be beneficial to residential buildings in Abuja, Nigeria, being that Abuja is a fast growing urban area with lots of existing buildings and an upsurge of new designs and construction.

Studies have established that the design and construction process of a building life cycle comprises the design team, construction team, operation and maintenance team, etc. and each of these teams are made up of different stakeholders (America Institute of Contractors, 2024).

According to the AIC (2024), the design team has architects, engineers, consultants, and designers, the construction team has contractors, builders, workers, etc., and in addition to them, the operational team is made up of the users.

However, for this thesis, the stakeholders that will be selected to represent the building design and construction cycle include; architects/engineers for the design team; contractors for the construction team and users to represent the operational/maintenance team. These stakeholders (architects, contractors and users) are selected to represent the building design and construction cycle because they are the individuals tasked with the core responsibility of ensuring proper designs and construction processes of buildings. Thus, assessing their knowledge on energy efficiency is pivotal.

Subsequently, due to my absence in Abuja and inability to carry out the fieldwork of taking photographs and distributing questionnaires myself, I delegated the work to a friend whom I mobilized, financially. He was able to distribute questionnaires to the stakeholders and take some photographs that aided and contributed to this study.

1.5 Methodology

This thesis is organized methodically to check the sufficiency of the existing building energy efficiency code in Nigeria and also to assess stakeholders' knowledge of energy efficiency in Nigeria by employing a comparison and survey research methodology. According to Check & Schutt, (2017), a comparison methodology is a type of methodology that compares variables, while a survey methodology is a type of research methodology that entails collecting data from survey questions and analyzing the responses from the survey to make inference from the information gathered from the survey questions.

Thus, these two research methods will be effective for this study. The comparison methodology will be vital in checking the sufficiency of the Nigerian Building Energy Efficiency Code by comparing the existing Nigeria energy efficiency code with selected global codes. The selected global codes for the comparison are the US and EU energy efficiency codes. The survey methodology on the other hand will be vital in assessing stakeholders' knowledge on energy efficiency. This survey methodology will involve distributing questionnaires amongst selected stakeholders in Abuja, Nigeria. The selected stakeholders will include architects/engineers, contractors and users residing in Abuja, Nigeria. These stakeholders are selected because of their important roles in enhancing energy efficiency in buildings. The questionnaire distributed for the survey methodology is aimed at collecting information from stakeholders on their knowledge of energy efficiency. The questionnaire will be analyzed using both qualitative and quantitative methods of data analysis. The qualitative method will involve the use of a concise summary to interpret interview results with the interviewed architects/engineers and contractors selected for the survey, while the quantitative method of data analysis will involve the use of simple percentages to analyze users' responses to the survey questions of the questionnaire before drawing inference.

These selected stakeholders comprising architects/engineers, contractors and users make up for the sample population of the survey. Thus, a sample size of 75 participants comprising of 25 architects/engineers, contractors and users each will make up the survey. These participants will be selected within Abuja, Nigeria. The architects/engineers and contractors will be selected from two companies in Abuja, namely, Forte Arcon and Lubel Nigeria Ltd. The company selected is limited to only these two companies because they are amongst the leading companies in Nigeria in terms of design and construction of buildings. The users on the other hand will be randomly selected from estates and other residential developments within Abuja, Nigeria. The selection technique for these stakeholders for the study will be random sampling technique. This probability sampling technique is adopted so as to give every participant who meets the selection criteria an equal chance of being selected for the survey. The selection criteria for selecting the stakeholders for this survey, are as follows:

1. For architects/engineers and contractors, the selection criteria will be based on *years of working experience*. Hence, only architects/engineers and contractors who have at least 2 years of post-graduation working experience will be selected for the study.
2. For the users, the selection criteria will be based on *age*. Hence, only users who are 18 years and above will be considered for selection for the study.

The general organization of the thesis is presented in Figure 2. From the figure, the thesis is organized into five chapters. The first chapter is the introduction, the second chapter reviews relevant literature to the study, and the third chapter provides further literature on energy efficiency in Nigeria; it analyzes the existing energy efficiency code in Nigeria and compares the code with global codes. The fourth chapter provides information on the energy efficiency for residential buildings in Abuja and also information of the survey conducted with selected stakeholders in Abuja, Nigeria; the fifth chapter focuses on the discussions, findings and conclusions.

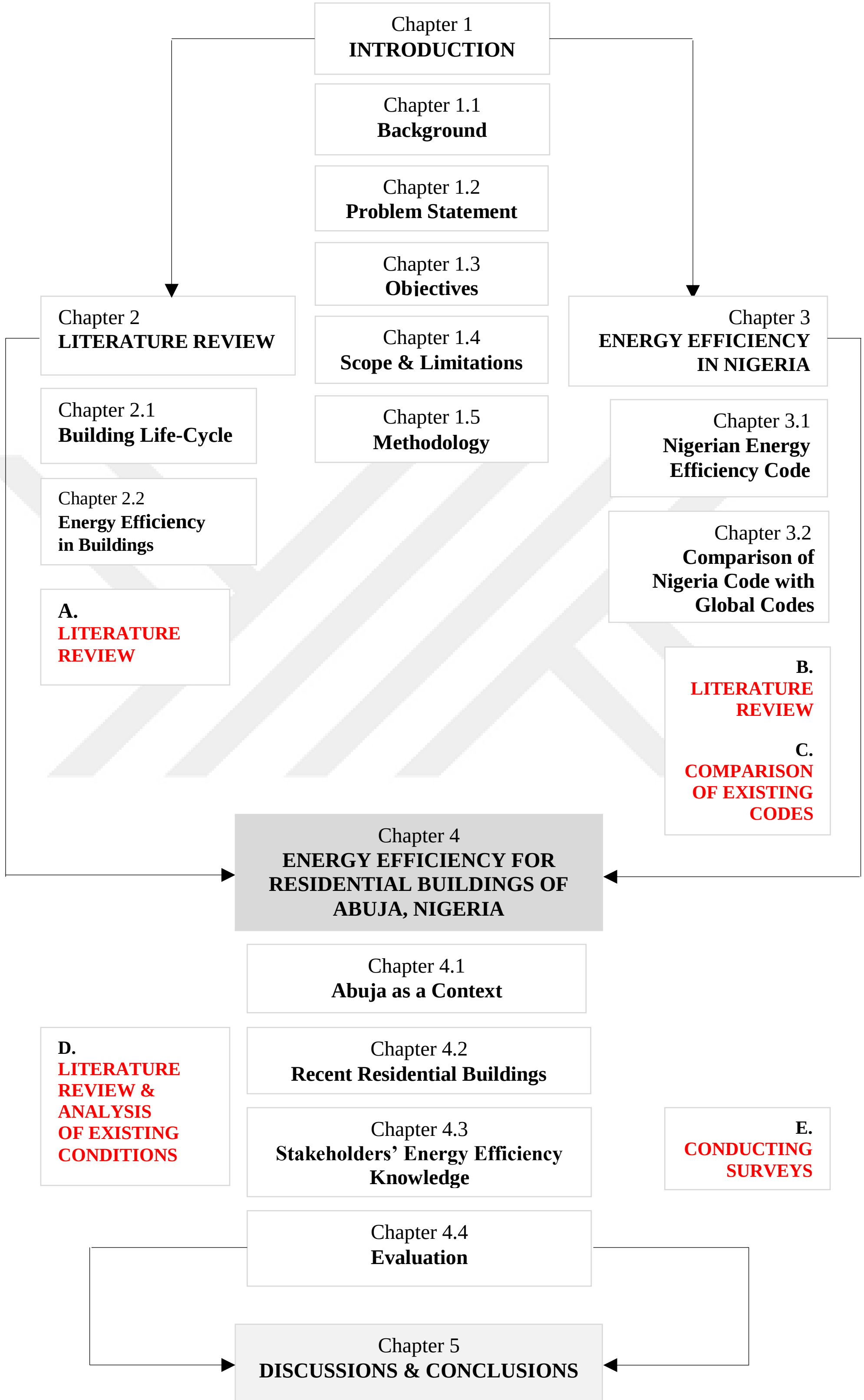


Figure 2. Methodology followed throughout the thesis

Chapter 2

Literature Review

The reviewed literature in this chapter of the thesis is given under two main headings namely; Building Life Cycle and Energy Efficiency in Buildings. The Building Life Cycle encompasses reviews on the concepts, phases and stakeholders active in the building life cycle process while the sub-chapter on Energy Efficiency in Buildings covers an overview of energy efficiency concepts, international energy efficiency standards and case studies of some energy-efficient buildings.

2.1 Building Life-Cycle

Building life-cycle is the path that defines the entire existence of a building. It covers not just the operational aspect of the building but also the design, construction, demolition and waste management (Shpresa, 2003). According to Brand (1997), like every living organism, a building has life too. This means that once a building is designed and constructed it is presumed to have a life of its own.

It is important to understand that buildings are significant components of the human environment because humans require buildings for different activities and survival. According to Ngwepe and Aigbavboa (2003), the built environment is the physical edifice created intentionally by man through science and technology for the purpose of his survival. However, it is a known fact that the processes involved in creating man's built environment have an impact on both users and the environment.

According to Horne, Grant and Verghese (2009) the study of the entire impact a building has on its environment is known as "Life Cycle Assessment". Bruce-Hyrkäs (2021) defines "building life cycle assessment as a scientific methodology used to calculate the impact of a building on its environment".

"Building life cycle assessment" provides information about how buildings are developed and the impacts these buildings will have on their environment throughout the duration of the building from the existence process, from extraction of the raw materials, to the demolition of the building. This simply implies that a building life cycle assessment can help determine what happens before and after a building is designed and constructed. It can also effectively measure the impact a building will have on users over a long time of period (Birgisdóttir, et al, 2016).

Therefore, an assessment of the life cycle of a building is needed in order to manage the impact a building will have from design to construction on its environment. It gives information on the likely future occurrences in the building, and it provides architects/engineers and relevant stakeholders in the building industry with the needed information required for making decisions on how to reduce the impact a building will have on its environment. In recent times, the drive of architects/engineers has increasingly been to focus on making designs that will have less environmental impact. Building life cycle assessment accords them the luxury of comparing numerous design options to choose the best cost-effective, functional, and aesthetically pleasing designs with the less environmental impact on users. It is pertinent to understand that building life cycle assessment does not just give information on the impact a building will have on its environment; it also gives beforehand information on the energy a building is likely to consume, so that stakeholders will make decisions on how efficiently the energy can be utilized (Condeixa, Haddad, *et al.*, 2014).

The U.S. Department of Environmental Affairs and Tourism states that "enhancing energy efficiency in buildings offers one of the most significant opportunities to reduce man's negative impact on his environment". This explains why the assessment of the building life cycle is a tool architects and other allied professionals use in quest to understand energy usage in building and its impact on the environment. Therefore, without rigorously assessing the life cycle of buildings, informed decisions on the energy usage of buildings are practically impossible to achieve. This implies that building life cycle assessment gives information on buildings from construction to demolition or waste disposal/treatment.

However, regardless of the importance of building life cycle assessment, there is little or no particularly standardization as regards undertaking "Life Cycle Assessment (LCA)" of buildings, because buildings undergo different changes in both forms and functions during their life cycle process. Thus, new choices and decisions are often birthed when a new building is to be designed and developed.

Hence, at the beginning of any building, there is a need for a life cycle assessment to identify the impacts the building is likely to have on the environment through all human processes involved in the stages of a building life cycle (Bruce-Hyrkäs, 2021).

2.1.1 Concepts. According to Ahmadi and Torabi (2020) over the years, different concepts and technological advancements have been developed in the quest of making products and materials that will be eco-friendly. These concepts also apply to the construction of environmentally friendly buildings in the form of green buildings. According to Ankrah, *et al.*, (2015) there are two concepts to describe a building life cycle assessment. These two concepts are scientific methods established to measure all environmental impacts of a building. They include; (1) cradle-to-grave and (2) cradle-to-cradle concepts (Ankrah, *et al.*, 2015).

1. *Cradle-to-Grave:* According to Ankrah, *et al*., (2015) cradle-to-grave concept is a concept linked to the ideas of Professor Michael Braungart and William McDonough. In terms of building life cycle assessment, this concept has to do with measuring the entirety of the impact a building has from the extraction of materials (cradle) to demolition (grave) which is the final / end stage (Shpresa, 2003; Ankrah, *et al*., 2015).
2. *Cradle-to-Cradle*: In cradle-to-cradle concepts, buildings are designed and constructed with the aim of limiting their impact on the environment with the idea of recycling and reusing their components in the near future. This reduces their environmental impacts. Shpresa, (2003) stated that “cradle-to-cradle does not let old products go to waste. Instead, a product’s materials and components are repurposed or recycled”. Cradle-to-cradle concept enhances energy efficiency because it encourages renewable energy sources in buildings thus saving energy (Shpresa, 2003; Ankhrah, *et al*., 2015).

From the foregoing definitions, the major variation that distinguishes these two concepts is that cradle-to-grave concepts end at the end-life stage while in the cradle-to-cradle concept, the end-life is replaced with the recycling/reuse stage. This explains why the cradle-to-grave concept is gradually becoming obsolete in building construction as stakeholders in the building sector are starting to embrace the use of sustainable materials that allows for recycling and reuse with less impact on the environment. Figure 3 presents an illustration of the processes involving the life cycle concepts of buildings.

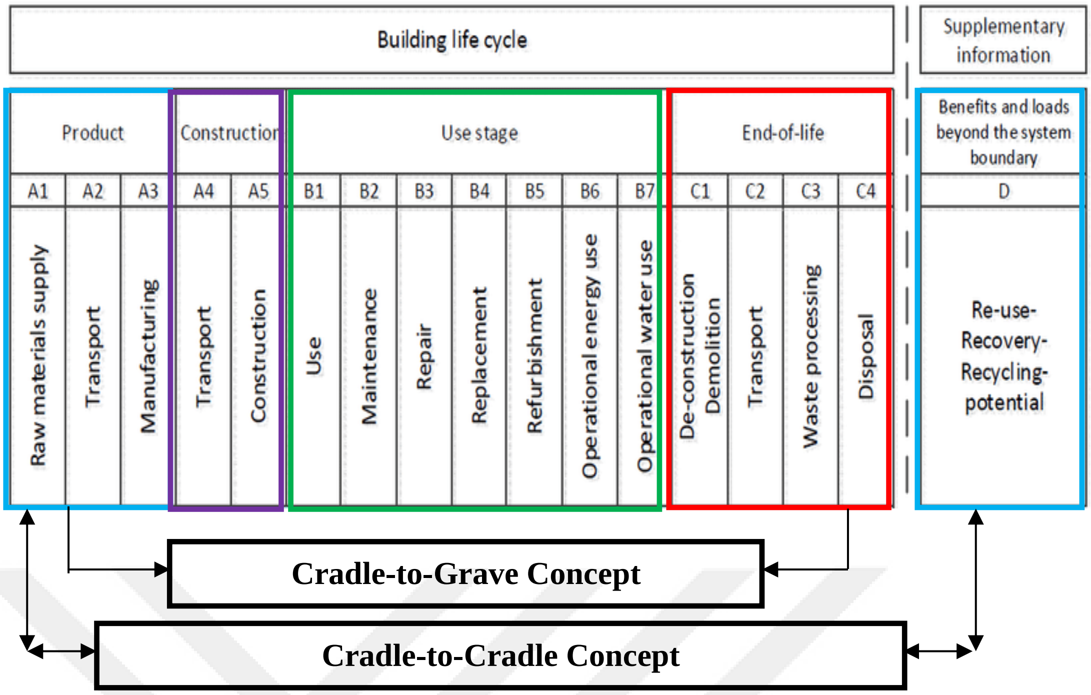


Figure 3. An illustration of the building life cycle concepts (Ankrah, *et al*., 2015; Ibrahim, 2023)

In addition, *Embodied Energy (EE)* is another concept synonymous with these two concepts. According to Lawson (2006) "embodied energy is the energy consumed by all the processes linked with the construction of a building". Lawson (2006) added that this energy includes "energy consumed from extraction of raw materials down to manufacturing and transporting products/materials to site for construction works". This means that embodied energy is involved in mainly production process of a building life cycle. It does not include energy consumption during the operational and disposal stages of a building's life cycle.

Hence, it is important to understand that all these concepts are important to stakeholders in the building industry because they afford stakeholders different means of assistance in terms of energy usage of building design and construction and their impact on the environment. This simply means that these concepts equip stakeholders with useful information required in organizing actions that will lead to more environmentally responsible and sustainable building designs and constructions.

2.1.2 Phases. The building life cycle is in phases. These phases are the different stages a building goes through during the course of its entire existence. According to Ngwepe, *et al.*, (2013), "these stages are categorized into six stages namely; extraction of raw materials, manufacturing, construction, operation and maintenance, demolition, recycling and re-use".

1. *The extraction of raw materials:*

The first stage of a building's life cycle is the extraction of raw materials. In building construction, this phase includes the extraction of raw materials for building construction. These materials include iron ore, limestone, granite, tin, petroleum, timber, etc. (Ngwepe, *et al*., 2013) These raw materials are naturally embedded in the ground and require processing into more useful forms of building and construction materials like steel, cement, aluminium and plastic using technologies. Studies have shown that the processes of extraction of these raw materials require large amounts of energy. Because the process often requires burning fossil fuel which in the long run causes pollution, global warming and emission of harmful gases, thus leading to the depletion of the environment (Bruce-hyrkäst, 2021). This explains why Ngwepe, et al., (2013) state that "the continuous extraction of raw materials for construction will eventually lead to their depletion, unless alternative solutions for meeting the resource demand are found".

2. *Manufacturing:*

The second stage of the life cycle of a building is the manufacturing stage. This stage has to do with developing raw materials into ready to use building materials such as steel, metals, plastic, wood, aluminium, etc. This process also involves more energy as most often it requires transporting manufactured building materials from factories to a construction site. This transportation and manufacturing process causes more fossil fuel to be used thus making more toxic waste and pollutants to be released into the environment (Crawford, 2011; Ngwepe, *et al*., 2013).

3. *Construction:*

The third stage of a building's life cycle is the construction stage. This stage involves processes that extend a little from the manufacturing stage. For instance, activities like sawing and shaping timbers into different sizes ready to be used for the construction of buildings make up this stage (Ngwepe, *et al.*, 2013). The construction stage of a building's life cycle is the assembling of different manufactured products to become a single structure (Carpenter, 2001). According to Carpenter (2001), “construction in its broadest sense, is responsible for the built environment”. This explains why it was recorded in an OECD (2003) report, that “the construction sector is estimated to account for between one-third and one-half of commodity flow worldwide”. Khasreen *et al.* (2009) claim that the “building construction industry consumes 40% of the materials entering the global economy”. The activities involved in the process of constructing a building consume energy and also generate waste. For instance, in construction processes, on-site activities that require electricity to run machines consume energy; while wrong materials selection and supply or application of wrong construction technology often lead to waste generation in the construction process. Hence, the energy consumed from construction works and the waste generated from the general construction process affect the environment adversely. According to Khasreen *et al.* (2009) “construction processes generate 40- 50% of the global output of GHG emissions such as CO_2”.

4. *Operation and maintenance:*

The operation and maintenance stage is the fourth stage of a building’s life cycle. This stage is presumed to be the longest because it spans for as long as the building is still in existence. Most of the activities in this stage of a building’s life cycle require water and energy. For instance, energy is required by users for activities that require lighting, heating, ventilation, air-conditioning (HVAC), etc. Most of the energy sources for these activities in building rely on fossil fuel based sources which have negative impacts on the environment because they are often characterized by the release of harmful gases and pollutants. However, a few use renewable energy sources with less impact on the environment (Ngwepe *et al.*, 2013).

It is important to understand that the environmental impact a building exerts during its operation and maintenance stage is twice as large as the environmental impact during other stages of a building’s life cycle. This is because a building during its operation and maintenance stage can undergo repair, reconstruction and refurbishment twice or more before its demolition. Thus, during these reconstruction processes, more energy is consumed which therefore creates more impact on the environment (Khasreen *et al.*, 2009).

5. *Demolition:*

Demolition is the fifth stage of a building's life cycle. It is the process whereby the components of a building are dismantled, thus ending the existence of a building. In most cases, this is the last stage of a building life cycle because most building materials are not recycled and re-used as their life ends in this stage. However, it is important to understand that at one point in life, demolition of buildings is a necessary thing; because like every product, buildings too have that end life (finite life). It is at this point that buildings need to be demolished to avoid the occurrence of disaster which could be in the form of building collapse; that will end up being detrimental to societal safety and health (Ngwepe *et al., 2013*). Like other stages of a building life cycle, the demolition stage is also characterized by energy consumption and waste generation, which is usually in the form of solid waste. Some of these solid wastes from building demolition are not bio-degradable and as such have negative impacts on the environment.

6. *Recycling and re-use:*

Recycling is the sixth stage in the life cycle of a building. At this stage building components are recycled so as to be re-used. In recent times, recycling/reuse has been linked with sustainability due to the fact that the recycling/reuse process exerts little/low impact on the environment. However, in building design and construction, it is important to understand that not all building components make it to this stage of the life cycle of a building as most building components end in the demolition stage. Some notable building elements such as doors, windows, etc., are the receptacles for the recycling/reuse stage of a building's life cycle. In most cases, they are reused directly thus limiting their impacts on the environment although many times they require certain actions which may impact the environment but the impact will not be as severe as making new components for the building from scratch. For instance, windows, doors and other building components may require re-painting and other refurbishing works. Thus, a certain amount of energy is required for this process and also certain gases that may impact the environment are exerted from the processes of preparing these materials for painting; however, their severity is not much, thus energy will be saved because there will not be any need to remake new building components (Gibberd, 2014).

Hence, each of these phases of s building's life cycle involves processes that will either consume valuable resources such as energy, water, etc. or release pollutants/harmful substances into the environment. Therefore, limiting their impact on the environment becomes a necessity. Figure 4 presents an illustration of the processes of the building life cycle.

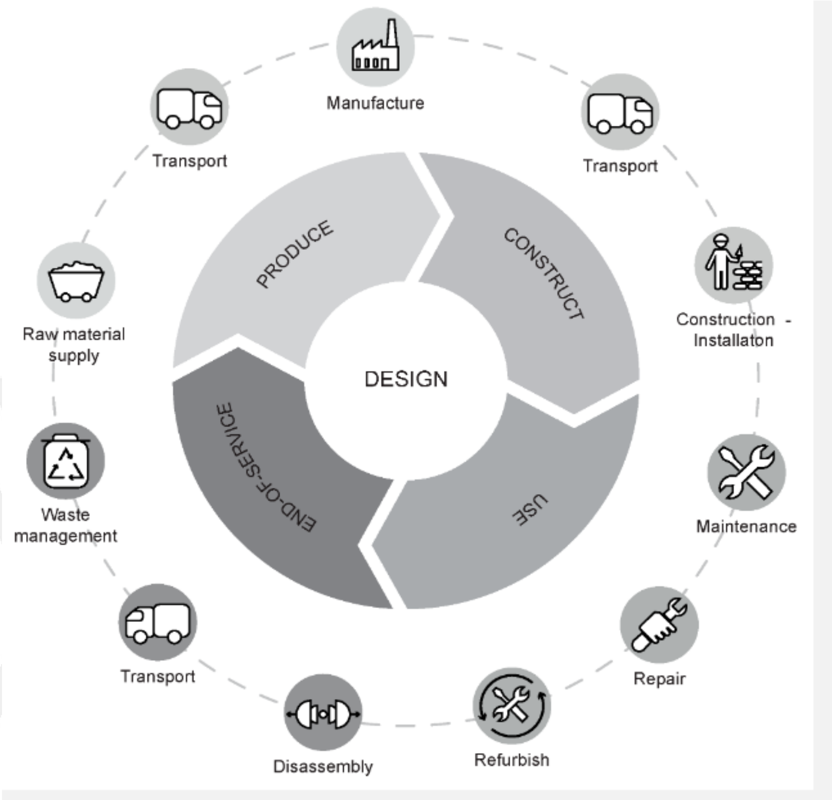


Figure 4. An illustration of the processes of a building life cycle (Shpresa, 2003)

However, it is important to understand that the design choice of architects and other stakeholders in the building and construction industry determines the severity of these processes of building life cycle will have on the environment. This explains the need why the global trend for building design and construction is moving towards sustainability and architects and relevant stakeholders are encouraged to embrace more sustainable design techniques for their designs and constructions. Studies have shown that more sustainable designs will exert little to no negative impact on the environment (Shpresa, 2003; Gibberd, 2014). Hence, this thesis recommends the need for more green buildings from locally sourced materials and the adoption of renewable energy sources for servicing buildings.

2.1.3 Stakeholders. There are various interpretations of the definition of stakeholders. However, the definition by Frederick (1998) is more appropriate in line with the context of this thesis. Frederick (1998) defines a stakeholder as "everyone in the community who has a 'stake' in what the community does"… and how the communities do it. This simply implies that stakeholders are a community of individuals actively involved in activities that have a common interest.

Hence, stakeholders involved in the design and construction of the built environment are saddled with the responsibility of ensuring that the impact a building's life cycle process has on the environment is minimized. They are also tasked with a significant role in developing sustainable designs and constructions using locally sourced materials that require less energy consumption.

According to Wallbaum, *et al.* (2010), different stakeholders are involved in the process of a building's life cycle. Wallbaum, *et al*. (2010) added that, these stakeholders are categorized into two, namely; (i) internal strategic stakeholders and (ii) external stakeholders.

i. *Internal strategic stakeholders:* Internal strategic stakeholders are the key stakeholders involved in the built environment life cycle. They appear in the role of designers, contractors, end-users etc.,

ii. *External stakeholders:* These are stakeholders that play oversight roles. They include; investors, non-governmental or media organizations (Wallbaum *et al*., 2010). The summary of the key stakeholders and their major concerns and roles in the life cycle of a building is presented in Table 1.

Table 1

A summary of stakeholders and their roles in the building life cycle

Category	Key Stakeholders	Major Concerns
Internal Strategic Stakeholders	Investor	Need for Return on Investment Economic feasibility
	Manufacturer/supplier	Materials (Natural resources) and Energy supply
	Contractors	Workforce
	Planners and Designers	Knowledge; Creativity and efficient application of technologies
	Users and Owners	Wellbeing; Maintenance
	Public Authorities	Regulations and Control
External Stakeholders	Research / Education	Technological advancement
	Media	Information dissemination

Source: (Wallbaum *et al.,* 2010).

However, it is important to understand that the major stakeholders that make up a building design and construction cycle are categorized into the design team, which comprises of architects, engineers, and consultants, etc., the construction team which has contractors, builders, workers, etc., and the users (AIC, 2024). Hence, for this thesis, the selected stakeholders are architects/engineers (from the design team), contractors (from the construction team), and users.

1. Architects:

Architects are stakeholders saddled with the task of making the built environment functional through their designs, concepts and innovations. Their focus leans on making designs with less impact on the environment in a creative manner using their knowledge of sustainable architecture, passive design techniques and efficient application of technologies (Wallbaum, *et al.,* 2010).

According to the AIC (2024), “Architects design, plan, and develop concepts to create construction plans and technical documents based on client requirements and ideas". Therefore, it is vital that architects are equipped with knowledge about different building codes/regulations, techniques and innovations that will improve the quality of life in the environment. They need to stay updated on laws, requirements, design and construction innovations, etc. required for the sustainability of buildings and the environment. This will enable them effectively to deliver their duties because building regulations are in constant evolution (Tobias, 2019).

2. Contractors:

The construction process of the built environment rests on the contractors. Contractors are accountable for the construction processes of the buildings that make up the built environment. These construction processes are known to require much energy consumption and, as such, require expertise in dealing with their impact on the environment. This explains why contractors work with architects to achieve a more structurally stable and sustainable environment. According to Wallbaum et al. 2010), in most cases, the contractors are answerable to the architects or the users (clients).

Tobias (2019) added that contractors are charged with the responsibilities of overseeing and organizing the building aspect of a construction project work from the start to the finish regardless of the size of the project. Their duties range from planning, overseeing construction activities and ensuring adherence to building codes and regulations stipulated in local code documents of the regions where the construction project is being carried out. In some cases, contractors may enlist subcontractors with specialized expertise for electrical works and HVAC systems.

3. Users:

The users play a specific role with their requirements that lead the decisions of the other stakeholders throughout the built environment design process. Building designs need to ensure users' well-being, economic feasibility, and lifestyle (Wallbaum *et al.,* 2010).

According to Tobias (2019), the role of users comes into play in the operational and maintenance phases. In this context, Tobias (2019), states that "the common domestic building end-user is a resident; i.e. an individual who uses the building as a residence on a permanent or temporal basis". Therefore, because they use finished products in buildings, their role entails having knowledge of energy certification and other techniques required for energy efficiency in buildings such as having ideas on appliances with low energy consumption for their comfort, which in the long run will help them save energy costs.

2.2 Energy Efficiency in Buildings

The phrase energy efficiency in buildings relates to less energy usage in activities in buildings. It is a process that helps in cutting energy bills and reducing pollution. Kelvin, Timothy, and Jonathan (2005) stated that "many products in buildings use more energy than they actually need". This explains why there is a need to make buildings more energy-efficient.

The United States, Department of Energy (DOE) in its quadrennial Energy Review (2015), states that "energy efficiency in buildings is not just about the reduction of energy for lighting, ventilation, and heating appliances; the design techniques and materials of the building envelope also have a significant role in energy efficiency in buildings". This explains why lighting, HVAC equipment and other building equipment and components, such as window sizes/types, are being made automated using smart technologies such as wireless communications gadgets, smart controllers, etc. to help maintain and enhance energy efficiency in buildings.

These systems are important because they aid in managing peak load in buildings, thus improving energy efficiency in buildings and providing utility services aimed at reducing energy consumption and cost of energy.

2.2.1 Energy efficiency concept. According to SERPA, (2015), " the energy efficiency of a building is defined as the extent to which the energy consumption per square meter of floor area of the building measures up to established energy consumption benchmarks for that particular type of building under defined climatic conditions" (SERPA, 2015). Energy efficiency concepts help in cutting the cost of energy bills and reducing pollution. This means that a significant increase in energy efficiency in a building reduces the energy consumption level of the building.

Energy efficiency concepts are rooted in making the interior environment of a building comfortable while minimizing energy usage for electric utilities. The advent of new technologies to support lighting systems in buildings and also to support heating, ventilating and air conditioning (HVAC) have helped in achieving energy efficiency in buildings. Energy efficiency concepts have a direct relation with the climatic conditions of an area where they are applied to a building, the building envelope and materials used for the construction of the building also play vital roles in achieving energy efficiency in the building. Different climates require different energy efficiency concepts to achieve a very good energy-efficient building.

Hence, the energy efficiency concept to be used in a building largely depends on the architectural prowess being displayed, efficient use and implementation of building energy efficiency codes, minimum standards/requirements and energy systems such as appliances for lighting, heating, cooling etc. (United States Department of Energy, 2015). Thus, achieving energy efficiency in buildings as identified by the US Department of Energy (2015) depends on:

1. "Good building designs including passive techniques";
2. "Improved building envelope including roofs, walls and windows";
3. "Improved equipment for heating, cooling and humidity";
4. "Thermal energy storage either as part of the building or separate equipment";
5. "Improved sensors, control systems, insulators and control algorithm for optimizing performance"; etc.

There are a number of energy efficiency concepts whose ultimate goal is to use reduced energy in buildings to ensure that the level of comfort in buildings is improved and maintained (SERPA, 2015). These concepts are focused on reducing heating demand, cooling demand, energy requirement for ventilation, energy for lighting in buildings, etc. These concepts are directly related to the passive and active design techniques/strategies.

2.2.1.1 Passive design measures. These measures are amongst the best/most effective measures for ensuring energy efficiency in buildings (Vallabhaneni, 2014). According to Marro (2018), "passive design measures are architects' first opportunity to increase the energy efficiency of a building before going more advanced technologies and building systems are explored for energy efficiency". Passive design measures include orientation, natural ventilation, landscaping, cooling pools/systems, air sealing, continuous insulation, properly designed windows and sizes, daylighting etc. (Marro, 2018).

The passive design measures principle is centered on less energy usage in buildings and reducing greenhouse gas (GHG) emissions. According to the Passive House Institute U.S. (PHIUS), passive homes use an estimated 80% less energy for lighting, heating, ventilation and air-conditioning (Rote, 2021).

There are a number of passive design techniques centered towards achieving the ultimate goal of energy-efficient buildings. The main techniques include building orientation, natural ventilation and daylighting, landscaping and shading devices.

1. Building orientation:

Building orientation is a passive design technique that has to do with positioning a building in such a way that it will naturally benefit from solar radiation from the sun and also the pattern of prevailing wind in a specific area. This simply means that building orientation basically has to do with the position of the building on site with utmost consideration of the sun's path and the climate of the area. According to NJ Green Building Manual (2022), "building orientation describes a building's placement on a site and the positioning of windows, rooflines and other features to benefit from the sun and prevailing wind".

A building that is properly oriented on site has great potential to ensure energy efficiency. It is important to know that building shapes are significantly related to achieving proper orientation. According to SERPA (2015), "the shape of a building determines how much area is exposed to the outdoor energy through external walls and ceiling". This means that building shapes are an important parameter to consider in achieving good building orientation. Therefore, explains why it is easier to orient buildings with simple square or rectangular designs of floor plans rather than buildings with complex shapes. Buildings with these shapes are also known to be economically flexible in terms of construction purposes (Rote, 2021).

A building orientated to take advantage of solar radiation is advantageous for both passive and active design strategies. The passive solar strategy advantage is that the building can be illuminated without much external mechanical energy source. This allows solar radiation to serve as a source of renewable energy as an active strategy to run appliances. This enhances comfort with low energy usage and zero emissions.

According to an article by Archi-Monarch (2020), "the best orientation for buildings is the solar North or South orientation". Studies have shown that in hot and humid climate regions like Abuja, the best solar orientation should see the short sides of the building face the East & West, thus making it a solar North or South orientation (Ochedi and Taki, 2022). This will enable the building to take advantage of the solar radiation and reduce heating in the building during hot weather (summer) and also keep the building relatively warm during cold weather (winter). A building orientation is illustrated in Figure 5.

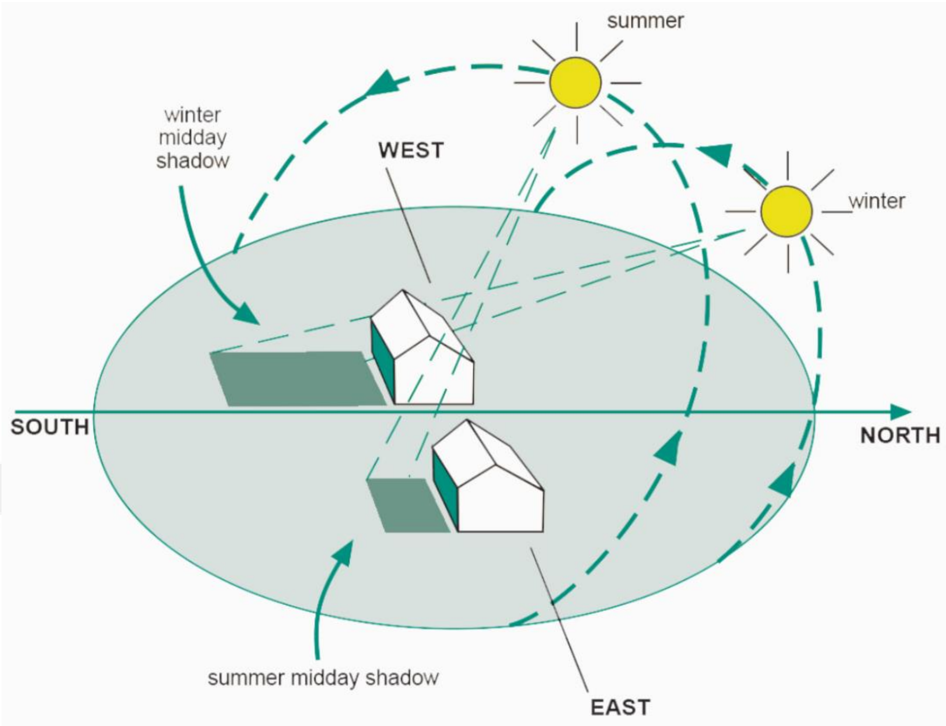


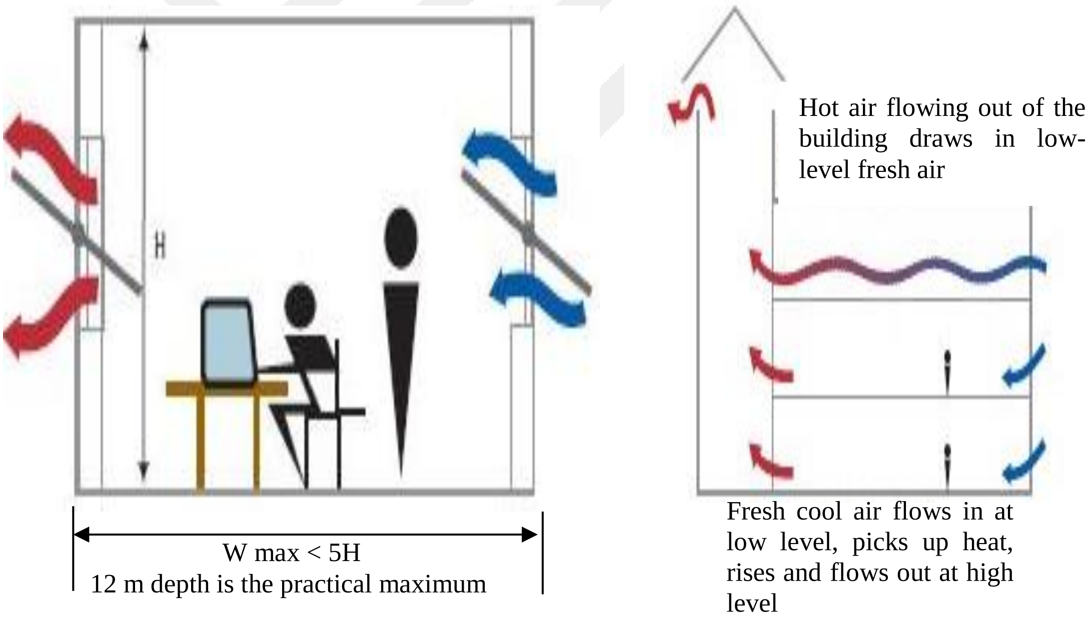
Figure 5. Building orientation illustration (Archi-Monarch, 2020)

2. *Natural ventilation and daylighting:*

'Natural ventilation' and 'daylighting' are important passive design measures proven to be effective for energy efficiency in buildings because they tend to make a building require less mechanical energy source for ventilating and lighting a building. These two strategies ('natural ventilation and daylighting') cohabit in building designs. They explain buildings designed for good natural ventilation also exhibit good daylighting potential.

Ventive (2024) defines "natural ventilation as a method of supplying free air to a building or room by means of passive forces, typically by wind speed or difference in pressure internally and externally". Similarly, Ogounsote, *et al*., (2003) define natural ventilation "as a way of providing new air to a home or office-building using passive force which is normally by wind velocity or pressure externally and internally difference". Natural ventilation reduces the amount of energy that would be spent on mechanical systems for ventilation and thereby reduces carbon emissions. Research has proven that the energy required for an air-conditioned building will be twice the energy that natural ventilation will require in the same building (Ogunsote, *et al*., 2003). According to Ogunsote, *et al.*, (2003) "in desirable climate, natural ventilation can be employed as a substitution for air-conditioning plants, preserving 10%-30% of entire energy utilization".

The common types of natural ventilation are cross ventilation and stack ventilation. According to (SERPA, 2015), "cross ventilation is a type of natural ventilation where air entering a building moves from one side of the building opening to the other side of the building opening". It is practically achievable only when the building is not more than 12-15m wide; while stack ventilation on the other hand requires introducing central atria that allows air to be drawn from the outer perimeter of a building wall into the building via the middle of the building. It is often most practically achievable in buildings with deep spaces (SERPA, 2015). Figure 6 presents an illustration of the process of achieving natural ventilation via cross ventilation and stack effect.



1. Cross Ventilation *2. Stack Effect*

Figure 6. Types of natural ventilation (SERPA, 2015)

On the other hand, Reinhart (2014) describes daylighting "as the controlled use of natural light in and around buildings". Daylighting is often achieved via fenestrations such as doors and windows, or other transparent media like reflective surfaces. In terms of energy efficiency, the idea behind daylighting is to allow natural light to provide illumination in interior spaces of buildings rather than over-reliance on mechanical energy sources for providing light to illuminate interior building spaces

(Reinhart, 2014). It is important to understand that positioning well-designed windows and doors with adequate sizes is vital in enhancing natural ventilation and daylighting in buildings.

According to SERPA (2015), windows should be designed, placed in appropriate positions and sized in a suitable way that will take advantage of the climate of the area to provide effective natural ventilation and daylight. The U.S. Department of Energy (2015) highlights that when daylight is provided by windows, they contribute majorly to not only the ambience of the interior environment of a building but also to the reduction of mechanical energy demand for light in the building. Thus, in designing and positioning windows, it is important to avoid excessive glazing. Because large, glazed areas tend to induce heat gains during the summer and heat losses in winter, thus, providing thermal comfort in the interior environment of buildings becomes an uphill task.

Window designs are of key importance to daylighting. They determine the amount of daylight and natural ventilation that enters a building. As a rule of thumb; “a window will introduce effective daylight into a room to a distance twice the head height of the opening” (SERPA, 2015). Building designs with high ceilings and clerestory windows, sun pipes and skylights are effective for producing efficient daylighting and natural ventilation in tall buildings. Sun pipes and skylights are often used to introduce daylight to windowless areas.

3. Landscaping and Shading Devices:

The use of landscaping and shading devices are important passive design strategies that serve as measures for enhancing energy efficiency in buildings. Studies have shown that excessive heat gain in buildings via solar radiation can be controlled through landscaping and introducing shading devices to building designs (Don, 2016).

According to Don (2016), “Architectural landscaping refers to any activity that modifies visible features of an area of land or building either by planting trees, shrubs, flowers, altering contour, fencing, creating walkways or other structures and materials, etc. Landscape designs that incorporate green architecture are suitable for improving energy efficiency in buildings. Van Antwerp (2019) defined green architecture as a philosophy that advocates the siting of buildings with consideration of its impact on the environment, sustainable sources of energy, designing efficient reuse of energy and updating buildings with new technology.

Shading devices, on the other hand, are used to control the amount of direct sunlight in a building. They serve as interceptors or blocks for direct sunlight before it reach the walls and glazing areas of buildings (Don, 2016). Shading devices are often categorized into two categories that include; fixed (external) or moveable (internal) shading devices.

According to Don (2016) “fixed shading devices (external) include eaves, awnings, canopy, window hoods, overhangs, pergolas, vegetation and trees, projecting horizontal or vertical fins, balconies, solar control glazing, mid blinds etc.; while moveable shading devices (internal) include internal blinds, curtains, internal or external shutters”. Fixed (external) shading devices are known to be more effective in reducing solar energy gain in a building than internal shading devices. Studies have revealed that fixed (external) shading can reduce solar heat gain by up to 80% (Don, 2016).

According to a report on the Sustainable Energy Regulations and Policy Making for Africa (SERPA, (2015), “high summer sun is best controlled on south-facing elevation using overhangs and other fixed shading devices such as pergolas, window hoods, etc., while the solar gain in the East and West is more difficult and as such require the use of adjustable internal shading devices e.g., window blinds, curtains, etc.” In terms of enhancing energy efficiency, landscaping and shading devices are vital in enhancing heating and cooling demands/requirements in buildings (Don, 2016). Figure 7 shows an illustration of window blinds and overhangs as shading devices.

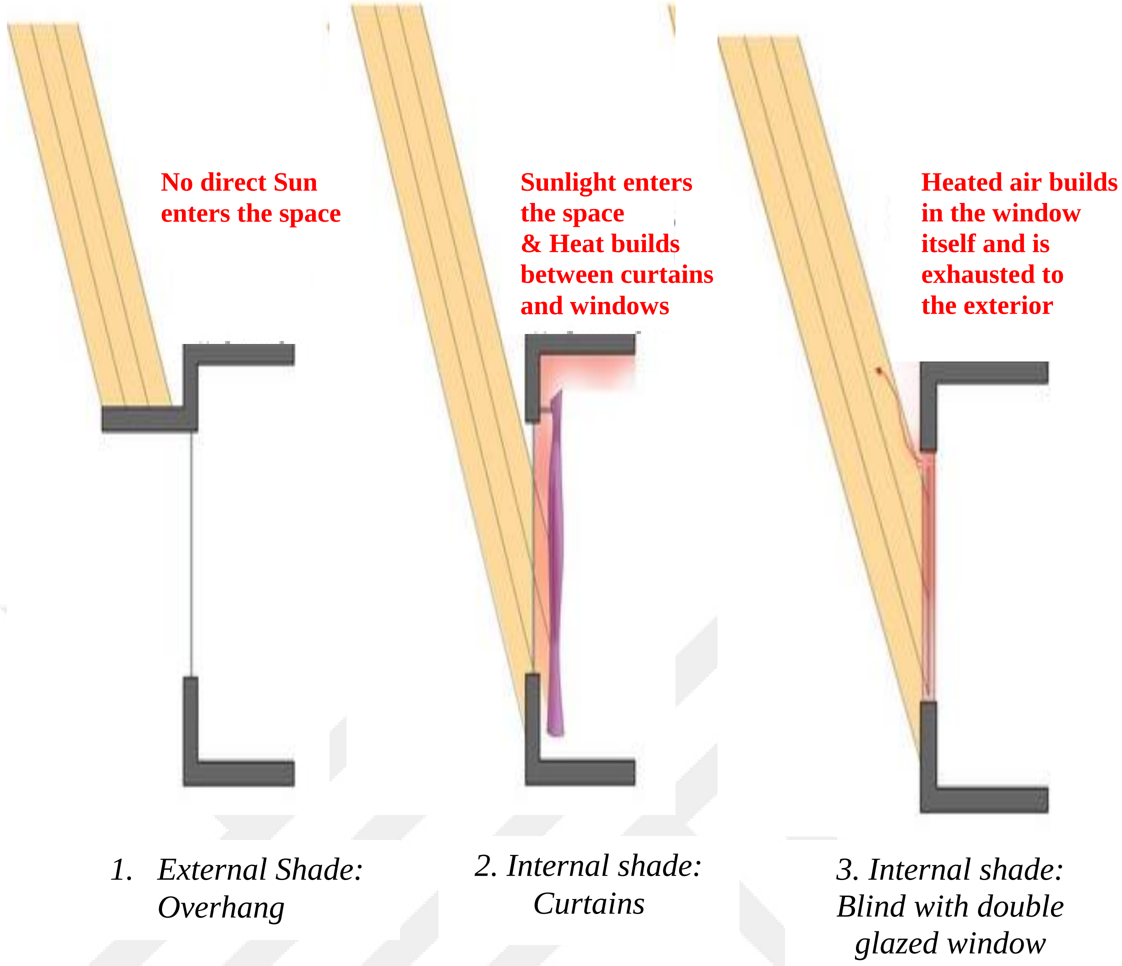


Figure 7. Types of shading devices (American Institute of Architects, 2019)

2.2.1.2 Active design measures. These are measures that use purchased energy to keep buildings comfortable. These purchased energies include electricity and natural gas (Anchal, 2021). There are a number of active design strategies which are either implemented using renewable energy systems (systems that generate energy) or mechanical system components.

According to Anchal (2021), globally, the use of renewable energy is at the forefront of achieving energy efficiency in buildings. Some notable active renewable energy design strategies aimed at energy efficiency include; solar-thermal panels, photovoltaic systems, wind turbines, etc.

a. Solar-thermal panels

A solar-thermal panel is one of the common strategies used as an active measure of energy efficiency. In regions with higher sunshine rates, solar energy is capable of generating electricity in several ways that will be beneficial for enhancing energy efficiency. One of these ways is via solar chimneys. This is applicable primarily in desert locations. According to Anchal (2021), "A solar chimney is a tall column surrounded by a glass solar collector or a greenhouse. The air is heated by the circular greenhouse and drawn through the chimney which acts as a thermal accelerator to generate electricity."

b. Photovoltaic system

Another reliable renewable energy system for generating energy is the photovoltaic system. This system comprises of photovoltaic (PV) cells that convert solar radiation into electric energy via a process known as 'photovoltaic effect'. The PV cells often generate electricity current when directly exposed to sunlight. The cells are unique in their method of creating electricity because they require low maintenance and they do not have moving parts that consume energy. However, the major setback of using PV cells is that they are usually expensive to set up and often give out low outages when the intensity of solar radiation drops. This explains why they are more efficient in daylight hours. Seasonal variations also make photovoltaic electricity generation prone to instability. However, PV system has long-term benefits that allow surplus energy to be returned to the grid, thus allowing users to earn monetary reimbursements (Colite Technologies, 2024).

c. Wind turbines

Wind turbines are renewable energy techniques that are used to generate wind power. They often require wind actions to create wind power. Wind power is generated when the wind blows air from high atmospheric pressure zones to nearby lower atmospheric pressure thus causing wind turbine blades or mills to rotate their propellers and generate wind energy. The propellers are often connected with generators. These generators increase the speed of turbine blades causing more rotation per minute which ends up converting kinetic energy into electrical energy (Sergio, 2013).

d. Mechanical systems

Mechanical systems are also vital in actively achieving energy-efficient buildings. Some notable mechanical systems strategies for actively achieving energy efficiency include; high-efficiency HVAC systems, heat recovery ventilators, electric building automation systems, high-efficiency appliances and electric lighting, reversible fans, etc. (Wrigley, 2021).

High- efficiency HVAC system:

HVAC systems are used to maintain desired comfort in building spaces and the environment. According to Anchal, (2021), “high- efficiency HVAC systems are mechanical systems that require less energy for heating, ventilating and air conditioning”.

Heat Recovery Ventilation (HRV) and Energy Recovery Ventilation (ERV):

HRV/ERV systems are mechanical systems that supply ventilation in buildings. This setup efficiently saves the energy required for heating and cooling in buildings. The process of achieving the aim of the setup requires the movement of fresh outdoor air into the HRV/ERV system. The system then pre-conditions the air by transferring the heat (HRV) or heat and humidity (ERV) from stale exhaust air into the fresh outdoor air" (Zhongzheng, 2000).

Building automation:

Building automation is the computerization of appliances for lighting, HVAC in buildings. (Wrigley, 2021) added that “building automation is the computer networking of electronic devices designed to monitor and control the HVAC, security, fire and safety, lighting, humidity and audio-visual control systems within a building”. Buildings that have undergone any form of computerization are often referred to as ‘smart buildings’ or ‘intelligent buildings’. According to Carpenter (2001), building automation holds the key as one of the most sought active measures for energy efficiency because smart and intelligent buildings are known to be able to adapt to changing conditions via digitization and automation; thus, this makes them one of the biggest energy saving potentials in active design measures for energy efficiency.

High-efficiency appliances and electric lighting:

High-efficiency appliances are appliances that run on less energy. They adhere to regulated targets for energy consumption labels. They aid in saving energy during everyday chores in buildings. These targets are set by regulating bodies such as Energy Star, LEED, etc. The targets required are standard requirements for the use of energy in appliances. These targets require that appliances use less energy to maintain comfort in buildings. In terms of energy efficiency, high-efficiency appliances and electric lighting are the basis for retrofitting in buildings. For instance, they require that incandescent general lighting service (GLS) lights be replaced with light-emitting diode (LED) (Wrigley, 2021).

Reversible ceiling fans

Reversible ceiling fans are active mechanical systems that are used to circulate indoor air in both heating and cooling seasons (Wrigley, 2021). According to Wrigley (2021), the principle of operation of the reversible ceiling fans in both heating and cooling seasons requires that "in the winter, cool air is drawn from the floor up towards the ceiling, pushing warm air from the ceiling down into the occupied space; while in the summer, air is directed down towards the occupied space to promote evaporative cooling".

In addition, achieving energy-efficient buildings requires the right implementation of active and passive design strategies in buildings. Hence, relevant stakeholders in the building sector ought to be equipped with the apt knowledge of passive and active design measures required for enhancing energy efficiency in buildings and reducing greenhouse gas emissions.

2.2.2 International energy efficiency standards. International Standards are policies and laws that cover energy efficiency on a global level (IEC, 2023). They are vital benchmarks adopted by different countries around the globe in order to measure and improve the energy efficiency of products, buildings or other related systems. They are beneficial to not just countries but individuals and organizations. They provide guides for reducing energy consumption, promoting sustainable practices, reducing greenhouse gas emissions, pollution, etc. Promoting international standards of energy efficiency has the potential of improving the quality of human life by enhancing cost-saving, clean energy and environmental benefits. It is important to understand that these standards can be categorized into both prescriptive based and performance based. Some notable international standards that relate to energy efficiency include ASHRAE standards, IEC standards, ISO 50001, Energy Star, LEED, GREENSTAR, BREEAM, CASBEE, DGNB etc.

1. *ASHRAE standards:* These are standards published by the "The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)." They are targeted at enhancing energy efficiency in buildings. These standards include

standards for HVAC systems, lighting, insulation and the general building envelope requirements.

2. *IEC standards:* The International Electrotechnical Commission (IEC) is responsible for publishing standards that are related to achieving energy efficiency for electrical and electronic products and systems. In most countries of the world, electronic companies comply with IEC standards for energy efficiency when making electronic products. This explains why 71% of European electrical and electronic standards are identical to IEC International Standards (IEC, 2023).
3. *ISO 150001:* The ISO standard is a global standard that provides a framework for organizations to establish, implement, improve and maintain healthy energy management systems which are achieved by reducing energy consumption and environmental impact of a building. This enables organizations to increase their profitability.
4. *Energy Star:* This is an energy labelling program in the US. The program is championed by the Environmental Protection Agency (EPA) and the Department of Energy (DOE). The program is aimed at setting energy efficiency standards for buildings and appliances used in homes.
5. *Leadership in Energy and Environmental Design (LEED):* This program, developed by the U.S. Green Building Council is a green building certification program targeted at setting standards for sustainable building design and construction (NJ Green Builders, 2022; USGBC, 2024).
6. *GREENSTAR:* GREENSTAR is an intentional code developed for the Australian environment in 2003 by the Green Building Council of Australia. The code is a voluntary code that sets guidelines and standards centered on promoting sustainable building practices based on the principles of green building. The code covers numerous aspects of construction such as energy efficiency, water conservation, indoor air quality, and materials selection with the aim of reducing the environmental impact of buildings. Adhering to GREENSTAR code helps in creating healthy and more energy-efficient buildings that minimize the consumption of resources and generation of waste during construction. GREENSTAR code encourages the use of renewable energy sources, efficient building systems and sustainable construction methods to create environmentally friendly structures (GBCA, 2013).

7. *BREEAM:* BREEAM is an acronym for Building Research Establishment Environmental Assessment Method. Developed in the UK, BREEAM is an internationally recognized certification scheme for sustainable buildings which sets the standards for the best practices in building design, construction and operation so as to minimize environmental impact on buildings and generally improve the performance of buildings (McPartland, 2016).
8. *CASBEE:* CASEBEE which stands for Comprehensive Assessment System for Built Environment was developed by the Japanese government in 2001 as a sustainability assessment method for evaluating and improving the environmental performance of buildings and urban developments. The code provides a systematic framework for the assessment of numerous areas of sustainability ranging from energy efficiency, resource conservation, and indoor environmental quality to overall environmental impact (IBEEC, 2024).
9. DGNB: Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) also known as the German Sustainable Building Council was founded in 2007 in Germany. DGNB is one of the largest set up for sustainable construction in Europe. DGNB has around 1,200 member organizations. The aim of the association is to foster sustainability in the design and construction of the real estate industry. DGNB system is based on a holistic understanding of sustainability, and it equally includes the environment, people and economic efficiency (Global Alliance for Building Construction, 2024).

Energy efficiency standards in buildings are grouped into the following major categories: *Prescriptive based or Performance based.*

Prescriptive based codes often recommend specific requirements for building construction, materials and systems. They are not flexible and must be adhered to. In the energy efficiency context, they are requirements that often specify insulating levels, HVAC requirements, window types, etc. which are based on already established standards and represented in tables. They are the basis for the practice required to attain the minimum energy efficiency levels in buildings".

Performance based codes on the other hand are regulations centered on the measurable performance of the buildings rather than the design and construction methods. This makes them flexible regulations, and as such allows architects and designers to be innovative and creative in finding measures that will enhance energy efficiency in buildings. In the energy efficiency context, performance codes set targets for overall energy consumption, energy use intensity (EUI), or other performance metrics rather than specifying particular building components or systems. Thus, this regulation permits designers to use any combination of design strategies, materials, and technologies to meet the performance requirements of a building which is always measured in terms of low energy usage.

Table 2 presents some notable international standards and their categories.

Table 2

Global standards categorization

S/N	Standards	Categories
1	ASHRAE standards	Both prescriptive and performance based
2	IEC standards	Prescriptive based
3	ISO 150001 standard	Performance based
4	Energy Star	Prescriptive based
5	LEED	Performance based
6.	GREENSTAR	Performance based
7.	BREEAM	Performance based
8.	CASBEE	Performance based

2.2.3 Energy efficient buildings. According to Sathi (2020), energy-efficient buildings could save up to 30-40% of operational costs, ensure comfort of occupants and also improve productivity of occupants. Hence, the need for energy-efficient buildings should not be underestimated because these buildings are important in the quest for reducing GHG emissions in the environment.

According to Wrigley (2021), it is a known fact that some appliances are more energy-efficient than others, and greater efficiency equals less money spent on electricity bills. In terms of energy efficiency in buildings, it is important to know that the major challenge today goes beyond just having efficient appliances; it requires an all-around energy-efficient building. However, achieving energy-efficient buildings is increasingly becoming difficult due to the lack of adherence to design practices, building codes and regulations, and designing without considering the climate and its impact on the building.

It is pertinent to state that an energy-efficient building has the potential to effectively reduce the emission of greenhouse gases because it ultimately opts for renewable energy sources to service a building. In addition to using renewable energy sources, energy-efficient buildings tap into passive design strategies which are aimed at using less energy to make buildings comfortable for humans. Energy-efficient buildings can be linked to climate responsive architecture. This is because climate responsive architecture which requires considering the climate of a particular region before designing and constructing buildings to suit the climate helps in enhancing energy efficiency in buildings as its construction techniques often require that building materials are sustainable and locally sourced so as to limit energy wastages for construction (Wrigley, 2021).

According to Sathi (2020), determining the energy efficiency potential of an energy-efficient building requires assessing if the design of the building envelope is one that is likely to take advantage of the climate and other environmental features of the region where the building is to be designed to attain a desirable level of energy efficiency. This can be achieved through proper active, passive and sustainable design practices and choosing building materials.

In summary, this chapter essentially gives an overview of the building life cycle. It extensively explains its concepts, phases and stakeholders involved in the process of a building life cycle and their respective roles in making apt decisions that will limit the impact of these buildings' life cycle process on the built environment. The literature reviewed in this chapter shows that the building life cycle begins with the extraction of raw materials before they are manufactured and supplied for the construction phases which all require large energy consumption down to the demolition stage where energy and waste are generated. However, the building life cycle stages could continue down to the recycling/re-use phase which consumes less energy, but in most cases, not all building components make it to this stage.

All these building life cycle stages are categorized by two concepts which are cradle-to-grave and cradle-to-cradle. The concepts are unique and they all require energy often delivered during the burning of fossil fuel, which leads to the release of pollutants and waste generation in the environment. However, this is minimal in the cradle-to-cradle concepts because of renewable energy and recycling/re-using capabilities. This chapter also looked extensively into the energy efficiency standards for buildings and their categories.

Chapter 3

Energy Efficiency in Nigeria

This chapter of the thesis is on energy efficiency in Nigeria. It covers information on Nigeria's energy efficiency code and its comparison with global codes. The global codes for the comparison are defined in this chapter; and also the comparison parameters and results are discussed.

3.1 Nigerian Energy Efficiency Code

The Nigeria Building Energy Efficiency Code, which was first developed and launched in 2017 by former Minister of Power, Works, and Housing Babatunde Raji Fashola**,** is a 28-page document targeted at attaining energy efficiency in buildings in Nigeria if effectively utilized in building designs and constructions.

The code is essential to Nigeria's progress towards encouraging sustainable development in concurrence with the 'Sustainable Development Goals of the United Nations', especially 'Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action)' (Sustainable Development Goals, 2002). The code also backs Nigeria's adherence to the 'Paris Agreement', aimed at promoting resilience against climate change impacts and assisting in ensuring an economy characterized by low-carbon emissions.

The code document titled "National Building Energy Efficiency Code" is also widely referred to as the 'Building Energy Efficiency Code (BEEC) of Nigeria'. The document is sectioned in 3 parts. The first part is the administrative part; the second part is the technical part and the third part is the annex section.

Part 1: Administrative part of the Code

The administrative part of the Nigeria BEEC document covers the Preface; and the Commencement / Definitions aspects are documented in 9 pages (pages 3-11), though the cover page and copyright page is documented in 2 pages (pages 1-2).

- *Preface aspect*

The preface covers the code overview and the acknowledgement of major contributors to the development of the code. The development overview gives an insight into the development of the 'National Building Energy Efficiency Code'. As recorded in the 'BEEC' document, the 2 stages paramount to the development of the code are the ‘National Building Energy Efficiency Guide’ and the ‘Technical BEEC study’.

The ‘National Building Energy Efficiency Guide (BEEG)’ is the first stage prior to the development of the ‘National Building Energy Efficiency Code of Nigeria’. This publication, approved in 2016, promotes bioclimatic buildings in Nigeria.

The technical BEEC study by stakeholders which includes architects, allied professionals/their respective regulatory bodies and the Federal Government of Nigeria is the second stage prior to the development of the ‘National Building Energy Efficiency Code of Nigeria. This technical BEEC identifies the minimum energy efficiency requirements and other necessary elements vital in developing the ‘BEEC’. Hence the findings from these 2 stages were vital in the development of the National Building Energy Efficiency Code draft itself.

The second aspect of the preface covers the acknowledgement of major contributors to the success of the code.

- *Commencement and Definitions aspect*

The commencement and definitions aspect is also documented in the administrative part of the BEEC. It covers the title, aim, scope and adoption of the code. It also spelt out the definitions of keywords used in the document publication.

As recorded in the document, the ‘BEEC’ is aimed at setting minimum requirements for energy efficiency of buildings. The BEEC scope covers the following elements.

- ‘Minimum energy efficiency requirements and verification methods’,
- ‘Calculation methods and tools’,
- ‘Building energy labels and energy efficiency incentives’,
- ‘Control and enforcement, qualification of experts’,
- ‘Review and adaptation’

All these elements that cover the BEEC scope are addressed in detail in the second part of the document which is the technical part.

The Nigeria BEEC document is the superior document in terms of enforcing energy efficiency in buildings in Nigeria. It is recorded in the code documents that the code contains the minimum requirements and regulations from which other energy regulations may be derived from in Nigeria. Hence, if there is any conflict with any other code regulation in Nigeria, the 'BEEC' prevails.

This code document under review documents that the buildings BEEC applies to are new buildings in Nigeria. These new buildings are grouped into 2 groups, namely: Group B and Group R, respectively. The Group B buildings include business and professional spaces used primarily as office workspace, while the Group R; is strictly for new residential buildings of different types.

The adoption of the BEEC is applied to all levels of government in Nigeria including the federal, state and local level constructions in Nigeria. This makes the code a nationally accepted code for buildings.

Part 2: The Technical Part of the 'National Building Energy Efficiency Code'

The second part of the 'National Building Energy Efficiency Code of Nigeria' is the 'technical part' compiled in 16 pages (pages 12-28). The technical part gives a detailed analysis of the elements that make up the scope of the BEEC code. The technical part of the BEEC document addresses the following.

- 'The minimum energy efficiency requirements and verification methods'
- 'Compliance methods'
- 'Performance methods to compliance'
- 'Calculation methods and tools'
- 'Energy efficiency labels and energy efficiency incentives'
- 'Control and enforcement'
- 'Qualification of BEEC experts'
- 'Review and adaptation of the code'

- *"Minimum energy efficiency requirement and verification methods":* The minimum energy efficiency requirements as recorded in the technical aspect of the code document apply to climates in all zones in Nigeria. The intervention of requirements is linked with 'bioclimatic principles' described in the national "Building Energy Efficiency Guidelines (BEEG)". These bioclimatic principles are:
- 'Reduction of overall window-to-wall ratio or implementing shading'
- 'Reduction of installed lighting power density'
- 'Minimum requirement for roof insulation'

- ‘Minimum performance of air conditioning equipment specified’
- ‘Installation of non-inverter split unit to be restricted’

However, minimum requirements for energy efficiency in relation to energy consumption for appliances in offices and households are not included in the “National Building Energy Efficiency Code” document. Also, energy consumption relating to industrial processes and those for heating water are also not included.

In terms of verification of energy efficiency documents to demonstrate compliance, documents are submitted to the competent authority twice. The first time is before getting the Building Permit, while the second time is before getting the Certificate of Use and Habitation.

- *Compliance methods*

Prescriptive approach and performance approach are the methods for compliance with the “National Building Energy Efficiency Code of Nigeria”.

Prescriptive approach: The prescriptive approach also known as the compliance method 1 is the first compliance route to the ‘National Building Energy Efficiency Code of Nigeria’. This approach requires building projects to be compelled to strictly adhere to all ‘minimum requirements for energy efficiency’ as stipulated in the code document. The minimum requirements, applicability and verification methods for compliance with the ‘National Building Energy Efficiency Code of Nigeria’ in the prescriptive approach are presented in Table 3.

Table 3 presents the minimum requirements, applicability and verification methods to compliance with the BEEC of Nigeria. The table reveals that the major prescriptive building requirements for energy efficiency in Nigeria are ‘window-to-wall ratio or shading; installed lighting power density, roof insulation and air conditioning’. The verification method to compliance with this code is done in two stages which include the design stage prior to approval and the as built stage which is after the completion of the project.

Table 3

Prescriptive Route to Compliance

Code	Minimum Requirement	Applicability	Verification Method
"Window- to – Wall Ratio or Shading";	Window-to-wall ratio for any orientation shall not exceed 20%. 'Where the design is such that this cannot be achieved, then all glazing elements on the relevant facades are to be adequately shaded'.	This requirement applies to all buildings within the scope of the code.	**Design stage** The documents to show compliance at Building permit stage are: • 'Architectural plan layouts and elevation drawings of facade and fenestration' • 'Fenestration schedules or drawings showing the areas of fenestration' • 'Calculation showing the window-to-wall ratio' • 'Completed BEEC Calculator for Window to Wall Ratio or shading' **As-built stage** Documents to show compliance after completion are: • Material from design stage updated to "as-built" *Note:* A comparison of physically implemented measures with submitted documents is conducted.

Table 3 (cont'd)

Code	Minimum Requirement	Applicability	Verification Method
"Installed lighting power density"	'Lighting power density shall not exceed 6 W/m² for residential buildings and 8 W/m² for office buildings'. 'Calculations are to be carried out over the gross floor area of a building'. 'Installed power and energy consumption of artificial lighting should be minimized by the use of more efficient lamp/ballast systems and luminaires'. The requirements include ballast loss.	This requirement applies to all buildings within the scope of the code. Exemptions are emergency lighting and outdoor recreational facilities.	**Design stage** Documents to show compliance at building permit stage include: • Lighting layout plan • Lighting schedules showing the numbers, locations and types of lighting luminaries used • Technical product information of the lighting luminaries used • Completed 'BEEC' Calculator for lighting **As-built stage** 'Documents to show compliance after completion' • Material from design stage updated to "as-built" Note: 'A comparison of the physically built-in fittings with submitted documents is conducted'.

Table 3 (cont'd)

Code	Minimum Requirement	Applicability	Verification Method
"Roof insulation"	'All roof constructions are to include a layer of insulation with thermal resistance not less than 1.25 m²K/W (R-value)'	This requirement applies to all buildings within the scope of this code.	**Design stage** Documents to show compliance at building permit stage • 'Plan layout and sectional details of the different roof types' • 'Detailed sectional drawings showing the roof' • 'Composition including the position of the insulation' • 'Technical product information showing the thermal conductivity in W/(mK) (k-value) of insulation' • 'Completed BEEC Calculator for insulation' **As-built stage** 'Documents to show compliance after completion' • 'Material from design stage updated to "as-built" Note: 'There must be a comparison of physically built-in products with submitted documents (during construction or after completion depending on accessibility of roof.'

Table 3 (cont'd)

Code	Minimum Requirement	Applicability	Verification Method
"Air conditioning"	'All air-conditioning units shall have a minimum EER/COP of 2.8 and shall be of the inverter type'. Only air conditioners with inverters shall be accepted for installation in buildings.	This requirement applies to all buildings within the scope of the code.	**Design stage** Documents to show compliance at building permit stage • 'Air-conditioning equipment schedule showing manufacturer and model number for all installed equipment' • 'Product technical data showing inputs required for BEEC Calculator' • 'Completed BEEC Calculator for air-conditioning' **As-built stage** 'Documents to show compliance after completion'. • 'Material from design stage updated to "as-built" Note: 'There must be a comparison of the physically built-in products with submitted documents. Buildings without active cooling systems (no air conditioning provided for the building) shall still adhere to the other prescriptive requirements of the code (lighting, insulation and window-to-wall-ratio)'.

- *Performance approach:*

The performance approach, also known as the "compliance method 2" is the second compliance route to the BEEC of Nigeria. In this compliance approach, the project team can deviate from the prescriptive energy efficiency requirements but the overall energy usage of the building they are working on must be less or equal to a reference (compliant) building model that adheres to prescriptive requirements for energy efficiency as stipulated in the 'BEEC' document".

Competent persons determine the energy efficiency of the designed building by using simulation software approved in the 'National Building Energy Efficiency Code document'. The simulation software subjects the building to a whole building analysis to determine its energy usage. As documented on page 18 of the 'National Building Energy Efficiency Code', verification for performance compliance method requires that building simulation be performed twice.

The first one is for the building as it has been designed. This implies that the first simulation is usually for the designed building while the second simulation is for the reference to the building which is designed in compliance with prescriptive requirements specified in the 'BECC' document.

Documents important for compliance with this method are the BEEC Calculator and the completed BEEC Modeling Report. The BEEC Calculator captures all inputs to energy modeling with respect to the prescriptive requirements. 'The completed BEEC Calculator clearly shows the predicted energy use of the building for lighting and cooling and its comparison to a BEEC-compliant building'. The completed BEEC Modeling Report is provided for the building to outline their adherence to the BEEC modelling.

"It is vital to understand that this compliance approach can be applied to buildings with no air-conditioning that do not meet the prescriptive requirements for roof insulation, lighting and window-to-wall ratio. In such cases, the buildings must be modelled with air-conditioning to show that they would still use less energy than the reference building if AC were provided in the future.

- *'Calculation methods and tools'*

As recorded in the 'National Building Energy Efficiency Code of Nigeria', "the 'BEEC' calculator shows compliance with both the Prescriptive route (compliance method 1) and the Performance route (compliance method 2). Simulation software packages for compliance with Compliance Method 2 need energy modelling certification by at least one of the following organizations or equivalent ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), IECC (International Energy Conservation Code)". It is worth noting that in Compliance Method 2 (Performance route), in addition to the 'BEEC' calculator, there is a need to follow a standardized reporting mechanism in accordance with the 'BEEC' Modelling Protocol.

- *Building Energy Label and Energy Efficiency Incentives*

This is another aspect of the technical part of the BEEC of Nigeria. As recorded in the BEEC "during the voluntary phase of introducing the BEEC, a comparative building energy label known as BEEC Label is awarded to the building owner together with the Certificate of Use and Habitation". The compliance to the '*Building Energy Label and Energy Efficiency Incentives'* is also carried out using two compliance methods which are; compliance method 1 (prescriptive route) and compliance method 2 (performance route). The 'BEEC' of Nigeria recommends that "for the prescriptive route to compliance, the BEEC Label rates a building depending on how many of the BEEC interventions/codes have been implemented". The scale for the star rating for compliance method 1, which is also known as the prescriptive route to compliance is displayed in Table 4. Table 4 presents 'the star rating for energy efficiency labels' for the prescriptive route to compliance. The table presents the rating, intervention/code and minimum specifications for compliance. From the table, the more intervention/code implemented in a building, the more the rating the building is likely to have. However, it is important to understand that compliance with the 'BEEC' (compliant building) has a 4 Star rating while a building with renewable energy is rated with 5 Star (National Building Energy Efficiency Code, Nigeria, 2017).

Table 4

Star rating for energy efficiency label

Rating	Intervention/code	Minimum Specification
1 star	• 'Window-to-wall ratio or shading'	• '20% maximum shading as per BEEC Calculator'
	'Lighting:'	
	• 'Residential lighting'	• 'Maximum lighting power density 6 W/m²'
	• 'Office lighting'	• Maximum lighting power density 8 W/m²
3 star	• 'Window-to-wall-ratio or shading',	• '20% maximum shading as per BEEC Calculator'
	'Lighting'	
	• 'Residential lighting'	• 'Maximum lighting power density 6 W/m²'
	• 'Office lighting'	• 'Maximum lighting power density 8 W/m²'
	• 'Roof insulation'	• 'Minimum R-value 1.25 m²K/W'
4 star	• 'Window-to-wall ratio or shading'	• '20% maximum and/or shading as per BEEC Calculator'
	'Lighting'	
	• 'Residential lighting'	• 'Maximum lighting power density 6 W/m²'
	• 'Office lighting'	• 'Maximum lighting power density 8 W/m²'
	• 'Roof insulation'	• 'Minimum R-value 1.25 m²K/W'
	• 'Air-conditioning minimum performance)'	• 'Minimum R-value 1.25 m²K/W Minimum EER/COP 2.8 and Inverter Compressor'
5 star	• 'On application only. This allows for taking into account, renewable energy systems (photovoltaic, solar water heating) which are currently outside BEEC'	

For compliance method 2, which is the 'performance route to compliance'; "the 'BEEC' Label rates a building depending on how much it exceeds the energy consumption when compared to the reference building with all BEEC interventions implemented". Table 5 shows the scale for the star rating energy efficiency label. Table 5 presents the star rating and the allowance for exceeding the BEEC-compliant building. From the table, a building is rated 1 star, if its energy usage does not exceed 40%. Buildings with 0% excess energy or below show compliance with the 'BEEC' code and as such have a star rating of 5 stars.

Table 5

Star rating for energy efficiency label (National Building Energy Efficiency Code, Nigeria, 2017)

Rating	Allowance for Exceeding BEEC-Compliant Building
‘1 star’	‘40% to 31%’
‘2 star’	‘30% to 21%’
‘3 star’	‘20% to 11%’
‘4 star‘	‘10% to 0%’
‘5 star’	‘Below 0%’

5. Control and Enforcement

The technical aspect of the BEEC, as recorded in the code document, also covers the control and enforcement of the code. For “control and enforcement, the competent authority needs to check the compliance of the building design with BEEC minimum energy efficiency requirements by inspecting the required documents for verification before issuing a Building Permit”. For compliance method 1 (prescriptive route), if there is non-compliance noticed at the building permit stage, there is a need for improvement. This is a vital condition before issuing any Building Permit approval.

In compliance method 2 (performance route), ‘the competent authority needs to also check compliance of completed building by inspecting the submitted verification documents prior to issuing the Certificate of Use and Habitation’. In this compliance method; ‘energy efficiency inspectors are required to physically check that measures, products, and systems have been installed in accordance with the submitted verification documents’.

6. Qualification of BEEC experts

‘The criteria for qualification of experts that prepare and submit verification documents to the competent authority must meet the defined minimum qualification requirements as recommended in the BEEC’. “These requirements stipulate that they must have completed undergraduate studies in any of building, architecture, or engineering. In addition, experts shall attend the specified training and pass examinations. The official version of the training to be passed is publicized by the competent authority.”

7. Review and adaptation

All elements of the 'BEEC' are reviewed to preserve their continuous effectiveness. This means that 'energy efficiency minimum requirements'; 'calculation methods and tools'; 'label and incentives'; and 'control and enforcement' requirements are subjected to review based on their effectiveness. As recorded in the BEEC, the minimum energy efficiency requirement of the Nigeria BEEC is to be 'voluntary for a maximum of two years'. This period defines the 'adoption and inception phase'. After this period, the state can make the requirement mandatory. Hence reviews take place after the voluntary phase ends which is usually 3-5 years after adopting the BEEC. After this period, adjustment is followed as appropriate.

As recorded in the BEEC code "the review investigates to what extent the BEEC stimulates bioclimatic design and good indoor comfort and how this can be improved. The review will pay specific attention to indoor air quality aspects. In the future, revised versions of the BEEC document will be made available, depending on the results of regular review and adaptation. The BEEC document shall be publicized by the competent authority and the most recent official version of BEEC shall be clearly marked".

Part 3: Annex

The third part of the' National Building Energy Efficiency Code' document of Nigeria is the annex part which is compiled in 2 pages (pages 27-28). This part covers the BEEC calculator, the BEEC Modelling protocol and the change log.

a) Annex 1: BEEC Calculator: The first annex is the 'BEEC calculator' available only in electronic format.
b) Annex II: The second annex is the 'BEEC modeling protocol'. The 'BEEC modeling protocol' highlights the guideline for reporting the 'BEEC' model report. The BEEC model protocol is also available only in electronic format.
c) Annex III: The third annex is the change log. The change log provides avenue for recording changes and revisions made on the code document. 'The first edition is named version 1.0. Small revisions will result in version 1.1, 1.2, and so on. In the advent of a major revision that will result in a new edition, named second edition version 2.0'. A sample of the change log table is shown in Table 6.

Table 6 presents a sample of the 'change log table of the National Building Energy Efficiency Code of Nigeria'. The table shows the version, date, affected chapter and description of the change. The table is important in the advent of any review or modification to the code. From the table, the current version of the BEEC is published 30^{th} June 2017. However, in the case of any change or upgrade to the BEEC version, it will be recorded accordingly in this table (National Building Energy Efficiency Code, Nigeria (2017).

Table 6

Change log table of the National Building Energy Efficiency Code of Nigeria

Version	Date	Affected chapter	Description of change
1.0	30th June 2017	-	-

In addition, it is important to know that if there are no goals to reduce energy consumption, then achieving energy efficiency globally becomes difficult. This explains why the European code has a sustainable goal targeted towards reducing energy consumption by 2030. In line with this, the Nigerian government also have some policies to help in achieving reduced energy consumption and efficiency goals in the various sectors of the country. These policies include; Energy efficiency standards and labels, industrial energy efficiency, renewable energy integration, Monitoring and compliance policies, Public awareness on energy efficiency, incentives and financing etc.

i. *Energy efficiency standards and Labels:* The policy is set by the Nigeria energy commission. They contain provision for Minimum Energy Performance Standards (MEPS) for appliances and equipment to ensure they meet specified energy efficiency label. They are also used to inform customers about the energy efficiency of products encouraging them to choose more efficient options.

ii. *Industrial Energy Efficiency*: This is a Nigerian government policy aimed at promoting energy audits and the adoption of energy management system in industries. These measures help identify energy saving opportunities, improve operational efficiency and reduce energy costs for industrial facilities.

iii. *Renewable energy integration:* This policy contains provisions for promoting the integration of renewable energy sources into the national energy mix of Nigeria. This policy aims to diversify the source of energy supply in the country and reduce reliance on fossil fuels. This policy will go a long way in reducing energy consumption and improving energy security/pollution.

iv. *Monitoring and compliance:* This is a Nigerian government policy that contains provisions which emphasize on monitoring and enforcing compliance with energy efficiency standards and regulations. The policy requires stakeholders to inspect, and issue certification for compliance and penalties for non-compliance to ensure that energy efficiency gains across the various sectors of the country are achieved.

v. *Public awareness on energy efficiency:* This is a government policy aimed at raising public awareness about energy efficiency and conservation through campaigns and education programs.

vi. *Incentives and financing:* These are policies implemented by the government to subsidize and finance mechanisms available to support investment in energy-efficient technologies and practices. These incentives help overcome initial cost barriers and encourage stakeholders to prioritize energy efficiency improvement (NEC, 2003).

3.2 Comparison of the Nigeria Code with Global Codes

It is a known fact that most countries across the globe have their specific energy efficiency codes aimed at regulating energy usage. These different country energy codes put together make up for global energy efficiency codes as used in the context of this study. Some notable countries' energy codes that are categorized as global energy efficiency codes include; the ‘U.S. Energy Efficiency Code’, the ‘European Union Energy Efficiency Code’, the ‘India Energy Conservation Building Code’, the ‘China Building Energy Efficiency Code’ etc. Table 7 presents some existing global building energy efficiency codes and their respective launch dates.

Table 7

Existing global building energy efficiency codes

SN	Global codes	Launch Date
1	India Energy Conservation Building Code	2017/2018
2	China Building Energy Efficiency Code	1986
3	U.S Energy Efficiency Codes (1975)	
	(ASHRAE) standard 90.1 & 90.2	1975
	International Energy Conversion Code (IECC)	1998
4	European Union Energy Efficiency Codes (1970)	
	Energy Performance of Building Directive (EPBD)	
	Energy Efficiency Directive (EED)	2002

However, the global codes within the scope of this thesis are limited to the 'U.S. energy efficiency codes', namely; "the International Energy Conversion Code (IECC)"; "ASHRAE standard 90.1 & 90.2" and the E.U. energy efficiency codes which comprises the "Energy Performance of Building Directive (EPBD)" and "Energy Efficiency Directive (EED)". These codes are compared with Nigeria's Building Energy Efficiency Code.

3.2.1 Definition of global codes. The leading global codes examined in this thesis are the US Energy Efficiency Code and the European Union Energy Efficiency Code. This thesis is limited to these 2 codes because of the leading roles each of the codes has played in enhancing energy efficiency in buildings and also producing sustainable developments and waste reduction worldwide. The examination of these codes is done by reviewing their respective documents.

The 'U.S Building Energy Efficiency Code documents reviewed are the 'International Energy Conversation Code (IECC)' and the 'ASHRAE 90.1 & 90.2 standard'; while the European Union Building Energy Efficiency Code document reviewed is the ‘Energy Performance of Buildings Directive (EPBD)’ and the ‘Energy Efficiency Directive (EED)’.

3.2.1.1 United States Codes. There is no unified national building energy code in the U.S. This means that energy codes in the U.S vary between states and jurisdictions, although recent studies have seen relevant stakeholders in the U.S. call for the adoption of a nationwide energy code that will cover all states in the U.S. (DOE, 2022). The ‘International Energy Conservation Code (IECC)’, and The ‘ASHRAE Standards 90.1 & 90.2’ are the major code documents that make up the U.S. Building Energy Efficiency Code. The review of the code documents for energy efficiency that make up the U.S energy efficiency code accessed online is carefully presented as follows.

1. ‘The International Energy Conservation Code (IECC)’

‘The International Energy Conservation Code (IECC)’ is a model code in the U.S. aimed at regulating energy conservation requirements of new buildings. It covers various factors of energy efficiency ranging from the cost of energy usage to the ‘environmental impact of the natural resources used in buildings’.

The International Energy Conservation Code (IECC) developed by the ‘International Code Council (ICC)’ is the code document that “sets the minimum efficiency standards for the new construction of a structure’s walls, floors, ceilings, lighting, windows, doors, duct leakage, and air leakage”.

The ‘IEEC’ has a similar development process to other model codes in the U.S. The ‘IEEC’ code document which was first put into effect a decade ago has recorded a tremendous impact in preventing millions of tons of carbon pollutants from entering the atmosphere. ‘Communities that have adopted IECC 2018 or later have seen significant savings for their businesses and residents since the decrease in energy use can save residents thousands of dollars each year’.

The ‘IECC’ as part of the ‘ICC’s’ is revised annually and published in full form every three years just like other collections of model codes. ‘The revision process is headed by an ICC committee but revisions and code changes can be proposed by any interested individual, business, or organization. The development and revision process includes two public hearings for considering revisions and testimony. The process concludes with a consensus vote, by IECC members, on all the changes’.

As documented in the IECC online code document, “the IECC has two separate sets of provisions namely, the Commercial Provision (CE) and the Residential Provisions (RE). These two provisions are applied separately to buildings within their respective scope”.

The ‘*IECC Commercial Provision’* applies to “all buildings except residential buildings that are three stories or less in height; while *the IECC Residential Provisions* applies to detached one-and-two-family dwellings and multiple single-family dwellings as well as Group R-2, R-3 and R-4 buildings that are three stories or less in height”. Hence, from the definitions of these two provisions, it is important to understand that the IECC commercial provision contains only provisions for ‘residential buildings which are four stories or greater in height’.

The IECC document has six chapters including appendixes and abbreviations. A summary of the chapters of the IECC document is presented in Table 8. Table 8 presents a summary of the chapters of the IECC online document chapters. From the table, chapter 1 of the code document covers the scope and administrations, chapter 2 covers definitions, chapter 3 is on climate zone and general materials requirement, chapter 4 is on ‘energy efficiency requirements’; chapter 5 is on ‘existing buildings’, while chapter 6 is on ‘referenced standards’ (International code council, 2022).

Table 8

The International Energy Conservation Code document chapters

Chapter	Contents
1	Scope and Administration
2	Definitions
3	‘Climate zones and general materials requirements’
4	Energy efficiency requirements
5	Existing buildings
6	Referenced standards
Appendixes / Abbreviations	
CA	Board of appeals
CB	Solar-ready zone
CC	Net zero energy

The first chapter of the IECC document covers the ‘scope and administration’. This part contains provisions for applying, enforcing and administering of subsequent requirements of the code. This chapter also states the need for establishing a ‘board of appeal’ to overhear appeals regarding determination established by the code. It also covers the ‘scope of the code’ in relation categorization of buildings and structures within the code jurisdiction. This chapter is characterized by the due process of instilling the code laws as used to enforce ‘energy conservation’ with respect to the main body of the ‘IECC’ code document.

The second chapter of the IECC document covers definitions of terms and their appropriate usage in the code documents. The two major categories of terms defined in the code document are CE and RE which simply stand for Commercial (CE) and Residential (RE) provisions respectively. The definitions of terms used in this chapter are applicable throughout the code document. This explains why this chapter of the code document is vital to interpreting the requirements of the code.

The third chapter of the ‘IECC’ code document covers the provision for the general requirement for energy efficiency. It specifies the climate zones that established the criteria for exterior design conditions for both commercial (CE) and residential (RE) buildings. It provides conditions for interior design which are often used as the framework for assumption in heating and cooling load calculations. This chapter further provides the requirement for the basic material required for insulation materials and fenestration materials. As it is a well-known fact that climate has a major impact on the energy use of most buildings, this section of the ‘IECC establishes many requirements such as wall and roof insulation R-values, window and door thermal transmittance (U-factors) and provision that affect the mechanical systems based on the climate where the building is located. This chapter also contains information that will be used to properly assign the building location to its correct climatic zone’.

The fourth chapter of the ‘IECC’ document contains “energy efficiency related requirement for the design and construction of most types of commercial buildings (CE) and residential buildings (RE) greater than three stories in height above grade”. This simply means that requirements for the portions of building designs and building systems that impact energy use in new commercial constructions and new residential constructions greater than three stories in height are defined in this chapter of the IECC document. In addition to energy efficiency requirements for the building envelope, this chapter of the IECC document contains requirements for the HVAC systems, electrical systems and plumbing systems.

Also, this chapter of the IECC document contains energy efficiency-related requirements for designing and constructing residential buildings (RE). It is important to understand that the definition of a residential building that this energy efficiency-related requirement applies to is unique under this IECC document. In the IECC document, 'residential buildings are defined as detached one and two-family dwellings, multiple single-family dwellings as well as R-2, R-3, or R-4 buildings three stories or less in height grade'. This means that all other residential buildings that are 'greater than three stories in height are regulated' under the commercial building (CE) provision of the IECC. The energy conservation requirement for residential buildings (RE) contained in this chapter of the IECC document includes; provisions for energy usage that promote energy efficiency in building envelope, heating and cooling systems and service water-heating systems of new residential buildings

The fifth chapter of the IECC document contains 'the technical energy efficiency requirements for existing buildings both commercial (CE) and residential (RE). This chapter's provisions address the maintenance of buildings in compliance with the IECC code as well as how additions, alterations, repairs and changes of occupancy need to be addressed from the standpoint of energy efficiency. It is important to note that in terms of historic buildings, specific provisions that enhance energy efficiency are provided in this chapter.

The sixth chapter of the IECC document contains 'numerous references to standards that are used to regulate materials and methods of construction. This chapter lists out all standards referenced in both the commercial (CE) and residential (RE) provisions of the IECC document. The standards are part of the code to the extent of the reference to standards. Compliance with the referenced standard is necessary for compliance with this code.

The organization of this chapter is done in a way that makes it easy to locate specific standards. "It lists all of the referenced standards alphabetically by using an acronym of the promulgating agency of the standard. Each agency's standards are listed in either alphabetical or numeric order based on their standard identification. The list also contains the title of the standard, the edition (date) of the standard referenced; any addenda included as part of the ICC adoption and the section or sections of the code that is referenced in the standard. The appendices of the IECC document though are often not part of the code but can become part of the code when specifically included in adopting ordinance".

2. 'The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1 & 90.2'

The 'American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has its origin form way back 1956 after the 'American Society of Heating and Air-Conditioning Engineers (ASHAE)' founded in 1894 and the 'American Society of Refrigerating Engineers (ASRE)' founded in 1904 were merged.

The development of the 'ASHRAE' society gave rise to a global society which led to the advancement of human well-being via the introduction of sustainable standards for the built environment. The 'ASHRAE society and its members' focus is on 'building systems, energy efficiency, indoor air quality, refrigeration and sustainability'. This has helped shape the built environment into a more energy-efficient setting. The ASHRAE standards 90.1 & 90.2 have since become the benchmark for both commercial and 'residential building energy codes' in the United States.

The ASHRAE standards (ASHRAE 90.1 & ASHRAE 90.2) enforced by the 'U.S. Green Building Council (USGBC)' and other institutions in the United States serve as the key legislation/guide for the formulation of codes and standards around the world for almost half a century. They offer in detail the "minimum energy efficiency requirements for design and construction of new sites and buildings and their systems, new portions of buildings and their systems, and new systems and equipment in existing buildings, as well as criteria for determining compliance with these requirements". These standards also serve as 'indispensable reference for engineers and other professionals involved in the design of buildings, sites, and building systems'.

'The development and revision process of the ASHRAE 90.1 & 90.2 follows a similar path of development and revision of the IECC. Though they are revised and published every three years just like the IECC, however, people can submit interim revisions at any time within this period. The process and votes on the final versions of the energy code are managed by the ASHRAE standards committee'.

a) The ASHRAE standard 90.1

The ASHRAE 90.1 is an energy standard for buildings that excludes low-rise residential buildings in the U.S. This simply means that The ASHRAE standard 90.1 provides the minimum requirements for 'energy-efficient design of most sites and buildings, except low-rise residential buildings'. The 2016 version of the ASHRAE standard 90.1 includes revisions to envelope, lighting, and mechanical directives. Also included in this version is a mandate for monitoring large, electric-driven chilled water plants and rating requirements for dedicated outdoor air systems,

The 2022 edition of Standard 90.1 incorporates over 80 addenda to the 2019 edition. Major additions appearing for the first time in a minimum-efficiency U.S. model energy standard or code at the national level include:

- 'A minimum prescriptive requirement for on-site renewable energy'
- 'An optional Mechanical System Performance Path allowing HVAC system efficiency tradeoffs based on the new total system performance ratio (TSPR) metric'
- 'New requirements to address the impacts of thermal bridging'

Other highlights include:

- 'An expanded scope to include sites as well as buildings'
- 'New energy credit requirements for a customized approach to improving energy efficiency'
- 'New informative guidance for using carbon emissions, site energy, or source energy as alternative performance metrics to the current energy cost metric'
- 'Significant efficiency increases in IEER for commercial rooftops and a new SEER2/HSPF2 metric for <65K sized air-cooled heat pumps'.

b) The ASHRAE standard 90.2

The 'ASHRAE standard 90.2' is an energy-efficient Standard for 'new low-rise residential buildings. ASHRAE Standard 90.2 establishes minimum whole-building energy performance requirements (design, construction, and verification) for energy-efficient residential buildings'.

The 2018 revision of Standard 90.2 seeks to 'deliver residential building energy performance that is at least 50% more efficient than the energy efficiency defined by the 2006 IECC'. The Changes from the 2007 edition include:

- 'New definitions, and clarifications to existing definitions'
- 'Clarification of which elements of the standard applies to new construction as well as to additions and alterations'

- ‘Guidance on the use of international climate data from Standard 169 for users outside of the U.S’.
- ‘Clarification to prescriptive envelope performance data tables’
- ‘New performance specifications for ground-source heat pumps’
- ‘Clarification on minimum lighting efficiency provisions for single-family, large single-family, and multifamily homes’
- ‘Clarification on pool heater pilot lights, pump motor efficiency, and roof and gutter de-icing systems’
- ‘Clarification on compliance verification authority in locations outside of the U.S’.
- ‘Revisions to emphasize key building data and reports necessary for compliance determination’
- ‘Clarification for modeling software requirements* Clarification for lighting modeling requirements’
- ‘Clarifications to address multi-zonal building air-leakage testing procedures* A new normative appendix that addresses proper installation techniques for critical components of buildings that provide thermal resistance’

In summary, the IECC is the model code and ASHRAE 90.1 is the standard in which the model code is based. In the U.S., states and municipalities typically modify the model IECC code by amendments.

The main difference between ‘IECC’ and ‘ASHRAE 90.1’ are inputs like ‘Lighting Power Density (LPD), Equipment Power Density (EPD), and sometimes equipment efficiencies’. The primary baseline for the development of the national model building energy codes is the International Energy Conservation Code (IECC), the ANSI/ASHRAE/IESNA Standard 90.1: Energy-Efficient Standard for Buildings Except for Low-Rise Residential Buildings (ASHRAE 90.1), and ASHRAE Standard 90.2: Energy-Efficient Standard of New Low-Rise Residential Buildings.

The two major private organizations charged with the responsibility of developing these codes are the ‘International Code Council (ICC)’ and the ‘American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)’. All these codes have provisions that apply to both residential and commercial buildings. It is important to mention that in the ‘U.S. these codes are adopted into legal building codes by areas around the United States. However, state and local jurisdictions often carry out amendments, addenda and provisions of their own to suit specific needs and preferences'. This explains why there is yet to be a nationally acceptable building code in the U.S.

In terms of adoption, energy codes in the U.S. follow legislation or regulatory action. Each of these avenues requires an advisory body for reviewing, and revising processes, and public hearings. In the *legislation route'* rather than 'creating an entire energy model code wholesale, the state legislation often references an already existing model energy code and standard like the IECC'. In this way, the state legislation is adopting the model code directly. While in the '*regulation route'* in order not to adopt the code directly like the legislation route, it delegates a regulatory agency or authority to adopt, implement, and enforce the energy code. However, as reported by the Pacific Northwest National Laboratory, there is one other path to code adoption in the U.S., but it is a rare path to code adoption. This path is via the local government and it is known as the 'home rule'. In this case, if a state has limited authority to adopt an energy code, units of local government have the option to assume the responsibility of adopting the code. A notable example is in 2001 when Chicago became the first jurisdiction in Illinois to adopt a building energy code – a modified version of IECC 2000.

In summary, both the IECC and the ASHRAE (ASHRAE 90.1&90.2) are useful for energy efficiency in buildings in the U.S., however, it is pertinent to understand that the application of these U.S. building energy codes and standards considers commercial and residential building to be separate to allow for the effective implementation and utilization of the different provisions and parameters that suits a particular building type.

The method of compliance of the U.S. energy codes provisions are: *Prescriptive* and *Performance-based*.

i. Prescriptive path: This path delineates the requirements or criteria a building component must be fulfilled to comply with the code specification/standards. The prescriptive method or path to compliance of the IECC treats the code as a set of rigid rules that must be adhered to as energy efficiency standards. This path is a quicker route but it is less flexible for design. The minimum requirements for compliance and applicability to the prescriptive method of compliance of the U.S. energy codes – IECC and ASHRAE standard is summarized in Table 9. Table 9 presents the minimum requirements for compliance and applicability to the U.S. energy codes.

From the table, the minimum requirements for prescriptive compliance to the US energy codes are summarized under the following categories – fenestration (window-wall-ratio), interior lighting, thermal zone, refrigeration equipment, energy cost, service water, service water temperature, fan efficiency Air leaks insulations, and ventilation

Table 9

The minimum requirements for compliance and applicability to the prescriptive method of compliance to U.S energy codes

Category	Minimum Requirement	Applicability
Fenestration (window-wall-ratio)	IECC: Fenestration for reference design must be at 40% window-wall-ration per C402.4.1 ASHRAE: Fenestration must be 40% window-wall-ratio in all climate zones	All buildings within the scope of the codes
Interior lighting	IECC: W/sf LPD for unknown occupancy classification ASHRAE: 0.6W/sf for dwelling units in reference design	All buildings within the scope of the codes
Thermal zone	IECC: For design thermal zones, block zones shall be created if: Space use classification defined Zone adjacent to glazing all have same orientation (within 45 degrees) and Served by same kind of HVAC system. ASHRAE: Zone blocking is same as IECC except if; Same use classification or peak internal load vary by less than 10Btu/hr-sf; and Zone schedules vary by 40 or less equivalent full load hours per week.	All buildings within the scope of the codes
Refrigeration Equipment	IECC: This is counted as gains- same in IECC ASHRAE: AHRI 1200 equipment model rated energy use, otherwise model actual capacity / efficiency. Reference Table 6.81-11 efficiency and capacity or matches shall be proposed if equipment is not in Table 6.8.1-11	All buildings within the scope of the codes

Table 9 (cont'd)

Category	Minimum Requirement	Applicability
Energy cost	IECC: Proposed model must be 15% less energy cost than reference design ASHRAE: Proposed model must be less energy cost than reference design. <15% improvement	All buildings within the scope of the codes
Service water	IECC: There must be 90% thermal efficiency requirement for gas-fired >1MMBtu/hr (293kw) ASHRAE: Storage capacity must be >140gal There must be: R-12.5 tank insulation No standing pilot Flue damper or fan-assisted exhaust	All buildings within the scope of the codes
Service water temperature	IECC: Has no mandated temperature controls for storage temperature adjustment ASHRAE: Temperature controls which allows for storage of temperature must be reduced or target120F or lower. Mandate 110F outlets control for lavatories.	All buildings within the scope of the codes
Fan efficiency	IECC: Fan must be in compliance for fan efficiency is determined using the fan efficiency grade for compliance per AMCA 205 ASHRAE: Compliance for fan efficiency is determined using the fan energy index.	All buildings within the scope of the codes
Ventilation	IECC: Ventilation requirement must meet chapter 4 of the IECC bas on the ASHRAE 62.1 ASHRAE: Ventilation shall meet minimums for ventilation and maintaining temperature set points.	All buildings within the scope of the codes

ii. Performance Path: This path allows for some more flexibility when compared to the prescriptive path. The basic principle required in the performance path to compliance has to do with providing a thorough analysis of a building when assembling its components. The performance path provides that each selected building component complies with the minimum requirement as outlined in the prescriptive path or method to compliance.

The IECC require that the 'building thermal envelope meet the requirements of Sections R402.1.1 through R402.1.4'. Tables 10 and 11 present the prescriptive R-value table compliance specification (Table R402.1.2) and the U-factor alternative respectively. Table 10 presents the prescriptive R-value compliance specification for a building assembly to the IECC. The table shows the R-value compliance specification in terms of the minimum insulation and fenestration requirement of a building component to climate zone, fenestration, skylight, glazed fenestration, ceiling, wood frame wall, mass wall, floor, basement wall, slab, crawl space wall.

Table 10

Prescriptive R-value table compliance specification (Table R402.1.2)

Climate zone	Fenestration U-Factor [b]	Skylight U-Factor [b]	Glazed Fenestration SHGC [b, e]	Ceiling R-Value	Wood Frame wall R-Value	Mass Wall R-Value [I]	Floor R-Value	Basement [c] Wall R-Value	Slab [d] R-Value & Depth	Crawl Space [c] Wall R-Value
1	NR	0.75	0.25	30	13	¾	13	0	0	0
2	0.40	0.65	0.25	38	13	4/6	13	0	0	0
3	0.35	0.55	0.25	38	20 or 13+5[h]	8/13	19	5/13	10.2ft	5/13
4 except marine	0.35	0.55	0.40	49	20 or 13+5[h]	8/13	19	10/13	10.2ft	10/13
5 and Marine 4	0.32	0.55	NR	49	20 or 13+5[h]	13/17	30[g]	15/19	10.2ft	15/19
6	0.32	0.55	NR	49	20+5 or 13+10[h]	15/20	30[g]	15/19	10.4ft	15/19
7 and 8	0.32	0.55	NR	49	20+5 or 13+10[h]	19/21	38[g]	15/19	10.4ft	15/19

Insulation and Fenestration Requirement of Components

U.S Department of Energy, 2016

For SI: 1 foot = 304.8mm

1. ‘R-values are minimums. U-factors and SHGC are maximums. When insulation is installed in a cavity which is less than the label or design thickness of the insulation, the installed F-value of the installation shall not be less than the F-value specified in the table’.
2. ‘The fenestration U-factor column excludes skylights. The SHGC column applies to all glazed fenestration: Exception: Skylights may be excluded from glazed fenestration SHGC requirements in climate zones 1 through 3 where the SHGC for such skylight does not exceed 0.30’
3. “15/19” means R-15 continuous insulation on the interior on the interior or exterior of the home or R-19 cavity insulation at the interior of the basement wall. “15/19” shall be permitted to be met with R-13 cavity insulation on the “interior of the basement wall plus R-5 continuous insulation on the interior or exterior of the home. “10/13” means R-10 continuous insulation on the interior or exterior of the home or R-13 cavity insulation at the interior of the basement wall’
4. ‘R-5 shall be added to the required slab F-values for a heated slab. Insulation depth shall be the depth of the footing or 2 feet, whichever is less in climate zones 1 through 3 for heated slabs’.
5. ‘There are no SHGC requirements in the marine zone’
6. ‘Basement wall insulation is not required in warm-humid locations’.
7. ‘Insulation sufficient to fill the framing cavity, R-19’
8. ‘The first value is cavity insulation, the second value is continuous insulation, so “13+5” means R-13 cavity insulation plus R-5 continuous insulation’
9. ‘The second F-value applies when more than half the insulation is of the mass wall’.

According to the U.S. Department of Energy – Building Energy Code program (2016), an assembly with a U-factor equal to or less than that specified in Table R402.1.4 shall be permitted as an alternative to the R-value in Table R402.1.2. Table 11 presents the U-factor alternative to the prescriptive path to compliance of a building assembly to the IECC. From the table, the minimum alternative U-factor for climate zone, fenestration, skylight, ceiling, wood frame wall, mass wall, floor, basement and crawl space wall are presented.

Table 11

U-factor Alternative (Table R402.1.4)

Climate zone	Fenestration U-Factor	Skylight U-Factor	Ceiling R-Value	Wood Frame wall U-Factor	Mass wall U- Factor	Floor U- Factor	Basement Wall R- Factor	Crawl Space wall U-Factor
1	0.50	0.75	0.035	0.084	0.197	0.064	0.360	0.477
2	0.40	0.65	0.030	0.084	0.165	0.064	0.360	0.477
3	0.35	0.55	0.030	0.060	0.098	0.047	0.091c	0.136
4 except marine	0.35	0.55	0.026	0.060	0.098	0.047	0.059	0.065
5 and marine	0.32	0.55	0.026	0.060	0.082	0.033	0.050	0.055
6	0.32	0.55	0.026	0.045	0.060	0.033	0.050	0.055
7 and 8	0.32	0.55	0.026	0.045	0.057	0.028	0.050	0.055

U.S Department of Energy, 2016

i.   Verification / Enforcement Method

In terms of verification, plans and other documents/reports that are relevant for approval are required. In addition to this, all applicable values from Table R402.1.2, details and descriptions of how building components will meet the mandatory value in terms of air barrier and insulation, system control requirements, duct sealing and testing if applicable, mechanical system piping insulation, service hot water system compliance, mechanical ventilation, equipment sizing, snow melt controls, pool and spas and lighting equipment need to be properly checked by authorized bodies (U.S. Department of Energy, 2016)

The Enforcement to compliance of the U.S. building energy codes is usually done at the local or municipal level by professionals trained to conduct field inspections and review construction plans. The enforcement to compliance of the U.S. building energy codes is a key challenge, even in jurisdictions with advanced building code processes. The local governments are often the most critical actors in supporting effective compliance to building codes. The compliance process requires cooperation at multiple levels and in multiple ways such as:

1. The issuance of proper permits and establishment of dedicated departments by state and local government
2. Education of building officials on new code developments
3. Charging building design and construction professionals with the responsibility to comply with the energy code.

3.2.1.2 European Union Energy Code. The European Union Energy Codes are the main legislative framework for energy efficiency and performance in buildings across the European Union. These codes generally apply to all member states that make up the European Union. There are 27 member states that make up the European Union namely; Austria, Belgium, Bulgaria, Croatia, the Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden. Hence, as members of the EU, these countries are mandated to adopt the European Union energy codes as the legislation for energy efficiency.

The main energy efficiency codes paramount to EU member states are the Energy Performance of Building Directive and the Energy Efficiency Directive. Although the EU Commission also have some established sets of standards and technical reports to support the EPBD and EED codes. These standards are known as the Energy Performance of Buildings Standards (EPB standards). They include the Energy Performance Certificate (EPC); The Renewable Energy Directive (RED); and the Eco-design and Energy Labeling Regulations. These standards are managed by the European Committee for Standardization (CEN/CENELEC). The main important trait of all these EU energy efficiency directives and standards put together promotes policies geared towards;

1. Achieving a highly energy efficient and decarbonized building stock; with the goal target set at year 2030.
2. Create a stable environment for investment decisions
3. Enabling consumers and businesses to make more informed choices to save energy and money.

i. Energy Performance of Building Directive (EPBD):

The EPBD was first adopted in 2002, recast in 2010, and amended in 2018, 2019 and 2021 respectively. The EPBD is the primary legislation guiding building construction and renovations in EU member states. The drive of this directive is to enhance energy performance and efficiency in buildings within EU member states through cost-effective measures that will regulate all types of energy use for heating, lighting, cooling, air conditioning, and ventilation in buildings. The main objective of the EPBD is to improve energy efficiency in new buildings and existing buildings undergoing renovations by enforcing requirements that embrace low energy consumption. Another objective of the EPBD is to increase reliance on renewable energy sources.

The recent EPBD document accessed online contained 31 Articles and 4 Annexes numbered; Annex I-IV. The key provision in this document covers; energy performance certificates; minimum energy performance standards; strategy for nearly zero-energy buildings target; inspection of heating and cooling systems in homes and also long renovation strategies for member states to adhere to.

In summary, Articles 1-4 of the EPBD accessed covers the purpose of the EPBD, its scope and definitions. Article 4-10 of the EPBD covers the provision for the minimum energy performance standards. The minimum requirements for EU Member States to establish energy performance standards in new buildings, major renovations, and under certain conditions/existing buildings are set out in this section (Article 4-10) of the EPBD document. It is important to understand that these standards are crucial in moving towards a stock of highly energy-efficient buildings. The literature revealed that the goal of the EPBD is to ensure that all new buildings are Nearly Zero-Energy Buildings (NZEBs) (DOE, 2021).

Studies have shown that NZEBs often exhibit a very high energy performance because this type of building unit requires a very low amount of energy for optimum performance (Oyebode, 2018; Abugu, 2022). The energy required for NZEBs is to a significant extent tied to renewable sources (Abugu, 2022). This explains why the EPBD encourages the integration of renewable energy sources into the design, construction, and renovation of buildings, thus, supporting the broader EU goals for renewable energy adoption.

Articles 4-10 of the EPBD also cover provisions for the minimum requirements the EU Member States need to establish in terms of long-term renovation. The long-term renovation strategies recorded in this section of the code document require Member States to formulate and publish long-term renovation strategies aimed at decarbonizing the national stock of residential and non-residential buildings in EU Member States. Effective execution of the requirements for these long-term renovation strategies contributes to achieving cost-effective transformations of existing buildings into NZEBs. Table 12 presents a summary of the measure for setting the minimum energy performance requirements to improve building stocks across EU Member States; as documented in the EPBD document.

Table 12

Measure for setting minimum requirements for energy

S/N	Requirements
1	EU countries must establish strong long-term renovation strategies, aiming at decarbonizing the national building stocks by 2050, with indicative milestones for 2030, 2040 and 2050. The strategies must contribute to achieving the national energy and climate plans (NECPs) energy efficiency targets.
2	EU member states must set cost-optimal minimum energy performance requirements for new buildings, for existing buildings undergoing major renovation, and for the replacement or retrofit of building elements like heating and cooling systems, roofs and walls.
3	All new residential buildings must be nearly zero-energy buildings (NZEB). All new public buildings must be NZEB. When a building is sold or rented, energy performance certificates must be issued and inspection schemes for heating and air conditioning systems must be established.
4	The directive needs to support electro-mobility by introducing minimum requirements for car parks over a certain size and other minimum infrastructure for smaller buildings.
5	There is also an optional European scheme for rating the smart readiness of buildings and smart technologies are promoted. The directive introduced requirements on the installation of building automation and control systems, and on devices that regulate temperature at room level. It addresses the health and well-being of building users, for instance through the consideration of air quality and ventilation.
6	EU member states must also draw up lists of national financial measures to improve the energy efficiency of buildings.
7	In addition to these measures, under the Energy Efficiency Directive, EU countries must make energy-efficient renovations to at least 3% of the total floor area of buildings owned and occupied by central governments. National governments are therefore recommended to only purchase buildings that are highly energy efficient.

Articles 11-13 of the EPBD cover provisions for the requirements need for energy performance certificates (EPCs). In this section of the EPBD documents, it was recorded that EPCs need to be provided for buildings or units when they are constructed, sold, or rented out. This section of the EPBD also recommended that EPCs be included in building adverts because EPCs provide data on the building's energy performance and suggestions for improvement.

Articles 14-18 of the EPBD document cover technical building systems, system inspections and smart readiness indicators. This section of the EPBD article provides provisions needed for regular inspections of heating and air conditioning systems. This section also provides provisions that introduce a "smart readiness indicator" to assess the ability of a building to adapt to electronic systems. This section of the EPBD also calls for the optimization of technical building systems (heating, cooling, ventilation, hot water, and lighting) to support the energy-efficient operation of buildings and to ensure that these systems are installed, sized, and adjusted to the requirements of the building.

Articles 19-33 cover reviews, enforcement for adoption, and penalties. As recorded in this section of the EPBD document, each EU Member State is tasked with transposing the directive into national law. This allows for the adaption of the provisions of the EPBD to their specific context.

In doing this, each member state ensures that the overarching goals and requirements of the EPBD are met by setting national definitions of NZEBs, establishing methodologies for calculating energy performance and creating inspection and certification schemes in line with the EU commission requirements/standards.

In addition to the 31 articles that made up the EPBD document reviewed, the document also contains 5 annexes, numbered; Annex I – V. These annexes are grouped into;

1. Annex I: Common general framework for the calculation of energy performance of buildings;
2. Annex II: Independent control systems for energy performance certificates and inspection reports
3. Annex III: Comparative methodology framework to identify cost-optimal levels of energy performance requirements for buildings and building elements
4. Annex IV: Part A; Repealed Directive with its successive amendment; Part B: Time limits for transposition into national law and application
5. Annex V: Correlation table

Table 13 presents a summary of the EPBD document and its content. The EPBD document accessed online contains 31 Articles and 4 Annexes (Annex i-iv).

Table 13

Summary of EPBD document content

Articles	*Content*
1	Subject Matter
2	Definitions
3	Adoption of a methodology for calculating the energy performance of buildings
4	Setting of minimum energy performance requirements
5	Calculation of cost-optimal levels of minimum energy performance requirements
6	New buildings
7	Existing buildings
8	Technical building systems
9	Nearly zero-energy buildings
10	Financial incentives and market barriers
11	Energy performance certificates
12	Issue of energy performance certificates
13	Display of energy performance certificates
14	Inspection of heating systems
15	Inspection of air-conditioning systems
16	Reports on the inspection of heating and air-conditioning systems
17	Independent experts
18	Independent control system
19	Review
20	Information
21	Consultation
22	Adaptation of Annex I to technical progress
23	Exercise of delegation
24	Revocation of the delegation
25	Objections to delegated acts
26	Committee procedure
27	Penalties
28	Transposition
29	Repeal
30	Entry into force
31.	Addressees
Annexes	
I	Common general framework for the calculation of energy performance of buildings (referred to in Article 3)
II	Independent control systems for energy performance certificates and inspection reports
III	Comparative methodology framework to identify cost-optimal levels of energy performance requirements for buildings and building elements.

Table 13 (cont'd)

Annexes	
IV	Part A: Repealed Directive with its successive amendment (referred to in Article 29) Part B: Time limits for transposition into national law and application (referred to in Article 29)
V	Correlation table

Verification Method

In terms of verification, competent authorities or bodies to which the competent authorities have delegated the responsibility for implementing the independent control system must make a random selection of at least a statistically significant percentage of all the energy performance certificates issued annually and subject those certificates to verification. The verification is based on:

1. The validity check of the input data of the building used to issue the energy performance certificate and the results stated in the certificate;
2. check the input data and verification of the results of the energy performance certificate, including the recommendations made;
3. full check of the input data of the building used to issue the energy performance certificate, full verification of the results stated in the certificate, including the recommendations made, and on-site visit of the building, if possible, to check the correspondence between specifications given in the energy performance certificate and the building certified must be assessed.

ii. Energy Efficiency Directive (EED):

The EED is another important directive that regulates energy usage across European Union member states. The EU Energy Efficiency Directive was first adopted in 2012. The directive updated in 2018, 2021, 2022 and 2023 aims to set rules and obligations for achieving the EU's ambitious energy efficiency targets. The most recent updated version of EED is the EU/2023/1791 published in the EU Official Journal on 20 September 2023. Figure 8 presents the timeline of the development of the EU Energy Efficiency Directive.

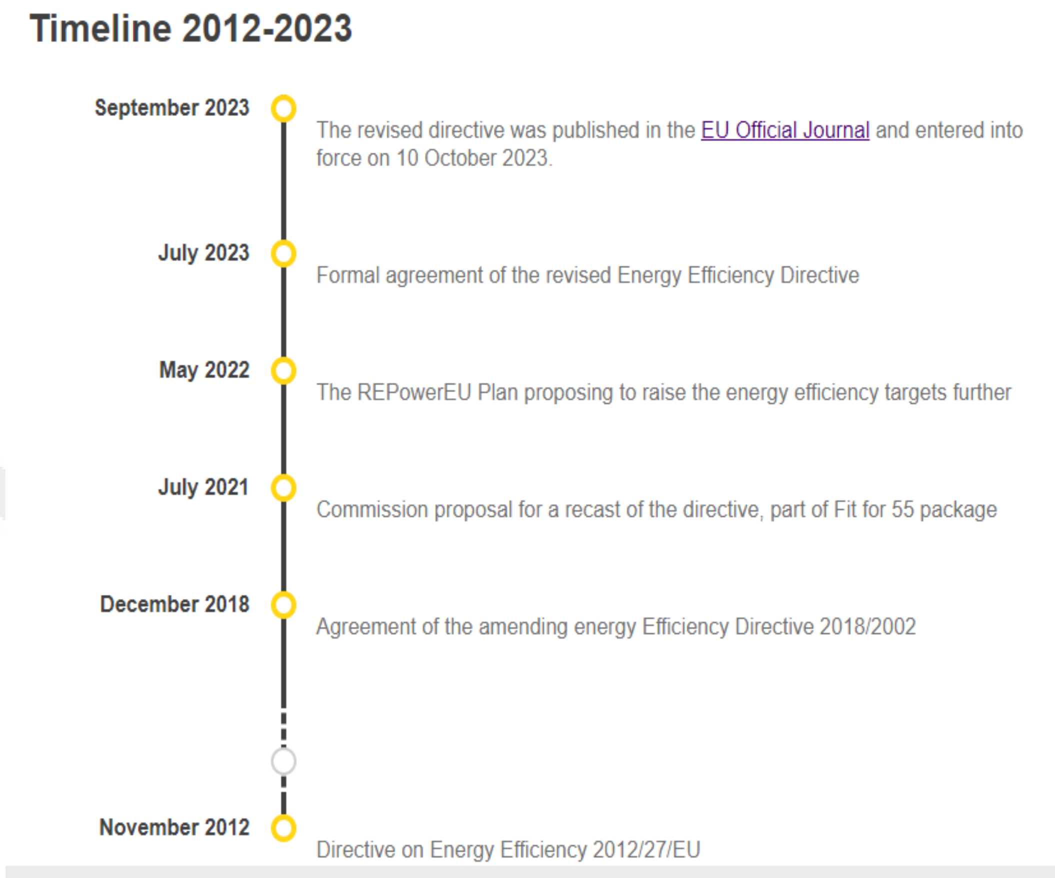


Figure 8. EU Energy Efficiency Directive Timeline (EU Journal, 2023)

The Energy Efficiency Directive (EED) – EU/2023/1791 and its subsequent amendments, is a key component of the European Union's policy framework to promote energy efficiency. Its main objective is to achieve a 20% energy efficiency improvement in 2020 and at least a 32.5% improvement by 2030. The EU Energy Efficiency Directive is part of the EU's broader commitment to reducing greenhouse gas emissions, improving energy security, and stimulating economic growth.

The review of the updated 2023 EED (EU/2023/1791) document accessed online is presented as follows. The EED (EU/2023/1791) document accessed online contains 7 chapters. These chapters are comprised of 40 articles numbered Articles 1 – 40. In addition to the chapters/articles, the EED document contains 14 Annexes numbered Annex I-XIV. The core provision in this EED (EU/2023/1791) document is summarized as follows:

Chapter 1 of the EED (EU/2023/1791) covers Articles 1 – 4. This chapter of the EED establishes the scope, definitions, and energy efficiency principles/targets. The provisions of this article cover the energy-saving obligation/target of the EU. It spells out the binding measures geared towards enabling EU Member States to use energy more efficiently at all stages of the energy chain from production to final consumption. A key central requirement of the EED is that energy companies are obliged to achieve yearly energy savings of 1.5% among their customers.

Chapter 2 of the EED (EU/2023/1791) is on the exemplary role of the public sector. This chapter comprises Articles 5 – 7. In the articles of this chapter, public bodies are called to lead by example. Each member state central government annually, is obliged to renovate at least 3% of the total floor area of heated and/or cooled buildings owned and occupied by the government to meet the minimum energy performance requirements, and the purchase of energy-efficient buildings, products, and services.

Chapter 3 of the EED (EU/2023/1791) is on metering and billing information. This chapter comprises Articles 8 – 20. These provisions for energy audits and management systems are contained in the articles of this chapter. The provision obliges large companies to conduct energy audits every 4 years and these energy audits need to be conducted by only qualified and accredited experts.

Chapter 4 of the EED (EU/2023/1791) is on consumer information and empowerment. This chapter comprises Articles 21 – 24. The provisions of the article in this chapter charge Member States to ensure energy consumers have easy and free access to their real-time energy consumption data, promoting informed choices and stimulating energy savings. These customers' rights to accurate and timely billing based on actual consumption are also stipulated in the articles of this chapter.

Chapter 5 of the EED (EU/2023/1791) is on energy efficiency in supply. This chapter comprises Articles 25 – 27. The provisions in this chapter spell out the need for each Member State to have a National Energy Efficiency Action Plan (NEEAP). The NEEAP obliges Member States to formulate national efficiency action plans every 3 years. These plans are required to outline the national energy efficiency targets of Member States and also provide measures to improve energy efficiency. The provisions in the article of this chapter also spell out the need for promoting efficiency in heating and cooling. As recorded in the document, the directive emphasizes the need to develop national roadmaps geared towards promoting efficient heating and cooling. It also encourages the need to use waste heat and cold renewable clean energy.

Chapter 6 of the EED (EU/2023/1791) covers horizontal provisions. This chapter comprises Articles 28 – 31. It covers the availability of qualification, accreditation and certification schemes, energy services, national energy efficiency fund, financing and technical support and also conversion factors and primary energy factors. The provisions in the articles of this chapter oblige Member States to provide accessible financing and technical support for energy efficiency improvements. It also charges Member States to recognize the significant investment needed to achieve these targets. This chapter of the EED is aimed at removing market barriers and creating a favourable context for the development of the energy service markets, particularly for energy performance contracting.

Chapter 7 of the EED (EU/2023/1791) covers the final provisions. This chapter of the EDD document reviewed comprises Articles 32 – 40. The key provisions in the articles of this chapter include provisions for penalties, enforcement, review and monitoring. The European Commission is tasked with monitoring the implementation of the directive and its impact on the EU's energy efficiency targets, with periodic reviews to assess progress and adapt strategies for more improvement when necessary. The EU Commission obliges each Member State's autonomy to provide stringent measures for the enforcement of the EED with respect to their respective countries' laws. The enforcement and penalties for non-compliance vary amongst Member States but the EU Commission possesses the powers for regulations of enforcement measures and penalties by each member state.

In addition to these chapters/articles the EED like the EPBD contains 24 Annexes numbered Annex I- XVII. Table 8 presents a summary of the chapters, articles and annexes of the EED document.

Table 14

Summary of the chapters, articles and annexes of the EED document

Chapters	Articles
CHAPTER I: Subject Matter, Scope, Definitions and Energy Efficiency Targets	Article 1: Subject matter and scope Article 2: Definitions Article 3: Energy Efficiency principles Article 4: Energy efficiency targets
CHAPTER II: Exemplary Role Of Public Sector	Article 5: Public sector leading on energy efficiency Article 6: Exemplary role of public bodies' buildings Article 7: Public procurement
CHAPTER III: Metering and billing Information	Article 8: Energy savings obligation Article 9: Energy efficiency obligation schemes Article 10: Alternative policy measures Article 11: Energy management systems and energy audits Article 12: Data centers Article 13: Metering for natural gas Article 14: Metering for heating, cooling and domestic hot water Article 15: Sub-metering and cost allocation for heating, cooling and domestic hot water Article 16: Remote reading requirement Article 17: Billing information for natural gas Article 18: Billing and consumption information for heating, cooling and domestic hot water Article 19: Cost of access to metering and billing information for natural gas Article 20: Cost of access to metering and billing and consumption information for heating, cooling and domestic hot water
CHAPTER IV: Consumer Information and Empowerment	Article 21: Basic contractual rights for heating, cooling and domestic hot water Article 22: Information and knowledge raising Article 23: Partnerships for energy efficiency Article 24: Empowering and protecting vulnerable customers and alleviating energy poverty
CHAPTER V Efficiency in Energy Supply	Article 25: Heating and cooling assessment and planning Article 26: Heating and cooling supply Article 27: Energy transformation, transmission and distribution

Table 14 (cont'd)

Chapters	Articles
CHAPTER VI Horizontal Provisions	Article 28: Availability of qualification, accreditation and certification schemes Article 29: Energy services Article 30: National energy efficiency fund, financing and technical support
CHAPTER VII Final Provisions	Article 31: Conversion factors and primary energy factors *Article 32:* Penalties Article 33: Delegated acts Article 34: Exercise of the delegation Article 35: Review and monitoring of implementation Article 36: Transposition Article 37: Amendment to Regulation (EU) 2023/955 Article 38: Repeal Article 39: Entry into force and application Article 40: Addresses
ANNEXES	
ANNEX I	National Contributions to The Union's Energy Efficiency Targets In 2030 In Final Energy Consumption And / Or Primary Energy Consumption
ANNEX II	General Principles for The Calculation Of Electricity From Cogeneration Part I: General Principles Part II: Cogeneration technologies covered by this Directive
ANNEX III	methodology for determining the efficiency of the cogeneration process High-efficiency cogeneration Calculation of primary energy savings Calculations of energy savings using alternative calculation Efficiency reference values for separate production of heat and electricity

Table 14 (cont'd)

ANNEXES	
ANNEX X	Potential For Efficiency in Heating and Cooling Part I: Overview of heating and cooling Part II: Objectives, strategies and policy measures part III: Analysis of the economic potential for efficiency in heating and cooling Part IV: Potential new strategies and policy measures
ANNEX XI	Cost-benefit analyses
ANNEX XII	Guarantee of origin for electricity produced from high-efficiency cogeneration
ANNEX XIII	Energy efficiency criteria for energy network regulation and for electricity network tariffs
ANNEX XIV	Energy efficiency requirements for transmission system operators and distribution system operators
ANNEX XV	Minimum items to be included in energy performance contracts or in the associated tender specifications
ANNEX XVI	Part A: Repealed Directive with list of the successive amendments thereto (referred to in Article 39) Part B: Time-limits for transposition into national law (referred to in Article 39)
ANNEX XVII	Correlation Table

In general summary, the EU codes comprising of the EPBD and EED are dynamic documents subject to revisions and updates. These updates are necessary to adapt the code to the evolving energy landscape and ambitions of the EU. These codes also play a crucial role in steering the EU towards a more sustainable and energy-efficient future because of their dynamism. The EU codes, being dynamic legislative instruments, continuously evolve to address the new challenges and technological advancements in the building sector and other sectors that require energy efficiency in European states. This explains why the EU codes present critical steps with common objectives of reducing environmental impacts on the built environment, promoting sustainability, and ensuring that energy efficiency remains at the heart of the European building sector and other sectors.

3.2.2Comparison parameters. Comparison parameters are a set of factors used for scoring similarities or differences between subjects (Jochen, 2004). The comparison parameters that will be used to compare the Nigeria Building Energy Efficiency Code with the U.S energy efficiency code and the European Union energy efficiency code are the strictness of the code and the technical requirements of the code.

1. *Strictness of the code:*

The strictness of a country's building energy efficiency code is an important measure for reporting the status of the code. Countries where energy efficiency codes are stricter present more stringent requirements for energy efficiency/performance while those with lesser stringency are likely to have more relaxed standards. Countries can implement codes with various levels of stringency which could be voluntary codes, mandatory codes and mixed codes (both voluntary and mandatory) depending on the region or state (Young, 2014). The strictness of an energy efficiency code is assessed via the following parameters; enforcement and compliance mechanism, qualification experts, review and adoption of the code. However, the selected codes of this study will be limited to stringency for enforcement and compliance mechanisms.

2. *Technical Requirements:*

The technical requirement is another parameter vital for comparing energy efficiency codes. It covers the scope of buildings' energy efficiency codes. Energy efficiency codes have different technical requirements which include minimum energy efficiency requirements and verification methods, calculation methodology and tools, energy efficiency labels and energy efficiency incentives. For this study, the technical requirements of the selected energy efficiency codes compared are limited to the minimum energy efficiency requirements of each of the codes.

3.2.3 Comparison results. The comparison results from the three energy code documents analyzed are presented under the defined comparison parameters as follows:

1. Strictness of the Code:

The enforcement and compliance mechanism set by a country's energy code is one of the most important parameters to analyze the strictness of a country's energy efficiency code. The enforcement and compliance mechanism parameter applied by a country goes a long way to improve effective energy efficiency/savings if properly implemented and adhered to. Table 15 shows the result of the enforcement stringency and coverage of the selected energy codes of this study.

Table 15 presents the enforcement stringency of the Nigeria Building Energy Efficiency Code document, compared to the U.S. energy efficiency codes (IECC, ASHRAE) and the EU energy directives/codes (EPBD, EED) document. From the table, the enforcement stringency of the Nigeria Building Energy Efficiency Code document is voluntary. The enforcement stringency of the U.S. energy efficiency codes is mixed while that of the EU energy directives is mandatory. The 'mixed' stringency terminology used here, simply means that the enforcement stringency could either be voluntary or mandatory as the case may be.

Table 15

Enforcement Stringency of the codes

Code	Stringency for Enforcement		Coverage
	Residential	Commercial	
Nigeria Building Energy Efficiency Code	Voluntary	Voluntary	Buildings
U.S Energy Efficiency Codes (IECC, ASHRAE 90.1 & 90.2)	Mixed (voluntary/Mandatory)	Mixed (voluntary/Mandatory)	Buildings
EU Energy Directives (EPBD, EED)	Mandatory	Mandatory	Buildings and other sectors

Comparison results from Table 15 show that the stringency of the Nigeria BEEC is voluntary; this makes the stringency for enforcement of the code weak compared to the U.S. energy efficiency codes and the EU energy directives. The EU has a strong stringency because energy efficiency regulations are mandatory for both residential and commercial buildings in all the member states of the European Union, while the U.S. energy code has mixed stringency because it comprises both voluntary and mandatory stringent measures for enforcement. The mixed stringency to enforcement of the U.S. energy efficiency codes is attributed to the fact that the U.S. does not have a national building energy code therefore the stringency for enforcement of the U.S. energy codes varies between states. The adoption and modifications are done at the state or local level. Although the Nigeria Building Energy Efficiency Code is a national building energy efficiency code, its stringency is voluntary. This makes compliance with the code to be weak.

However, there are provisions in the Nigeria BEEC code that stipulate that minimum requirements for energy efficiency are only voluntary for 3 years duration before authorities begin to make them mandatory. The compliance to this stipulation has not gone so well in Nigeria because of the shortage of manpower to follow up on building design and construction to ensure the mandatory stringency of the code. This explains why despite the fact that Nigeria has made efforts to align its energy codes with international standards; the stringency of the energy efficiency codes in the country is still poor. Hence relevant stakeholders in Nigeria need to work towards establishing more stringent measures for enforcement of the Nigeria Building Energy Efficiency Code.

The coverage of the Nigeria Building Energy Efficiency Code and the U.S. energy code is adopted for only residential buildings and commercial buildings while that of the European Union energy directives covers the buildings and other sectors such as transportation, industrial productions, etc.

The compliance mechanism of the 3 codes is compared. For this comparison, the compliance path is compared. The key to checking the compliance mechanism is as follows.

A: If the country where the code is applied has specific policy packages and incentives that complement or motivate compliance with building codes.

B: If the building does not comply with the code, developers will be refused permission for occupancy or construction pending review.

C: Penalties for non-compliance with the building codes include fines and demolition.

Table 16

Compliance Mechanism

Energy Code	Compliance path		Compliance
	Prescriptive based	Performance based	
Nigeria BEEC	X	X	A, B, C
US Energy Code	X	X	A, B, C
EU Energy Directives	X	X	A, B, C

From Table 16, all three codes have a defined path for compliance which includes both prescriptive and performance based routes. The result shows the stringency of the compliance mechanisms defined in this study. As a measure to improve compliance, incentives and disincentives are implemented as compliance mechanisms to help push stakeholders – architects, contractors and users to comply with the energy codes. The Nigerian code was rated 'A, B, C' because in Nigeria during the voluntary phase, incentives are given to building owners for compliance and in terms of control, competent authority checks the compliance of the building design with BEEC minimum energy efficiency requirements by means of the submitted verification documents prior to issuing the Building Permit for the compliance method 1 (prescriptive route). If there is non-compliance noticed at the building permit stage, improvements are required. This condition is vital before issuing any Building Permit approval.

In compliance method 2 (performance route), the competent authority checks the compliance of the completed building performance by inspecting the submitted verification documents prior to issuing the Certificate of Use and Habitation. Energy efficiency inspectors physically check that measures, products, and systems that have been installed are in accordance with the submitted verification documents in terms of energy usage. If buildings do not meet the building codes, demolition notices are served for non-compliance.

The stringency of the compliance mechanism of the US energy codes is rated 'A, B, C'. The U.S. adopts a local compliance third-party inspection, post-occupancy control, which commissions requirements that vary in different states across the country. There is a refusal of permission to occupy and a refusal of permission to construct for noncompliance. Also, incentives are provided to encourage compliance with the U.S. energy codes. These incentives include; sales and use of tax exemption for renewable energy equipment, solar renewable energy certificates, Local options—Clean Energy Loan Program, Be SMART Home Efficiency Loan Program, Be SMART Multifamily Efficiency Loan Program, and Home Energy Loan Program, etc.

The enforcement mechanism for the EU energy code is also rated 'A, B, C'. This is because the EU Commission has mandated that all EU Member States must adopt and adhere to the energy efficiency measures and compliance mechanisms in line with the provision of the EU directives (EPBD, EED). Hence most Member States of the EU ensure local enforcement, third-party inspection from the EU Commission, accreditation of applicants by competent authorities, issuance of certificates and incentives for compliance. Above all punishment is meted for non-compliance to the directives. These punishments/penalties for non-compliance range from fines/fees for noncompliance by the central EU authorities to demolition.

In conclusion, the Nigeria energy code is sufficient in terms of stringency of compliance when compared to the US and EU codes. But, the implementation of the code practices in the country is weak.

2. Technical Requirements:

The key for comparison of the technical requirements of the energy code is the availability and non-availability of the identified minimum requirements for energy efficiency of the respective codes selected. The symbol [X] indicates the 'Availability' while the symbol [–] indicates the 'Non-Availability' of a variable. Table 17 presents the results of the technical requirements of the codes in relation to the minimum requirements for energy efficiency.

Table 17 presents the comparison of the technical requirements of the codes. The parameters for comparing the technical requirements of the codes selected for this study are the minimum requirements for residential building energy efficiency.

The parameters that are used to compare the minimum requirements for the building energy codes include; HVAC systems, insulation requirement, window U-Factor and shading/Solar Heat Gain Coefficient, air sealing, lighting system requirement, technical installation, renewable energy, and design orientation.

Table 17: *Comparison of technical requirements of the codes*

Energy Codes	Minimum Requirements							
	HVAC Systems Requirement	Insulation Requirement	Window U-Factor and Shading/ Solar Heat Gain Coefficient	Air Sealing	Lighting System Requirement	Technical Installations	Renewable Energy	Design, Orientation
Nigeria BEEC	X	X	X	X	X	X	X	X
US Energy efficiency code	X	X	X	X	X	X	X	X
EU Energy efficiency code	X	X	X	X	X	X	X	X

- HVAC systems: This provides requirements for heating and cooling equipment so as to improve their operation efficiency.
- Insulation requirement: This provides minimum insulation level requirements for floor, ceiling, foundation, wall, and roof etc., so as to reduce heat transfer between interior and exterior spaces.
- Window U factor and shading / Solar Heat Gain Coefficient: These are requirements energy models used to predict the energy usage compliance of a building in terms of design specification.
- Air Sealing: These are requirements that enhance building performance. They limit air leakage to ensure that buildings are tightly sealed so as to minimize heat loss or gain via unintended gaps.

- Lighting System Requirement: This provides standards for energy-efficient lighting systems such as LED technology, daylight, etc.
- Renewable Energy Requirement: These requirements incorporate the provisions of renewable energy sources such as solar panels or geothermal systems in order to offset some building energy demand.
- Design orientation: This sets the minimum requirements for optimizing building orientation and layout to enhance energy efficiency and reduce overall energy consumption

The comparison results from Table 17 show that all reviewed code documents have standards and guidelines contained in them. These guidelines are the minimum requirements set to attain energy efficiency in each of the code documents. However, the EU energy efficiency code and the US energy efficiency code have more vast requirements for energy efficiency compared to the Nigeria energy efficiency code because theirs contains all the minimum requirements identified for energy efficiency. The US and EU energy codes have provisions for HVAC systems requirement, insulation requirement, window U-factor and shading/ solar heat gain coefficient, air sealing, lighting system requirement, technical installation, renewable energy and design orientation. The Nigerian code also contains these provisions but their implementation level is low in Nigeria.

In summary, this chapter of the thesis tackles ‘energy efficiency in Nigeria’. It analyzes the sufficiency of the Nigeria Building Energy Efficiency Code by comparing the code with the global codes. The US energy efficiency code (IECC & ASHRAE 90.1/ 90.2) and the EU energy directives (EPBD & EED) are the global codes selected for the comparison. The comparison entails reviewing the content of all the selected codes. The parameter for comparison of the code includes; ‘strictness of the code’ and ‘technical requirement of the code’. The strictness of the code was defined with the following parameters; enforcement and compliance mechanism adopted while the technical requirement was defined with the minimum requirement for energy efficiency in building. These requirements include ‘heating’ and ‘cooling requirement’, ‘installation in ceilings’, ‘window U-Factor (WWR)’ and ‘shading/solar heat gain coefficient’, ‘air sealing’, ‘lighting efficiency’, ‘technical installations’, ‘renewable energy’ and ‘design orientation’. The comparison showed some weaknesses in the Nigeria Energy Efficiency Code in terms of stringiness and enforcement mechanisms. However, the Nigeria Building Energy Efficiency Code is sufficient in terms of the minimum technical requirements for energy efficiency.

Chapter 4

Energy Efficiency for Residential Buildings in Abuja, Nigeria

This chapter of the thesis is on energy efficiency for residential buildings in Abuja, Nigeria. It covers an overview of the city in terms of climatic and economic conditions. It also focuses on the recent residential buildings in Abuja, Nigeria in terms of their general features, energy usage and saving potential. The chapter further assesses stakeholders' energy efficiency knowledge.

4.1 Abuja as a Context

Abuja is the capital city of Nigeria. The city is among the world's rapidly growing urban cities with a significant surge in population and an increase in the number of ongoing building developments. The city's estimated population is over 6,000,000 people (FCT, 2021). The city lies on latitude $9^{0}4$'N and longitude $7^{0}29$'E with an elevation of 360m (FRN, 2020). Figure 9 shows the map of Abuja, its coordinates and common borders.

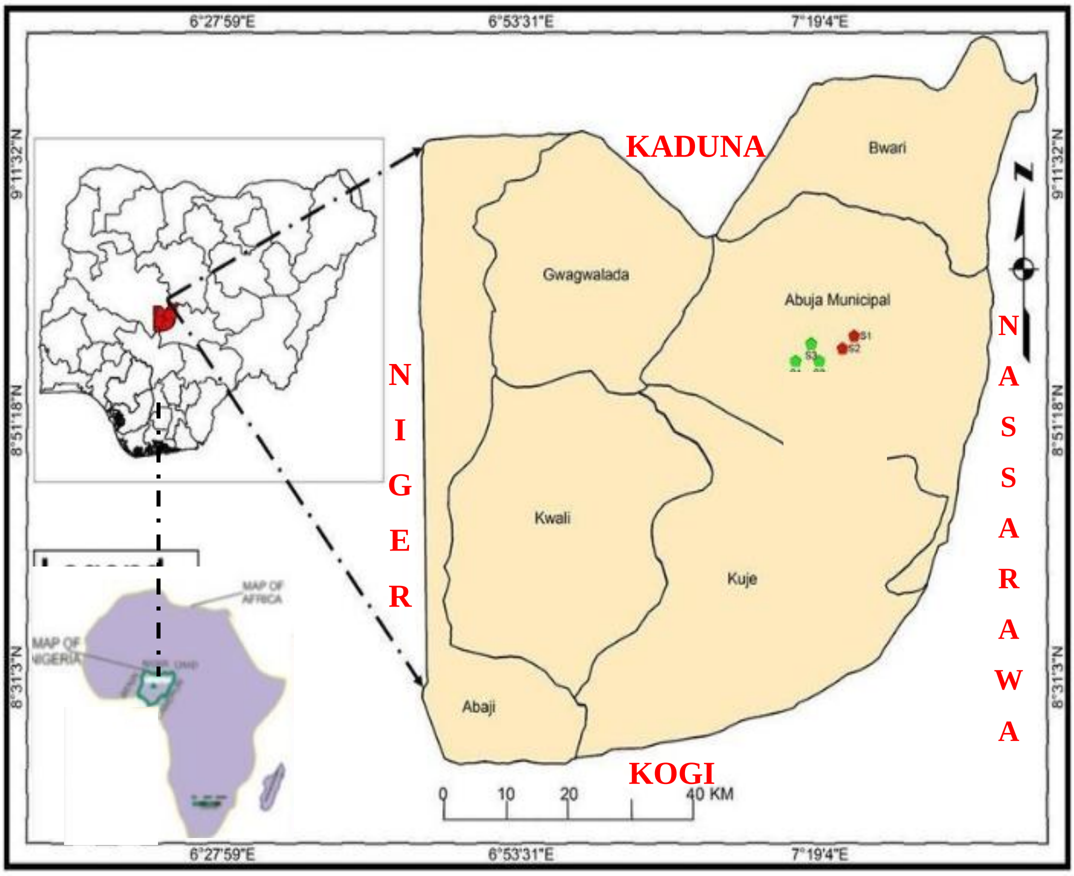


Figure 9. Map of Abuja (adapted from Google maps, 2023)

The city is the first planned city in Nigeria with its master plan designed by Architect Kenzo Tange (Ekoko, 2006) which initially was characterized by mid-rise buildings and a few tall buildings. However, recent developments have seen a remarkable upsurge in the development of tall buildings to reflect the embrace of modern architectural forms in the city (FRN, 2020; McKenna, 2023). Figure 10 shows an aerial photo of the Abuja cityscape.

Figure 10. Aerial capture of Abuja cityscape (FCT, 2020)

According to McKenna (2023), “Abuja falls within the Guinean forest-savanna mosaic zone of the West African sub-region with Patches of rain forest around the Gwagwa plains, especially in the rugged terrain to the southeastern parts of the territory, where a landscape of gullies and rough terrain is found”. Figure 11 shows a map of Nigeria indicating the vegetation pattern of Abuja city.

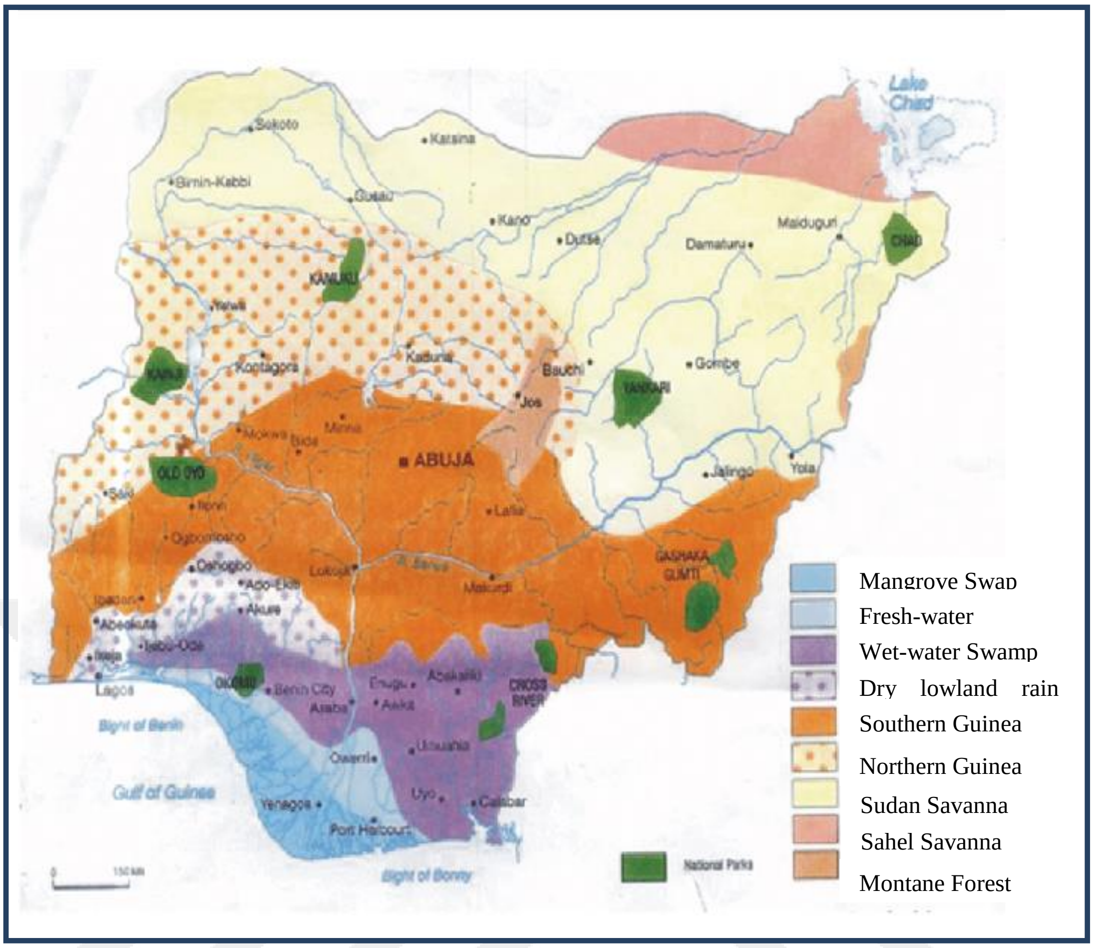
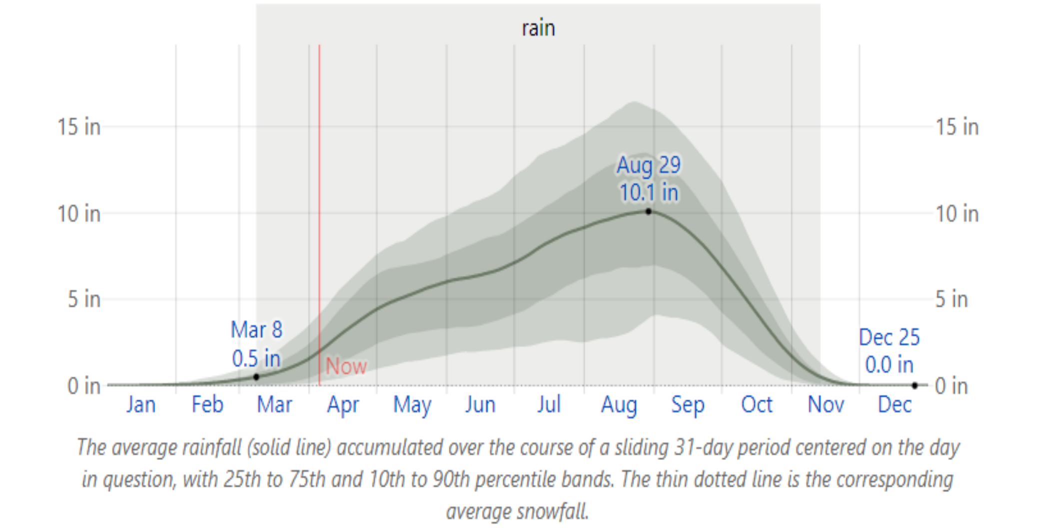


Figure 11. Map of Nigeria showing vegetation zones (Ogundipe, 2009)

Nigeria is not a region linked with high seismic activity (Nigeria Space Agency, 2018). This makes the chances of earthquake occurrence low in Nigeria when compared to other regions along major tectonic plate boundaries. In the past, there have been minor records of earthquake risk in Abuja; however, the Nigerian Government via agencies like the Nigeria Geological Survey Agency has reported that Abuja is situated on the African plate which is relatively stable though some parts within the Benue trough are likely to be susceptible to earthquake. In response to this, the Nigeria building code and standards incorporate seismic resistant design principles in more urbanized and high risk areas in Abuja. Though older buildings constructed before modern seismic code requirements stipulated in the Nigeria building code are vulnerable to earthquake damage (Tsalha, *et al*., 2015).

4.1.1 Climatic conditions. The climate of Abuja is classified under Köppen climate classification as a tropical wet and dry climate. This means that the city is characterised by the dry and wet seasons. However, between the wet and dry seasons lies a brief period of harmattan often characterized by cold haze dusty winds and cloudless skies. Studies have shown that this harmattan period is caused by the northeast trade winds (Climate Records, FCT, 2023).

The climatic records of the city show that the wet season which is also referred to as the rainy season begins from April to October every year. During this period, daytime temperatures reach 28 °C to 30 °C and nighttime gets lows and hover around 22 °C to 23 °C. Peak rainfall is experienced in Abuja around August with an average rainfall of 9.8 inches (FCT-Weather Spark, 2023). Figure 12 shows the average monthly rainfall in Abuja.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	0.0"	0.1"	0.7"	3.0"	5.3"	6.4"	8.3"	9.8"	9.0"	4.2"	0.4"	0.0"

Figure 12. Average monthly rainfall in Abuja (FCT- Weather Spark, 2023)

According to Orisakwe *et al*., (2017) the rainfall in the FCT reflects its territory's location on the windward side of the Jos Plateau and the zone of rising air masses with the city receiving frequent rainfall during the rainy season from April to October every year.

On the other hand, the dry season commonly characterized by hot weather sees daytime temperatures rise to as high as 40 °C, though night temperatures may dip to 15 °C. Even on the coolest nights during this period, the daytime temperatures can go well above 30 °C (Weather Spark, 2023). The dry season usually lasts from January to April and March is the hottest month during this period with an average high of 36 ^{0}C and a low of 21 °C.

The harmattan period, which is normally cold, comes in between the rainy and dry season around October to January. December is the coldest month during this season averaging a low temperature of 16°C and a high temperature of 30°C (FCT-Weather Spark, 2023). Figure 13 shows the average hourly temperature in Abuja.

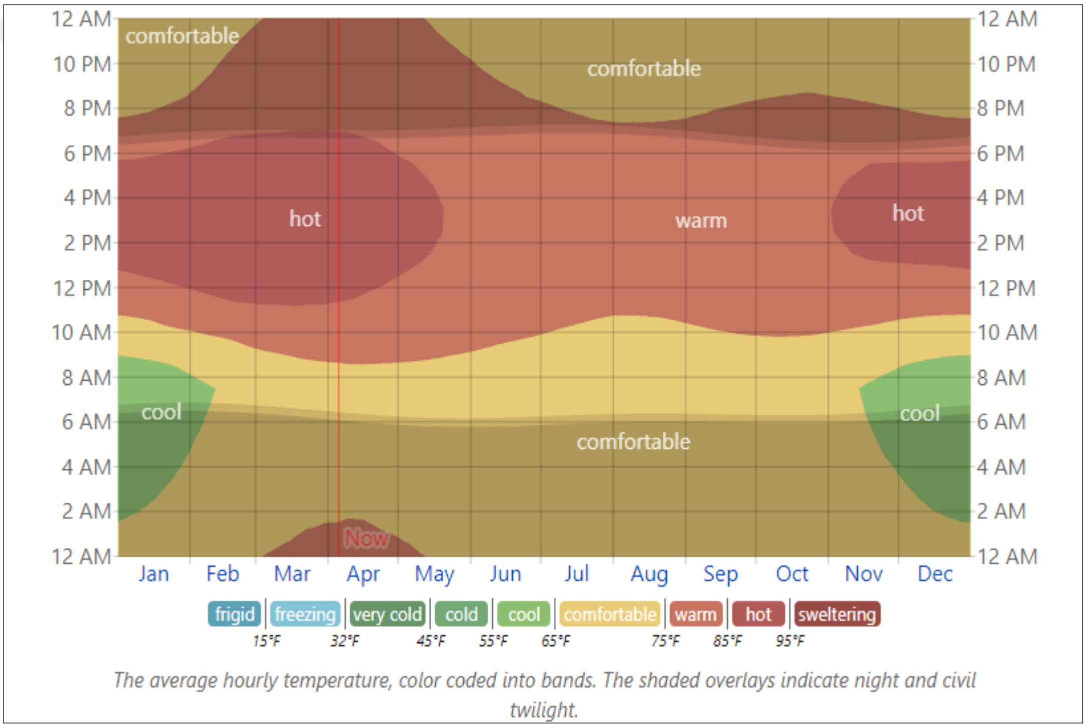


Figure 13. Average hourly temperature in Abuja (FCT-Weather Spark, 2023)

Studies on climate change in Abuja by the Nigerian Meteorological Agency and Atmospheric Science Group of Imo State University between 1993 and 2023 have shown that there has been a downward trend in rainfall experienced in Abuja since 2016 and at some point, the probability of drought occurring in Abuja was at 15.4%; in a similar fashion, the average maximum temperature trended downwards but the average minimum mean temperature trended upwards Ajileye, *et al.,* 2015; Hassan *et al.,* 2020). This has resulted in the extremely hot temperatures experienced in the city in recent times and as such the need for mechanical sources to maintain comfort is on the rise. Thus stakeholders are tasked with the role of harnessing the extreme temperature to provide energy efficiency and comfort in building without much reliance on mechanical energy sources that run on fossil fuels.

4.1.2 Economic conditions. The economic conditions in Abuja before it became the capital of Nigeria on 12th December 1991 was predominantly Agriculture with the indigenous habitat - the Gbagyi (Gwari), engaging predominantly in yam, millet, corn (maize), sorghum, and beans farming, (McKenna, 2023). However, upon making Abuja the capital of Nigeria, the significant influx of people has seen the capital city divert from agriculture to real estate development as the major economy. According to the Abuja Real Estate Development and Project Watch (2019), real estate is now the major driver of the Abuja economy. This is evident in the substantial development and investments growing in the social hub city. According to The Abuja Real Estate Development and Project Watch (2019), Abuja has experienced a significant amount of investment in real estate since it became urbanized over the years and as such foreign and local investors have massively invested in this sector. This has left a somewhat progressive influence on the economy of the city and has increased the employment projection in this sector.

4.2 Recent Residential Buildings in Abuja, Nigeria

Abuja is amongst the fastest developing cities globally. The city has experienced a tremendous increase in the upsurge of residential buildings. This is due to the continuous influx of people from diverse parts of the country into the capital city. In recent times, residential building developers are starting to opt for more story buildings and duplex designs that are smart in estates to improve the energy efficiency of buildings in the city and also to improve the quality of life of the growing population of the city. Figure 14 shows a sample of a recent residential estate development in Abuja comprising of story buildings and terraces as the major building typologies.

Figure 14. A smart residential estate development in Wuye, Abuja (Abuja, 2023)

However, studies have shown that bungalow design still occupies the major residential building typologies in Abuja (Umoh, 2022). Hence, this thesis will analyze some randomly selected recent residential building developments in Abuja, Nigeria to serve as case studies. The general features, energy usage and potential energy savings of these buildings will be assessed.

4.2.1 General features. The general features of buildings determine their energy consumption and saving potential. The general features that make up a building include walls, fenestration (doors and windows), roof, floor finish, etc. It is important to understand that the materials and design of these building features have a significant impact on energy efficiency. Therefore, the general features of buildings in Abuja are analyzed using these general features: walls, fenestration (doors and windows), roof, floor, etc.

1. Wall:

Walls are important building features that can have a significant effect on energy consumption and thermal comfort in buildings (Ochedi *et al.*, 2022). Studies have shown that the walls of most existing and recent residential buildings in Abuja are made from hollow blocks. According to Ochedi *et al*., (2022) these types of walls are good for energy efficiency and thermal comfort due to their lightweight. Ochedi *et al*., (2022) added that regardless of the fact that hollow block walls support the use of lightweight walling which is good for energy efficiency, it is important to still incorporate traditional building materials such as mud bricks and adobe etc., for wall construction because of their sustainable properties and ability to adjust to different climate to improve good indoor comfort. These traditional building materials can be used as cladding materials to improve energy efficiency. This explains why new trends of wall construction in some buildings in Abuja are cladded with bricks; ceramic tiles, etc. so as to reduce the amount of direct sunlight penetrating the building, thus enhancing energy efficiency.

According to Mirrahimi *et al*., (2016), to reduce energy consumption and improve thermal comfort in buildings in tropical regions low thermal mass wall construction is preferred. Thus, Abuja being a tropical wet and dry climate favours the use of this type of wall for most building typologies. A bungalow design with block wall is presented in Figure 15.

Figure 15. A detached bungalow in Abuja showing hollow block wall

2. Fenestration (doors and windows):

Fenestrations (doors and windows) are also important building features that are vital in terms of energy efficiency. The placement of doors and windows in a building and the materials used for their construction have a direct impact on how efficient the building is in terms of energy efficiency. In Abuja, Nigeria, most of the recent residential buildings are designed with aluminium and framed glazing glass. According to Ochedi *et al*., (2022), these materials are known to have thermal capacity that enables them to maintain thermal comfort in buildings. Recent residential developments have seen the introduction of overhangs on windows to serve as shading devices. This enhances thermal comfort and improves efficiency in buildings (Ahmadi *et al.*, 2020).

Figure 16. A detached bungalow in Abuja showing fenestration

3. *Roof:*

The roof *is* another important feature of a building. Studies from literature have shown that a well-designed energy-efficient roof can help to improve indoor comfort conditions, and reduce energy consumption and energy bills due to a decrease in cooling loads (Mirrahimi, *et al.*, 2016; Ahmadi *et al.*, 2020 and Ochedi, *et al.*, 2022). Most of the existing and recent residential buildings in Abuja widely adopted good roofing construction methods for residential buildings.

The majority of these existing buildings use high pitched roofs. However, recent residential developments have seen the introduction of low flat roofs which is not only cost effective but also have good thermal capacities (Ahmadi, *et al*., 2020). The flat roofed design is the wave of the roof in Abuja. It is presumed to be a feature of modern contemporary architecture and it is currently the trend practiced in Abuja. However, Ochedi (2022) argued that 'the pitched roof is the most suitable for this region because of the region is a hot humid tropical climate'. Ochedi (2022) added that pitch roofs with appropriate eave size to shade building elevations are the common tropical architectural design recommended for humid and hot tropical climates like that of Abuja (Ochedi, *et al.,* 2022).

The type of roofing sheet and colour also has a significant impact on the performance of the roof of a building in terms of energy efficiency. Studies from literature have shown that the choice of roof in Abuja is greatly affected by affordability, aesthetics, choice and design rather than their effects on energy consumption and performance (Ahmadi, *et al*., 2020 and Ochedi, *et al.,* 2022). This is because some building owners and property designers/developers are not even aware that the colour and type of a roof sheet have a significant effect on energy efficiency in the building.

In Abuja, the traditional common type of roofing sheets is the corrugated iron sheets. However, the advent of new roofing sheets such long span corrugated aluminium roofing sheets, stone-coated aluminium stepped roofing tiles and other roofing materials of different colours and varieties known to be good in terms of enhancing energy efficiency are gradually replacing the traditional corrugated iron roofing sheet common in Abuja, Nigeria (Ochedi, *et al*., 2022). The advent of these new roofing sheets has seen corrugated iron sheets becoming almost outdated.

Also, it is important to understand that aside from the type of roofing sheet used in a building, the roofing technology adopted also has a significant role in terms of enhancing energy efficiency. Studies have shown that roofing technology that incorporates roof insulation is important for energy efficiency (Mirrahimi, *et al*., 2016). The majority of the roofing construction in Abuja is without proper insulation; however, few buildings incorporate the use of ridge vents but do not have an eave vent. Studies have shown that a combination of eave and ridge vent can remove hot air from the roof space thereby improving thermal comfort (Ochedi, *et al*., 2022; Mirrahimi, *et al.*, 2016) This explains why recent roofing design in Abuja have begun to adopt roof vents such as sun breakers so as to improve thermal comfort and energy efficiency in buildings.

Figure 17. A bungalow in Abuja showing a pitch roof design

4. Floor:

Floor type is an important building feature. The floors of a building have an advantage in energy efficiency. According to Ochedi, *et al.*, (2022) floors with high thermal mass in concrete have potential cooling abilities, especially in preventing the effect of solar radiation. This makes concrete floor finish a recommended floor finish for residential buildings. Most residential buildings in Abuja, Nigeria are finished with reinforced concrete with ceramic tiles finish. These floor types are good because of their durability and also because they keep the building cool during hot weather conditions (Ochedi, *et al*., 2022).

Therefore, it is safe to recommend an on-ground concrete floor finish for residential buildings in Abuja. Architects and builders are aware of the advantage and energy efficiency potential of this type of floor finish which explains why the majority of the residential bungalows in Abuja use on-ground concrete slab.

Figure 18. A residential bungalow in Abuja showing a concrete floor finish

4.2.2 Energy usage and potential savings. The energy usage and potential saving of a building depends on compliance with energy codes, design strategies and materials used for construction. Some of the parameters that determine a building's energy usage and potential savings include; compliance with local codes, building orientation, natural ventilation and daylighting, landscaping and shading devices. The energy usage and potential energy savings of some case study buildings in Abuja are as follows.

According to Sholanke, *et al.*, (2022), most of the existing building designs in Abuja, Nigeria lack some of these features that will enhance energy efficiency. This is because architects are not consulted for construction works, especially in the outskirts of the city and also the compliance and implementation level of the minimum requirements for energy efficiency stipulated in the National Building Energy Efficiency Code is low. Figure 19 presents a case study of a residential building at Adeyi Street, Kubuwa in Abuja, Nigeria. This building lacks some vital parameters that will reduce energy usage and enhance potential energy savings.

Checklist	*Design Observation*	*Remark*
Building orientation	North-South Orientation	Good
Natural Ventilation and daylighting	Proper placement of fenestration (Doors and Windows) but without cross ventilation and reduced effect of daylighting	Good
Landscaping and shading device	Landscape and shading device present	Good

Figure 19. A semi-detached residential bungalow in Abuja, Nigeria

However, recent residential building designs in estates and other locations within the city are starting to engage architects for construction works. Thus, this has improved compliance with the Building Energy Efficiency Code of Nigeria and has made recent buildings in Abuja incorporate the right mix of passive and active design techniques in building designs. This is evident in one of the case studies of a residential bungalow in Karu, Abuja, Nigeria presented in Figure 20.

Checklist	Design Observation	Remark
Building orientation	North-South Orientation	Good
Natural Ventilation and daylighting	Proper placement of fenestration (Doors and Windows) for natural ventilation and daylighting	Good
Landscaping and shading device	Landscape and shading device present	Good

Figure 20. A residential bungalow in Abuja, Nigeria

In terms of energy usage, The National Bureau of Statistics (NBS) in its recent reports on Electricity Distribution Companies (DisCos) stated that energy consumption in Nigeria increased from 6.99 million in 2015 to 10.37 million in 2022 (Business Day News, 2022) and Abuja Electricity Distribution Company (AEDC) recorded the highest number of metered customers with about 710,870 customers in 2022 (Okonkwo, 2022). This equates to about 60% of the total increase in the number of metered customers as reported by the NBS in 2020 (Business Day News, 2020). This connotes that there is more energy consumption in the city as a result of poor energy efficiency techniques.

It is therefore, logical to attribute the increased energy consumption to the influx of people to the city and the upsurge in the design of the residential building typologies in Abuja, especially bungalows since studies have shown that bungalows occupy the majority of the building typologies in the city. However, to tackle this situation, the need for more energy-efficient building designs is important in the city in both new constructions and existing buildings.

According to (Ochedi, *et al.*, 2020), the process of designing an energy-efficient building starts with compliance with local building codes, understanding the right design strategy, climate and unique characteristics of a particular area the building is to be designed, planning effectively to make the building energy efficient. This can only be achieved by engaging the right stakeholders to carry out the design and construction of the building and also by ensuring adherence/compliance to the minimum requirement for energy efficiency stipulated in the National Building Energy Efficiency Code of Nigeria.

From the case studies analyzed and reviewed literature on existing and recent buildings in Abuja, it is evident that the energy efficiency in residential buildings designed prior to the development of the Nigeria Building Energy Efficiency Code in 2017 will be limited. However, recent residential building designs after the development of the Nigeria Energy Efficiency Code will tend to be more energy efficient and as such limit energy usage and improve potential energy savings in residential buildings in Abuja (Macaulay, *et al.*, 2023). Studies still show that the general implementation and compliance level to the Building Energy Efficiency Code of Nigeria is still low and there is a need for more improvement to increase the potential energy saving in residential buildings in Abuja, Nigeria. This is in line with the study of Macaulay, *et al.* (2023) on the assessment of compliance to building energy efficiency strategy in the development of housing estates in Abuja, Nigeria. Findings from the study deduced that compliance with the local energy efficiency strategies stipulated in the Building Energy Efficiency Code of Nigeria significantly reduces energy consumption in buildings thus improving energy saving and sustainability.

In addition, Yüksek and Karadayi (2017), stated that aside from compliance with local Building Energy Efficiency Codes, creating an energy-efficient building that has the tendency of low energy usage and increased potential energy savings starts with the right design approach, microclimate considerations of the site, orientation and shaping of building forms, conscious selection of building materials and the use of envelope systems aimed to minimize building heat gains. This is in agreement with Ochedi, *et al*. (2020) earlier assertion.

Thus, properly planned buildings with good orientation, proper placement of windows for natural ventilation and daylighting, adequate use of shading devices, and proper landscaping to maintain the thermal comfort of the surrounding buildings and give good ambience are vital in maintaining indoor temperature, enhance energy efficiency and also thermal comfort. According to Ahmadi, *et al*. (2020), simple rectangular buildings are best for achieving orientation in humid – hot climatic regions for energy-efficient buildings. This is evident in the case study in Figure 16 which is properly planned and as such, has the tendencies of low energy usage and improved potential energy savings unlike buildings that are not properly planned and as such have tendency of high energy usage in the quest for maintaining a comfortable indoor environment in terms of thermal comfort (heating and cooling) and air quality (ventilation), thus exhibit low potential energy savings tendencies (Figure 15).

This agrees with the research Macaulay, *et al.* (2023) where findings revealed estates and residential buildings in Abuja that do not achieve energy efficiency are those that exhibit poor planning standards and lack compliance with energy efficiency code. More studies from the literature also revealed that the majority of existing buildings in Abuja were not designed by architects and as such they lack compliance with the building energy code of Nigeria and the implementation of passive design techniques was not employed in these buildings. Therefore, these buildings tend to consume more energy making their energy usage quite high (Macaulay, 2023).

In conclusion, the potential energy savings of a building is a measure of how energy-efficient the building is. There are a number of factors that make a building energy-efficient. These factors are categorized into passive and active design strategies as earlier mentioned in previous chapters of this thesis.

Studies from the literature reveal that buildings with poor passive and active energy efficiency design strategies have low energy saving potentials while buildings with good and properly implemented passive and active design strategies/systems have high energy savings potential (Macaulay, *et al.*, 2023, Ochedi, 2022).

Although the active energy efficiency strategies for lighting, heating ventilating and air conditioning (HVAC) of the case studied buildings were not ascertained at the time of the study, however, studies from the literature have recommended the use of renewable energy sources to run appliances for lighting, ventilating, and air conditioning (HVAC). This complies with the provisions in the Nigeria Energy Efficiency Code. If adhered to, it will go a long way in increasing potential energy savings in residential buildings.

Studies also show that in most countries where energy efficiency regulations were strictly adhered to, a cost-effective energy savings of about 10% was achieved in 2020 which is projected to rise to about 20% by 2030 (European Commission, 2023). This agrees with the study of Abugu, *et al.* (2022) where it was established that globally energy saving potentials of buildings are increased when building energy codes are strictly adhered to. In relation to this, only a few users in Abuja have adhered to the recommended planning standards and design procedure as recommended by the National Building Energy Efficiency Code of Nigeria (Macaulay, *et al.*, 2023). This is also evident in the case study of Figure 15 analyzed in this thesis.

Again, studies from the literature have shown that most buildings especially residential bungalows in Abuja have not adopted the use of renewable energy sources like solar panels and inverters for energy supply thus limiting the energy-saving potential of most buildings in the city (Macaulay, *et al.* (2023)). Macaulay, *et al.* (2023) added that the majority of the residential buildings in Abuja still run on fossil fuel generators which contribute greatly to the emission of greenhouse gases. It is therefore recommended that the use of renewable energy to run LED appliances for lighting, HVAC coupled with and building certification should be encouraged in the study area due to their high potential for energy savings.

In summary, learning from reviewed literature and the case studies assessed in this thesis have shown buildings designed prior to the development of the Nigeria Building Energy Efficiency Code in 2017, are presumed to consume more energy and have a tendency of limited energy efficiency. However recent residential development estates in Abuja Nigeria are presumed to be more energy efficient because architects/engineers are starting to adhere to the minimum requirements stipulated in the Nigeria Building Energy Efficiency Code. However, the compliance level to this code is poor, and the majority of the buildings in Abuja especially towards the peripheral parts are not properly planned (Macaulay, 2023). Hence implementing passive and active design strategies like building orientation, landscaping, wind direction, HVAC systems, building automation etc. are not widely considered during construction. This affects the energy-saving potential of most buildings in the city. Recently, active energy efficient design strategies like solar power, and inverters, are starting to be incorporated into the design of the buildings in Abuja this will aid in improving potential energy savings in Abuja.

4.3 Stakeholders' Energy Efficiency Knowledge

The assessment of the stakeholders' knowledge of energy efficiency is important because stakeholders play a vital role in achieving energy efficiency in buildings worldwide.

4.3.1 Definition of the stakeholders. The building design and construction cycle can be categorized into different processes namely: design, construction, and use. Stakeholders are involved in these processes. For this study, a representative stakeholder is chosen for each of the building design and construction processes according to their active involvement in the phase. These phases include the design phase, construction phase and operation/maintenance phase.

Hence, for this study, the stakeholders selected to represent each of the respective phases are architects/engineers, contractors and users. The architects and engineers represent the design phase; the contractors represent the construction phase and the users represent the operation/maintenance phase.

4.3.2 Preparation of questionnaires. The questionnaire for this study is designed in 3 sections. Section A sorts for information about stakeholders' data, section B is on the knowledge of architects/ engineers, and contractors while section C is on the knowledge of users on energy efficiency. The questions in the questionnaire will be a mix of open and closed questions. The questions for section B which sort for architects/engineers and contractors' knowledge will be structured in two parts, namely; part I & II. These two parts will seek architects/engineers and contractors' knowledge on energy efficiency by following the aspects defined for improving energy efficiency in the previous chapters.

A sample of the questionnaire is presented below.

Research Questionnaire

Please tick [✓] to the option that suits your answer.

Section A: Demographic Data of Respondent

[Architects/Engineers and Contractors only]

1. Name of company………………………………………………………...
2. Years of experience…………………………………………………………….
3. Location of company ………………………………………………………….
4. Number of residential building projects involved in? …………………………
5. What is the building type that you live in (a) bungalow [] (b) duplex (c) single detached room (c) other specify……………………………………………

Section B: Information on Architects/Engineers and Contractors' Knowledge on Energy Efficiency

Part I: Architects/Engineers' Knowledge on Energy Efficiency

1. Do you adhere to the minimum requirements for design and construction of buildings as stipulated in the National Building Energy Efficiency Code of Nigeria?

   (a)Yes [] (b) No [] If No, please state your reasons………………………………
2. Do you seek for building permits before embarking on any construction project you are involved in?

   Yes [] (b) No [] If No, please state your reasons…………………………………
3. How would you rate your knowledge of energy efficiency?

   (a)Excellent [] (b) Good [] (c) Fair []
4. What are the common passive building energy efficiency techniques you adopt in your design for heating, ventilation and air conditioning?………………………
5. What are the active measures you think can improve energy efficiency in residential buildings?……………………………………………………………

Part II: *Contractors' knowledge on Energy Efficiency*

1. What are the enforcement measures you adopt as a contractor for enhancing energy efficiency?…………………………………………………………………
2. Do you change architect designs specifications on site during construction?
   (a) Yes [] (b) No (c) If Yes, please state your reasons……………………………
3. What are key considerations you consider while selecting materials for building elements/ components such as doors, windows, roofs, etc.?………………………
4. How can renewable energy sources be integrated into buildings so as to promote energy efficiency? ………………………………………………………………
5. What is the environmental and financial savings you think are attributed to potential energy efficient buildings?……………………………………………….

Section C: Information on Users Knowledge on Energy Efficiency

1. Do you have any idea about energy efficiency in buildings?
   (a) Yes [] (b) No [] If Yes, what does it mean?……………………………………
2. Are the lights and appliances in your homes energy saving?
   (a) Yes [] (b) No [] (c) I don't know []
3. Do you often switch off your lights when not in use?
   (a) Yes [] (b) No []
4. What are some of the simple actions you take to save energy in your home?
   ……………………………………………………………………………………...
5. Do you know that your personal habits and behaviour can contribute to energy efficiency?
   (a) Yes [] (b) No [] (c) If Yes, how?……………………………………………….
6. What factors do you look out for while buying appliances for your homes?
   ....
7. Do you know that if your home is energy efficient in terms of design and appliance usage it gives you an advantage of reduced potential energy consumption and cost saving?
   (a) Yes [] (b) No []
8. Have you done any retrofitting in your home?
   (a) Yes [] (b) No []

9. Are there any energy-efficient incentives or programs from the government to promote energy efficiency in your homes?
   (a) Yes [] (b) No [] (c) I don’t know []

4.3.3 Conducting surveys. The procedure for conducting the survey is via questionnaire administration to surveyors. The survey will be done using a remote technique. This technique will involve conducting an online session in the form of interviews with selected architects, engineers and contractors. The session with each stakeholder is expected to last 5 minutes. For users, a sample of the questionnaire will be sent as a Google form which will be distributed among users in Abuja to seek their knowledge on energy efficiency.

4.3.3.1 Administering questionnaires. The questionnaire for this study is aimed at assessing the knowledge of the selected stakeholders in terms of energy efficiency. The procedure for administering the questionnaire will first involve seeking the consent of the participants using a consent form. Then, participants who agree to take part in the survey will be presented with the research questionnaire to seek their knowledge of energy efficiency.

4.3.3.2 Definition of surveyors. The surveyors for this study are architects/engineers, contractors, and users, all residing in Abuja, Nigeria. The architects/engineers and contractors for this study will be selected from companies in Abuja, Nigeria. The companies where these architects and contractors are selected include Forte ARCON and Lubel Nigeria Ltd while the users are selected from different residential developments and estates in Abuja.

4.3.3.3 Survey results. A total of 75 questionnaires were distributed for the survey. Figure 21 presents the distribution pattern of the questionnaire.

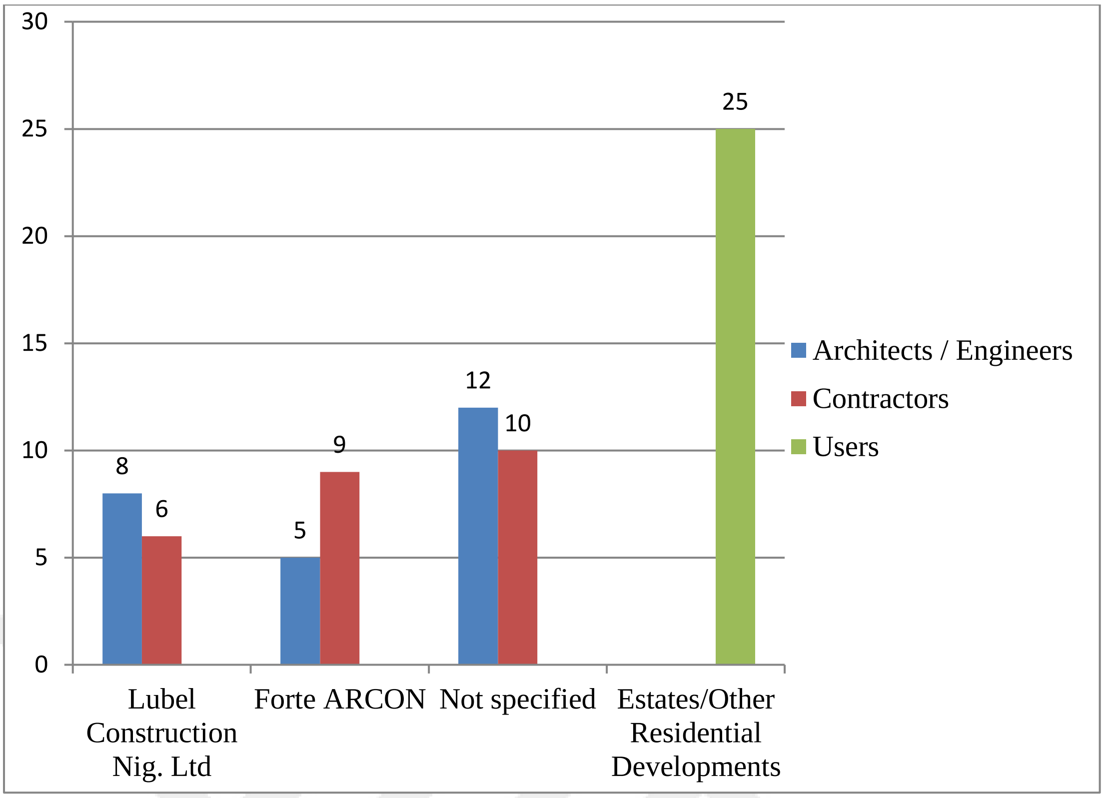


Figure 21. Bar chart showing questionnaire distribution pattern

The questionnaire distribution pattern shows that 75 stakeholders comprising 25 architects/engineers, contractors and users each participated in the survey. This implies that 50 respondents comprising architects/engineers and contractors represent the design and construction team and 25 respondents represent the users. Out of the 25 architects/engineers, 8 architects represented Lubel Construction Nig. Ltd., 5 represented Forte ARCON, and 12 architects did not specify the identity of their company. Also, from the 25 contractors, 6 represented Lubel Constructions Nig. Ltd., 9 represented Forte ARCON, and 10 represented contractors who did not specify the identity of their company. The 25 participants that represent the users were drawn randomly from estates and other residential developments in Abuja, Nigeria. The results from the survey are presented in Table 18.

Table 18

Survey Results

General Information of stakeholders (Architects/Engineers, Contractors and Users)			
Awareness Question	*Response*	*No. of Respondents*	*Percentage (%)*
Type of Building Stakeholders Live in	Story building	1	1.3
	Bungalow / Semi-Detached Bungalow	35	46.7
	Duplex	8	10.7
	Studio Apartment	6	8.0
	Unknown	25	33.3
	Total	*75*	*100.0*

General Information of Architects/Engineers and Contractors [only]			
Awareness Question	*Response*	*No. of Respondents*	*Percentage (%)*
Design Teams' company	Forte ARCON	13	26.0
	Lubel Nigeria Ltd	15	30.0
	Unknown	22	44.0
	Total	*50*	*100.0*
Design Team Experience	<3	0	0.0
	3 – 6 Years	25	50.0
	7> Years	9	18.0
	Unknown	16	32.0
	Total	50	*100.0*
Number of Residential Buildings Design Team have been Involved in;	3 – 6 Years	15	30.0
	> 7 Years	16	32.0
	Unknown		38.0
	Total	50	*100.0*

Table 18 (cont'd)

Results of Architects/Engineers Knowledge on Energy Efficiency			
Awareness Question	*Response*	*No. of Respondents*	*Percentage (%)*
Architects/Engineers response to if they adhere to the minimum requirement in the National Building Energy Efficiency Code	Yes	28	56.0
	No; Due to reasons like client preference, budget and affordability	22	44.0
	Total	*50*	*100.0*
Common Passive Building Energy Efficiency Techniques adopted by Architects/Engineers	Landscaping, cooling pools, site orientation, cross ventilation, daylighting, use of shading devices and glazing	28	56.0
	Solar controls such as renewable energy,	18	36.0
	None, I barely Implement them	4	8.0
	Total	*50*	*100.0*
How Renewable energy sources can be integrated to buildings	Use of inverters/solar panels, energy-efficient lighting, roof windmills and smart home automation.	24	48.0
	Use of Passive design strategies such as natural lighting / cross ventilation	22	44.0
	Don't Know	4	8.0
	Total	*50*	*100.0*

Table 18 (cont'd)

Awareness Question	*Response*	*No. of Respondents*	*Percentage (%)*
Architects / Engineers thought on the active measures that can improve energy efficiency in residential buildings	Adherence to the Nigerian Energy Efficiency Code and Energy efficiency auditing	6	12.0
	Retrofitting / Switching to less energy appliances/lights	26	52.0
	Switching to Renewable energy sources	6	12.0
	Building automation / Smart home system	8	16.0
	Didn't Answer	4	8.0
	Total	*50*	*100.0*
Architects/Engineers thought on the extent to which they think they are responsible for energy efficiency in Residential Buildings	High Extent	30	60.0
	Minimal Extent	14	28.0
	Uncertain	6	12.0
	Total	*50*	*100.0*
Architects/Engineers rating of their Energy Efficiency Knowledge	Excellent	8	16.0
	Good	32	64.0
	Fair	6	12.0
	Didn't answer	4	8.0
	Total	*50*	*100.0*

Table 18 (cont'd)

Results of Contractors Knowledge on Energy Efficiency

Awareness Questions	*Response*	*No. of Respondents*	*Percentage (%)*
Enforcement measures contractors adopt for enhancing energy efficiency	Investigation of fines and demolition of buildings as penalties	12	24.0
	Consistent Site visitation to monitor construction process	20	40.0
	Standard practice and strict adherence to National building codes	14	28.0
	None, due to implementation difficulty	4	8.0
	Total	50	*100.0*
Contractors thought on the Potential environmental and Financial saving of energy efficient buildings	Thermal comfort and wellbeing in buildings / Minimization of cost on energy charge (Net zero buildings)	24	48.0
	Conservation of natural resources; Reduction of greenhouse gas emission; minimization of air and water pollution (eco-friendly environment)	26	52.0
	Total	*50*	*100.0*
Contractors response to changing architects design specification	Yes, If it undermines the expected goal/purpose of the design	14	28.0
	No	32	72.0
	Total	*50*	*100.0*

Table 18 (cont'd)

Awareness Questions	*Response*	*No. of Respondents*	*Percentage (%)*
Extent contractors think they are responsible for the energy efficiency of residential building	High Extent	12	24.0
	Minimal Extent	38	76.0
	Total	*50*	100.0
Contractors rating of their knowledge on energy efficiency in buildings	Excellent	12	24.0
	Good	32	64.0
	Fair	6	12.0
	Total	*50*	*100.0*

Results of Users' Knowledge on Energy Efficiency

Awareness Questions	*Response*	*No. of Respondents*	*Percentage (%)*
Users thought on how a building can be made energy efficient	No Idea	6	24.0
	Retrofitting, use of energy efficient devices and renewable energy	8	32.0
	Good housekeeping / switching off lights / appliances when not in use	5	20.0
	Engaging professional to build house	6	24.0
	Total	*25*	*100.0*
Users response on if the appliances and lighting in their homes is energy saving	Yes	6	24.0
	No	6	24.0
	No idea / Don't know	13	52.0
	Total	25	100.0

Table 18 (cont'd)

Awareness Questions	*Response*	*No. of Respondents*	*Percentage (%)*
Simple actions users take to save energy in their homes	None	11	44.0
	Switching lights and appliances off when not in use	8	32.0
	Use of LED bulbs and appliances that consume less energy	6	24.0
	Total	*25*	*100.0*
Users response on whether energy labels of products is a parameters that impacts their decision in selecting a building to live in or a home appliances to use	Yes	12	24.0
	No	10	20.0
	I don't know	28	56.0
	Total	*25*	*100.0*
Users response to if they have done any retrofitting in their homes to save energy and to decrease energy cost	Yes	8	32.0
	No	7	28.0
	Unsure	10	40.0
	Total	*25*	*100.0*
Information on if there are energy efficient incentives or programs from government to promote energy efficiency in users home	Yes	5	20.0
	No	8	32.0
	Don't Know	12	48.0
	Total	*25*	*100.0*

Table 18 (cont'd)

Awareness Questions	*Response*	*No. of Respondents*	*Percentage (%)*
Extent to which users think 'they are responsible for the energy efficiency of their buildings'	High extent	8	32.0
	Minimal extent	7	28.0
	Uncertain	10	40.0
	Total	*25*	100.0
Users rating of their knowledge on energy efficiency	Excellent	3	12.0
	Good	5	20.0
	Fair	8	32.0
	Poor	9	36.0
	Total	*25*	*100.0*

4.4 Evaluation

The evaluation of the results from the distributed questionnaires for the survey is presented in charts as follows:

i. Evaluation of stakeholders' general information

The evaluation of stakeholders' general information is presented as follows. Figure 22 presents information on the building type stakeholders live in.

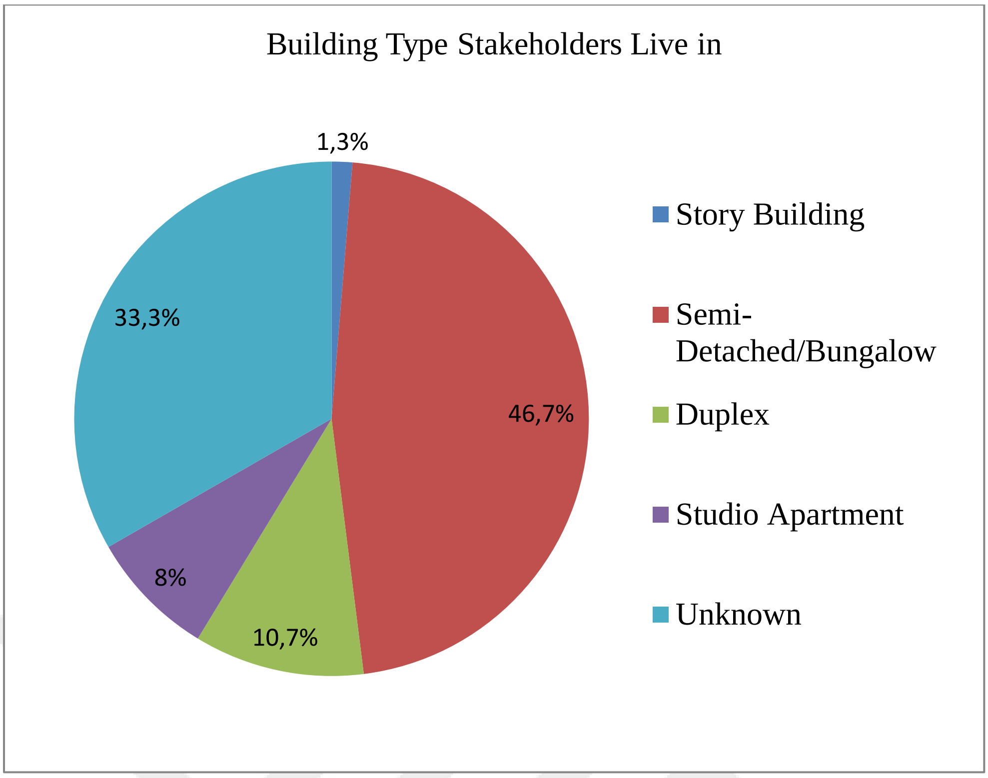


Figure 22. Pie chart showing information on the type of building stakeholders live in

From Figure 22, 46.7% of the stakeholders live in semi-detached /bungalows, 33.3% did not disclose the building type they live in, 10.7% of the stakeholders live in duplexes and 8% live in studio apartments. Only 1.3% of the stakeholders live in story buildings. This implies that the majority of the stakeholders that took part in the survey comprising both the design team and users representing 46.7% live in semi-detached buildings/bungalows. This is attributed to the fact that detached buildings/bungalows are amongst the most common building types in Abuja, Nigeria.

Figure 23 presents information on the percentage of the design team representatives per the respective companies that took part in the survey.

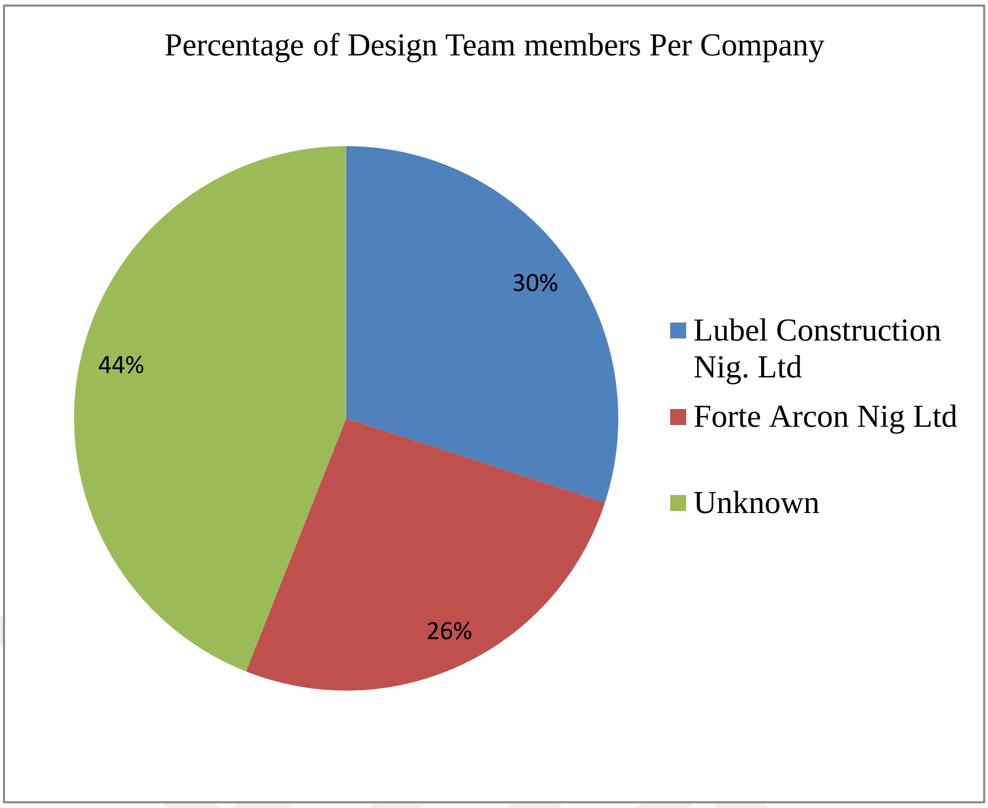


Figure 23. Pie chart showing the percentage of design and construction team representative per company

From Figure 23, the majority of the design team members representing 44.0% did not disclose the identity of their company, however, 30.0% of the design team are attached with Lubel Construction Nig. Ltd while 26.0% identified Forte ARCON as their company. This implies that most of the respondents preferred not to disclose their company name.

The years of experience of the design and construction team were also assessed. Figure 24 presents information on the design team's years of experience

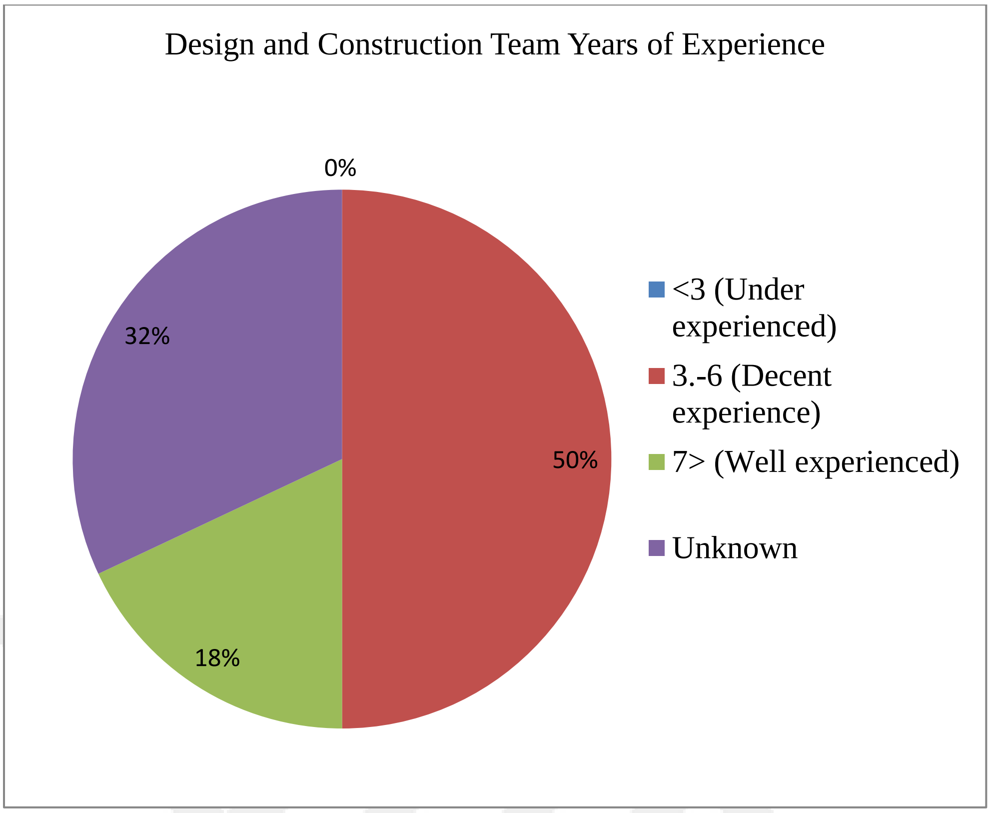


Figure 24. Pie chart showing the design and construction team's years of experience

From Figure 24, the majority of the design and construction team representing 50.0%, have a decent experience of about 3-6 years, 18.0% are well experienced with >7 years of experience, 32.0% of the design and construction team did not disclose their years of experience, while none representing 0% of the design and construction team member that participated in the survey are under-experienced. This implies that majority of the design and construction team members that took part in the survey have a decent experience while no member of the design team who took part in the survey is under experienced.

The evaluation of the number of residential projects each member of the design team has been involved in is presented in Figure 25.

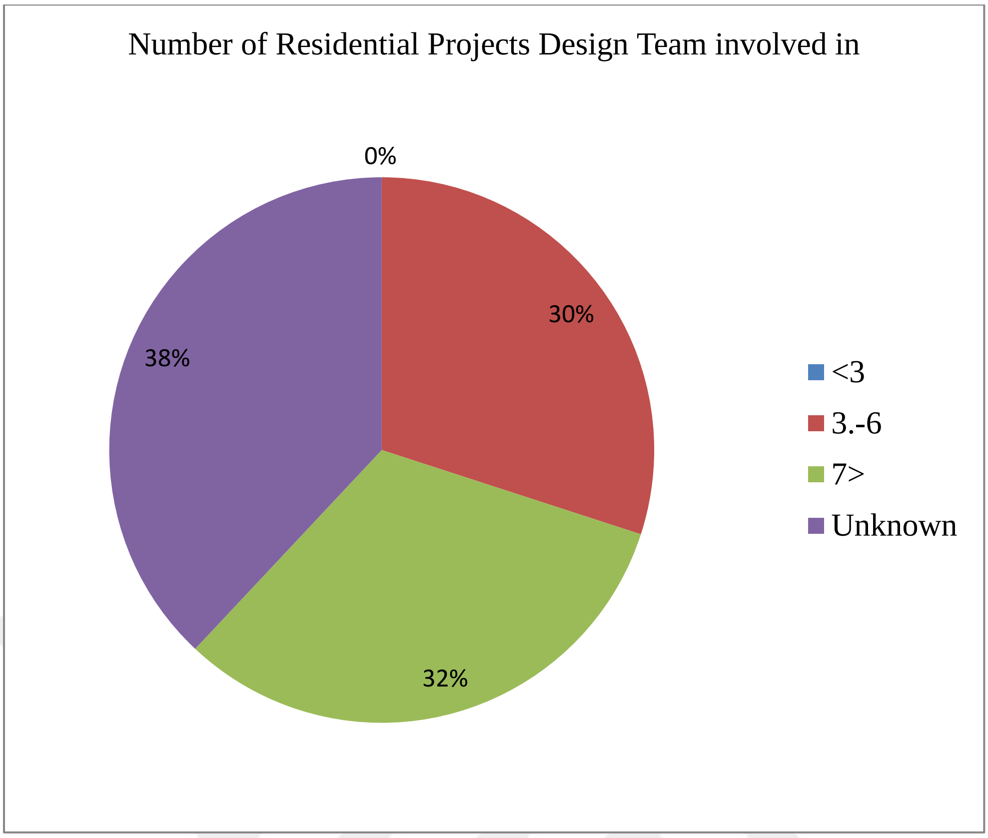


Figure 25. Pie chart showing residential projects design team involved in

From Figure 25, most members that make up the design team representing 38.0% did not disclose the number of projects they have been involved in, and as such were labeled unknown. However, a decent number of the design team represented by 30.0% and 32.0% have been involved in a good number of residential projects ranging from 3 -6 to 7> projects, respectively. No design team member representing 0% have been involved in <3 residential projects. This can be attributed to the fact that the majority of the design team have decent working experience.

ii. Evaluation on Architects/Engineers Knowledge on Energy Efficiency

The evaluated results on the knowledge of architects/engineers on energy efficiency are presented as follows. Figure 26 presents information on architects/engineers adherence to minimum requirements for the design and construction of buildings as stipulated in the National Building Energy Efficiency Code of Nigeria.

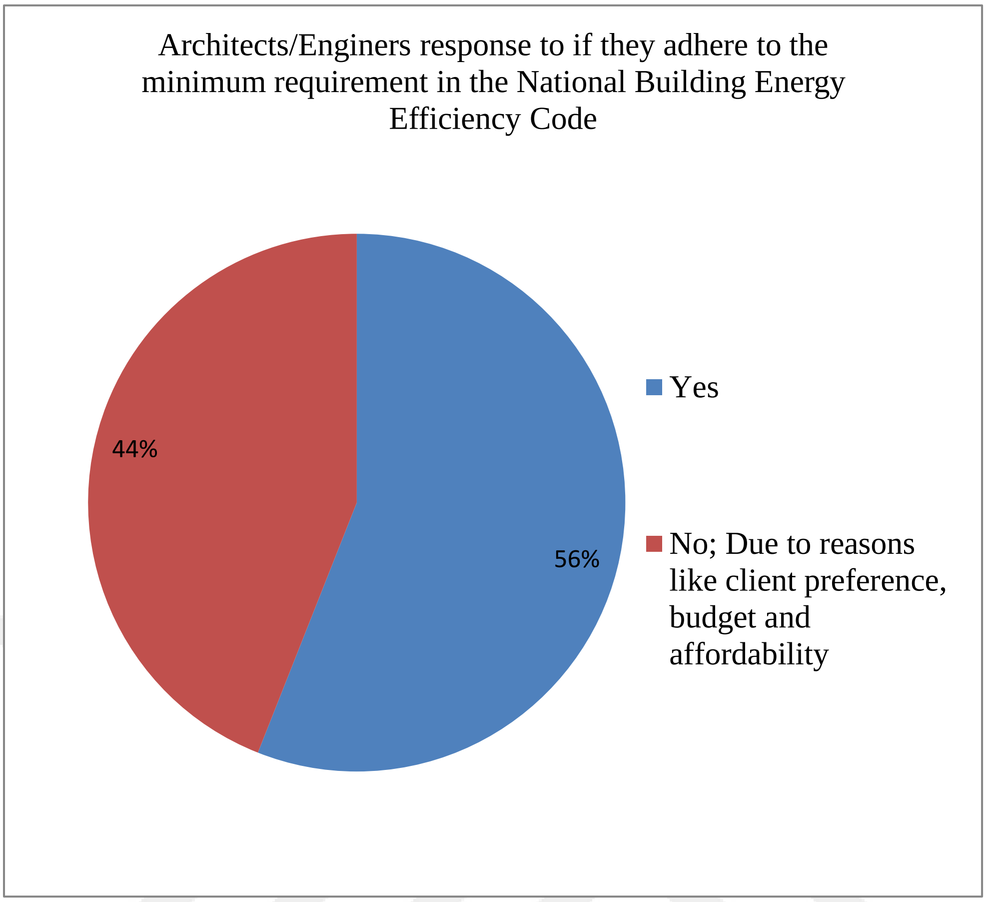


Figure 26. Pie chart showing information on architects/engineers adherence to Nigeria's National Building Energy Efficiency Code

Figure 26 provides information on architects/engineers adhere to the minimum requirements for the design and construction of buildings as stipulated in the National Building Energy Efficiency Code of Nigeria. The results show that the majority of the architects/engineers representing 56.0% adhere to the minimum requirements for the design and construction of buildings as stipulated in the National Building Energy Efficiency Code of Nigeria while 44.0% of the architects/engineers do not adhere to the minimum requirements for energy efficiency owing to the fact that client choices/preferences and budgets make it difficult to adhere to certain minimum requirements for construction of buildings as stipulated in the National Building Energy Efficiency Code of Nigeria.

The evaluation of the results on the common passive building techniques adopted by architects/engineers in the design for heating, cooling, ventilation and lighting is presented in Figure 27.

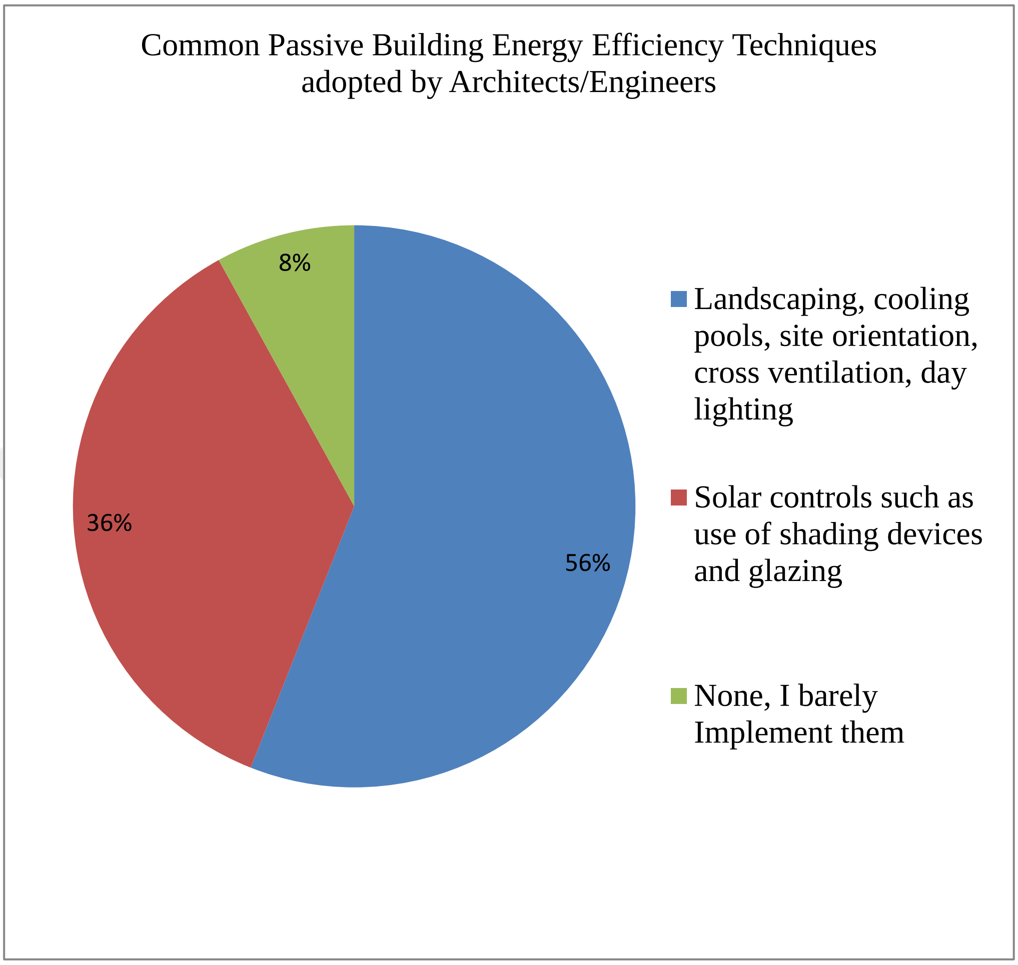


Figure 27. Pie chart showing the common passive building energy efficiency techniques Architects/Engineers adopt for HVAC

From Figure 27, 8% of the architects/engineers barely implement/adopt any passive building technique in their designs. 36% adopt the use of solar controls such as the use of shading devices and glazing while 56% implement/adopt the use of landscaping, cooling pools, site orientation, cross ventilation and daylighting as their common passive building techniques for energy efficiency for heating, cooling, ventilation and lighting efficiency. This implies that the common passive building techniques most architects/engineers adopt in Nigeria for heating, cooling, ventilation and lighting include; landscaping, cooling pools, site orientation, cross ventilation, daylighting, use of shading devices and glazing.

The evaluation of the results on architects/engineers thought on how renewable energy sources can be integrated into buildings so as to improve energy efficiency is presented in Figure 28.

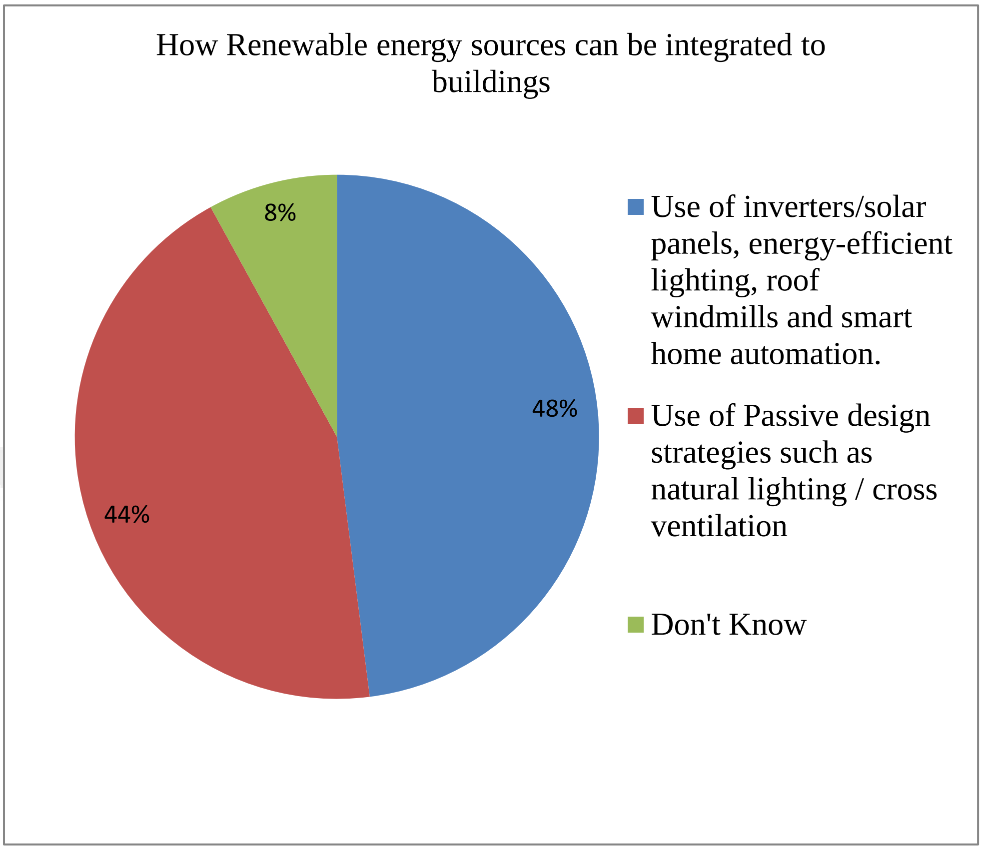


Figure 28. Pie chart showing architects/engineers thoughts on how renewable energy sources can be integrated into buildings

Figure 28 presents information on how renewable energy sources can be integrated into building design and construction so as to improve energy efficiency. From the results, a good number of the architects/engineers representing 48% suggested that the use of inverters/solar panels, energy-efficient lighting, roof windmills and smart home automation as a way renewable energy sources can be integrated into building designs and constructions, 44% suggested the use of passive design strategies such as natural lighting/cross ventilation. Only a few architects/engineers representing 8% stated that they do not know how renewable energy sources can be integrated into the design and construction of buildings. From the results, it is safe to infer that the majority of the architects/engineers are aware of renewable energy and how it is beneficial to energy efficiency in buildings.

The evaluation of the results on the active measures architects/engineers think can improve energy efficiency in residential buildings is presented in Figure 29.

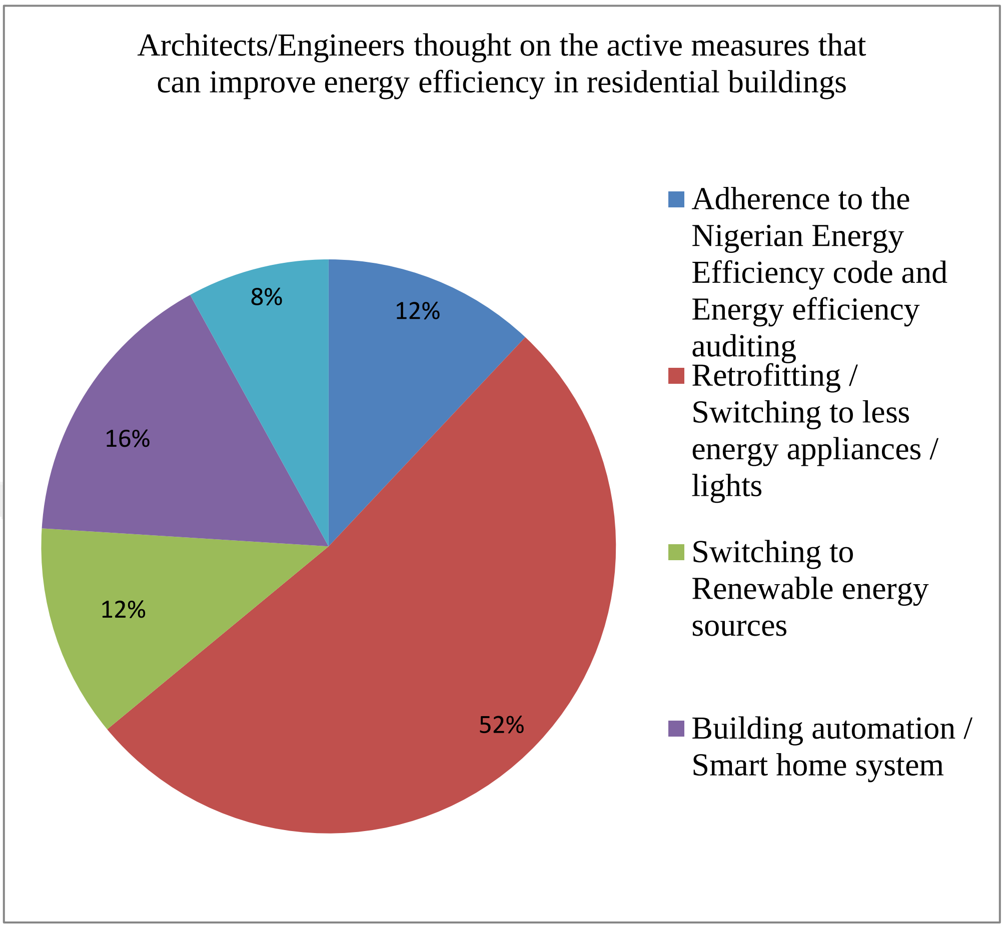


Figure 29. Pie chart showing the active measures architects/engineers think can improve energy efficiency in residential buildings

From the results in Figure 29, on the active measures a good number of the architects/engineers representing 52% think can improve energy efficiency is retrofitting/switching to less energy consuming appliances/lights, 16% think building automation / smart home systems for HAVC can improve energy efficiency, while 12% think adherence to the National Building Energy Code; energy efficiency auditing and switching to renewable energy sources, respectively think can improve energy efficiency in residential buildings. Only 8% did lend that opinion of the active measures that can improve energy efficiency in residential buildings.

The information from the results on the extent to which architects and engineers are responsible for the energy efficiency of residential buildings is presented in Figure 30.

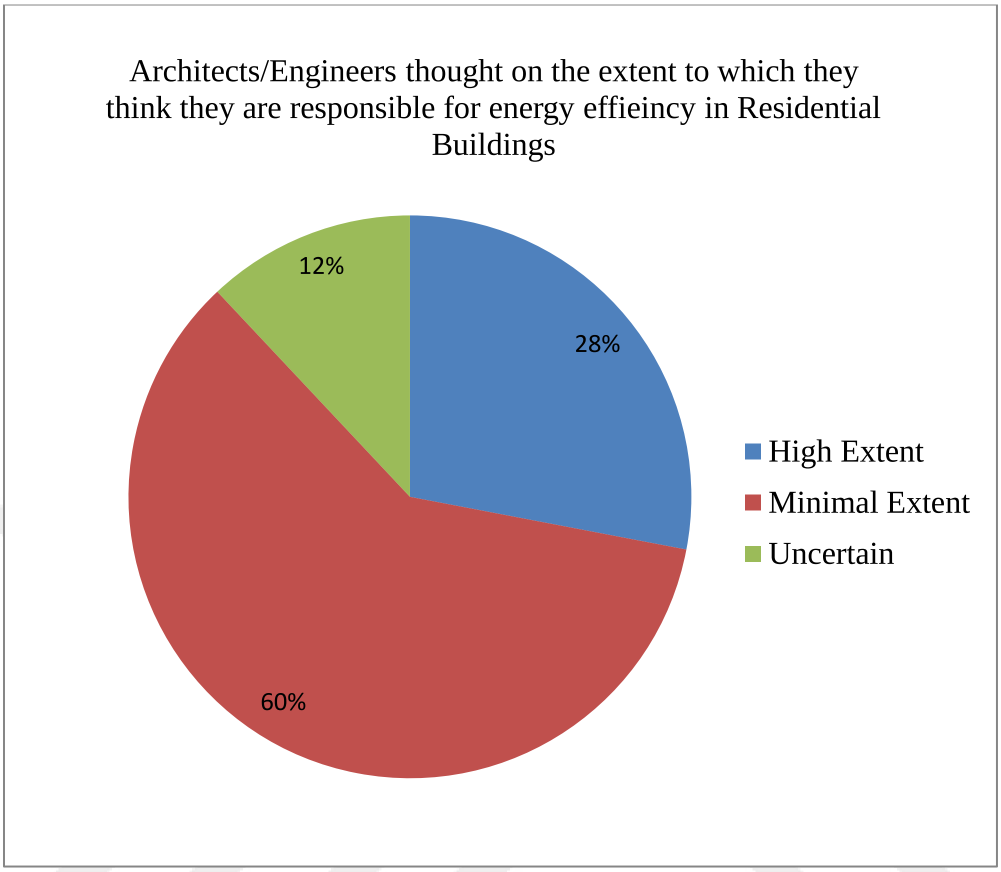


Figure 30. Pie chart showing the extent Architects/Engineers think they are responsible for energy efficiency in residential buildings

Figure 30 presents the extent to which architects/engineers think they are responsible for energy efficiency in residential buildings. The results show that most of the architects/engineers representing 60.0% think they are responsible for the energy efficiency in residential buildings to a high extent, 28.0% think it is to a minimal extent while 12.0% are uncertain about the extent to which they are responsible for achieving energy efficiency in residential buildings.

The evaluation of the results on how architects/engineers would rate their knowledge of energy efficiency is presented in Figure 31.

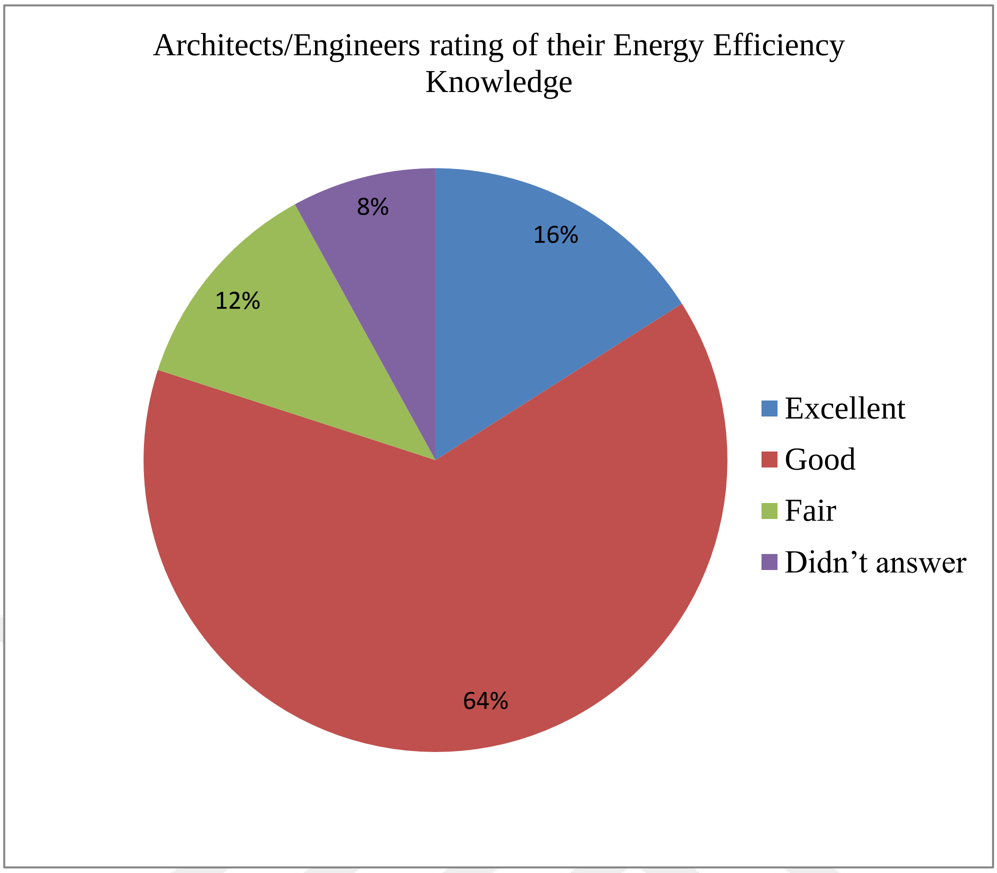


Figure 31. Pie chart showing architects/engineers rating of their knowledge of energy efficiency

Figure 31 presents the results of architects/engineers knowledge on energy efficiency. The results show that the majority of the architects/engineers representing 64.0% have a good knowledge of energy efficiency, 16% have an excellent knowledge while 12% of the architects/engineers have a fair knowledge of energy efficiency. However, 8% of the architects/engineers did not answer.

iii. *Evaluation on Contractors Knowledge on Energy Efficiency*

The evaluation of the results on the knowledge of contractors on energy efficiency is presented as follows. Figure 32 presents information on the enforcement measures contractors adopt to enhance energy efficiency.

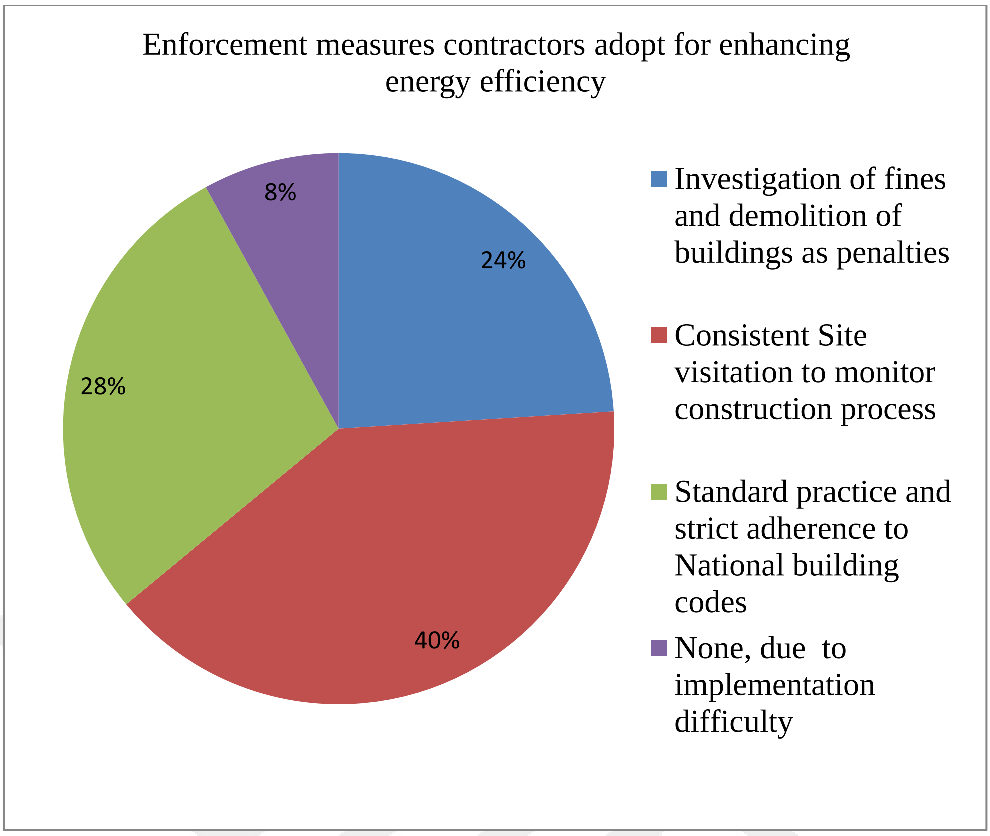


Figure 32. Pie chart showing the enforcement measures contractors adopt to enhance energy efficiency

Figure 32 presents the results of enforcement measures contractors adopt to enhance energy efficiency. The results reveal that the enforcement measures most contractors representing 40.0% adopt for enhancing energy efficiency are consistent site visitation to monitor the construction process and issue queries to offenders, the enforcement measures 28.0% of the contractors adopt are ensuring standard practice and strict adherence to the national building codes, 24.0% adopt instigation of fines and demolition of buildings as penalties to serial offenders. Only 8.0% of the contractors do not adopt any enforcement measures due to the difficulty of their implementation in Nigeria.

The information on the results of the potential environmental and financial savings contractors think can be achieved through energy-efficient buildings is presented in Figure 33.

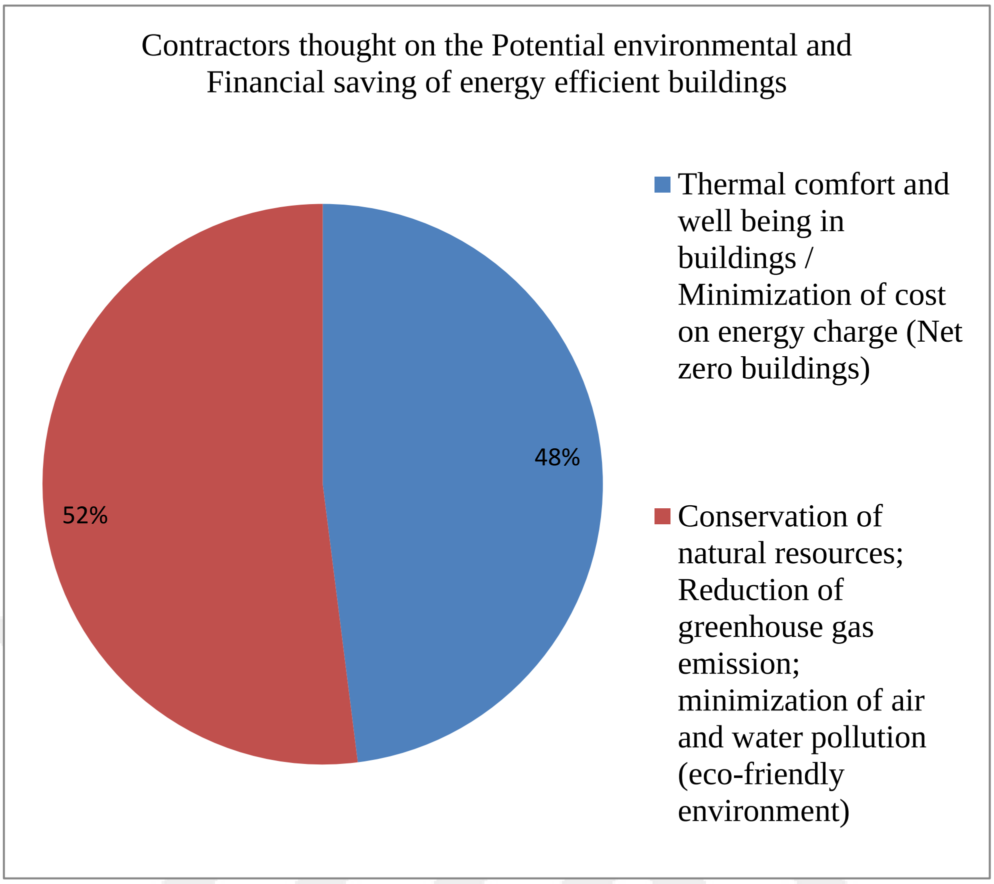


Figure 33. Pie chart showing the potential environmental and financial saving of energy-efficient building.

Figure 33 presents the resolution of the potential environmental and financial savings that can be achieved through energy-efficient buildings. The results reveal that 52.0% of the contractors outline the conservation of natural resources; reduction of greenhouse gas emissions and minimization of air and water pollution (eco-friendly environment) as the potential environmental saving that can be achieved through energy-efficient buildings while 48.0% of the contractors outlined thermal comfort and well-being in buildings and minimization of cost on energy charge (net zero building) as the financial saving that can be achieved through energy-efficient buildings.

The information on the results of if contractors change architects' or engineers' design specifications during construction is presented in Figure 34.

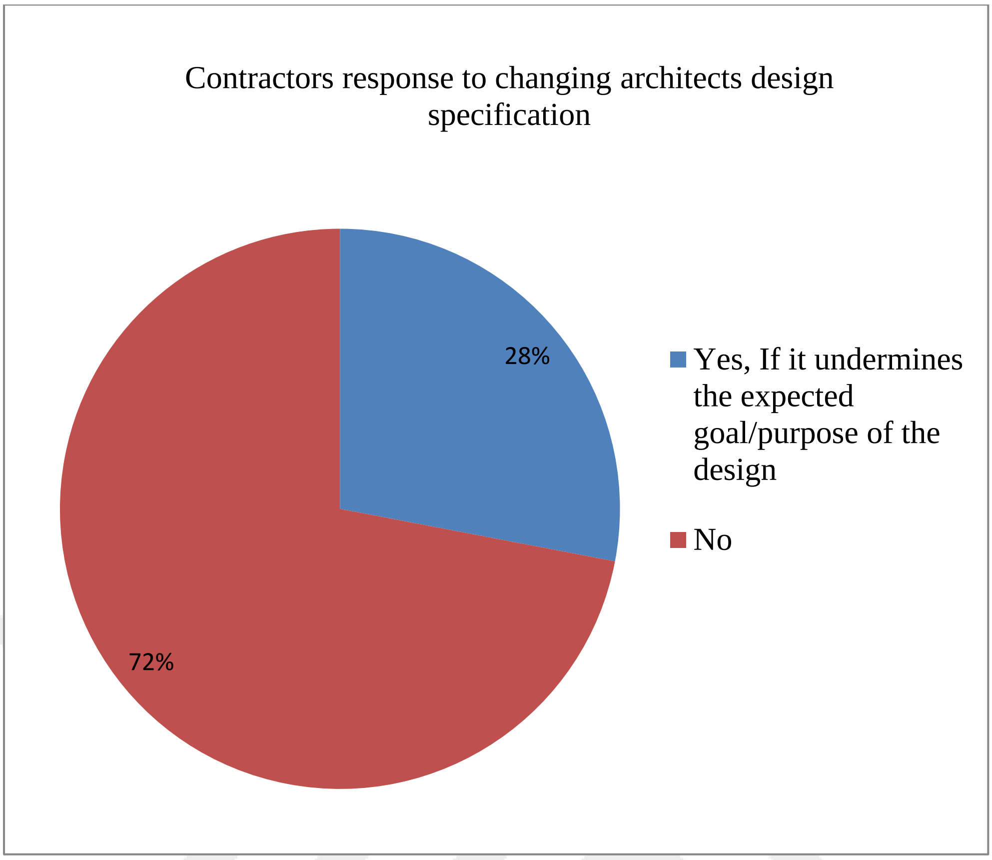


Figure 34. Pie chart showing contractors' response to changing architects' design specifications during construction

Figure 34 presents the results on whether contractors change architects' design specifications. The results reveal that the majority of the contractors representing 72.0% do not change architects' design specifications during construction, however, 28.0% of the contractors admit to changing architects' design specifications during construction if it undermines the expected goal/purpose of the design in regard to energy efficiency.

The evaluation of the results on the extent to which contractors think they are responsible for the energy efficiency of buildings is presented in Figure 35.

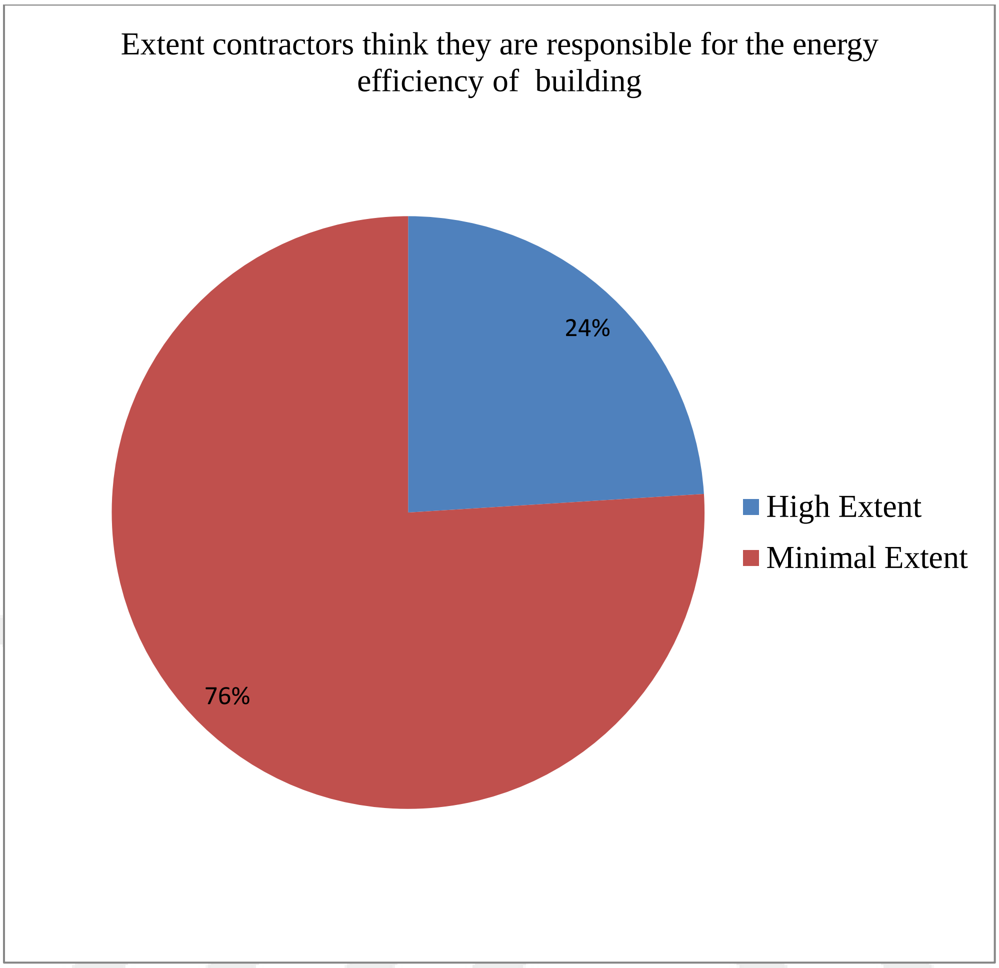


Figure 35. Pie chart showing the extent contractors are responsible for energy efficiency of buildings

The results from Figure 35 on the extent to which contractors think they are responsible for the energy efficiency of residential buildings reveal that the majority of the contractors representing 76.0% think they are responsible for the energy efficiency of residential buildings to a minimal extent while 26.0% of the contractors think they are responsible for the energy efficiency of residential buildings to a high extent.

The information of the results on contractors' rating of their energy efficiency knowledge in buildings is presented in Figure 36.

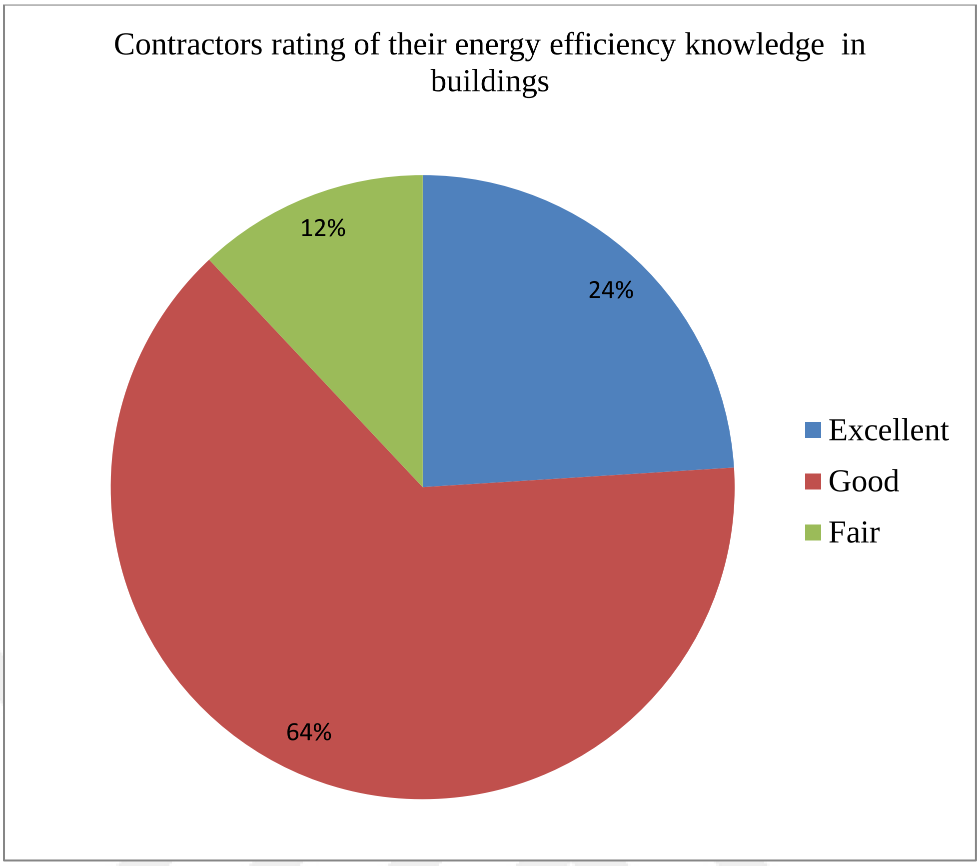


Figure 36. Pie chart showing contractors' rating of their energy efficiency knowledge in buildings

The results from Figure 36 on contractors' rating of their knowledge on energy efficiency in buildings reveal that the majority of the contractors representing 64.0% have a good knowledge on energy efficiency in buildings, 24.0% of the contractors think they have an excellent knowledge of energy efficiency in buildings while only 12.0% think they have a fair knowledge on energy efficiency in buildings.

iv. Evaluation on Users Knowledge on Energy Efficiency

The evaluation of users' knowledge on energy efficiency is presented as follows. Figure 37 presents information on how users think a building can be made energy efficient.

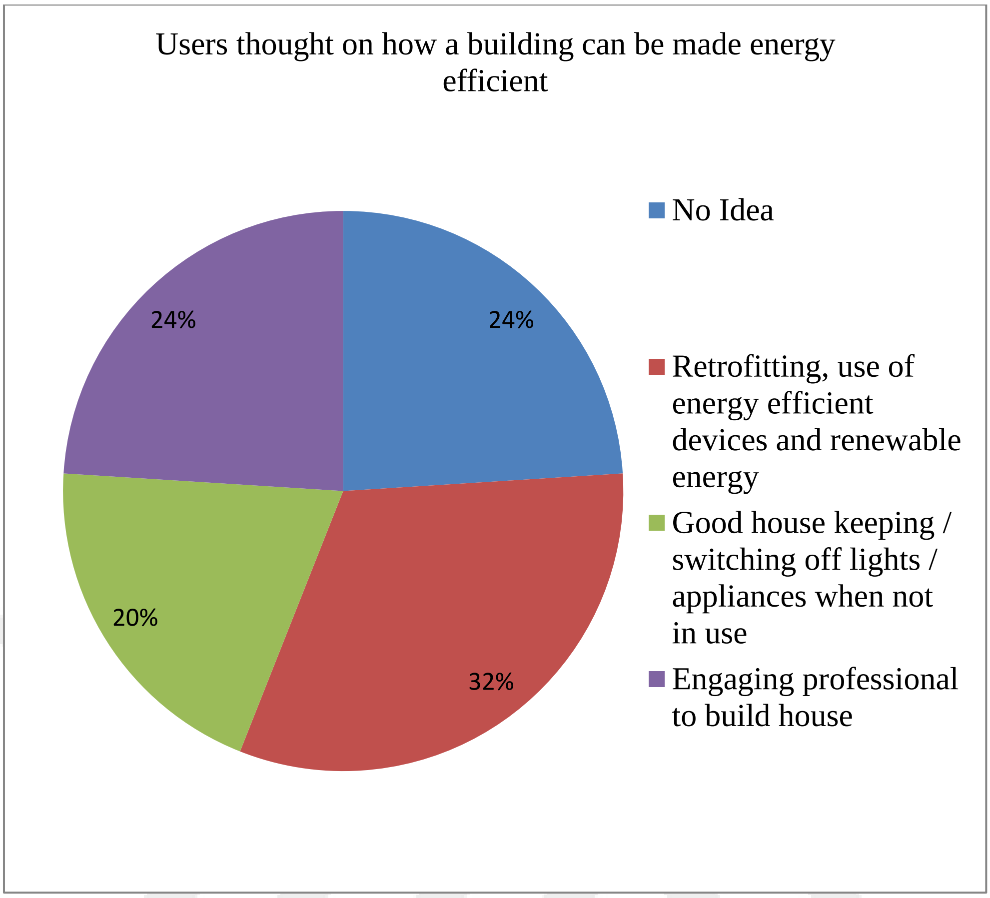


Figure 37. Pie chart showing users' thoughts on how a building can be made energy efficient

The results from Figure 37 on users' thoughts on how a building can be made energy efficient reveal that a good number of the users representing 24.0% had no idea on how a building can be made energy efficient, while the majority of the users representing 32.0% think a building can be made energy efficient by retrofitting; use of energy-efficient devices and renewable energy sources, 24.0% think engaging professional to build houses can make the building energy efficient, 20.0% think good house-keeping practices such as switching off lights/appliances when not in use can make a building more energy efficient.

The information on the results of whether the appliances and lights in users' homes are energy-saving is presented in Figure 38.

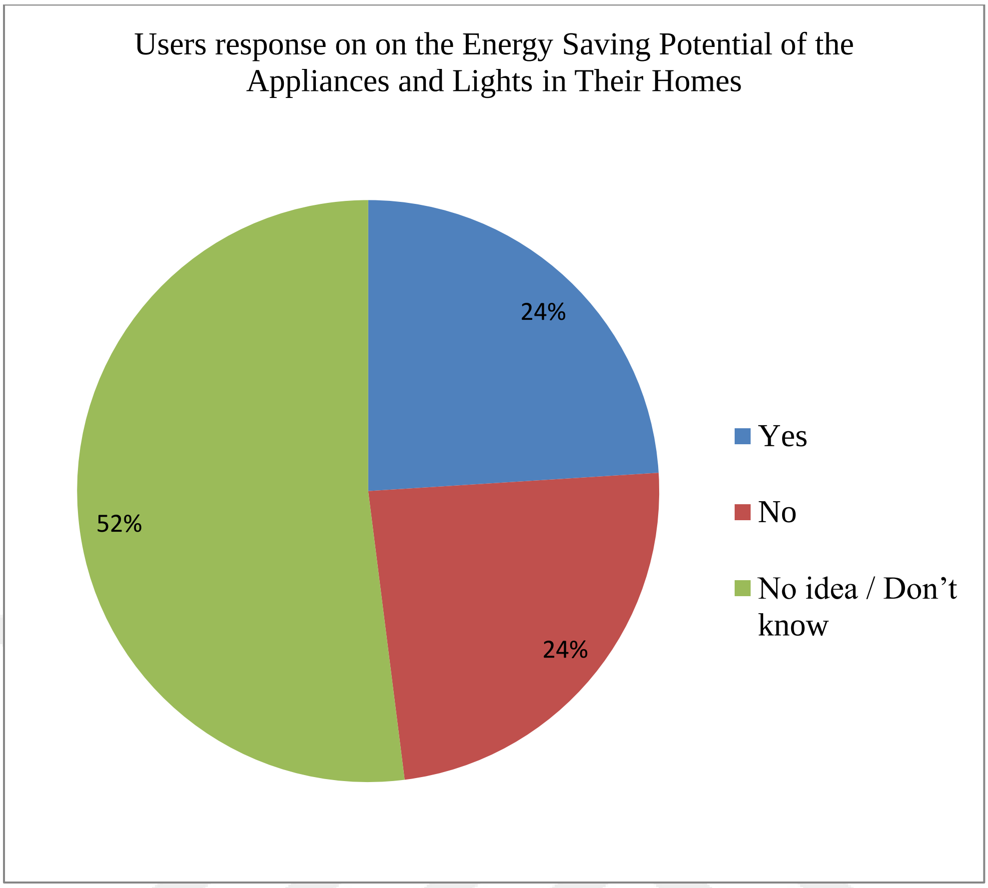


Figure 38. Pie chart showing users’ response on the energy saving potential of the appliances and lights in their homes

The results from Figure 38 on the energy-saving potential of the appliances and lighting in users’ homes reveal that the majority of the users representing 52.0% have ‘No idea / Do not Know” about the energy-saving potential of the appliances and lights in their homes, while 24.0% of the users said ‘Yes’ and ‘No’ respectively that the appliances and lighting in their homes are energy saving.

The evaluation of the results of the simple actions users take to save energy in their homes is presented in Figure 39.

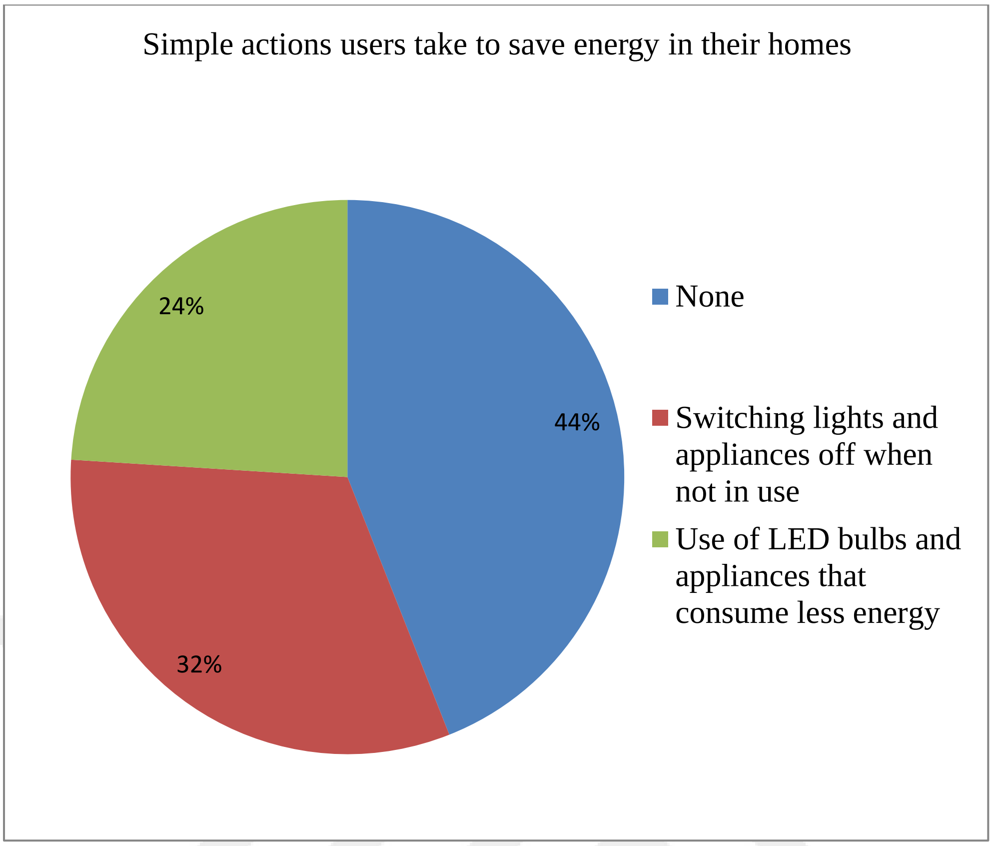


Figure 39. Pie chart showing the simple actions users take to save energy in their homes

The results from Figure 39 on the simple actions users take to save energy in their homes reveal that the majority of the users representing 44.0% have none. This implies that they do not take any simple action to save energy in their homes. However, the simple action 32.0% of the users take to save energy in their homes is to switch off their lights and appliances when not in use, while the simple action 24.0% of the users take in order to save energy in their homes is that they use LED bulbs and appliances that consume less energy.

The information on the results on whether energy labels of products are one of the important parameters that influence users' decision making for selecting a residential building to live in or a home appliance to use is presented in Figure 40.

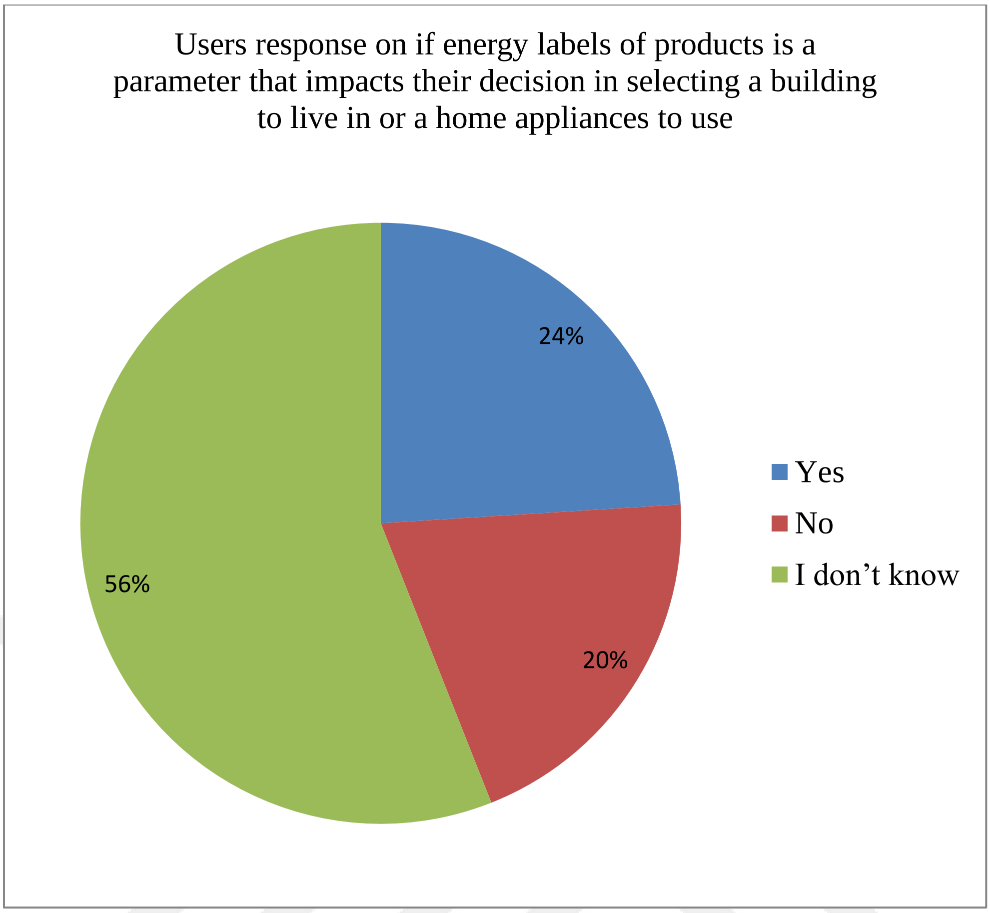


Figure 40. Pie chart showing information on whether the energy label of products impacts users’ decision in selecting buildings to live in or home appliances to use

The results from Figure 40 on whether the energy label of products is one of the important parameters that impact users’ decision-making in selecting buildings to live in or home appliances to use shows that the majority of the users representing 56.0% do not know if the energy label of products is one of the parameters to look at in selecting buildings to live in or home appliances to use. 20% said ‘No’ that energy labels of products are not one of the important parameters that impact their decision-making while 24.0% said ‘Yes’ that the energy label of products is one of the parameters that look at in selecting buildings to live in or home appliances to use.

The information on the results of whether users have done any retrofitting in their homes to save energy and decrease energy costs is presented in Figure 41.

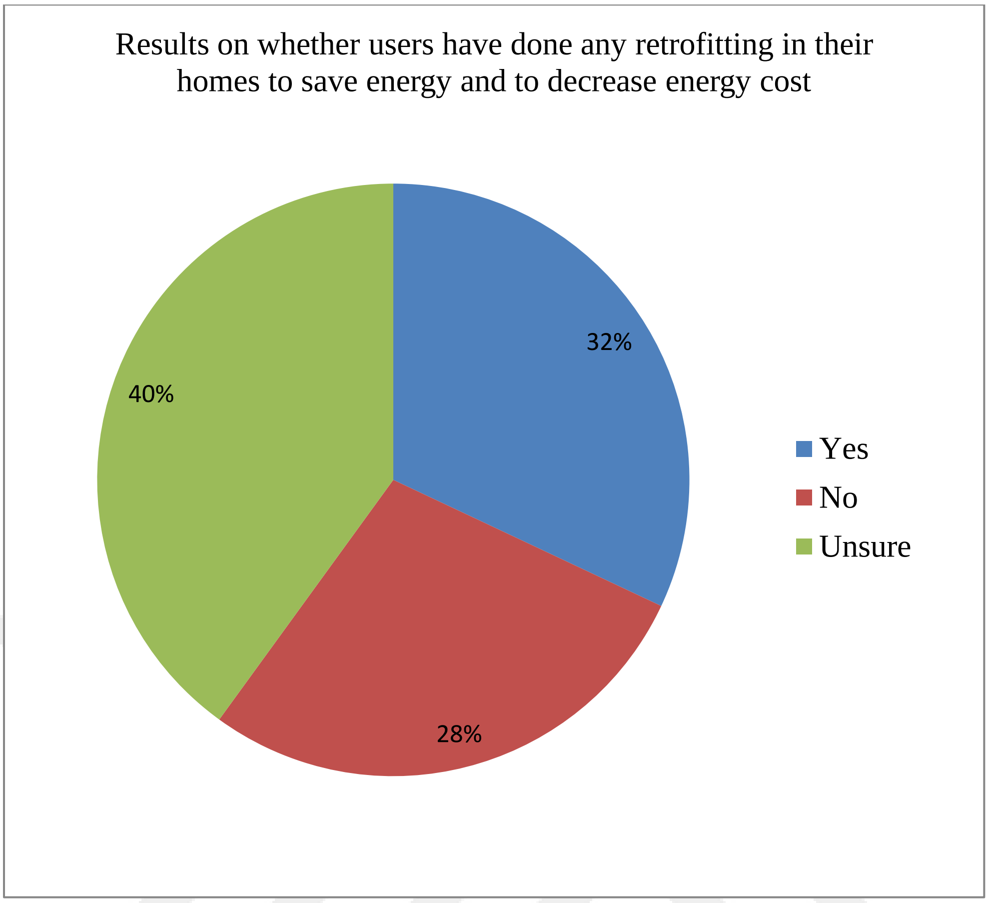


Figure 41. Pie chart showing if users have done retrofitting in their homes to save energy and decrease energy costs

The results from Figure 41 on whether users have done any retrofitting in their homes to save energy or decrease energy costs reveal that the majority of the users representing 40% are unsure if they have done any retrofitting in their homes to save energy or decrease energy cost, 28.0% s have not done any retrofitting in their homes to save energy or decrease energy cost reveals that majority of while 32.0% have done retrofitting in their homes to save energy or decrease energy cost.

The information on the results on whether there are energy-efficient incentives or programs from the government to promote energy efficiency in users' homes is presented in Figure 42.

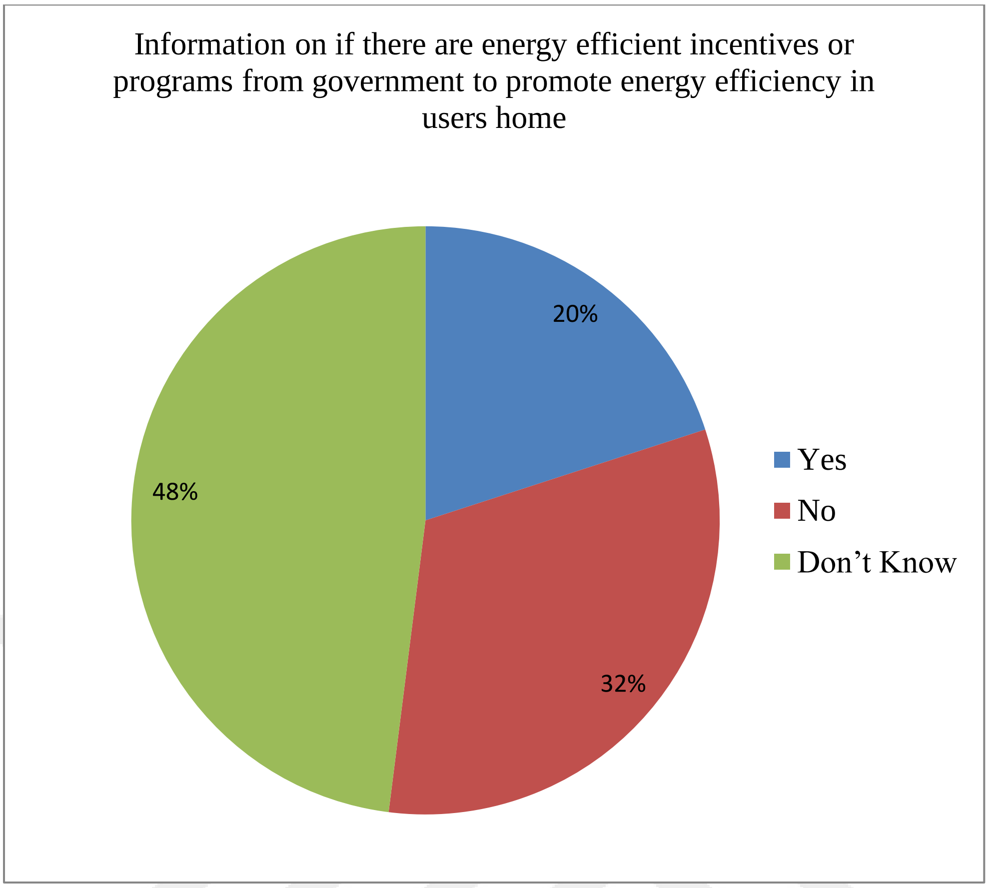


Figure 42. Pie chart showing information on whether users benefit from any energy efficient incentives or programs from the government to promote energy efficiency in their homes

The results from Figure 42 on whether there are any energy-efficient incentives or programs from the government to promote energy efficiency in users’ homes reveal that the majority of the users representing 48.0% do not know. This implies that they are unaware, 32.0% said there are no energy-efficient incentives or programs from the government to promote energy efficiency in their homes, while 20.0% said ‘Yes’. This implies that they agree that there are energy-efficient incentives or programs from the government to promote energy efficiency in users’ homes.

The information on the extent users think they are responsible for the energy efficiency of their buildings is presented in Figure 43.

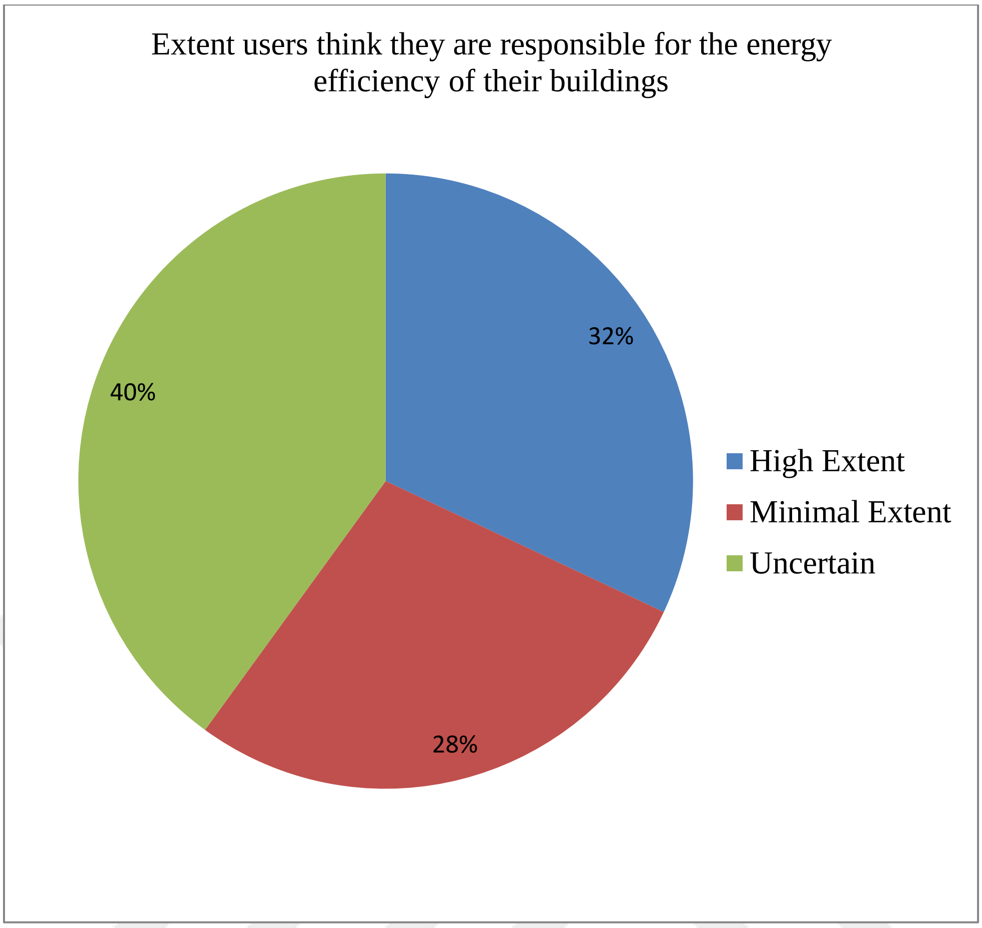


Figure 43. Pie chart showing information on the extent users think they are responsible for energy efficiency of their buildings

The results from Figure 43 on the extent to which users think 'they are responsible for the energy efficiency of their buildings' reveal that the majority of the users representing 40.0% are uncertain about the extent to which they are responsible for the energy efficiency in their buildings, while a good number representing 32.0% think 'they are responsible for the energy efficiency of their buildings' to a high extent and 28.0% of the users think they are responsible to a minimal extent. This implies that the majority of the users are unsure of the extent to which they are responsible for the energy efficiency of their buildings.

The information on users rating their knowledge of energy efficiency in buildings is presented in Figure 44.

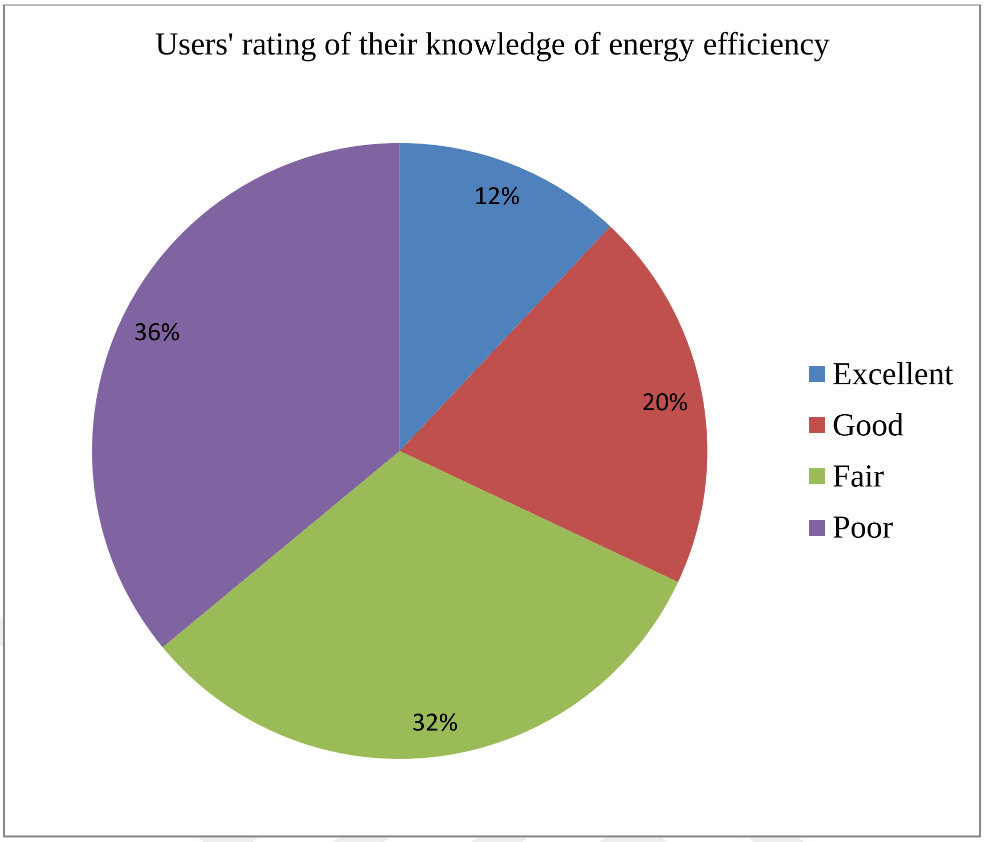


Figure 44. Pie chart showing users' rating of their knowledge of energy efficiency

The results from Figure 44 on users' rating of their knowledge of energy efficiency reveal that the majority of the users, representing 36.0% rate their knowledge of energy efficiency as poor, 32.0% of the users rate their knowledge of energy efficiency as fair, 20.0% of the users rate their knowledge of energy efficiency good while only 12.0% of the users rate their knowledge of energy efficiency excellent.

In summary, this chapter of the thesis tackles energy efficiency for residential buildings in Abuja, Nigeria. It gave an overview of the climatic and economic conditions of Abuja, Nigeria. The chapter also extensively looked at recent residential buildings in Abuja. The general features such as walls, fenestration, roofs, and floors of these recent buildings with respect to energy efficiency were carefully analyzed in this chapter. The chapter further addressed the energy usage and potential energy savings of residential buildings in Abuja, Nigeria. Finally, the chapter also provides the information on the assessment and evaluation of stakeholder knowledge on energy efficiency.

Chapter 5

Discussions and Conclusions

This chapter of the thesis provides in-depth discussions and conclusions of the entire thesis. The chapter contains recommendations for future projections as it relates to improving energy efficiency in Abuja, Nigeria.

5.1 Discussions

Energy efficiency in buildings is at the forefront globally, and stakeholders are being tasked with the role of providing measures that will improve energy efficiency in buildings. This explains why different countries of the world have their own specific energy efficiency codes to provide minimum standards that must be adhered to so as to enhance energy efficiency.

The Nigeria Building Energy Efficiency Code developed in 2017 is the principal legislation that regulates energy efficiency in buildings in Nigeria. This study looks extensively into the sufficiency of the Nigeria Energy Efficiency Code by comparing the code with selected global codes. The selected global codes for the comparison are the US and EU energy efficiency codes.

Findings from the comparison results show that the Nigeria Building Energy Efficiency Code is sufficient because the code contains all the technical requirements and compliance mechanisms required to maintain energy efficiency in buildings as captured in the US and EU energy efficiency codes. However, the stringency for the enforcement of the Nigeria Building Energy Efficiency Code is voluntary. This makes the stringency for the enforcement implementation of the code to be weak compared to the US and EU codes whose stringency for enforcement is mandatory. Another the enforcement of the Nigeria Building Energy Efficiency Code is not properly implemented is due to the negligence of the government in enforcing and maintaining the penalties for non-compliance with the provisions in the Nigeria Energy Efficiency Code.

This study also tries to assess the knowledge of stakeholders involved in the design and construction of a building life cycle by conducting a survey among them. The selected stakeholders for the survey are architects/engineers, contractors and users. These stakeholders are selected to represent the design team, construction team and operation/maintenance team, respectively. The findings from the survey are presented as follows;

i. Findings on stakeholder general information

The findings from the stakeholders' general information show that none of the design and construction team members (architects, engineers, and contractors) who took part in the survey had less than 3 years of experience. This explains why most of the design and construction team members have been involved in more than 3 residential building projects. The vast experience embedded in the architects, engineers, and contractors explains why they adhere strictly to the minimum requirements for designs and constructions stipulated in the National Building Energy Efficiency Code of Nigeria. However, some challenges such as client preferences, client budget and affordability make some architects/engineers and contractors not to adhere the minimum requirements documented in the National Building Energy Efficiency Code of Nigeria. A summary of more findings from each of the stakeholders that took part in the survey is presented as follows:

i. *Findings on Architects / Engineers knowledge of energy efficiency*

Findings from architects/engineers show that landscaping, cooling pools, site orientation, cross ventilation, and daylighting are amongst the major common passive building techniques architects adopt for energy efficiency in buildings. Other passive techniques architects adopt for enhancing energy efficiency in buildings include the use of renewable energy and insulations. More findings show that the use of inverters, solar panels, energy-efficient lighting, roof windmills and smart home automation are the major ways renewable energy sources can be integrated into building designs.

Architects also identify retrofitting and switching to less energy-consuming appliances and lights as the major ways to improve energy efficiency in buildings in Abuja, Nigeria, especially in existing buildings. Architects and engineers also identify other measures like adherence to the Nigeria Energy Efficiency Code, switching to renewable energy sources, building automation and smart home systems to be effective in improving energy efficiency in buildings.

Findings also show that the level at which architects think they are responsible for the energy efficiency in buildings is to a high extent as revealed from survey results.

This is attributed to the fact that architects and engineers are responsible for the design of buildings.

However, the architects’ and engineers' awareness and adherence to energy efficiency in residential buildings according to BEEC's minimum requirements came in at 56% to 44% split, almost at breakeven. The next question on their thoughts of passive and active measures improving energy efficiency, the adherence to the BEEC option came in at 12%, indicating an obvious discrepancy.

In conclusion, the majority of the architects and engineers in Abuja, Nigeria have a good knowledge of energy efficiency but the actual compliance with specific technical requirements of BEEC is significantly lower due to practical challenges.

ii. Findings on Contractors knowledge of energy efficiency

Findings from the survey also show that the contractors identified consistent site visitation to monitor the construction process as the major enforcement measures they adopt for enhancing energy efficiency. Other measures such as standard practices and strict adherence to the national building code, instigation of fines and demolition of buildings as penalties are also implemented but not as pronounced as consistent site visitations to monitor the construction process, though some contractors do not implement any of these measures due to the difficulties that come with their implementation.

Findings show that contractors understand that energy-efficient buildings have potential environmental and financial energy savings. Thermal comfort and well-being in buildings, minimization of cost on energy charge, conservation of natural resources, and reduction of greenhouse gas emissions, minimization of air and water pollution are amongst the potential and financial energy savings contractors identify. These potentials in the long run enhance a global eco-friendly community.

The majority of the contractors are aware of job ethics and professional standard practices and as such, they do not change architects’ design specifications; however, some contractors admitted to changing architects’ design specifications when it undermines the goal of the design, though they seek for architects and engineers on consent before changing the design specifications.

The contractors admit to being responsible for the energy efficiency in buildings to a minimal extent. This is understandable because contractors do not directly determine the nature of the design but they work as team members with architects to provide the best solutions for energy efficient buildings. Some of the solutions contractors identify include choosing materials and enhancing design specifications are adhered to. In conclusion, just like the architects, contractors have a good knowledge of energy efficiency.

iii. Findings on Users knowledge of energy efficiency

In the context of this thesis, the users make up for the operation/maintenance team. Their knowledge on energy efficiency reveals that the majority of the users understand that retrofitting, use of energy-efficient devices and renewable energy can make a building energy efficient, while some of the users identify good housekeeping practices such as switching off lights and appliances when not in use and engaging the services of professional to build their houses as the ways a building can be made energy efficient. However, some users still do not have any idea of what energy efficiency is.

The study reveals that the majority of the users in Abuja, Nigeria do not have any idea if the appliances and lights in their homes are energy saving. This is because they do not have any idea about energy labels to influence their decisions on the type of lights and appliances to use in their homes as revealed in the survey.

The majority of the users do not have any simple action they take in their homes in order to save energy. This is attributed to their lack of knowledge on energy efficiency. However, some users adopt simple actions such as switching off lights and appliances in their homes when not in use, some adopt the use of LED bulbs and appliances that consume less energy as the simple actions they take to save energy in their homes.

Findings also show that users are unsure if they have done any retrofitting in their homes to save energy and decrease energy costs because they do not have any idea about energy labels to aid in their decisions while selecting appliances and lights to use in their homes, though some users have changed their appliances and lights to less energy consuming ones at some point.

More findings show that users do not receive any energy-efficient incentives or programs from the government to promote energy efficiency in their homes. This explains why the enforcement of the national energy code of Nigeria is poor. Findings also show that the majority of the users are also uncertain about the extent to which they are responsible for the energy efficiency in their homes. In conclusion, most users in Abuja have poor knowledge of energy efficiency.

5.2 Future Projections

Globally, studies have shown that energy-efficient buildings have the potential to enhance an eco-friendly environment and also reduce the cost of energy consumption. To this effect, buildings need to be made energy-efficient in Nigeria. The inconsistency in enforcing and implementing energy efficiency regulations in Nigeria has limited the impact of achieving more energy-efficient buildings in Nigeria. In order to provide solutions to the problem from the research findings of this survey and reviewed literature, the following recommendations are made.

1. The government needs to create more public awareness programs on energy efficiency to capacity building amongst users.
2. Architects, engineers and contractors that make up the design and construction team should incorporate more passive building techniques in their designs and construction practices to improve energy efficiency in buildings.
3. Users need to engage professionals for their building designs.
4. The government and other relevant stakeholders need to create incentives that will increase adherence to the National Energy Efficiency Code of Nigeria in practice.
5. Thus, knowledge of energy labels of products needs to be encouraged to help users make proper decisions on lights and appliances to use.

Globally, the world is tilting towards cleaner energy aimed at reducing pollution and encouraging conservation and sustainability. Thus, the future relies on renewable energy sources to help achieve this. Therefore, as a future projection, this study recommends the design and construction of greener buildings with solar energy sources.

In conclusion, the poor implementation of the Nigeria Energy Efficiency Code is attributed to the voluntary nature of the enforcement stringency of the code. As a future projection, this proposes that the enforcement stringency of the Nigeria Building Energy Efficiency Code needs to be made mandatory by the government. This will go a long way in improving the implementation of the code.

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